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Typical Clothing Ensemble Insulation Levels for Sixteen Body Parts

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1. BACKGROUND

In the past, clothing insulation data have been available only for the body as a whole [1-3]. This is because early human physiology and thermal comfort models treat the whole-body surface as one segment [4]. As models become more advanced and divide the body into individual parts [5, 6], whole-body clothing insulation values become inadequate. In this study, we obtained body-part-specific insulations using a 16-part thermal manikin, testing 40 typical clothing ensembles for summer, spring/fall, and winter. The clothing insulations are provided for each of the 16 body parts and for the whole-body (because left and right extremities can be considered identical, 10 parts are reported). A new database is provided for use by multiple-segmented models of physiology and comfort.

2. ABSTRACT

In order to accurately simulate skin and core temperatures and thermal comfort, some human physiology and comfort models now divide the human body into multiple body parts (such as head, hand, chest etc). Most of these parts are normally covered with clothing insulation, which must be quantified in the simulation. Unfortunately, existing clothing insulation databases only characterize clothing insulation for the whole body, not for individual body parts. That means every body part has the same clothing insulation level, even over the head and hands. In this study, we measured clothing insulation for 40 typical clothing ensembles using a 16-segment thermal manikin, and present here the insulation values for each body part, as well as for the whole body.

3. METHODS

The experiments were carried out in a climate chamber at the Center for the Built Environment (CBE) at University of California, Berkeley, between September and December 2012. The manikin used in the experiment is an average-sized Danish adult female as shown in Fig. 1. Its 16 segments are independently controlled and measured. Table 1 shows the 16 segments and their respective

surface areas. Table 2 shows the experimental conditions. Air temperature was kept at 20°C, and was measured continuously at 0.1m, 0.6m and 1.1 m height. All skin temperatures were set at 34°C. The testing followed the recommended ASTM and ISO procedures [7, 8]. Each test continued for 2 hours to ensure that the manikin reached a stable condition. The manikin was seated in a mesh arm chair whose insulation level was measured.

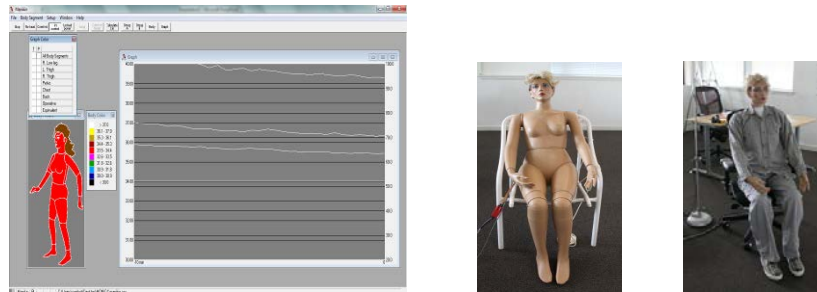


Figure 1. Thermal manikin control screen (left), climate chamber/thermal manikin 'Monica' (right).

	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	0.16
6	Right Thigh	0.165
7	Pelvis	0.182
8	Head	0.1
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

Table 1. Body segments and respective areas of the manikin.

Ambient temp (°C)	Skin temp.	RH (%)	Air velocity	Posture	Chair
20.22 ±0.13	34	50	0.1	Sitting on a chair	Mesh arm chair

Table 2. Experimental Conditions.

4. CLOTHING ENSEMBLE CONDITIONS AND CLOTHING INSULATION RESULTS

We calculated the total insulation for 16 body parts for 40 typical ensembles including the nude condition, using Equation 1 and the manikin skin temperatures $T_{s,i}$ and heat fluxes $Q_{t,i}$ measured for each body part:

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

where T_a is the ambient air temperature, and 1 clo = 0.155 m² °C/W. The intrinsic insulation of the clothing itself was calculated by Equation 2:

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

The thermal resistance of the nude body sitting on the mesh chair was measured as 0.8 clo during this experiment.

For whole-body clothing insulation, the summer ensembles tested range from 0.22 ~ 0.57 clo. The spring/fall ensembles range from 0.53~0.80 clo. The winter clothing ranges from 0.8 clo to 1.4clo.

Table 3 shows all clothing ensembles and clothing insulation results. Values for left and right extremities are averaged and combined.

6. CONCLUSIONS

We measured and calculated the clothing insulation for 16 body parts for 40 typical ensembles. The values are useful for multi-segmented models of thermophysiology and comfort. They will be available in a public database maintained at the Center for the Built Environment.

Clothing ensemble	description	Whole-body	head	chest	back	Upper arm	Lower arm	hand	pelvis	thigh	Lower leg	foot
	Nude (Mesh Chair)	0.01	0.13	0.01	0.01	0.02	0.00	0.01	0.04	0.01	0.03	0.05
	Nude (Nude Chair)	-0.02	0.13	0.05	-0.14	-0.01	-0.01	-0.02	-0.01	-0.10	0.00	0.00
	panty	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.24	0.05	0.00	0.05
	Bra+pany	0.05	0.00	0.22	0.00	0.00	0.00	0.00	0.18	0.03	0.03	0.08
	Bra+pany, tank top, shorts sandals	0.22	0.00	0.57	0.27	0.04	0.02	0.02	0.92	0.51	0.01	0.38

<i>Clothing ensemble</i>	<i>description</i>	<i>Whole-body</i>	<i>head</i>	<i>chest</i>	<i>back</i>	<i>Upper arm</i>	<i>Lower arm</i>	<i>hand</i>	<i>pelvis</i>	<i>thigh</i>	<i>Lower leg</i>	<i>foot</i>
	Bra+pantry long-sleeve shirt, shorts sandals	0.43	0.00	1.43	1.02	0.29	0.22	0.01	1.45	0.57	0.01	0.40
	Bra+pantry sleeveless dress, sandals	0.29	0.00	0.85	0.48	0.00	0.00	0.00	0.94	0.72	0.00	0.41
	Bra+pantry T-shirt, long pants, socks,sneakers	0.52	0.00	1.14	0.84	0.42	0.00	0.00	1.04	0.58	0.62	0.82
	Bra+pantry sleeveless dress, cardigan, sandals	0.53	0.00	1.78	1.42	0.65	0.41	0.05	1.19	0.77	0.00	0.39
	Bra+pantry song-sleeve dress, socks,sneakers	0.54	0.00	1.49	1.10	0.72	0.58	0.03	0.91	0.73	0.07	0.77
	Bra+pantry long-sleeve dress, cardigan socks,sneakers	0.67	0.00	2.05	1.32	1.14	0.63	0.04	1.39	0.84	0.05	0.78
	Bra+pantry tank top, skirt,sandals	0.31	0.00	0.83	0.22	0.00	0.00	0.03	0.99	0.88	0.05	0.44
	Bra+pantry long sleeve shirts, Skirt,Sandals	0.52	0.00	1.62	0.99	0.31	0.28	0.03	1.41	0.82	0.04	0.41
	Bra+pantry dress shirts, skirt,stocking, formal shoes	0.62	0.00	1.58	0.99	0.91	0.64	0.04	1.31	0.87	0.05	0.81
	Bra+pantry dress shirts, skirt, leggings, sandals	0.65	0.13	1.59	1.04	0.91	0.67	0.07	1.36	1.26	0.12	0.43

<i>Clothing ensemble</i>	<i>description</i>	<i>Whole-body</i>	<i>head</i>	<i>chest</i>	<i>back</i>	<i>Upper arm</i>	<i>Lower arm</i>	<i>hand</i>	<i>pelvis</i>	<i>thigh</i>	<i>Lower leg</i>	<i>foot</i>
	Bra+ panty Thin dress shirts, long pants, socks, sneakers	0.69	0.10	1.33	0.93	0.79	0.66	0.13	1.39	0.60	0.57	0.76
	Bra+ panty long sleeve shirts, long pants, socks, sneakers	0.80	0.00	2.47	1.48	0.98	0.58	0.04	1.58	0.69	0.65	0.89
	Bra+ panty T-shirt, long sleeve shirts, long pants, socks, sneakers	0.83	0.25	3.88	2.28	1.89	1.41	0.16	2.07	0.83	0.66	0.86
	Bra+ panty T-shirt, jeans, socks, sneakers	0.57	0.00	1.29	0.93	0.68	0.00	0.00	1.30	0.65	0.47	0.73
	Bra+ panty long sleeve shirts, jeans, socks, sneakers	0.74	0.00	1.58	0.98	0.86	0.71	0.07	1.35	0.74	0.48	0.74
	Bra+ panty Oxford shirts, Long thin pants, Socks, sneakers	0.83	0.16	1.39	1.02	0.83	0.69	0.22	1.34	1.02	0.68	0.80
	Bra+ panty Thin dress shirts, Long pants, socks, sneakers	0.82	0.00	3.35	1.73	1.99	1.49	0.11	1.63	0.60	0.43	0.68
	Bra+ panty Thin dress shirts (roll-up), Long pants, socks, sneakers	0.81	0.00	3.60	1.83	2.16	1.49	0.13	1.71	0.64	0.43	0.69
	Bra+ panty Thin dress shirts (roll-up), Long pants, socks, sneakers	0.81	0.00	3.60	1.83	2.16	1.49	0.13	1.71	0.64	0.43	0.69
	Bra+ panty T-shirts, Short sleeve shirt, long pants, socks, sneakers	0.71	0.12	2.15	1.40	1.22	0.02	0.05	1.71	0.79	0.48	0.67

<i>Clothing ensemble</i>	<i>description</i>	<i>Whole-body</i>	<i>head</i>	<i>chest</i>	<i>back</i>	<i>Upper arm</i>	<i>Lower arm</i>	<i>hand</i>	<i>pelvis</i>	<i>thigh</i>	<i>Lower leg</i>	<i>foot</i>
	Bra+ panty, Sports shirts, long pants, socks, sneakers	0.80	0.05	1.92	1.31	1.14	0.86	0.18	1.41	0.59	0.49	0.75
	Bra+ panty, sports shirts, sports pants, sports socks, sports shoes	0.87	0.07	1.87	1.17	1.20	1.07	0.09	1.26	0.62	0.77	1.58
	Bra+ panty, sports shirts, sports pants, sports socks, sports shoes	0.87	0.07	1.87	1.17	1.20	1.07	0.09	1.26	0.62	0.77	1.58
	Bra+ panty, Thin-dress shirts, Long pants, Wool sweater, Socks, sneakers	0.92	0.09	2.39	1.64	1.36	1.29	0.21	1.71	0.70	0.52	0.77
	Bra+ panty, Thin dress shirts, Long pants, Cashmere sweater, Socks, sneakers	0.87	0.10	2.40	1.72	1.33	1.23	0.08	1.67	0.61	0.47	0.77
	Bra+ panty, T-shirt, Long sleeve shirts, Long pants, Winter Jacket, socks, sneakers	1.15	0.12	4.37	2.56	2.72	2.23	0.19	2.14	0.82	0.57	0.70
	Bra+ panty T-shirts, long sleeve shirts, jeans, sports jumper, socks, sneakers	1.07	0.28	3.99	2.12	1.70	1.36	0.10	2.00	0.92	0.48	1.07
	Bra+ panty, T-shirt, long sleeve shirts, long pants, ventura jacket, socks, sneakers	0.90	0.09	2.66	1.42	1.32	0.99	0.14	1.57	0.73	0.66	0.85
	Bra+ panty, turtle neck, long pants, short trench coat, socks, sneakers	1.24	0.06	3.22	1.99	1.62	1.50	0.37	2.03	1.51	0.65	0.80

<i>Clothing ensemble</i>	<i>description</i>	<i>Whole-body</i>	<i>head</i>	<i>chest</i>	<i>back</i>	<i>Upper arm</i>	<i>Lower arm</i>	<i>hand</i>	<i>pelvis</i>	<i>thigh</i>	<i>Lower leg</i>	<i>foot</i>
	Bra+panty T-shirt, long sleeve shirts, long pants, winter jacket socks,sneakers	1.08	0.31	3.76	2.00	2.00	1.37	0.25	1.92	0.83	0.61	1.08
	Bra+panty, tank top, long sleeve shirts, blazer, skirt, sandals	0.86	0.00	3.24	1.81	1.98	1.13	0.07	2.06	1.19	0.04	0.44
	Bra+panty long sleeve shirts, wool skirt, socks, formal shoes	0.59	0.00	1.21	0.74	0.44	0.24	0.17	1.56	1.52	0.09	0.74
	Bra+panty turtleneck, wool skirt, socks, formal shoes	0.70	0.00	1.11	0.94	0.73	0.62	0.14	1.52	1.53	0.09	0.85
	Bra+panty long sleeve shirt, wool skirt, sweater, socks, formal shoes	0.91	0.14	2.82	1.53	1.22	0.97	0.08	1.79	1.53	0.11	0.83
	Bra+panty, Thin dress shirts,slacks, tie, socks, sneakers	0.57	0.00	1.69	0.80	0.67	0.58	0.07	1.08	0.36	0.39	0.74
	Bra+panty Thin dress shirts,slacks, blazer,tie, belt, socks, formal shoes	0.93	0.00	3.60	1.83	2.16	1.49	0.13	1.71	0.64	0.43	0.69
	Bra+panty Long sleeve shirts,Long pants, Blazer, socks,sneakers	0.96	0.04	3.30	1.67	2.10	1.43	0.09	2.20	0.72	0.42	0.67
	Bra+panty T-shirts, Long sleeve shirts,Long Pants, Winter Jacket(Notica), socks,sneakers	1.05	0.04	3.88	2.26	1.82	1.46	0.17	1.97	0.81	0.57	0.78

<i>Clothing ensemble</i>	<i>description</i>	<i>Whole-body</i>	<i>head</i>	<i>chest</i>	<i>back</i>	<i>Upper arm</i>	<i>Lower arm</i>	<i>hand</i>	<i>pelvis</i>	<i>thigh</i>	<i>Lower leg</i>	<i>foot</i>
	Bra+ panty T-shirts, Long sleeve shirts, Long Pants, Winter Jacket, socks, sneakers	1.18	0.65	5.26	3.07	3.14	2.07	0.08	2.20	0.67	0.54	0.77
	Bra+ panty, Turtle neck, Ski-Jumper, Skin pants, sports socks, sports shoes	1.84	0.89	5.24	2.87	2.55	2.16	0.46	2.64	1.49	1.82	1.56
	Bra+ panty Turtle neck, Ski-Jumper and hood, Skin pants, sports socks, sports shoes	1.87	1.63	5.12	2.70	2.58	2.16	0.49	2.57	1.44	1.76	1.54
	Bra+ panty, Turtle neck, Goose down, ski pants, sports socks, sports shoes	2.53	1.17	15.44	5.50	6.55	5.58	0.35	5.20	2.12	1.70	1.54
	Bra+ panty, Turtle neck, Goose down-with hood, ski pants, sports socks, sports shoes	2.75	3.52	12.62	3.99	6.20	5.73	0.53	5.05	2.11	1.81	1.58
	Bra+ panty, Turtle neck, Goose down-with hood and gloves, ski pants, sports socks, sports shoes	3.27	3.92	16.13	4.47	7.12	5.37	2.54	5.71	2.14	1.82	1.61

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