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Original Article

Validation of ISO 9920 clothing item insulation summation method based on an ambulance personnel clothing system

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Abstract: This study aimed to validate the summation methods suggested by ISO 9920. Twenty seven items from an ambulance personnel clothing system were selected for testing. The basic insulation of each garment item (I_{clu}) was calculated based on the thermal manikin tests. More than 100 realistic clothing combinations were compiled and basic insulation (I_{cl}) of these ensembles was calculated according to ISO 9920. These were ranked after the calculated insulation, and 14 sets covering insulation from 0.63 to 3.33 clo were measured on the thermal manikin for acquiring the basic clothing insulation (I_{cl}). Regression analysis was used to compare the summed and measured I_{cl} values. The difference between values varied from −18 to 12%. The highest percentual difference was for the lightest clothing sets, while the absolute differences were similar over the whole insulation range ranging between −0.17 to 0.18 clo with an average difference of 0.02 clo (−0.16%). All basic insulation values stayed very close to the line of identity (R^2=0.98). The summation equation gave, in the case of this ambulance clothing system, very close results to the measured values. This encourages evaluating and selecting protective clothing combinations for thermal comfort based on individual item measurements.

Key words: Standard method, Basic insulation, Garment item, Modelling, Thermal comfort, Optimal clothing selection, Protective clothing

Introduction

Clothing insulation is one of the basic parameters that affects human heat exchange with the environment. It is used as a common behavioural thermoregulatory measure and is a powerful means to maintain thermal comfort in a wide range of temperatures[1)]. The two most important clothing properties that affect human heat exchange with the environment, are thermal insulation and evaporative resistance. Commonly, these are not evenly distributed over the body surface due to the material choice, clothing design, layering, fit etc. Clothing parameters for body regions can be measured, and the change due to walking and wind can be estimated[2–4)]. Local values can be used in advanced physiological models for exposure evaluation[5, 6)] and as a feedback for clothing manufacturers to improve their products, or for industries to select the clothing provided to their employees.

There are several methods available to measure or estimate clothing items' or their combinations' insulation,

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e.g. ASTM F1291[7], ISO 15831[8], ISO 9920[9]. ISO 9920[9] presents databases of clothing ensembles allowing us to sum individual items and presents possibilities to calculate effect of wind and motion. However, it does not account for many effects that occur when dressing the clothing combination and related to clothing fit etc., while some of these effects may counterbalance or amplify each other. The standard has earlier not considered much different clothing styles than western clothing, and corrections are commonly based on workwear, while recent publication cover that gap[10, 11]. Also, modern western clothing has been measured and detailed thermal properties have been reported in literature[3, 12].

It may be quite laborious to test all the possible clothing combinations that people may wear, and therefore a summation method[9] can be very useful in adding up individual items' insulation into the insulation of the whole ensemble. Such an outcome can be utilized in standards on evaluation of human thermal environments, e.g. ISO 11079[13] (IREQ: insulation required for cold environments), ISO 7933[14] (PHS: predicted heat strain for heat exposure), ISO 7730[15] (PMV: predicted mean vote; PPD: predicted percentage of dissatisfied for indoor climate range), that require clothing insulation as input for the evaluation of the protection, stress, comfort or thermal climate. These standards allow exposure evaluation by combining environmental and clothing parameters and human activity levels on thermo-physiological basis to predict thermal stress and estimate exposure[16–18], or allow their use in mobile apps for decision support to plan for and cope with unfavourable climate conditions[19]. Even the recent version of ISO 7243[20] (WBGT: wet bulb globe temperature index for work in hot climates) includes a limited table with clothing examples for adjustment of the calculated exposure limits.

However, prediction accuracy depends on the accuracy of its components. A 5% deviation, for example, is accepted for manikin tests by ISO 15831[8]. It counts, for example, for the differences that may occur during dressing of the manikin. To counterbalance the focus on percentual differences then a rough estimation by experience has shown that a measured insulation difference of less than 0.02 m^2K/W can hardly be noticed by a user as other factors including fit and dressing habits etc. do influence the outcome more. Thus, for predictions of clothing insulation we can assume that the difference from the true insulation value of less than ± 10% can be acceptable[21]. The very same presentation[21] showed, that for various available data sets the summation method could allow for differences far above 20% depending on clothing, confirming the conclusions of Kakitsuba[22] on the influence of many other factors on clothing thermal parameters.

The aim of this study was to validate the summation method suggested by ISO 9920[9] based on the example of an available ambulance personnel clothing system from the same manufacturer, where various items were meant to work together and fulfil their protective/comfort function.

Methods

Twenty seven items from the Taiga AB (Sweden) ambulance personnel clothing system, shoes and gloves were selected for this study (Table 1). All items were tested individually on the thermal manikin Tore[23, 24] at Lund University according to ISO 15831[8] following ISO 9920[9] recommendation (low air velocity), and basic insulation of each garment item (I_{clu}) was calculated. During testing, there was a small difference from suggested air velocity as the chamber air motion could not be set below 0.2 m/s due to the influence on vertical temperature distribution and function of the regulation system. Air velocity in the chamber stayed in average at 0.22 ± 0.08 m/s. Air layer insulation (I_a) was measured in the same conditions.

Based on 27 clothing items over 100 realistic clothing combinations were compiled and basic insulation (I_{cl}) of these clothing ensembles was calculated according to the summation equation given in ISO 9920[9]:

$$I_{cl} = 0.161 + 0.835 \times \Sigma I_{clu} \quad (1)$$

Also, the simplified equation was used for comparison:

$$I_{cl} = \Sigma I_{clu} \quad (2)$$

The ensembles were sorted based on the calculated insulation, and 14 sets were selected to reasonably cover the range of insulation values from 0.63 to 3.33 clo. Basic insulation (I_{cl}) of the selected sets were calculated based on thermal manikin measurements. Photographic method based on 2 photos was used to estimate clothing area factor (f_{cl}) of the individual garments and the ensembles[11]. The front and the side photos were used. The f_{cl} estimation and calculation analysis for these particular clothing-sets is described in detail a separate paper[25].

Simple t-test for paired two sample for means and regression analysis were used to evaluate and compare the estimated and measured basic clothing insulation values.

Table 1. Clothing items used in the study

Layers' position	Item/Ensemble	Material	Weight (g)
Feet	Hopedale sock	76% wool, 23% polyamide, 1% lyckra (size 40–42)	64
Feet	Swede sneakers (by Arbesko AB)	Leather/textile (size 44)	843
Feet	Bylot sock	43% wool, 28% akrylic, 26% polyamide, 1% lyckra (size 40–42)	109
Feet	Kodiak sock	43% wool, 28% akrylic, 26% polyamide, 1% lyckra (size 40–42)	273
Feet	Woodman winter shoes (by Arbesko AB)	Uppers: impregnated leather, Thinsulate®, nylon fur; soles: nitril rubber (size 43)	1,852
Hands	Fleece gloves (by Hestra AB)	100% polyester (size 10)	106
Hands	Grizzly mitten 2.0	Fabric:100% polyamide; Palm: Goatskin; Insul: Polyfill; Lining: 100% polyester	217
Head	Hillside cap 3.0	90% polyester, 10% elastane	35
Head	Biwak cap	Outer shell: 100% polyamid; lining:100% polyester	92
Underwear	Hawk boxer shorts	100% polyester	123
Underwear	Eagle PW trousers	78% polyester, 22% merino wool	182
Underwear	Hawk T-shirt	100% polyester	183
Underwear	Eagle PW sweater	78% polyester, 22% merino wool	212
Middle layer	Power trouser	53% polyester, 38% polyamide, 9% spandex	240
Middle layer	Sitka trouser lining	100% polyester	453
Middle layer	Pike Polo shirt	100% polyester	252
Middle layer	Wilmore AMB sweater shirt	100% polyester	487
Middle layer	Power sweater 2.0	53% polyester, 38% polyamide, 9% spandex	334
Middle layer	Ruby AMB softshell	100% polyester	816
Middle layer	Denver lining	100% polyester	530
Middle layer	Thule base jacket 2.0	100% polyester (fiberpile)	703
Outer layer	Riverside shorts	65% polyester, 35% cotton	374
Outer layer	Trader trousers 2.0	65% polyester, 35% cotton	671
Outer layer	Alarm trousers	100% polyester	1,237
Outer layer	Emergency WP trousers	Outer textile and liner: 100% polyester	1,146
Outer layer	Alarm jacket	100% polyester	1,052
Outer layer	Emergency WP reflex jacket	Outer textile and liner: 100% polyester	1,538

Weight is given for size L unless given differently.

Results and Discussion

Table 2 shows the insulation of all single items and lists the finally selected combinations' composition. The evaporative resistances of the selected combinations are available and analysed in Toma *et al*[26].

The difference between measured and estimated basic insulation values varied from −18 to 12% for equation 1 (Table 3), and from −18 to 9% for equation 2 (Table 3). Correlation between measured and calculated insulation values is shown in Fig. 1. Correlation for these randomly picked and measured clothing ensembles was good for both equations.

For equation 1 the differences were commonly less than 10% that was defined by Kuklane and Havenith[21] as an aim to be reached for reasonable predictions when used in thermal models. In spite of high difference (over 10–15%) in light clothing (Table 3) the absolute difference in measured and summed insulation values of the tested

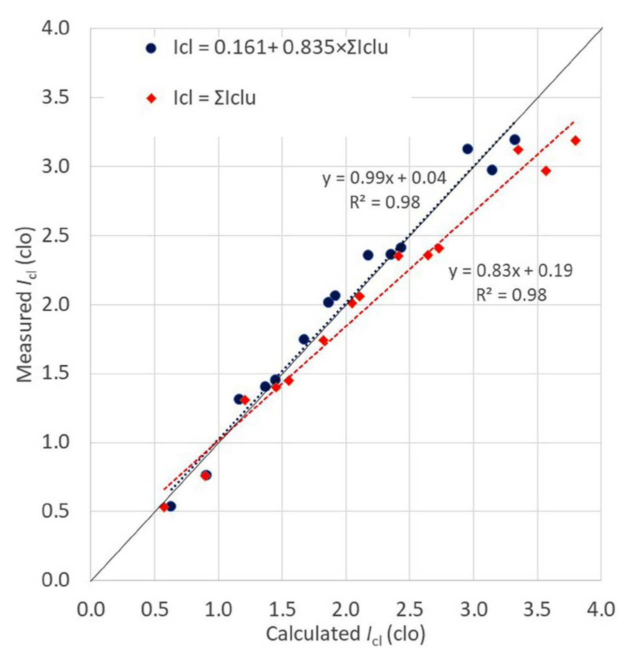

Fig. 1. Calculated vs. measured insulation of a clothing system (I_{cl}).

Table 2. Individual clothing items' insulation and their presence in tested combinations

Item/Ensemble	I_{tot} (m^2K/W)	f_{cl}	I_{clu} (clo)	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14
Air layer insulation	0.094	1.00															
Hopedale sock	0.097	1.02	0.03	X	X	X	X										
Swede sneakers	0.097	1.04	0.05	X	X	X	X	X	X	X	X	X					
Bylot sock	0.102	1.01	0.06					X	X	X	X	X	X				
Kodiak sock	0.109	1.02	0.11											X	X	X	X
Winter shoes	0.105	1.09	0.12										X	X	X	X	X
Hestra fleece gloves	0.096	1.01	0.02					X	X		X	X	X				
Grizzly mitten 2.0	0.101	1.02	0.06											X	X	X	X
Hillside cap 3.0	0.095	1.00	0.01							X							
Biwak cap	0.097	1.01	0.03					X	X		X	X	X	X	X	X	X
Hawk boxer shorts	0.104	1.02	0.08	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Eagle PW trousers	0.114	1.03	0.15					X	X		X			X		X	X
Hawk shirt	0.120	1.07	0.21		X	X	X										
Eagle PW sweater	0.131	1.09	0.29					X	X		X			X		X	X
Power trouser	0.125	1.11	0.26							X		X	X	X	X	X	X
Sitka trouser lining	0.137	1.21	0.38												X	X	X
Pike Polo shirt	0.125	1.10	0.26	X													
Wilmore AMB sweater shirt	0.139	1.08	0.34				X	X				X		X			X
Power sweater 2.0	0.144	1.04	0.35							X		X	X	X	X	X	X
Ruby AMB softshell	0.142	1.13	0.38		X												
Denver lining	0.153	1.15	0.46								X				X	X	X
Thule base jacket 2.0	0.167	1.17	0.56			X			X		X		X		X	X	
Riverside shorts	0.111	1.07	0.15	X	X												
Trader trousers 2.0	0.126	1.14	0.28			X	X			X							
Alarm trousers	0.132	1.18	0.34					X	X								
Emergency WP trousers	0.142	1.20	0.41								X	X	X	X	X	X	X
Alarm jacket	0.153	1.17	0.47				X	X	X	X							
Emergency WP reflex jacket	0.158	1.22	0.52								X	X	X	X	X	X	X

sets, according to equation 1, was not higher than in more insulating clothes—the absolute differences were similar and ranged between −0.17 to 0.18 clo (<0.028 m^2K/W) with an average difference of 0.02 clo (−0.16%, Table 3). Such difference occurs during manikin testing and may depend on the measuring accuracy of the system, chamber regulation stability and accuracy and consistency of manikin dressing. Measuring standards, e.g. ISO 15831[8], commonly allow differences up to 5% between individual determinations. At the same time, the human thermal responses will largely be related to the absolute values. I.e. for evaluation of the results the relative difference (%) cannot be the only criteria, but it is important to consider the absolute value depending on clothing insulation. For equation 1 two-tailed *t*-test between measured and calculated values did not show significant differences (p=0.61), and all basic insulation values for equation 1 stayed very close to the line of identity (R^2=0.98, Fig. 1).

The calculated insulation values according to equation 2 were commonly higher than the measured values and absolute differences increased with increasing insulation (Table 3 and Fig. 1). Although the correlation was good (R^2=0.98, Fig. 1), then the absolute values differed and the two-tailed t-test between measured and calculated values did show significant differences (p<0.01). Still, as it can be seen from Fig. 1 the equation 2 did provide quite close results for the clothing ensembles up to about 2 clo.

In addition to the extensive ISO 9920[9] database (originates from McCullough *et al.*[27]) and the databases of modern clothing combinations[11, 12], there is a need for more information on modern individual garments' properties. However, it must be remembered, that the tested clothes in this study were the modern western type of industrial style clothing, that have been relatively well studied. Items influenced by modern fashion ideas or from traditional clothing of the other world regions may not get as good

Table 3. Insulation of selected clothing combinations' and differences between measured an calculated values (air layer insulation is given in Table 2)

	f_{cl}	Measured			Calculated							
		I_{tot} (m^2K/W)	I_{cl} (m^2K/W)	I_{cl} (clo)	$I_{cl} = 0.161 + 0.835 \times \Sigma I_{clu}$ *m^2K/W*	clo	*Diff (meas.-calc.)* *Absol. diff*	*Relative diff (%)*	$I_{cl} = \Sigma I_{clu}$ *m^2K/W*	clo	*Diff (meas.-calc.)* *Absol. diff*	*Relative diff (%)*
T1	1.15	0.164	0.082	0.53	0.098	0.63	−0.11	−18.1	0.088	0.57	−0.04	−6.9
T2	1.18	0.197	0.118	0.76	0.141	0.91	−0.15	−17.6	0.139	0.90	−0.13	−16.2
T3	1.27	0.277	0.204	1.31	0.181	1.17	0.15	11.8	0.187	1.21	0.11	8.6
T4	1.29	0.290	0.218	1.40	0.212	1.37	0.03	2.4	0.225	1.45	−0.04	−3.1
T5	1.39	0.336	0.269	1.74	0.261	1.68	0.05	3.1	0.282	1.82	−0.09	−4.8
T6	1.38	0.380	0.312	2.01	0.290	1.87	0.14	7.4	0.317	2.05	−0.03	−1.6
T7	1.28	0.298	0.226	1.45	0.225	1.45	0.00	0.2	0.240	1.55	−0.09	−6.0
T8	1.44	0.431	0.366	2.36	0.366	2.36	0.00	0.0	0.408	2.64	−0.27	−11.0
T9	1.40	0.386	0.319	2.06	0.298	1.92	0.13	6.7	0.327	2.11	−0.05	−2.6
T10	1.44	0.430	0.365	2.35	0.337	2.18	0.18	7.9	0.374	2.41	−0.06	−2.5
T11	1.41	0.440	0.373	2.41	0.378	2.44	−0.03	−1.3	0.423	2.73	−0.32	−12.5
T12	1.49	0.546	0.484	3.12	0.459	2.96	0.16	5.3	0.520	3.35	−0.23	−7.2
T13	1.49	0.557	0.495	3.19	0.517	3.33	−0.14	−4.4	0.589	3.80	−0.61	−17.4
T14	1.45	0.525	0.460	2.97	0.488	3.15	−0.17	−5.7	0.554	3.57	−0.60	−18.4
					Mean difference		*0.02*	*−0.16*			−0.18	−7.26
					Mean square deviation		*0.01*				0.07	
					Root mean square deviation		*0.12*				0.27	

match between measured and calculated values[10, 11]. More research is needed to validate the relationship or develop new ones based on clothing design, that considers draping, overlap, length and number of the layers, material stiffness, material compressibility etc. The recent studies in the field have started to fill this gap[3, 5, 28].

Conclusion

The equation 1 to estimate basic clothing insulation (I_{cl}) from individual items' insulation (I_{clu}) gave, in the case of this modern ambulance personnel clothing system with a relatively even insulation distribution over the whole body surface, very close results to the measured values (root mean square deviation 0.12 clo) and placed the trendline practically overlapping the line of identity (inclination 0.99 and intercept 0.04, R^2=0.98). This encourages evaluating and selecting protective clothing for ambulance personnel based on individual item measurements. It also allows to assume, that the calculations work for other modern workwear systems, at least from this manufacturer's assortment. For clothing insulation up to 2 clo, it can be assumed that simplified method (equation 2) works reasonably well, too. Considering that many manufacturers follow the modern, sporty workwear design based on layer-by-layer principle and use similar materials, then it can be assumed that the tested items' insulation values are relevant even for other manufacturers' products and could help to estimate basic insulation of various clothing ensembles for estimating exposure limits and thermal load in human thermal environments.

Disclaimer

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of their respective organizations.

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