Eur J Appl Physiol (2004) 92: 683–688
DOI 10.1007/s00421-004-1116-3

ORIGINAL ARTICLE

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Comparison of thermal manikins of different body shapes and size

Accepted: 9 January 2004 / Published online: 29 April 2004

Abstract Differences between manikins may be present due to manikin body shapes (male versus female). In order to examine such differences a study was designed. Comparisons were carried out based on: (1) tight versus loose clothing; (2) serial versus parallel calculation models; (3) even versus uneven clothing (insulation) distribution; and (4) the effect of donning clothes. Differences were observed between female and male manikins depending on body shape. However, these differences were within the range that was observed in the Subzero project, and were comparable with differences between manikins of male body shapes. Manikins behaved differently according to clothing adjustments. Tight-fitting clothes resulted in smaller differences. The effects of donning clothes were more pronounced with the serial calculation model, while the results generated by the serial and parallel calculation models differed more if the insulation was unevenly distributed (24% and 12% respectively). In order to examine the effect of body size, two baby manikins were compared to an adult manikin. The experimental conditions involved air layer insulation measurements (AL), lying on the back on an insulating surface (OB), and lying on the back on an insulating surface, covered with a sheet (OBS, baby manikins only). The acquired AL insulation for all manikins were very similar. The insulation value of adult manikin tested under condition OB differed from the others. This was related to flexible joints allowing the arms and legs to be in contact with the insulating surface, while baby manikins retained their arms and legs in the air. The baby manikins performed similarly in OBS tests.

Keywords Manikin · Female · Male · Thermal insulation · Calculation model · Insulation distribution

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Introduction

Several comparative studies on thermal models, or co-operative studies where models of similar size have been tested, are available (Anttonen 2000; Kuklane et al. 2003; McCullough et al. 2002; Meinander et al. 2003). Those studies present differences, although these are generally small (< 10%), between manikins tested in dry conditions. Here we raise the question of whether some of these differences can be related to the body shape of the manikin. Comparisons of the effects of different model sizes or relating the test results to body size have not been made. However, the importance of clothing fit and limiting body size for standard testing has been noted (ISO/DIS 15831, 2001).

Baby manikins have successfully been used for the evaluation of equipment for neonatal care (Sarman et al. 1992). We decided to use two different sized baby manikins in a comparison with an adult manikin in order to assess the maximum differences in the effects of body size.

Methods

In order to study the differences in body size and shape in detail two studies were designed. In the first study measurements were carried out on two manikins representing male (Tore) and female (Lady) body shapes (Fig. 1). Tests were carried out combining ensemble B garments of the Subzero project (Meinander et al. 2003). In the second study two baby manikins were compared to the adult manikin Tore (Table 1, Fig. 1 and Fig. 2).

Fig. 1 Lady and Tore during testing

Table 1 Manikins in Study 2

Manikin	Body area (m^2)	Height (cm)
B2	0.090	40
SB	0.309	66
T1 (Tore)	1.772	171

In Study 1 comparisons were carried out based on:

1. tight versus loose clothing
2. serial (individual area-weighted thermal insulation of all body segments are calculated and then summed) versus parallel (heat losses, area-weighted temperatures and segment areas are summed before the insulation calculation) calculation model (ISO/DIS 15831 2001)
3. even versus uneven clothing (insulation) distribution
4. the effect of donning clothes

In order to make the comparison and eliminate uncertainties both manikins in Study 1 were tested in the same lab. Garments with the correct fit and the same cut (clothes for males) were chosen and the same person dressed the manikins in the same way. The tests were carried out simultaneously on both manikins at +5°C and <0.3 m/s, and the same calculation and data control routines were used. As differences are usually reduced by motion all tests were carried out in stationary mode.

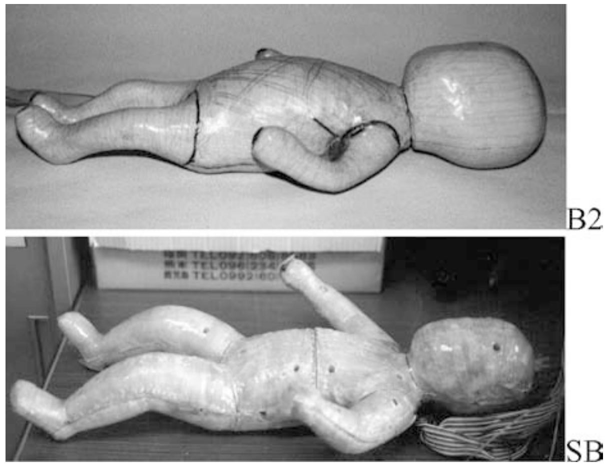

Fig. 2 B2 and SB

All the manikins in Study 2 were tested using the same computer program and similar measuring and control units. The conditions involved air layer insulation measurements (AL), lying on the back on an insulating surface (OB), and lying on the back on an insulating surface while covered with a sheet (OBS, baby manikins only). During the tests the air velocity in the test chamber was always $<0.4\ m \cdot s^{-1}$ (ISO/DIS 15831 2001). During the AL measurements for all models the contact with surrounding surfaces was minimized. The adult manikin was hanging vertically while baby manikins laid horizontally supported by wires at the neck and the ankles. The accuracy of power measurement of the systems in both studies was within 2% of the average power for the test period and deviations from the mean surface and air temperature did not exceed 0.1°C. Insulation was calculated from the surface (skin) to air temperature gradient and the power input (heat losses) to keep the manikins' surface temperature constant. Heat losses from all manikins stayed above 50 W/m^2 even for the warmest condition.

Results and discussion

The differences between replicates were less than 2% of the mean value for all measurements. Thus, the differences between the means of double determinations from manikins exceeding 4% would be statistically significant. Also, the standard sets a 4% difference limit for a double determination (ISO/DIS 15831 2001). This difference is commonly not important for practical use for lighter clothes but may gain importance with increasing insulation.

Study 1

Differences in the percentages between the measured total insulation for the serial and parallel methods, and Lady and Tore are presented in Table 2.

Table 2 Differences (%) between total insulation for the serial and parallel calculation methods, and Lady and Tore

Conditions	Serial versus parallel		Lady versus Tore	
	Lady	Tore	Serial	Parallel
Airlayer	3.3	3.8	2.3	2.9
Underwear (shirt inside)	5.1	4.3	3.3	2.5
Underwear (shirt outside)	5.5	4.3	5.0	3.7
Middle layer	10.1	15.0	8.0	2.8
Middle layer with cord	11.7	13.4	3.4	1.5
Middle layer (jacket in trousers)	11.4	13.5	2.4	0.0
Underwear and middle layer	13.4	15.7	3.9	6.5
SZ B	10.6	13.8	3.2	6.6
SZ B (no underwear and middle layer trousers and shoes, gloves)	22.3	26.5	5.8	10.9
SZ B (no underwear and middle layer trousers and shoes, gloves, cord)	19.5	23.0	6.9	10.9
SZ B (middle layer jacket outside outer layer trousers)	12.0	15.4	6.1	9.8
SZ B (with cord)	9.7	12.0	7.9	10.3

Air layer insulation

The differences in air layer insulation of the manikins were not considerable (Fig. 3). Lady had slightly higher insulation than Tore. As expected, the insulation measurement calculated by the serial method was only slightly higher than the insulation calculated by the parallel method.

Thin, tight-fitting clothes (underwear)

There were insignificant differences between Lady and Tore if the shirt was tucked inside the pants and the insulation was calculated by the parallel method (Fig. 4). If the shirt was worn outside the pants then the differences were slightly greater, but still not considerable in practical terms. The differences were in the same range as those for air layer insulation for both the parallel and serial calculation methods if the shirt was tucked inside the pants. However, if the shirt was worn outside the pants then the differences were greater. This was especially clear for Lady when the serial calculation method was used. This could be related to the body shape and the increased air layer that was created between the chest and the hips, but also to the fact that the serial calculation method is more sensitive to uneven insulation distribution.

Loose clothing (middle layer of ensemble B)

It should be noted that even if worn outside the pants, the underwear shirt still fitted the body quite tightly, while the middle layer was left hanging relatively freely. With loose clothing we see a different pattern of insulation (Fig. 5). While Lady had higher insulation for air layer and underwear than Tore, for loose clothing the opposite was found. This could be related to the fact that loosely hanging clothes allow more heat to escape directly from the body surface from the female body shape (more ventilation due to body curvature) than

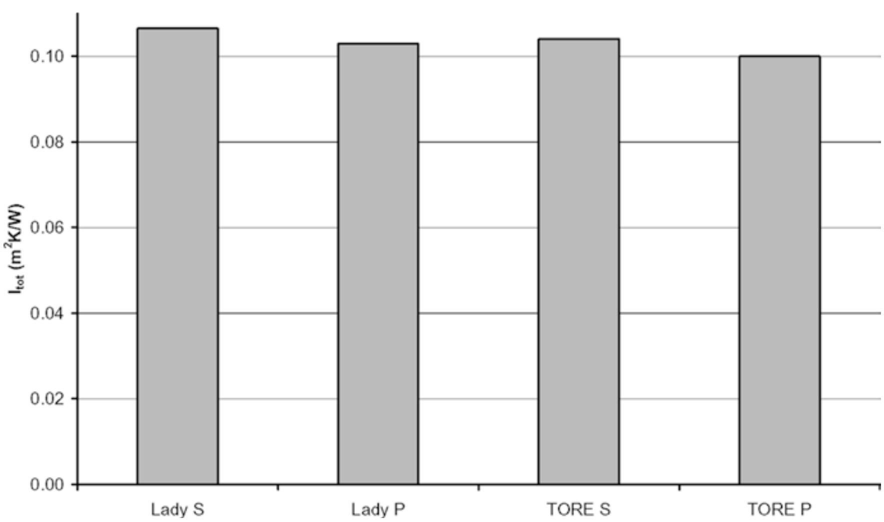

Fig. 3 Air layer insulation calculated with serial (*S*) and parallel (*P*) calculation methods

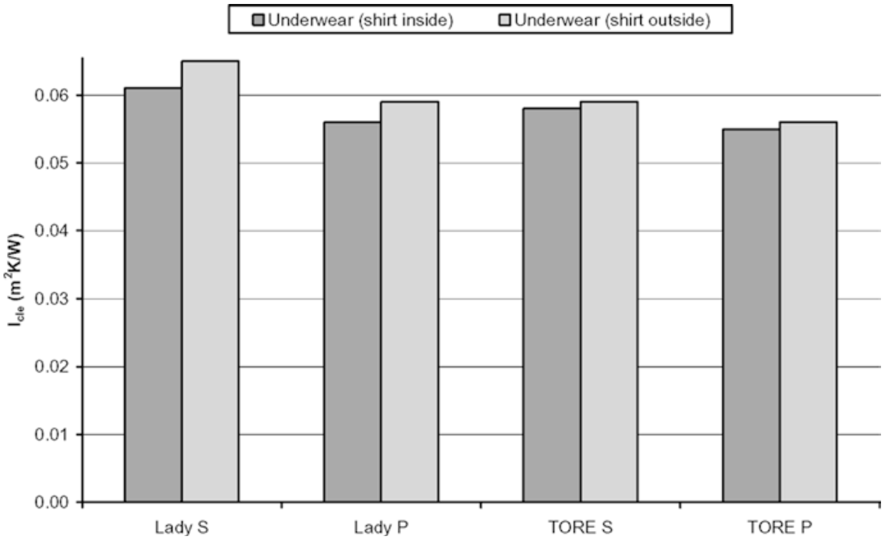

Fig. 4 Effective clothing insulation of tight fitting clothes (underwear) calculated with serial (*S*) and parallel (*P*) calculation methods

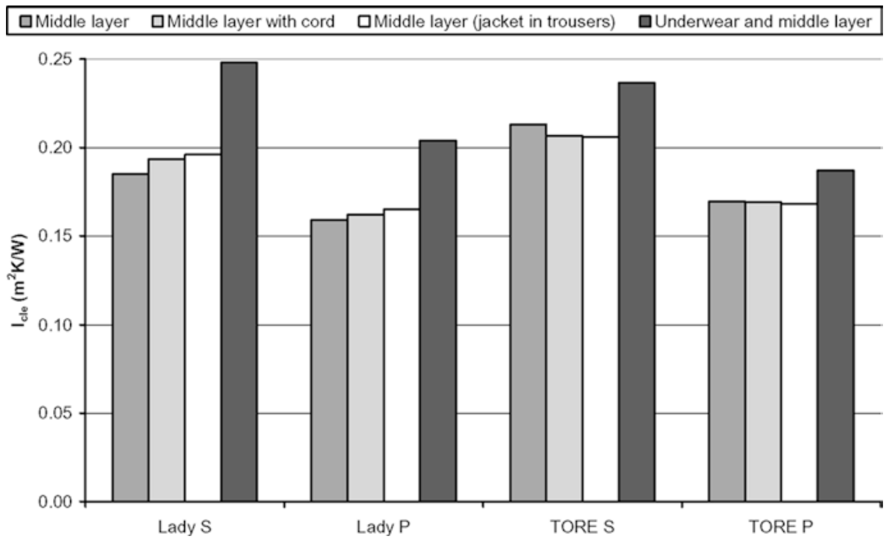

Fig. 5 Effective clothing insulation of loose fitting clothes (middle layer) calculated with serial (*S*) and parallel (*P*) calculation methods

from the male shape (flat chest). This effect was not present when underwear was combined with a middle layer. For example, the data in Fig. 5 show that in this case, once again Lady had higher insulation than Tore.

To check the behavior of the ensemble, tests with a cord round the waist (jacket outside pants) and with the jacket worn inside the pants were carried out. Although the changes were insignificant, a certain pattern was present. For Lady, both actions increased insulation indicating reduced ventilation, and for Tore they decreased insulation, indicating a compression of the layers. With the serial calculation method this effect was clearer, while with the parallel method the effect was almost unnoticeable.

Still, the differences between Lady and Tore did not exceed those observed in other comparative studies using manikins (Anttonen 2000; McCullough et al. 2002; Meinander et al. 2003). These differences between Lady and Tore were generally found to be more pronounced when using the serial calculation method for single-layer ensembles (underwear and middle layer, on average 4% serial and 2% parallel) while for multiple-layer ensembles (cold protective clothing) it was the opposite—the parallel calculation method gave bigger differences (on average 6% serial and 9% parallel).

Protective clothing against cold

The use of a cord on winter clothes had a similar effect as on loose clothing (middle layer), i.e. it increased slightly the insulation measured for Lady and reduced it for Tore (Fig. 6). However, if the cord was worn on clothing with an uneven insulation distribution (less insulation on the legs), the insulation was reduced for both manikins, an effect which was more pronounced when using the serial calculation method.

The differences in calculations with the serial and parallel methods increased with increased insulation (from 4 to 14%) and with unevenly distributed clothing (from 12 to 24%). A difference of 24% is very high and

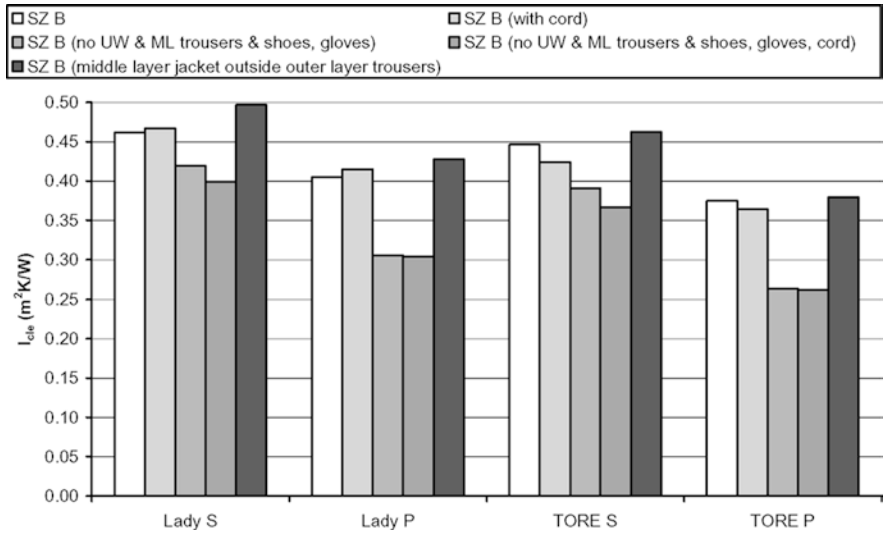

Fig. 6 Effective clothing insulation of winter clothes (Subzero B) calculated with serial (*S*) and parallel (*P*) calculation methods

should be considered during clothing choice. The effect on the user of unevenly distributed insulation must be evaluated, especially if clothing ensembles are chosen according to current recommendations, e.g. IREQ (ISO/CD-11079 2001). Furthermore, as seen in Fig. 6, the way of dressing the manikin could effect the insulation. Leaving the middle layer jacket outside the outer-trousers could increase the insulation from 1% (Tore, parallel method) to 6% (Lady, serial method).

Study 2

Figure 7 shows the total insulation for the baby and adult manikins. It can be seen that AL insulation for all manikins are very similar. In OB conditions, T1 differs from the others. This was due to flexible joints which allowed the arms and legs to be in contact with an insulating surface while the baby manikins still had their arms and legs in the air (Fig. 2). The baby manikins performed similarly in the OBS test. The insulation values for various body parts differed considerably more than those for whole manikins. This is possibly due to postural effects, including the contact area of various zones with the surface.

Conclusions

Differences were observed between female and male manikins depending on body shape. However, these differences were within the range that were observed between manikins of male body shapes during the Subzero project (Meinander et al. 2003). Manikins behaved differently according to adjustments of their clothing; for example, placing a cord around the waist commonly increased the insulation measured for the female manikin, while it reduced the insulation

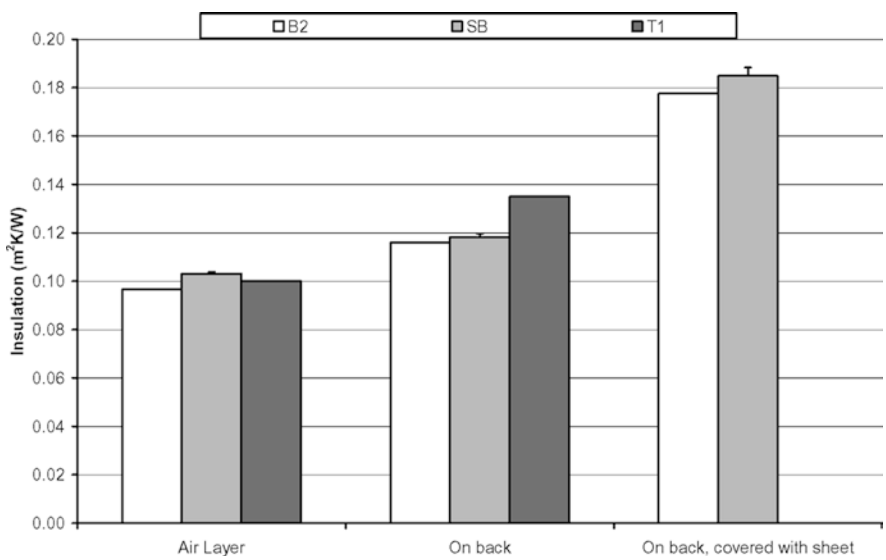

Fig. 7 Total insulation of baby and adult manikins

measured for the male manikin. Tight clothes allowed less difference between the two body shapes. The effect of donning clothes was more pronounced when calculated with the serial model, while the results from the serial and parallel models differed more with unevenly distributed insulation (up to 24%).

In order to obtain more homogenous test results from male and female manikins it is recommended not to tighten jacket cords at the waist. Donning of clothes should be clearly defined, or must be described in the test protocol, and taking photos is recommended. The effect of unevenly distributed clothing insulation should be studied further. Also, the behavior of clothes especially made for females must be studied.

No significant differences depending on the body size were observed. On the other hand, body posture related to rigid/flexible joints, e.g. lying on the back, had an effect. Care should be taken when interpreting results related to measurement values from separate body zones or relatively small zone groups, because of large errors. The same problem was encountered in Subzero project (Meinander et al. 2003) where a low standard deviation was found in the insulation values for the whole manikin, while the insulation for separate body parts or sections was much higher.

ISO/DIS 15831 (2001) determines very clearly the size of the manikin and emphasizes the importance of clothing fit. Here, Study 2 revealed no significant differences between manikins of different size. However, only simple, undressed conditions were tested. Therefore, the question becomes at which body size and insulation level differences occur and/or become critical. A study with specially manufactured well-fitting clothes on manikins of different sizes could answer this question.

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