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Introduction

An adequate assessment of the impact of thermal environments on human heat exchange, requires knowledge about clothing heat transfer properties. Material testing is not sufficient to enable accurate, reliable and quantitative predictions of the total body heat losses. Clothing design, fit, drape, layering and coverage of the body surface are factors that affects heat exchange, but are not accounted for in material tests.

Man-sized thermal manikins for test of clothing ensembles have been used for more than 50 years (2). In recent years thermal manikin testing has developed rapidly with new types of manikins and new application fields. In several international standards (3, 5) or draft standards (6) information about clothing thermal properties is required. Other documents (1, 4, 7) provide details for the actual testing of these properties. However, test and evaluation methods differ and the extent to which this influences the actual value of clothing is poorly investigated. Also, the relevance of the value for the final function of clothing in practice remains to be more extensively validated.

The problems have been addressed during the development of the draft document for Protective clothing against Cold within working group 4 of CEN TC122 (Protective clothing). The purpose of the first European seminar on Thermal Manikin Testing was to

- give examples of the use of physical models for clothing testing
- identify and discuss some of the problems related to test methods and interpretation of results
- propose appropriate ways of solving the problems and improving methods.

Ingvar Holmér

References

1. ASTM-F1291-96. Standard method for measuring the thermal insulation of clothing using a heated thermal manikin. ASTM, Philadelphia, 1996.
2. Holmér I. Use of heated manikin for clothing evaluation. Annals of Occup. Hyg. (95)
3. ISO-7933. Hot environments - analytical determination and interpretation of thermal stress using calculation of required sweat rates. ISO, Geneva, 1989.
4. ISO-9920. Ergonomics - Estimation of the thermal characteristics of a clothing ensemble. International Standards Organisation, Geneva, 1993.
5. ISO-EN-7730. Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. ISO, Geneva, 1995.
6. ISO/TR-11079. Evaluation of cold environments - Determination of required clothing insulation (IREQ). International Standards Organisation, Geneva, 1993.
7. prENV-342. Protective clothing against cold. CEN, Brussells, 1996.

Thermal manikin measurements for human thermoregulatory modelling: the needs and the options

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Background
Heat transfer from the human skin to the environment is modified by the presence of clothing. This effect is caused by the fabric of the garments, and the air trapped in and between the clothing layers, which add a resistance to the loss of evaporative (R_{ecl}) and sensible ((R_c) convective, radiative and conductive) heat [2, 13]. It is therefore necessary to measure or to estimate the magnitude of these variables if the influence of clothing on body temperatures are to be adequately considered in predictive thermal models.

What are predictive thermal models?
In recent years there has been an increasing interest in the development of mathematical models that can predict human heat strain or sensation. Two general categories of model can be recognised: those based on the heat balance equation which consider net heat balance, and those which attempt to predict individual components of heat strain [9].

The stimulus for the development of models of the latter type - heat strain models - derives from the practical need to avoid the risk and expense of experiments using human subjects to determine empirically thermal risks in the work-place. Complex thermal modelling has been made possible by the availability of easy-to-use computers, and by a deeper understanding of the science of human heat strain. As the models become more accurate they have become a valuable tool to define safe indoor and outdoor exposures to heat and cold. They have also been adopted for use in International and European Standards relating to heat [5] and cold [6] strain, and thermal comfort [7] because they offer a fast, low-cost and harmonised way of limiting risk and maximising effectiveness in the work-place.

Two main types of heat strain model have developed. First, empirical models which use 'curve-fitting' techniques to describe human test data, and then extrapolate those curves to make predictions of heat strain in conditions where no test data are available [1]. Second, rational (analytical) models which use the principles of human thermoregulation and heat exchange to develop equations to predict heat strain [1]. Rational models are validated using human test data, and may contain empirically-derived information (for example, the specific heat of body tissues), but otherwise they are not dependent on human subject tests.

What are thermal models used for?

Thermal models usually predict values of one or more indicators of human heat strain (core and skin temperatures, sweat loss, heat storage *etc*) at specific time intervals during a simulated exposure. These values themselves are then used to predict safe or practicable working practices in a variety of work-place situations *eg* in the heat: the duration of safe work or of rest periods, measures to prevent dehydration; and in the cold: the need for whole-body insulation [6].

Inputs needed by thermal models

The human response to a heat or cold stress depend on an interaction of variables which describe 4 factors: the individual being exposed (size, gender, physical fitness, state of heat acclimation *etc*); the thermal environment (air temperature, air speed, water vapour content and radiant temperature; the clothing worn (resistance to sensible and evaporative heat loss, weight, air permeability *etc*) and the nature of the work being carried out (duration, metabolic heat produced, mechanical work achieved *etc*).

It is relatively easy to estimate, or to measure, to the required accuracy variables relating to the individual, thermal environment and work. It is often more difficult to do the same for the clothing being worn. Yet sensitivity analysis of thermal models has shown that the output predictions are critically dependent on the values of clothing resistances used at the input stage. Hence, if predictive models of human heat strain are to be of practical value, it is vital that accurate and precise measurements of sensible and evaporative resistances are available.

A problem with nomenclature

The scientific literature defines several types of resistance for garments and clothing ensembles, depending on the exact method of measurement [12]. Each definition has limitations. The main definitions of interest here are:

What is measured in practice?

Measurements of thermal resistances can, in principle, be made using human test subjects or physical techniques. It is important to distinguish that in this case the human subjects are being used to measure the biophysical properties of the clothing, not as a means of measuring the effects of clothing on the human. Sensible and evaporative resistances of fabrics are measured using small samples, singly or in combinations that represent the use of the layers to make multi-layered clothing ensembles. Methods of this type are frequently referred to as 'flat-plate' measurements. However, there is yet no satisfactory way of using these 'flat-plate' data to predict the resistances of garments or ensembles made up from the fabrics. This is a fruitful topic for empirical and theoretical studies.

Resistance	Definition	Comment
Intrinsic (basic)	A fundamental property of clothing whose magnitude is independent of the thermal environment.	By definition this does not account for effects of trapped air and external air penetration (wind). May be inadequate for multi-layer ensembles.
Total	The sum of the intrinsic resistance and that of the surrounding (boundary layer) air.	Magnitude is dependent on the thermal environment.
Resultant	The value obtained when the clothing is used by human subjects.	Takes account of factors that reduce insulation when the clothing is worn: sizing and fit, posture, movement, clothing compression *etc*.

Note: This terminology is applicable to both sensible and evaporative resistances.

Because of the absence of an adequate method of making predictions from 'flat-plate' data, sensible and evaporative resistances of garments and clothing ensembles are often measured using thermal manikins housed in controlled-conditioned rooms [4]. The advantages of this technique over using human subjects include speed and ease of measurements, less inter-measurement variability and lower cost per measurement. However, manikins are expensive to acquire and to maintain, and require skilled technicians to make the measurements.

Limitations of thermal manikin measurements

If thermal manikin data are to be of value in predictive models they must reflect the resistances that would be experienced by humans in similar circumstances. This implies that factors such as fit, sizing, drape *etc* should be similar on the manikin and on humans. Furthermore, resistances measured on humans will reflect the distribution of skin temperature and wettedness that the human would have in the test conditions - factors that are known to influence the value of clothing resistances. There is another important factor to consider. In use on moving subjects the resistance offered by a given clothing ensemble will be lower than that measured on a static manikin. This occurs because movement, changes of posture, ventilation of the clothing by ambient air and many other factors lower the resistance [12]. In other words, the intrinsic resistance represents an idealised resistance value; the value experienced by the clothing user is the resultant resistance.

Manikins are usually limited in the range of postures they can adopt (if any) and the range and speed of movements they can make (if any). Hence it is common practice to limit manikins to measurements of intrinsic or total resistance, often at more than one 'wind' speed [8]. Reported values often fail to specify the posture, fit and design of clothing, or thermal conditions in which the values were obtained. Hence modifying these values to reach an estimate of the resultant insulation is often difficult.

Furthermore, measurement of evaporative resistance requires that the 'skin' of the manikin is wet. For convenience and practicability the skin wettedness is often set at 100%. In most currently-used thermal manikins this is achieved by manually spraying the skin with water before dressing the manikin. This means that the skin can partially dry during the measurement period, resulting in non-stable values with unquantified errors. Ways of keeping the skin 100% wet have been developed, including the use of artificial 'sweat glands' or continuously pumping water onto the skin during measurements.

Another problem arises from the definition of sensible and evaporative resistance. R_c and R_{ecl} are values are valid only for dry clothing; in the case of R_{ecl} it is a value of the permeation of the clothing by water vapour. So, unless steps are taken to prevent water from the skin wetting the clothing, the resulting resistance values contain errors. These errors are not usually considered in published data.

In work-place applications there is an infinite variety of clothing ensembles; measuring resistances for every one is impossible. This problem has been overcome by publishing databases of resistances for individual garments [8]. Techniques have been developed to allow the prediction of ensemble resistance values from the resistance values of individual garments. The technique depends on suitable regression equations relating ensemble resistance to summed garment resistances being validated [10]. A further difficulty is that resistance values obtained from the measurement of a garment is dependent on whether part or all of the manikin was heated, and on the area of the heated manikin that is covered by the garment [11]. Published data seldom consider these important factors.

Use of manikin measurements in heat strain predictions

From these considerations it is clear that in attempting to model human thermal responses for practical applications, many explicit or implicit limitations must be taken into account. However, even when this is done problems remain. For example, the choice of which model to use will be strongly influenced by the nature of the application, the availability of reliable input data, and the accuracy needed of the input variables. An example calculation will show in more detail the importance of this latter point.

Suppose the requirement is to predict the time-course of trunk core (equivalent to rectal) temperature change in a population exposed to hot conditions whilst wearing protective clothing. Figure 1 shows predictions using the measured value of sensible thermal resistance (I_{cl}), 1.68 clo, and values 20% higher and lower than this. The model is of the empirical (curve fitting) type. It can be seen that in this case the predicted trunk core temperature is little influenced by changes in the value of I_{cl} for these particular input conditions. (This does not, of course, mean that if the output would show this very low sensitivity for all valid values of the input variables.)

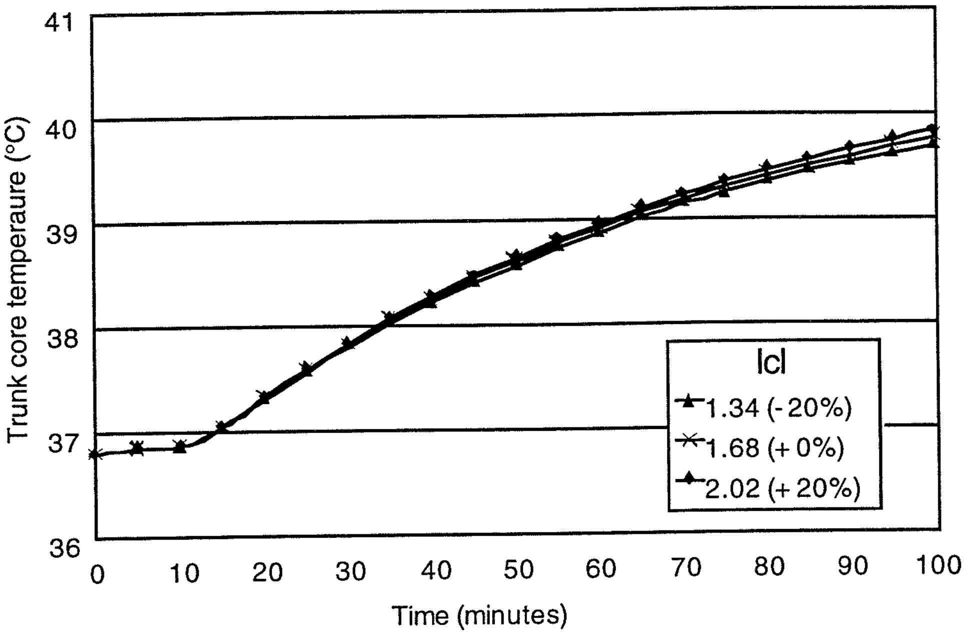

Figure 1
Predicted trunk core temperature using an empirical heat strain model.
Note the lack of sensitivity of output to changes in values of the intrinsic clothing insulation (I_{cl}). Input variables for these predictions were air temperature = globe temperature = 35°C; relative humidity = 50%; air speed = 1.1 ms^{-1}; work rate = 175 Wm^{-2} ; External work done = 0 Wm^{-2} ; Woodcock moisture permeability index (i_m) = 0.3.

Figure 2 shows the predicted trunk core temperature for the same input conditions using a rational thermal model. In this case 20% changes of sensible resistance (expressed as the intrinsic clothing insulation I_{cl}) have a marked effect on the time-course of the trunk core temperature.

Comparison of Figures 1 and 2 clearly shows that the type of predictive thermal model chosen will dictate the accuracy required of the resistance measurements. It will be inappropriate in some circumstances to require the measurement of resistance values with a high accuracy; low accuracy measurements or estimates may be adequate. Subject-matter experts are required to make these choices. One factor that will influence their choice is the degree to which the output is dependent on changes in input values - the sensitivity of the predictive thermal model.

It is possible to examine the importance of this sensitivity by plotting the time taken to reach a chosen, limiting trunk core temperature as a function of change in the values of I_{cl}. This is done in Figure 3, which shows the effect of changes in I_{cl} on time to reach trunk core temperatures of 38°C and 39°C.

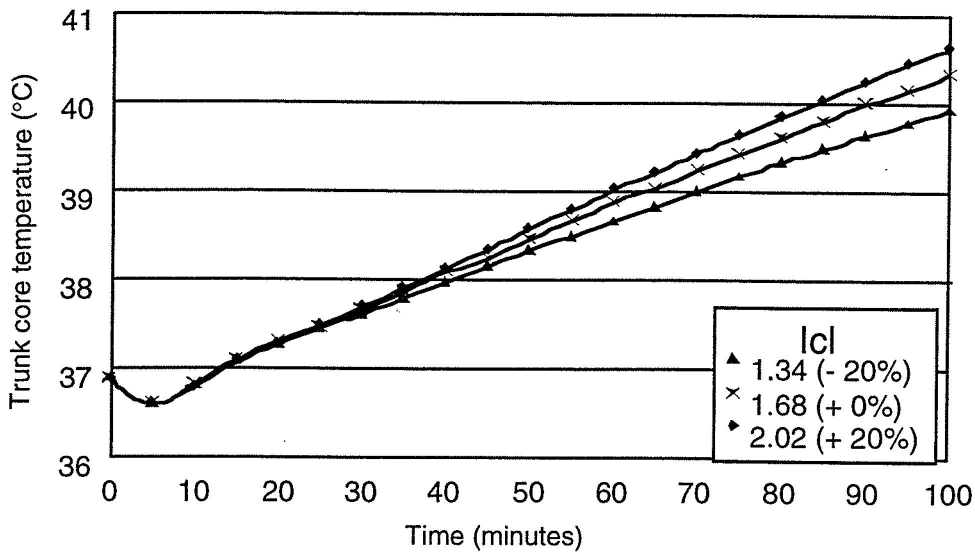

Figure 2

Predicted trunk core temperature using a rational (analytical) heat strain model.

Note that the output is sensitive to changes in values of the intrinsic clothing insulation (I_{cl}).

Input variables for these predictions were the same as for Figure 1.

Time to reach the limiting temperature is reduced by 14% and 18% respectively for 50% changes in the value of I_{cl}. The particular quantitative relationship shown in Figure 3 is, of course, true only for the specific values of input variables used; it will change as the values of the variables change.

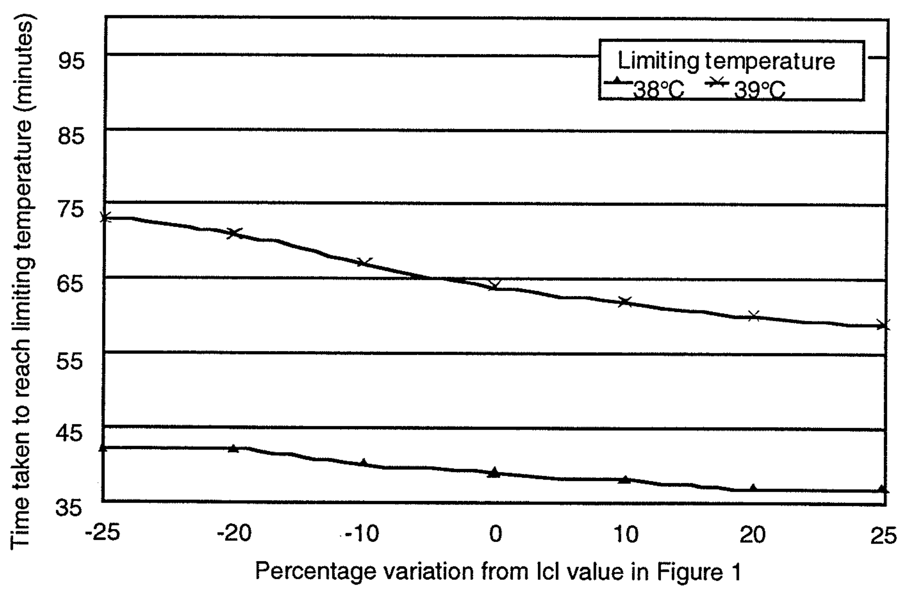

Figure 3

The effect of changes in values of sensible heat resistance (Icl) on time to reach limiting trunk core temperature.

This figure shows the need to consider the accuracy required from thermal manikin measurements.

To illustrate this point compare Figure 3 with Figure 4, in which the air temperature has been reduced from 35°C to 31°C, with all other variables being held at the values used in Figure 3. The relationship between time to reach the limiting trunk core temperature and changes of I_{cl} has changed: a 50% change in I_{cl} now reduces time to limiting trunk core temperatures of 38°C and 39°C by 22% and 29% respectively.

The implication of the results shown in Figures 3 and 4 is that the accuracy needed from measurement or estimation of any of the input variables depends on the values of the other variables. A sensitivity analysis should always be done before a predictive model is used.

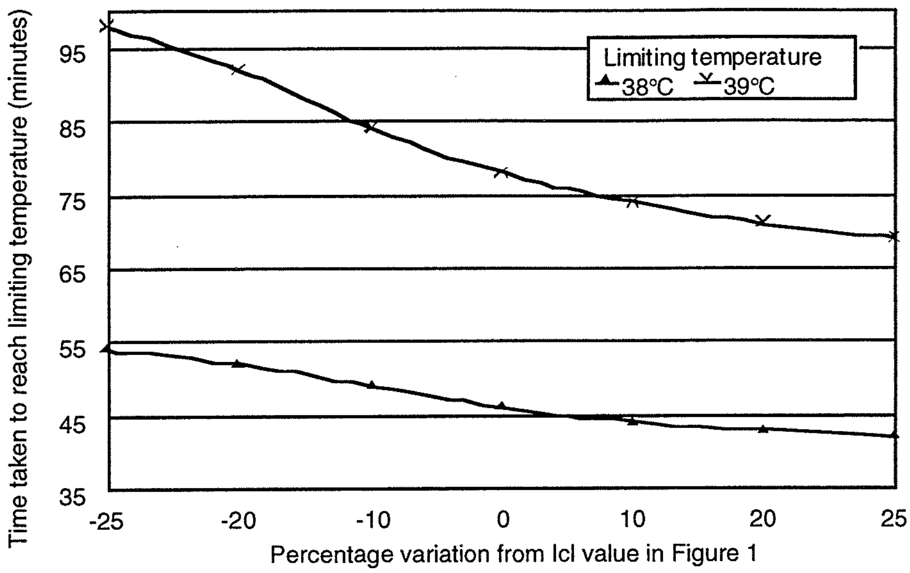

Figure 4
The effect of changes in values of sensible heat resistance (Icl) on time to reach limiting trunk core temperature.

The data used to generate this graph are the same as those used to generate Figure 3, with the exception that air temperature has been reduced by 11.5%.

Clothing measurements for use in thermal models

It is therefore apparent that in order to make reliable predictions of heat strain using thermal models it is essential to consider both the variables needed for accurate prediction and the required accuracy in their measurement. In the case of clothing variables (sensible and evaporative resistances) the values inputted to the models must account for the effect of use in human subjects on the resistances. This demands that resultant, rather than intrinsic or total, resistances are measured or estimated [3]. In the empirical model used to calculate Figure 1 this is done by calculation; in the rational model used to calculate Figure 2 it is achieved by incorporating a correction based on empirical data.

Clothing variables measured on thermal manikins or humans?

It is possible to measure both intrinsic and total, and resultant resistances using thermal manikins and human subjects. The broad implications of these two methods of measurement are set out below:

Required characteristic	Thermal manikin	Human subjects
Accommodates garments and ensembles of different fit, sizing and design	Single size, so fit of different garments is difficult.	Range of sizes
Simulate movement	Must be articulated with range of types and speed of movement. Movement must reproduce human motion.	Accurate movements possible
Posture	Articulated to simulate standing, sitting, crouching etc	All postures possible
Segmental heating	Needed to measure garment resistances. To cater for all garment designs segments must be infinitely adjustable.	Not possible. Evaporative resistance can be measured segmentally by wrapping uncovered parts in water-vapour-impermeable material.
Adjustable skin temperature in different segments	Possible, but to cater for all garment designs, the size of segments must be infinitely adjustable.	Possible
Segmental sweating	Feasible but mechanically difficult	Possible
Control of clothing wetting	Not possible. But can limit to resistances of non-wetted clothing by covering wet 'skin' with water- vapour-permeable material.	Not possible. But can limit to resistances of non-wetted clothing by covering wet skin with water- vapour-permeable material.

It is clear from this analysis that in most cases measurements using human subjects give the required design features. To simulate the human by developing more sophisticated thermal manikins is technically complex, expensive and probably not cost-effective. Even the most complex thermal manikin imaginable is a poor substitute for the human. However, thermal manikins can, in principle, make accurate and reproducible measurements and are cheaper per measurement.

Conclusions

It is apparent then that to model human heat strain with the accuracy need for practical application in the work-place the following principles should guide thinking and progress:

Heat strain predictions require the use of resultant sensible and evaporative resistances.

If intrinsic resistances only are measured, many more methodological details must be reported than is customary, so that adjustments can be made to intrinsic values to represent resultant values (see The way forward).
Heat strain predictions are sensitive to the input values of clothing resistances, so systematic estimates must be made of the practical accuracy needed of clothing resistance measurements.
Simple methods of measuring intrinsic and resultant sensible and evaporative resistance may be adequate for many practical uses.
Development of complex thermal manikins with wide range of complex movements, surface temperatures and sweating patterns is probably unnecessary for most uses, but may be of value in clothing science research. Further development should be limited to essential requirements based on a systematic review of the need for the measurements.
Standards and other guidelines which require the use of clothing thermal resistances must take account of the application of the data so as not to over-specify the accuracy needed.
Methods of using thermal manikins must be practicable, repeatable, sensitive to key variables and valid.

The way forward

Based upon the considerations discussed above, the following way forward is proposed as a pragmatic approach to making scientifically-valid and cost-effective progress in thermal manikin measurements of clothing resistances, and in predictive thermal modelling.

When values of intrinsic and total sensible and evaporative resistances only are reported

1. Report all relevant variables:
posture
movement
thermal environment
segments heated
temperature distribution
garment design, size, fit, number and type of openings, area of manikin covered *etc* [This assumes there is a systematic taxonomy to describe these factors.]
detailed methodology, to include:
sensitivity
repeatability
accuracy

2. Standardise measurement methods
manikin design
thermal environment
posture etc
methodology
terminology

When the end use requires values of resultant sensible and evaporative resistances

3. Use empirical methods to modify intrinsic values to resultant values.

4. Develop analytical models of multi-layer clothing to:
identify major factors modifying intrinsic resistances in use
quantify these factors
prioritise the factors for use in practical applications
[This could also be achieved, of course, by empirical methods, but this will be less versatile and will be costly.]

5. Develop current thermal manikins to measure resultant resistances of garments and clothing, having taken account of the inevitable limitations of the methods, the accuracy need and the prioritised features identified as a result of the analysis proposed in Paragraph 4 above.

References

1. Haslam, R A and Parsons K C: A comparison of models for predicting human response to hot and cold environments.
*Ergonomics 1987 **30** (11) 1599-1614.*
2. Haslam, R A and Parsons K C: Quantifying the effects of clothing for models of human response to the thermal environment.
*Ergonomics 1988 **31** (12) 1787-1806.*
3. Holmer, Ingvar: Resultant or basic insulation - which is the best predictor of clothing performance?
Proceedings of the International Conference of Environmental Ergonomics IV, Austin, Texas, USA. 1 to 5 October 1990 88-90.
4. Holmer, Ingvar and Nilsson, Håkan: Heated manikins as a tool for evaluating clothing
*Annals of Occupational Hygiene 1995 **39**(6) 809-818.*
5. International Standardisation Organisation: Hot environments - Analytical determination and interpretation of thermal stress using calculation of required sweat rate. *ISO 1933;1989.*
6. International Standardisation Organisation: Evaluation of cold environments - determination of required clothing insulation (IREQ). *ISO Technical Report ISO/TR 11079: 1993.*
7. International Standardisation Organisation: Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort. *ISO 7730: 1994.*
8. International Standardisation Organisation: Ergonomics of the thermal environment - estimation of the thermal insulation and evaporative resistance of a clothing assembly. *ISO 9920: 1994*
9. Lotens, W A: Comparison of thermal predictive models for clothed humans
*ASHRAE Transactions 1988 **94** 1321-1340.*
10. Lotens, Wouter A: The actual insulation of multi-layer clothing

Scandinavian Journal of Work, Environment and Health 1989 ***15*** *(Supplement 1) 66-75.*
11. Neale M S, Withey, W R, Mishan, C E and Parsons, K C. Theoretical maxima for clothing insulation values.
Environmental Ergonomics: Recent progress and new frontiers. 7th International Conference on Environmental Ergonomics, Jerusalem, 27 October - 1 November 1966. editors; Shapiro Y, Moran, D S and Epstein, Y. Freund Publishing House Ltd, London and Tel Aviv. 389-392.
12. Olesen B W, Sliwinska E, Madsen, T L and Fanger, P O: Effect of body posture and activity on the thermal insulation of clothing: measurements by a movable manikin.
ASHRAE Transactions 1982 ***88*** *791-805.*
13. Parsons, K C: Protective clothing: heat exchange and physiological objectives
Ergonomics 1988 ***31****(7) 991-1007.*

Analysis of two methods of calculating the total insulation

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Introduction

In the new proposed European standard prENV 342:1997 only one method for calculating the total thermal resistance is used. This presentation shows how that method and previously widely used methods (ASTM-F1291-96 1996, ISO-9920 1993) gives under some conditions very different results.

The formulas used in the 1995 version of the draft standard have two different ways of summing up the total insulation of the garment ensemble. The 95' version performs a "Total" summation which means all heat losses, temperatures (area weighted) and areas are summed up before the calculation of the total insulation. This is the method used mostly over the world (McCullough E. A. et. al. 1996, Olesen B. W. et. al. 1983). The other principle makes a summation of all "Local" heat losses weighted by the area factors for the different zones.

prEN 342:1995

$$I_{t,r} = \frac{\left(\left(\sum_i f_i \cdot T_{si}\right) - T_a\right) \cdot A}{\sum_i H_{ci}} \quad \frac{m^2K}{W}$$ referred to as $I_{t,r}(95)$ or "Total"

$$f_i = \frac{a_i}{A}$$

prENV 342:1997, prEN 342:1995

$$I_{t,r} = \sum_i f_i \left[\frac{(T_{si} - T_a) \cdot a_i}{H_{ci}}\right] \quad \frac{m^2K}{W}$$ referred to as $I_{t,r}(97)$ or "Local"

$$f_i = \frac{a_i}{A}$$

Figure 1. Calculation of test results

If the manikin is covered with exactly the same insulation over all sections the results from the two formulas is the same. If the heat loss from one ore more sections are substantially lower, compared to the other zones, the "Local" formula will give a higher value. This could easily happen when some garments, of many reasons, have very different insulation on different body parts. For example is the insulation around the waist is often higher due to overlapping of the clothing. One way for a manufacturer to get a higher value would be to distribute the insulation so that the ensemble has a very high insulation on the upper body. Consequently very low insulation on the lower body could increase the total insulation. The insulation calculated with the "Local" equation would then be higher compared to the "Total", that would give the same value as if the insulation was evenly distributed.

Calculations
The following calculation tries to show this difference. An imaginary thermal manikin with an area of 2 m^2 and a surface temperature of 34 °C. The manikin gives a constant heat loss of 100 W at two different temperature gradients, or imaginary clothing's, 20 and 30 °C.

Table 1a. Thin "imaginary" clothing

T_{s1}, T_{s2} (°C) = 34.0 T_a (°C) = 14.0 a_1, a_2 (m^2) = 1.0 H_c (W) = 100

H_{c2}, H_{c1}	H_{c2}/H_{c1}	$I_{t,r}$ (96)/ $I_{t,r}$ (95)	$I_{t,r}$ (95)	$I_{t,r}$ (96)	clo (96)
50, 50	1.000	1.000	0.400	0.400	2.58
60, 40	1.500	1.042	0.400	0.417	2.69
70, 30	2.333	1.190	0.400	0.476	3.07
80, 20	4.000	1.563	0.400	0.625	4.03
90, 10	9.000	2.778	0.400	1.111	7.17
95, 5	19.000	5.263	0.400	2.105	13.58
99, 1	99.000	25.255	0.400	10.101	65.17

Table 1b. Thicker "imaginary" clothing

T_{s1}, T_{s2} (°C) = 34.0 T_a (°C) = 4.0 a_1, a_2 (m^2) = 1.0 H_c (W) = 100

H_{c2}, H_{c1}	H_{c2}/H_{c1}	$I_{t,r}$ (96)/ $I_{t,r}$ (95)	$I_{t,r}$ (95)	$I_{t,r}$ (96)	clo (96)
50, 50	1.000	1.000	0.600	0.600	3.87
60, 40	1.500	1.042	0.600	0.625	4.03
70, 30	2.333	1.190	0.600	0.714	4.61
80, 20	4.000	1.563	0.600	0.938	6.05
90, 10	9.000	2.778	0.600	1.667	10.75
95, 5	19.000	5.263	0.600	3.158	20.37
99, 1	99.000	25.255	0.600	15.152	97.75

It is easily seen that a shift in heat loss between the two virtual zones of only 20% or 10 W/m^2 gives a difference of 4.2% between the different methods. With greater differences does the increase grow very rapidly. In reality can some zones, for instance the inside of the arms, specially with well insulated clothing produce insulation values that heavily distorts the total insulation value. The relationship between the heat losses and the differently calculated results are shown in the figure below.

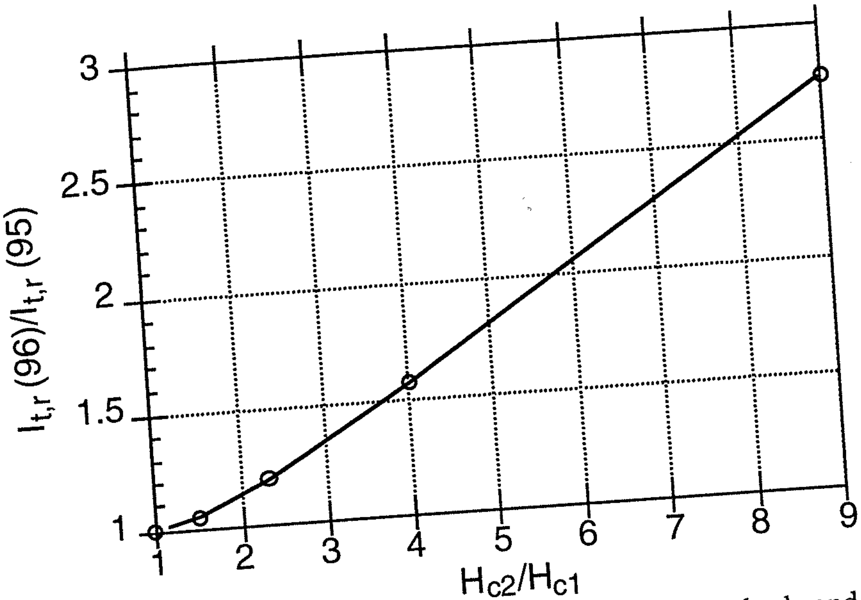
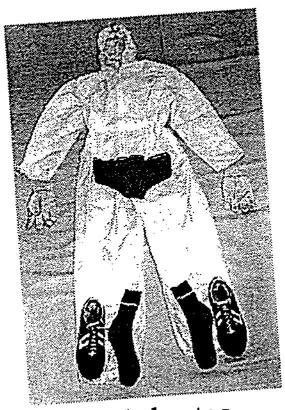


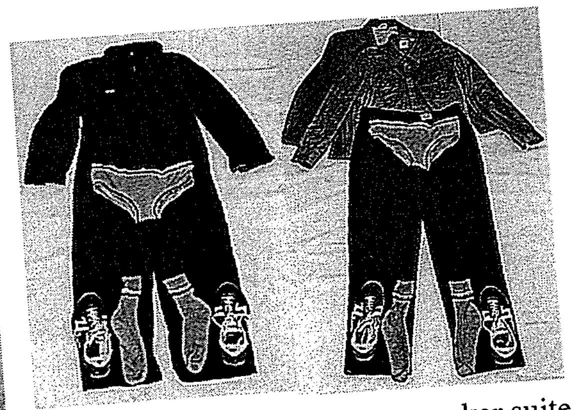
Figure 2. Relationship between the two calculation methods and different heat loss on the two virtual zones.

Measurements
The discussions above states that an uneven insulation distribution gives *higher* insulation values calculated with $I_{t,r}$ (96) Local instead of $I_{t,r}$ (95) Total. The following clothing ensembles have been used in recent insulation investigations. They represents a wide choice of different personal protective garments regarding insulation as well as number of layers.

1, Asbestos protection - Tyvek

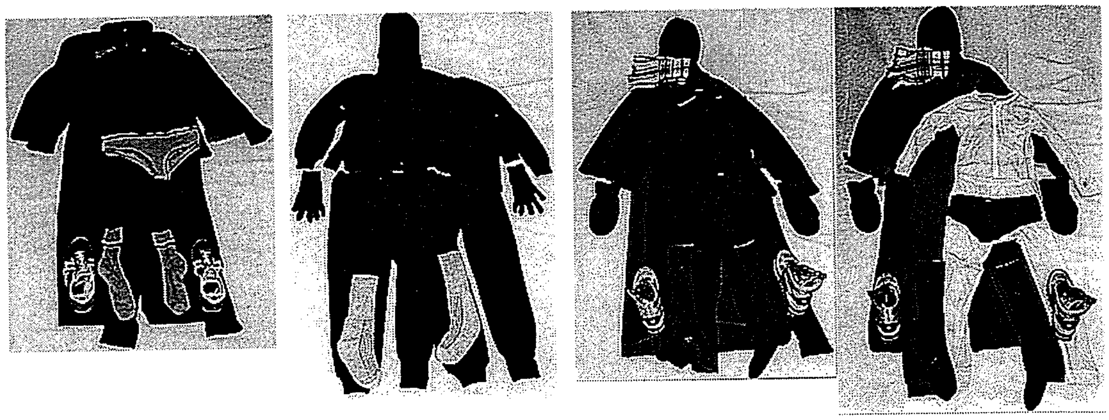


2. Asbestos protection - Polypropylen



3. Overall without underwear

4. Store worker suite



5. Overall with underwear

6. Standard (prENV 342:1997 type B)

7. Work clothes - synthetic

8. Work clothes - wool

Figure 3. The different clothing combinations used in the investigation.

In the table below the results from measurements made with the different ensembles in standing low wind conditions is shown. The differences between "Local" (L), always higher, and "Total" (T), lower, is clearly shown. The nude or lightly clothed measurements show similar results but the difference increases with different number of layers and the degree of overlapping.

Table 2. Calculation of insulation values with both methods

Clothing combination	$I_{t,r}$ (clo)	$I_{t,r}$ (m^2K/W)	
Working clothes synthetic	2.78	0.430	*L*
More around the waist	2.54	0.394	*T*
Working clothes wool	4.61	0.715	*L*
Thick around the waist	3.47	0.538	*T*
Light suite	1.84	0.284	*L*
Thick around the waist	1.51	0.234	*T*
Asbestos protection Tyvek	1.33	0.207	*L*
Evenly distributed	1.30	0.202	*T*
Asbestos protection PP	1.38	0.214	*L*
Evenly distributed	1.33	0.207	*T*
Overall w/o. underwear	1.45	0.225	*L*
More around the waist	1.38	0.214	*T*
Overall with underwear	1.72	0.267	*L*
More around the Waist	1.62	0.250	*T*
Standard A	2.24	0.348	*L*
More around the waist	1.97	0.306	*T*
Undressed	0.73	0.114	*L*
Evenly distributed	0.71	0.110	*T*

Table 3. Relative differences between *Total* and *Local* calculations

Clothing combination	From	To	
Working clothes synthetic	**8%**	**13%**	(%)
More around the waist	**0.000**	**0.009**	m^2K/W
Working clothes wool	**15%**	**25%**	(%)
Thick around the waist	**0.000**	**0.014**	m^2K/W
Light suite	**16%**	**22%**	(%)
Thick around the waist	**0.000**	**0.002**	m^2K/W
Asbestos protection Tyvek	**2%**	**6%**	(%)
Evenly distributed	**0.000**	**0.004**	m^2K/W
Asbestos protection PP	**2%**	**7%**	(%)
Evenly distributed	**0.001**	**0.012**	m^2K/W
Overall w/o. underwear	**5%**	**13%**	(%)
More around the waist	**0.000**	**0.011**	m^2K/W
Overall with underwear	**6%**	**17%**	(%)
More around the Waist	**0.000**	**0.015**	m^2K/W
Standard A	**12%**	**15%**	(%)
More around the waist	**0.000**	**0.010**	m^2K/W
Undressed	**1%**	**6%**	(%)
"Evenly distributed"	**0.000**	**0.008**	m^2K/W

In the table above are the relative differences in percent calculated. The proposed standard suggests that differences between double determinations should be less then 5%. It is obvious that there is a danger in calculating these values in different ways. An "error" of 25, or more, percent can easily be accomplished.

Suggestions

How ever there is a point in making the calculations in the two ways. The "Local "calculation could serve as an indicator for possible erroneous measurements. Also serve as a warning for ensembles that have to extreme distribution of the insulation and hence probably will create problems for the wearer. The "Total" value is a more stable indicator of the insulation of the ensemble and should therefore be used for clothing declaration purposes.

The suggestions are; make both calculations.

• *IF* the difference is greater than, for instance, 33% then either there is a measurement error *OR* the insulation distribution is to extreme.

• Label with the *Total* value. This prevents manufacturers to manipulate insulation distribution to get higher values.

References

ASTM-F1291-96, Standard method for measuring the thermal insulation of clothing using a heated thermal manikin . ASTM, 1996,

ISO-9920, Ergonomics - Estimation of the thermal characteristics of a clothing ensemble . International Standards Organisation, 1993.

McCullough E. A. and Kim C. S. Insulation values for cold weather clothing under static and dynamic conditions. ICEE 96, Environmental Ergonomics, Tel Aviv. Freund Publishing House, Ltd. 1996: 271-274.
Olesen BW, Nielsen R. Thermal insulation of clothing measured on a movable thermal manikin and on human subjects . Technical University of Denmark, ECSC Programme Research Nr 7206/00/914, 1983.

Methods for handwear, footwear and headgear evaluation

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Introduction

There are several whole body thermal models/manekins available for evaluation of climatic conditions and clothing (Holmér and Nilsson, 1995; Holmér et. al., 1995; Meinander, 1992). Generally the main principles are to keep certain variables constant, e.g. surface temperature of the model and environmental temperature, and changing other parameters, e.g. clothing and measureing the difference in third parameters, e.g. power input. Further analysis can give useful information on products. The regulation program for thermal models that is used in our laboratory allows to choose a constant surface temperature, a constant heat loss or a physiological surface temperature. However, most commonly, constant surface temperature is used (usually 34 °C) for measuring heat losses or calculation of clothing insulation. The calculations are carried out by 2 basic formulas:

$$Q_m=P_m/A_m \quad (1)$$

$$I_{tr}=(T_m-T_a)/Q_m \quad (2)$$

P_m - power to a model (W); A_m - surface area of a model (m^2); Q_m - heat loss from a model (W/m^2); T_m - surface temperature of a model (°C); T_a - environment (ambient air) temperature (°C); I_{tr} - insulation ($m^2 °C/W$).
Models are divided into zones and heat losses for each zone can be calculated separately. It allows more precise evaluation of climatic condition or clothing. For evaluation of clothing insulation a total insulation is always calculated, too.
Often full-scale manekin are not made for specific measurements, for example hand, finger or foot measurements. A more exact evaluation of various local areas is needed. Our laboratory has developed three thermal models - hand, head and foot model - for studying more precisely the thermal properties of gloves, headgear and footwear. These models work on the same principles as whole body mannequins. The heat losses and/or insulation values are calculated for each zone separately and as total for all or some specific combination of zones.

Handwear evaluation

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The hand model is divided into ten zones (Figure 1). All fingers make a separate zone as well as palm, back of hand, wrist and lower arm. The tenth zone is a guard zone.
The measurements are carried out according to standard EN 511. The standard setup is shown in Figure 2. A gloved hand is placed into a wind tunnel upside down so that the wind blows into palm. Air temperature is measured inside a tunnel and wind speed is set to 4.0 ± 0.2 m/s. A detailed description of hand and experimental conditions is given in standard EN 511. However, for research purposes it is important to study various conditions and situations. The effect of wind and combining double gloves are studied and the result shown in Figure 3. Test with wind is the standard test.

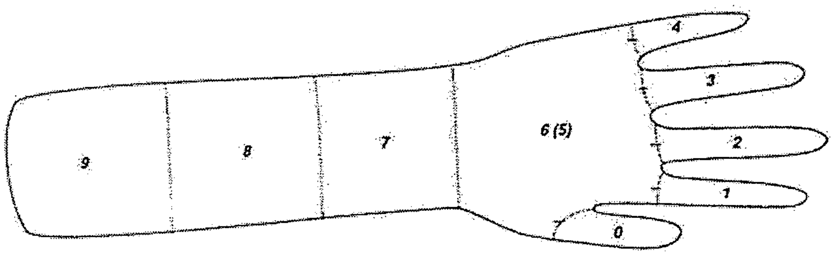

Figure 1. Zones of thermal hand model: 0 - thumb; 1 - index finger; 2 - long finger; 3 - ring finger; 4 - little finger; 6 (5) - back of hand (palm); 7 - wrist; 8 - lower arm; 9 - guard. (with permission from author, Nilsson et. al., 1992)

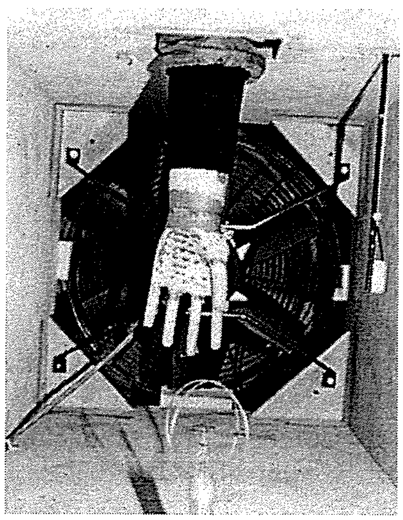

Figure 2. Setup for thermal hand standard measurement.

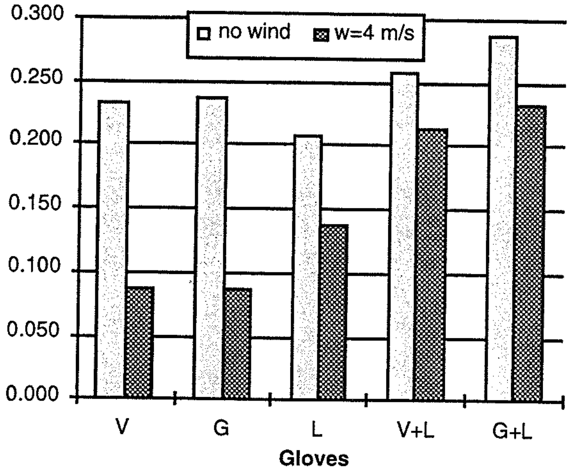

Figure 3. Effect of wind (standard test) on two types of woollen gloves (V and G) and leather glove (L) and their combinations (V+L and G+L).

Headgear evaluation

The thermal head model can be seen in Figure 4. The model is divided into 6 zones: top of head, forehead with eyes, face, left and right ear, and neck. It has 5 sweat glands and is covered with "cotton" skin for better water distribution. The model has no hair and water is supplied only in liquid form. The water distribution to all zones is homogenous, that is it does not take into account physiological difference of sweat rate at various areas of a head. The model is not a physiological model of a human head, but it is a useful tool for evaluation and comparison of thermal properties of various headgears.

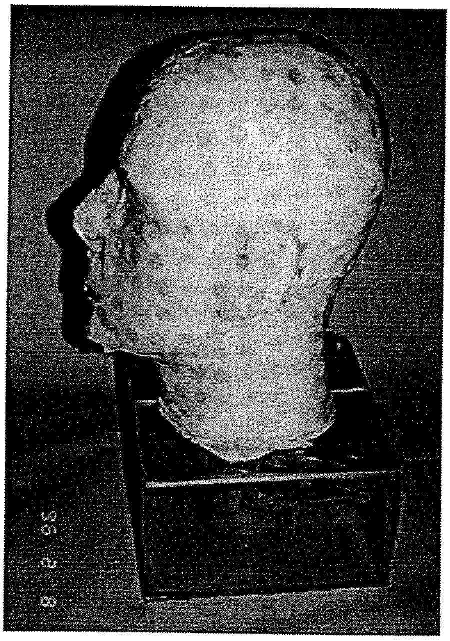

Figure 4. Thermal head model.

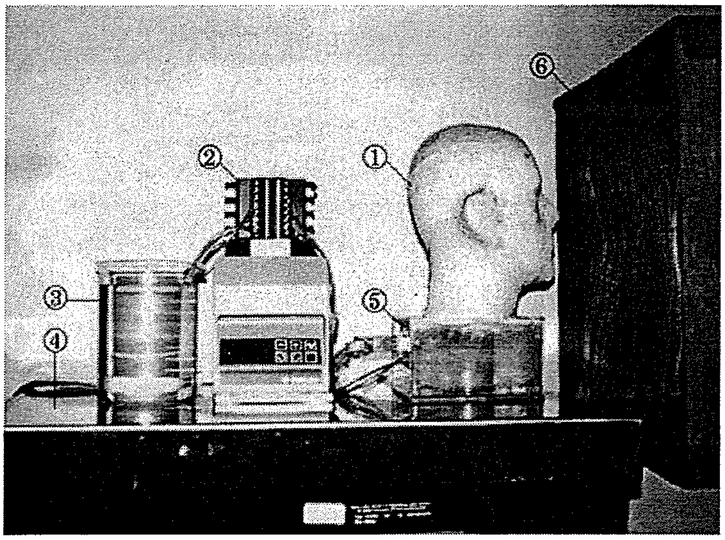

Figure 5. Setup for evaporative heat loss measurements: 1 - head model; 2 - peristaltic pump; 3 - water supply; 4 - weighting scale; 5 - a box for collecting of dripping water; 6 - wind tunnel (with permission from author, Liu and Holmér)

The model has been used for evaluating safety helmets for hot environments. Important factors to consider during such tests are wind speed, relative humidity and surface wetness (Liu and Holmér, 1997). Setup for evaporative heat loss measurements is shown in Figure 5. To eliminate the effect of dry heat loss, the air temperature of a climatic chamber is kept at the same level as head surface temperature (34 °C). Surface wetness can be controlled with a perforated plastic film and a peristaltic pump is used to supply water to the head at determined rates. The dripping water is collected into a box under the head model. As all equipment is placed on a weighting scale, making it possible to measure the amount of evaporated water (g). Figure 6 shows the reduction of evaporative heat loss by various types of helmets compared to heat loss from nude head (100 % heat loss). At the same time it is possible to evaluate the effect on various zones.

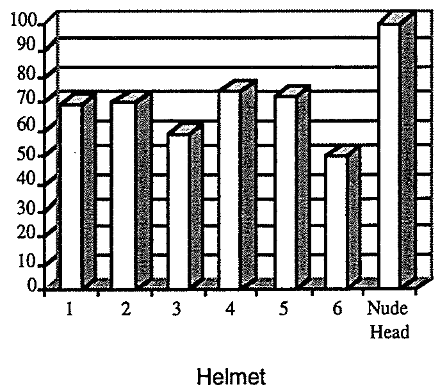

Figure 6. Evaporative heat loss (with permission from author, Liu and Holmér, 1996)

Footwear evaluation

The thermal foot model (Figure 7) is divided into 8 zones: toes, sole, heel, mid-foot, wrist, lower calf, mid-calf and guard. It has three sweat glands: on top of toes, under sole and at lateral wrist The model has a flexible wrist joint that makes it easy to put on and take off boots. The size of the model is 40 and boots of size 41 have been used for measurements. The effect of weight and walking has been studied with thermal foot models (Bergquist, 1995). Now it is also possible to study effect of wetting and combined effects.

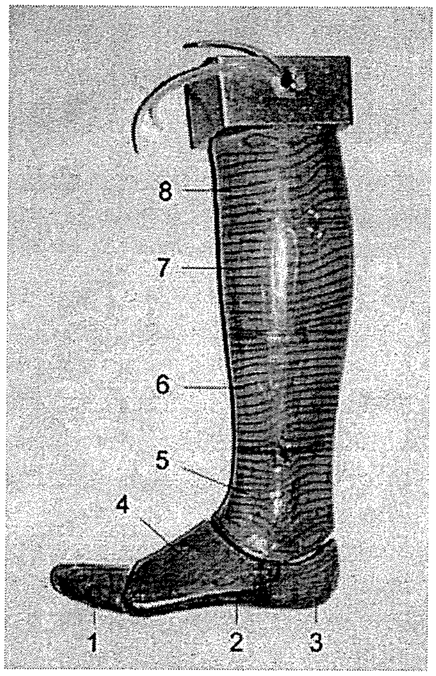

Figure 7. Thermal foot model: 1 - toes; 2 - sole; 3 - heel; 4 - mid-foot; 5 - wrist; 6 - lower calf; 7 - mid-calf; 8 - guard

A thin cotton sock is used during the experiments. One reason is that the boots are usually worn with socks. Another is that it allows better water distribution from sweat glands. For static measurements the clad thermal foot is placed on top of a copper-zinc alloy plate in upright position. On the top of the leg an additional weight of 35 kg is placed to simulate the pressure on soles from a 70 kg standing person. Wetting works by similar principle as in the case of the head model. The maximum water supply is limited to 10 g/h that corresponds to a very high sweating rate (Lotens et. al., 1988). With the peristaltic pump the water flow is regulated to around 3.3 g/h per sweat gland. A test starts with dry sock and boot and at the end of the 90 minute test the total water flow to foot is 15 g. Because of the location of sweat glands the distribution of water is not equal over all foot zones.

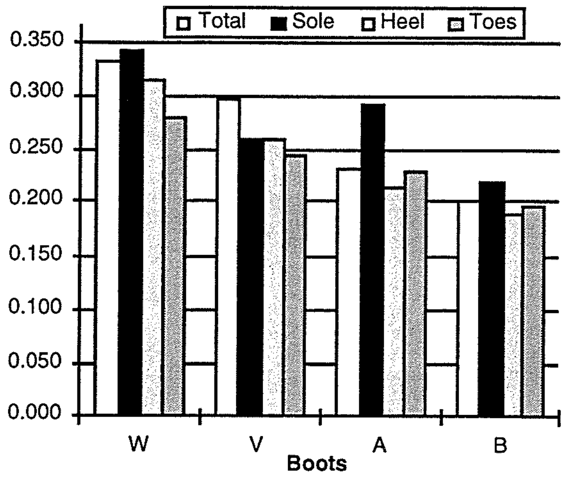

Figure 8. Total insulation of zones from toes to wrist and local insulation of Sole, Heel and Toe.

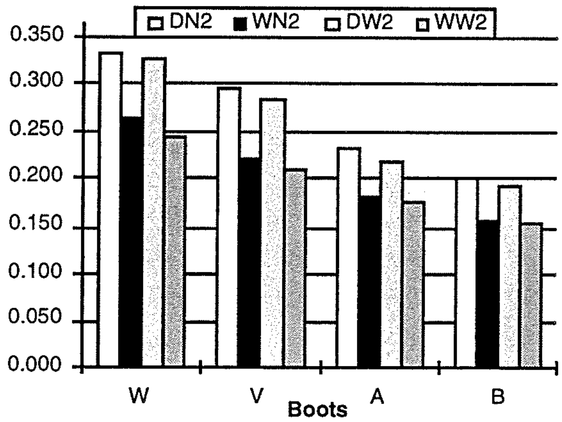

Figure 9. Effect of wetting (10 g/h) and weight (35 kg) on insulation of various boots, total insulation of all zones from toes to wrist (DN - dry without weight; WN - wet without weight; DW - dry with weight; WW - wet with weight).

During wet tests both dry and evaporative heat loss is taken into consideration as well as insulation reduction due to wetting of insulation layers. In Figure 8 can be seen the total insulation of various boots as well as local insulation of specific zones in dry condition. Zones from toes to wrist were used for calculation of total values. A range from well insulated winter boots (W) to rubber boots (B) is presented in the figures. Figure 9 shows the effect of wetting and weight on total insulation of footwear. The effect in specific zones, for example toes and sole, is different depending on zone location and on boot materials around that zone.

Conclusions

1. Thermal models are useful tools in evaluation of various types of garment pieces, comparison of them and analysing weak points in their construction.
2. Thermal models are suitable for standardisation and procedures should be worked out for head and foot measurements.

References

Bergquist, K. and Holmér, I. A method for dynamic measurement of the resistance to dry heat exchange by footwear. In: Bergquist, K. Ergonomiska krav på skyddsskor i kallt klimat. Licentiatuppsats, Luleå University, Division of Industrial Ergonomics, Sweden, 1995

EN 511 Protective gloves against cold. CEN European Committee for Standardisation, 1993

Holmér, I. and Nilsson, H. Heated manikins as a tool for evaluating clothing. Ann. Occup. Hyg., Vol. 39, No. 6, pp. 809-818, 1995

Holmér, I., Nilsson, H., Bohm, M., Norén, O. Thermal aspects of vehicle comfort. Appl. Human Sci., Vol. 14, No. 4, pp. 159-165, 1995

Liu, X. and Holmér, I. An improved method for evaluation of evaporative heat transfer characteristics of helmets. Proceedings of the 4th Pan Pacific Conference on Occupational Ergonomics, November 11-13, 1996, Taipei, Taiwan

Liu, X. and Holmér, I. Evaluation of Evaporative Heat Transfer Characteristics of Helmets. Appl. Human Sci., accepted

Lotens, W. A., van de Linde, E. J. G. and Heus, R. Prediction of foot temperature and foot comfort. Proceedings of 3rd International Conference on Environmental Ergonomics, eds. Ilmarinen, R. and Påsche, A., 8-12 August 1988, Helsinki, Finland, p. 68

Meinander, H. Determination of clothing comfort properties with the sweating thermal manikin. Proceedings of the Fifth International Conference on Environmental Ergonomics, eds. Lotens, W. A. and Havenith, G., November 2-6, 1992, Maastricht, Netherlands, pp. 40-41

Nilsson, H., Grahn, S., Holmér, I. Protection against cold - a method for evaluation of handwear. Proceedings of NOKOBETEF IV, Quality and usage of protective clothing, 5-7 February 1992, Kittilä, Finland, pp. 224-229

Experiences with manikin measurements at ITF Lyon

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This paper presents the collection of about 30 tests performed over the past year with our thermal mannikin MARTIN in relation with ENV 342. It concerns coveralls, ensembles jacket + trousers, and jackets alone (one concerns trousers alone). The aim is to analyse :
. influence of the model (global or serial) on global thermal insulation
. relative levels of global and local insulation (chest and legs).

1 - Description of the results

1.1 - Clothing systems

Results are presented in table 1. They refer to total resultant insulation : measurements are made with mannikin walking, and insulation includes external air layer (measurement of insulation on nude mannikin yields to a value of 0.51 clo for this insulation which is to be subtracted from the values of the table to obtain intrinsic insulation).

Columns 1 to 4 specify which type of clothing system was tested. Underwear is usually type B of ENV 342 ; when type A is specified, the clothing system also includes an extra internal layer so that total internal layers can be considered as roughly equivalent to type B. Columns 2 to 4 mention which pieces the clothing system is composed of ; « c » means the clothing system is a coverall (boiler suit) and « x » means the pieces are separate.
Last lines of the table refers to reference clothing systems used to check repetability of our mannikin :
• underwear type B + reference boiler suit
• underwear type B alone.
• nude mannikin

Our reference boiler suit has also been tested at Hohenstein Institute and the result is reported at the end of the table.

1.2 - Calculation of insulations

Our mannikin MARTIN, one of the Heatman serie, is divided into 35 areas, with total skin surface of 1.67 m2. Heat loss is measured for each of these areas, and a local thermal resistance can be calculated.

Usual definition of thermal insulation is based on total heat loss of the mannikin, obtained by adding up the heat loss of each of the 35 areas. This corresponds to an underlaying hypothesis of uniform skin temperature, thermal insulation being the sum of local insulations according to a resistive parallel model. In that model, importance is given in the result to areas with low thermal resistance. The value is reported in column 5.

If global insulation of the clothing system is calculated with hypothesis that heat flux is uniform over the whole body, then global insulation of the clothing system corresponds to addition of the local thermal resistances according to a serial model ; this gives more importance in the result to areas with high thermal insulation.

Therefore it can be expected that the number of areas of the mannikin should affect the result. In particular, if special areas concern parts of the body highly insulated (internal part of upper arm, area between thighs) then local insulation of these areas highly affects the serial value of global insulation. Therefore two serial insulations have been calculated :

- One corresponds to the 35 areas (column 7).
- The other corresponds to a recombination of the individual heat loss of the 35 areas into a more integrated system of classical 15 areas : head, chest front, chest back, upper arm (laft / right), lower arm, hand, upper leg (left / right), lower leg, foot. The corresponding serial insulation is then calculated and reported in column 6.

Local insulation has been calculated for chest, legs and head, simply adding up the heat losses of the different areas these parts of body are composed of (this correspond to a parallel model applied on the concerned part of body). Values are in columns 8, 9 and 10.

Last columns 14 and 15 are only difference between parallel and serial model applied on the 35 areas and recombination in 15 layers.

Columns 11, 12 and 13 concern local insulation of chest, legs and head. They are obtained by subtracting on these areas, total insulation obtained with underwear B + clothing and total insulation obtained with underwear B alone.

2 - Statistical analysis

Table 2 presents some statistical analysis performed on table 1 : mean value and standard deviation of the different insulations calculated for specific types of clothing system.

2.1 - Influence of the model

(a) Considering indifferently all the clothing systems (point 1), it can be seen that on our mannikin, serial model increases global insulation :

• by 14% when calculated on a recombination into 15 areas (17% for intrinsic insulation)

• by 20% when calculated on the 35 original areas. (25% for intrinsic thermal insulation).

As expected, serial value on 35 areas is higher than on 15 areas, because locally insulated areas intoduce high resistive values in the calculation ; these areas have less influence when integrated in larger ones.
This clearly demonstrates that definition of the mannikin influences the result when calculation is operated according to a serial model, and therefore clear definition of the areas should be made.
We would suggest to retain the 15 areas definitions, which is probably both the most widespread and the least sensitive to fluctuations. Therefore we shall only refer to this situation for our further comments.

(b) It can be seen from table 2 that if the mean difference between parallel and serial model (recombination into 15 areas) is 14%, that value differs widely depending on the presence of a wood :

• for coverall or ensemble jacket + trousers including a wood, the difference between both models reduces to about 9% (11% for intrinsic insulation)

• for ensembles without wood, the difference increases to about 18% (21% on intrinsic insulation).

The reason is that, considering thermal insulation, the head is the weakest part of the body. Then the parallel model, sensitive to low resistance values, is highly affected by the value of the head : the wood modifies the global insulation by 0.2 clo. At the same time, the serial model, sensitive to the high resistance values, is not affected by local insulation of the head.

(c) In a more general way, we could say that the more homogeneous the clothing, the more homogeneous the results between the different models.

This directly comes from the formulas of insulation. As additive illustration the underwear type B, rather homogeneous, shows only a difference of 4% between both models, and measurements on nude mannikin (homogeneous clothing !) do not show any difference.
For clothing systems with a jacket only, as there is big difference between chest and uncoverd legs, we could expect also a big difference between parallel and serial models. In fact, the difference turns out to be of the same order as for the wood : the legs are not an extreme case, neither the most nor the least insulated, and as such their influence on the model is intermediate.

(d) If we consider intercomparison tests between mannikin Martin (ITF - 35 areas) and Mannikin Charlie (Hohenstein - 15 areas) results show that :

• Values differ by 0.20 clo on the parallel model (6.5 % on total insulation, 8% on intrinsic insulation)
• Values are in good agreement for the serial model when equivalent recombination in 15 areas is used for Martin.
• Values are in good agreement for nude mannikin which corresponds to an homogeneous clothing.

2.2 - Testing parts of clothing
(a) It can be seen from table 1 or from statistics n°6 in table 2 that when testing jacket alone in combination with underwear type B, the range of values obtained differs widely depending on the definition of insulation :
• with parallel model, values are between 2.10 and 2.30 clo (intrinsic insulation : 1.60 - 1.80 clo)
• with serial model, values are between 2.40 and 2.80 clo (intrinsic insulation : 1.90 - 2.30 clo)
• for local chest insulation : 4.00 - 4.80 clo (intrinsic insulation : 3.50 - 4.30 clo)
Additively, intrinsic insulation of the jacket only can be calculated by subtracting local chest insulation of underwear B alone from local chest insulation of underwear B + jacket. The range of values obtained is then : 1.70 - 2.50 clo.

These ranges of datas are presented in following table.

	Underwear B + jacket Global Parallel model	Underwear B + jacket Global Serial model	Underwear B + jacket Local chest insulation	**Jacket only** **Local chest insulation**
Total insulation	2.10 - 2.30 (9%)	2.40 - 2.80 (15%)	4.00 - 4.80 (18%)	
Intrinsic insulation	1.60 - 1.80 (11%)	1.90 - 2.30 (18%)	3.50 - 4.30 (20%)	**1.70 - 2.50** **(38%)**

(b) Global insulation is valuable for homogeneous clothing systems, but does not differentiate parts of clothing when the system is not homogeneous over the body. It is clear that the most valuable data for comparaison of local protection provided by a jacket is the local chest insulation.

Therefore we would suggest to characterise jackets by local chest insulation : the value retained could be the instrinsic insulation of the jacket alone, obtained by difference of local total insulation between underwear B and underwear B + jacket. The same procedure could also be applied for legs and head. For one garment to be tested, we could provide then, with exactly the same testing as defined in prENV 342 :
• global insulation of the whole clothing system according to a serial model

• local intrinsic insulation of chest, legs and head for characterisation of parts of clothing

The remaining question then would be : when the chest (or the legs) is itself divided into separate areas (8 areas for our mannikin) should these areas be added in a parallel or a serial model ? I would personnaly suggest to simply add up the heat losses of the different areas (equivalent to parallel model). Another way could be to integrate them into two parts - chest front and chest back - and add these two large areas according to a serial model. Some further intercomparaison should be investigated to answer which of both ways is the most reproducible between different mannikins. For our mannikin, these values are available in our data bank if needed.

(c) Yet if the measurement of thermal resistance had been made on the complex of the jacket only (measurement on a hot plate according to ISO 11092 or ISO 8085-2), we would have obtained a much bigger difference than observed on the mannikin : the mannikin measures the combination of the textile complex and internal air layers, which somewhat reduces importance of the insulation of the textile complex.

Which value is the most meaningfull ? If we consider the shoulders and upper chest, the complex is directly in contact with the body ; this corresponds to measurement on a hot plate. If we consider the other parts of the chest (back, lower chest), the mannikin value is nearer to reality as it reproduces internal air gaps, internal convection and eventual air exchange with ambiance through openings of the clothing.
In fact both measurements represent each one part of reality : hot plate is local and probably more suitable for comfort assesment ; mannikin is global are more devoted to limit of use... Some more reflexion is needed.

I would personnally encourage mannikin testing as it integrates confection parameters (internal air layer, openings of the clothing) and inhomogeneity (for instance thickness is increased over the pockets).

2.3 - Predictive temperature for use
Can we determine a temperature for use for local protection ?

Obviously, the predictive physiological models have been established for an homogeneous clothing system, on the basis of the total heat loss of the body - and so on the basis of the global insulation provided to the body.

The first question is : do we have a valid model for inhomogeneous clothing system ? If the answer is no, it means that prediction can only be made for homogeneous clothing. Then two cases may happen which are developped here after.

(a) The clothing is intended to be worn alone (jacket alone in most cases).

Then we do not have the answer. We can only define a level of protection (intrinsic chest insulation, legs insulation, head insulation) provided by the piece of garment.
Further investigation or experience is needed to correlate that value of protection with temperature rating.
(b) The clothing is intended to be integrated in an homogeneous clothing covering whole body. In that case the question is : if I combine this jacket with this trousers, which protection do I obtain ?
Then, global insulation of the complete system can be calculated in three stages:

• For each part of the body add up local insulation of each layer : local intrinsic insulation of the jacket + local intrinsic insulation of the trousers + local total insulation of underwear type B.

• Add up local total insulations on the different parts of the body according to a serial model : this gives global total insulation of the clothing system (including underwear type B) as it would have been measured if whole combination had been tested on mannikin.

• Calculate temperature for use as we do it today in prENV 342.

We have then two questions :

- It should be verified that when testing a clothing system with underwear type B, the local insulation obtained when both parts of the clothing system are tested in combination is with acceptable agreement the sum of local insulations issued from individual testings. This verification could be performed aesily.

- Determination of temperature of use is not difficult for laboratories, but difficult and even impossible for end users. Perhaps a more simple system could be found, which consist in defining class of protections, which would add up simply.

3 - Conclusion
From our observation, following conclusions could be suggested, provided they correlate with experience of other laboratories :

(a) Define 15 standard areas for mannikins, and calculate global insulation by a serial model applied on these 15 areas.

(b) Characterise local protection provided by pieces of garment (jacket, trousers) by local insulation measured on mannikin (chest, legs, head). This insulation would be intrinsic insulation of the garment itself, obtained by difference between local insulation of underwear B + piece of garment and local insulation of underwear B.

(c) Determine temperature of use for complete clothing system as it is performed today.

(d) Determine temperature of use for combination of jackets and trousers (and hoods ?) tested separately by considering the clothing system for which local insulation is the sum of local intrinsic insulations of the external parts of clothing plus local total insulation of underwear B ; temperature is then calculated as in (c).

(e) For piece of clothing used alone, not provide any temperature for use : these pieces of garment are used only for moderate cold, and only level of protection as measured in (b) is provided.

Table 1

1	2	3	4	5	6	7	8	9	10		11	12	13		14	15
				Total resultant *Global* insulation It,r (clo)			Total resultant *Local* insulation Iloc,r (clo)				Local intrinsic insulatic of clothing only					
Un	Jac	Tro	Ho	Parallel model	Serial model 15 areas	Serial model 35 areas	Chest	Legs	Head		Chest	Legs	Head		Diff between Parallel and Serial 15 areas	Diff between Parallel and Serial 35 areas
															(%)	(%)
B	c	c	c	3.01	3.23	3.40	4.5	3.3	2.1		2.2	1.5	1.1		7	13
B	c	c	c	2.94	3.23	3.38	4.1	3.4	2.0		1.8	1.6	1.0		10	15
B	c	c	c	3.05			4.3	3.5	2.6		2.0	1.7	1.6			
B	c	c	c	2.90	3.27	3.41	5.2	3.0	2.2		2.9	1.2	1.2		13	18
B	c	c	c	2.83	3.08	3.21	4.4	3.1	2.1		2.1	1.3	1.1		9	13
B	x	x	x	3.32	3.69	3.94	5.1				2.8					
B	x	x	x	2.63	2.79	2.99	3.6	2.8	2.0		1.3	1.0	1.0		6	14
A	x	x	x	2.95	3.18	3.42	4.2	3.3	2.2		1.9	1.5	1.2		8	16
B	x	x	x	3.00	3.35	3.62	4.7	3.5	2.2		2.4	1.7	1.2		12	21
A	x	x	x	2.90	3.04	3.23	4.0	3.2	2.1		1.7	1.4	1.1		5	11
B	x	x	x	2.79	3.04	3.22	4.3	3.0	1.9		2.0	1.2	0.9		9	15
B	c	c		2.75	3.37	3.54	5.0	3.4	1.0		2.7	1.6	0.0		23	29
B	c	c		2.61	3.17	3.38	4.7	3.3	1.0		2.4	1.5	0.0		21	30
B	c	c		2.80	3.21	3.42	4.5	3.4	1.4		2.2	1.6	0.4		15	22
B	x	x		2.95	3.38	3.62	4.3	3.8	1.3		2.0	2.0	0.3		15	23
B	x	x		2.34	2.68	2.83	3.6	2.8	1.0		1.3	1.0	0.0		15	21
B	x	x		2.26	2.55	2.70	3.5	2.6	1.0		1.2	0.8	0.0		13	19
B	x	x		2.93	3.66	3.91	4.9	4.0	1.0		2.6	2.2	0.0		25	33
B	x		x	2.41			4.4	2.0	2.5		2.1	0.2	1.5			
B	x		x	2.38			4.5	2.0	2.0		2.2	0.2	1.0			
B	x		x	2.55	2.90	3.01	4.8	2.1	2.2		2.5	0.3	1.2		14	18
B	x			2.22	2.76	2.85	4.8	1.9	1.0		2.5	0.1	0.0		24	28
B	x			2.14			4.1	1.9	1.2		1.8	0.1	0.2			
B	x			2.11			4.0	1.9	1.2		1.7	0.1	0.2			
B	x			2.27	2.58	2.73	4.1	2.0	1.3		1.8	0.2	0.3		14	20
B	x			2.21	2.55	2.65	4.2	2.0	1.3		1.9	0.2	0.3		15	20
B	x			2.11	2.42	2.50	4.0	1.9	1.1		1.7	0.1	0.1		15	18
B	x			2.19	2.51	2.70	4.3	2.0	1.2		2.0	0.2	0.2		15	23
B	x			2.17	2.54	2.66	4.3	1.8	1.3		2.0	0.0	0.3		17	23
B	x			2.30	2.80	2.93	4.7				2.4					
B		x		2.27	2.66	2.82	2.8	3.8	1.0		0.5	2.0	0.0		17	24
Reference clothing ITF																
B	*c*	*c*	*c*	*3.09*	*3.31*	*3.46*	*4.4*	*3.5*	*2.2*		2.1	1.7	1.2		*7*	*12*
B alone				*1.74*	*1.81*	*1.86*	*2.3*	*1.8*	*1.0*		0.0	0.0	0.0		*4*	*7*
nude				*0.51*												
Reference clothing ITF tested at Hoh																
B	*c*	*c*	*c*	*2.88*	*3.29*											
nude				*0.50*	*0.51*											

Table 2

					STATISTICAL ANALYS							
		2	3	4	5	6	7	8	9	10	11	12
					Total resultant Global insulation It,r (clo)			Total resultant Local insulation Iloc,r (clo)				
		Jac	-	Ho	Parallel model	Serial model 15 areas	Serial model 35 areas	Chest	Legs	Head	Diff between Parallel and Serial 15 areas (%)	Diff between Parallel and Serial 35 areas (%)
		xc	xc-	xc-	(1) Influence of the model - All type of clothing							
Mean value	(clo)				2.62	2.98	3.15	4.3	2.9	1.6	14	20
Std deviation	(clo)				0.3	0.3	0.4	0.4	0.7	0.5	5	6
Variation coef.	(%)				12	12	12	10	23	31	39	28
		c	c	c	(2) Coverall (with wood)							
Mean value	(clo)				2.92	3.20	3.35	4.6	3.2	2.1	10	15
Std deviation	(clo)				0.1	0.1	0.1	0.4	0.2	0.1	2	2
Variation coef.	(%)				2	2	2	9	5	3	21	12
		x	x	x	(3) Jacket + trousers (with hood)							
Mean value	(clo)				2.85	3.08	3.30	4.2	3.2	2.1	8	15
Std deviation	(clo)				0.1	0.2	0.2	0.4	0.2	0.1	2	3
Variation coef.	(%)				5	6	6	9	8	6	30	20
		c	c	-	(4) Coverall (no hood)							
Mean value	(clo)				2.72	3.25	3.45	4.7	3.4	1.1	20	27
Std deviation	(clo)				0.1	0.1	0.1	0.2	0.0	0.2	3	3
Variation coef.	(%)				3	3	2	4	1	17	18	12
		x	x	-	(5) Jacket + trousers (no hood)							
Mean value	(clo)				2.62	3.07	3.27	4.1	3.3	1.1	17	24
Std deviation	(clo)				0.3	0.5	0.5	0.6	0.6	0.1	5	5
Variation coef.	(%)				12	15	16	14	18	12	29	23
		x	-	-	(6) Jacket only (no hood)							
Mean value	(clo)				2.20	2.56	2.68	4.3	1.9	1.2	17	22
Std deviation	(clo)				0.0	0.1	0.1	0.3	0.1	0.1	4	3
Variation coef.	(%)				2	4	4	6	4	10	22	15
		-	x	-	(7) Trousers only (no hood)							
Mean value	(clo)				2.27	2.66	2.82	2.8	3.8	1.0		
Std deviation	(clo)				0.0	0.0	0.0	0.0	0.0	0.0		
Variation coef.	(%)				0	0	0	0	0	0		

Experience with a sweating thermal manikin - Ready for standard use?

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The sweating thermal manikin Coppelius was developed within a Scandinavian cooperation project in the 1980's. It was the first true sweating thermal manikin in the sense that a controlled amount of moisture is continuously supplied to its heated surface, where the moisture evaporates and causes an increase in the total heat loss. The original intended uses for the manikin were measurements of the thermal comfort properties of clothing systems as well as indoor climate comfort, but in fact it has been used only for clothing studies. The first tests were performed in VTT's new climatic chambers in 1991.

Manikin construction and measurement principle

The manikin construction is based on that of the Swedish dry thermal manikin Tore, with the addition of the sweating mechanism. The basic features of Coppelius are:

- electrical heating, 18 separately controlled body sections,
- continuous sweating through 187 individually controlled "sweat glands" (head, hands and feet are non-sweating)
- anatomic body dimensions, size C50
- prosthetic joints in knees, hips, elbows and (shoulder) permit simple movements (not in use).

Figure 1 shows the cross section of a sweat gland. Liquid water is supplied to the manikin surface through a tube in the shell material. The "skin" consists of two layers: an inner nonwoven material which spreads the water to a larger area (max. 100 cm^2) and outer microporous membrane which transmits water in vapour but not in liquid form. The supplied water is therefore evaporated by the heating system and the manikin surface produces heat and vapour similarly as the human skin. The maximum amount of water supply is 200 $g/m^2 \cdot h$, corresponding to a moderate sweating level.

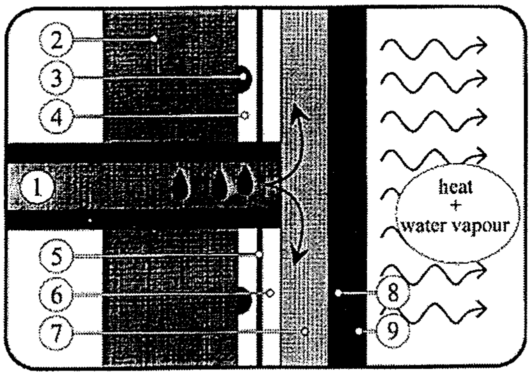


Figure 1.

The tests are performed in a climatic chamber, where the manikin is suspended in a balance system in order to record weight changes during the test, figure 2. Liquid water is supplied from a reservoir, which stands on a balance near the ceiling in the control room. The normal test procedure is:

- weighing of dry garments (conditioned in +20 C/65 % RH),
- dressing of the manikin,
- dry test, 0,5 - 1,5 hours,
- sweating test at determined sweating level, 3 hours,
- undressing of the manikin,
- weighing of moist garments.

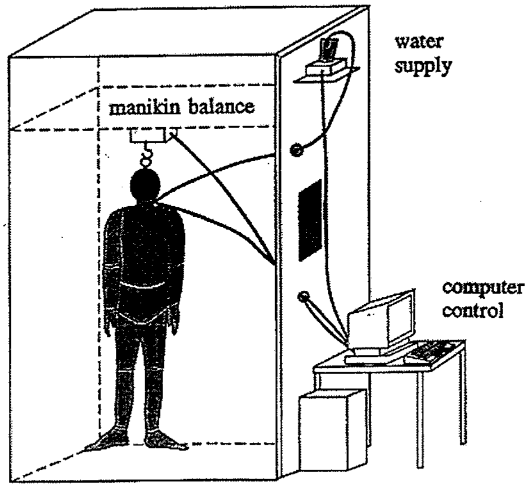


Figure 2.

The thermal insulation I_T of the dry clothing system is determined from the results of the dry test, using the generally accepted equations. In the sweating situation the heat supply to the manikin is higher, partly due to the evaporation of moisture from the manikin surface and partly to the condensation of water in the clothing layers. The amount of evaporation is determined as the difference between the water supply and the weight increase of the manikin during the test. The thermal insulation at the end of the sweating test (the corrected thermal insulation) is calculated using the formula

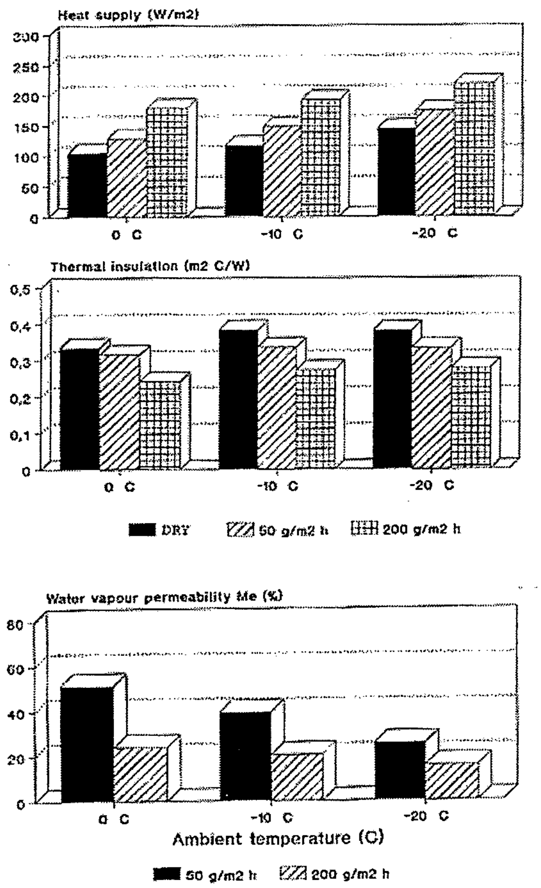
$$I_{Tcorr} = \frac{t_s - t_a}{P - P_e} \cdot A$$

where t_s is the skin temperature, t_a the ambient temperature, P the heat supply to the manikin, P_e the calculated heat of evaporation and A is the manikin surface area.

Test results, cold protective clothing

Most of our research work and testing with Coppelius has been concerned with the thermal properties of cold protective clothing systems. The reported results are from a study made for the Finnish Defense Forces, but similar tendencies have been observed in other studies.

Figure 3 shows the influence of ambient temperature (0, -10 and -20 °C) and sweating level (0, 50 and 200 g/m2·h) on the heat supply, thermal insulation and water vapour permeability for one 4-layer clothing ensemble. With the same ambient temperature, an increase in the sweating rate causes a corresponding increase in the heat supply and a drop in the calculated thermal insulation. The water vapour permeability in % of the supplied water is higher at the low sweating level, but the absolute value in g/m2·h is higher at the higher sweating level.



Heat supply, thermal insulation and water vapour permeability values of the new winter clothing under the different test conditions

Figure 3.

When the temperature drops, there is again an increase in the heat supply but a small decrease in the thermal insulation values. The water vapour permeability values also drop with a decreasing temperature. The condensation of water in the different layers of the clothing are shown in figure 4, and it can be noted that at 0 °C most of the water is found in the underwear whereas at -20 °C the moisture in the outer layers has increased substantially.

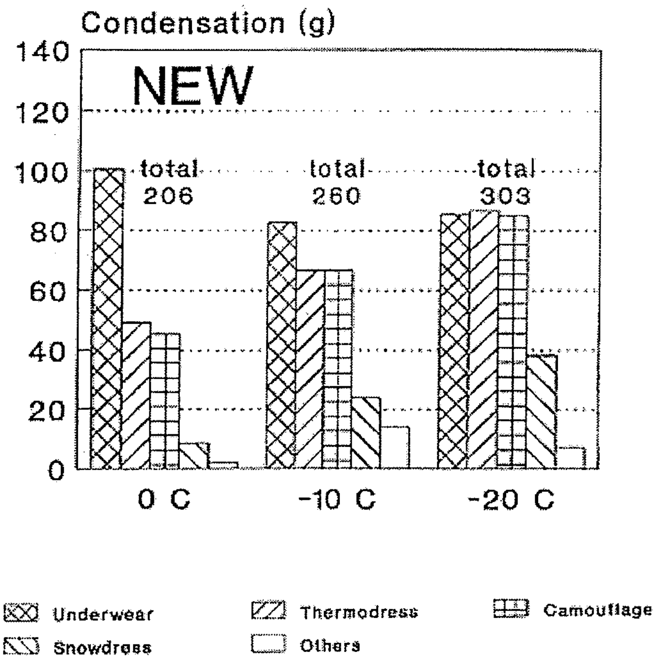


Figure 4.

Two clothing ensembles were also studied in a dynamic sweating / non-sweating test procedure at -10 °C, figure 5. Period a is the initial cooling of the climatic chamber; period b sweating 200 g/m2·h with an increase in the heat supply and weight; period c non-sweating with a slow decrease in heat supply and weight; period d a second sweating with increase in heat input and weight; period e a second nonsweating but with an additional insulating layer (rest coat). It can be noted that the weight change in the last period is very slow, which means that the evaporation of the moisture from the thick clothing would require several more hours.

Coppelius ready for standard use?

The measurements with the sweating thermal manikin Coppelius give essential new data regarding the functional properties of e.g. cold, rain and chemical protective clothing. It could seem quite attractive to write a standard test method, based on a selected standard set of test parameters, and to include this in the European requirements / classification standards on protective clothing.

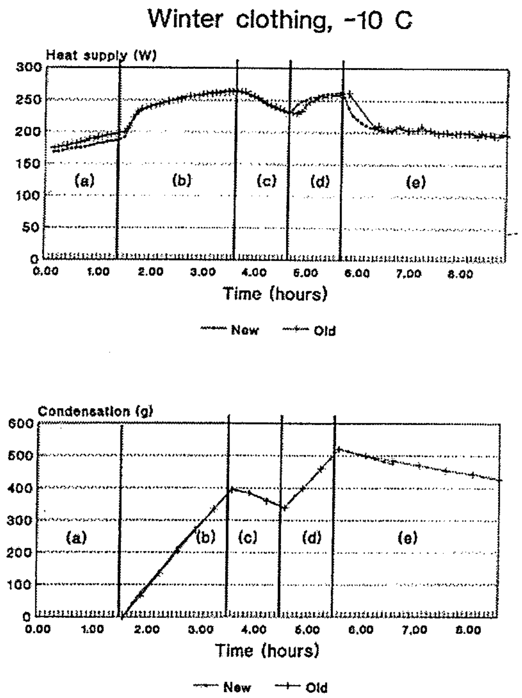


Figure 5.

However, as there is only one sweating thermal manikin operating in Europe at the moment, it is not likely that such a standard would be accepted. A copy of Coppelius has been constructed at the North Carolina State University in the USA, and discussions about the possibilities to create an ASTM standard have started. And when the Swiss manikin SAM is finished and necessary interlaboratory tests have been performed, it might be time to consider a European standard.

Sweating Articulated Manikin SAM for thermophysiological assessment of complete garmants

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Designation of the project:
Construction of an anatomically shaped dummy of human size which can be heated and move and is able to "sweat", i.e. to evaporate as much water as man evaporates sweat whilst performing a heavy workload.

Reasons for the necessity of such an equipment:
This manikin should allow to assess the thermophysiological wear comfort of complete clothing systems under conditions which are as near to practice as possible in order to predict the practice behaviour of these clothing systems. For this purpose it is now necessary to perform expensive wear trials with human test subjects. These wear trials have a very low reproducibility and must therefore be repeated many times in order to get statistically significant predictions for a clothing system. With a sweating manikin in a way a standardized man would be available and such predictions could be made at much less effort and even more precise.
A field in which such an equipment would be of outstanding importance is the assessment of the thermophysiological wear comfort of protective clothing. In most cases the demands of protection and those of wear comfort are in contradiction to each other. It is therefore very essential to find an optimal balance between these two aspects. Only then accidents of users of protective clothing (e.g. firemen) due to heat stress may be prevented.
The possibility of testing their products with a sweating manikin is of great economic importance for the project partners and for the whole clothing industry because hereby a quicker and much less expensive product development is possible.
For the EMPA St.Gallen the construction of a sweating manikin is a consequent continuation of the hitherto existing development strategy in the fields of clothing comfort and protective equipment. Quite a range of test apparatus has already been developed which allow near to practice tests at complete systems (sweating arm, sweating torso, manikin in rain tower etc.).

Goal of the project:
An equipment should be developed and constructed which allows the assessment of the thermophysiological wear comfort of clothing in interaction with different environmental conditions like temperature, humidity, wind, rain etc. It is known that the transport of heat and water vapour in multi-layer garment assemblies follows very complicated rules (evaporation and condensation, even freezing effects inside the clothing) and that the manufacturing has an important influence on the wear comfort.
The manikin to be developed should correspond in size and shape to an average human being (based on antripometric data). It should be able to sweat sufficiently in order to simulate the wear situation under a relatively heavy workload. As the influence on wear comfort of microclimate ventilation due to the movement of man is considerable, arms and legs of the manikin should be movable during measurements. By this the influence of openings in the clothing on the wear comfort could be studied too.
With the manikin planned in this project quite a considerable progress compared with existing manikins can be reached. The only sweating manikin in Europe, "Coppelius at VTT in Finland, has a much lower sweating rate and cannot be moved during measurements. Outside Europe no manikins with the specifications aimed at in this project are known.

Specifications:
- same size (50) as the thermal manikins of Du Pont, BTTG and University of Alberta i Edmonton, Canada,
- shape of the manikin based on antropometric data,
- manikin in accordance with EN 342 (protective clothing against cold),
- adjustable sweat rate up to 1.0 l/m^2h,
- at minimum 18 body domains with separately controlled temperature and sweating rate,
- temperature or heating power regulation possible alternatively,
- distribution of sweating on the body analogous to humans,
- possibility to deliver evaporated and liquid sweat,
- possibility to regulate on constant temperature as well as on constant heating power (metabolic heat),
- hands, feet and head should be heatable and able to sweat,
- program controlled skin temperature, heating power and sweat rate in analogy to human values,
- arms and legs movable in shoulder, elbow, hip and knee simulating the movement of a human body,
- velocity of the movement infinitely variable up to a walking speed of 8 km/h,
- domain of environmental temperature: -30°C to 40°C,
- relative humidity 30 to 95 % r.h.,
- wind speeds up to 5 m/s,
- possibility of raining.

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Prediction of motion effects from static manikin measurements

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Introduction

The preliminary standard (prENV 342:1997) suggests that the testing should be made on a moving thermal manikin. The results can then be used as input in other standards, for assessment of proper clothing insulation for different working tasks. It is known in prior work that insulation values measured with subjects can be reduced with up to 50% from the value measured on a standing thermal manikin. The body movements make the air circulate underneath the clothing.

This presentation will focus on the principals of reduction made on total insulation calculated according to methods presented in prENV 342:1997.

Materials and Methods

The thermal manikin used is one in the TORE-series that has been described earlier (Hänel S-E 1994, Hänel S-E 1983, Nilsson H O 1992). Modifications have been made both in the joint construction, as well as to the body shape, to make long-term use possible. Considerations concerning testing of thick protective clothing have also been made. Selected body parts have been reduced in size so that the right body shape has been achieved. New heating and measuring wires has been put on with methods developed in the group.

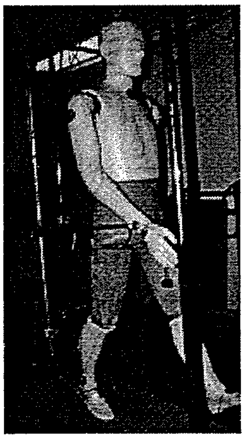

Figure 1. The moving thermal manikin TORE,
adapted for measurements according to prENV 342:1997.

The power transmission, in the walking apparatus, has been made with pneumatic cylinders, which gives a simple and durable construction with a minimum of mechanical components. The external walking system gives a realistic walking movement for arms and legs up to 4 km/h. The motion is controlled so TORE can "walk" with different step length and speed. Two different step lengths can be simulated, 645 mm (heel to heel) with 500 mm cylinders and 970 mm (heel to heel) with 800 mm cylinders. This means walking speeds from standing to a speed of 0.8 m/s with the shorter step and 1.2 m/s with the longer. An adjustable framework has been built of tubes. Ball bearings in some joints for lowered friction and better durability, have been implemented. This walking apparatus meets the demands for low cost, reliability, durability and gives a natural and reproducible walking style.

A simplified wind tunnel construction for laboratories with limited space has been developed. The climate chamber was divided into two halves with the manikin placed in the middle of one half. Three fans (Indola, Type VWB 50) directs the air stream past the manikin, leads it back in the other chamber half, and then presses it back in front of the manikin through a honey comb screen over the whole area. To minimize the flow and pressure difference a guide rail has been positioned in the corner in front of the screen. In that way most of the disturbances are reduced and a "controlled" turbulence is obtained, well in line with the limitations of the standard.

To investigate the relevance of the testing method, and create a relationship between the influences of wind and motion on the insulation, a number of experiments where made in a climatic chamber. The tests comprised 8 different types of working clothes, as well as measurements with no clothes on. Starting with a thin one layer asbestos protective suits continuing with two layer overalls and suites to thick forestry working suites with three layers. The clo values differed from in total insulation from 0.73 clo to 4.61 clo. The clothing systems represented different insulation values and number of layers as well as air permeability.

In this study the walking speed was set to 0.37, 0.8 and 1.2 m/s. The measurements were made in the climatic chamber where the wind speed was set to 0.2, 0.5 and 1.0 m/s. The repeatability for the used method for determination of insulation values was high; the difference between double determinations was less than 5% of the mean value of the two measurements based on 216 independent measurements.

Results

The results are given as percentage of the total insulation (I_t) measured with a standing manikin during wind still (0.2 m/s) conditions (ASTM-F1291-96 1996, ISO-9920 1993). The results show that the clothing insulation is strongly influenced by wind and body movements. The combined effect of body movements and wind increases the heat loss from the human body substantially. There were clearly noticeable differences between all changes in wind and walking speed. The total insulation was reduced to 57%, compared to the windstill condition, with TORE standing without clothes in 1 m/s wind speed. Furthermore reduced to 47% with TORE walking in 1.2 m/s as well.

Relationships with number of layers and permeability as well as clothing insulation have also been examined with stepwise multiple regression. They did only show small improvements of the accuracy and where consequently left out in the final equations. The choice of exponential function makes it possible that with multiple regression determine the equations for the different clothing combinations. The validity interval for the equations is 0.2 - 1.0 m/s wind speed and 0 - 1.2 m/s walking speed. If they are used outside this interval the reduction will be over estimated. The relative change is large when changed from standing to light walk or when the wind goes from zero to low wind. Addition of more wind and movement make the reduction to stabilize.

With just a minor increase in the error the individual equations can be put together in the following relationship:

$$I_{t,r}/I_t = e^{(-0.325 \cdot v - 0.217 \cdot w)} \qquad (R = 0.856) \qquad (10)$$

The standard deviation of the difference between measured and calculated data becomes with this equation only 0.04 clo with a Max./Mean/Min. of 0.14/0.05/0.00. This equation is illustrated in figure 2.

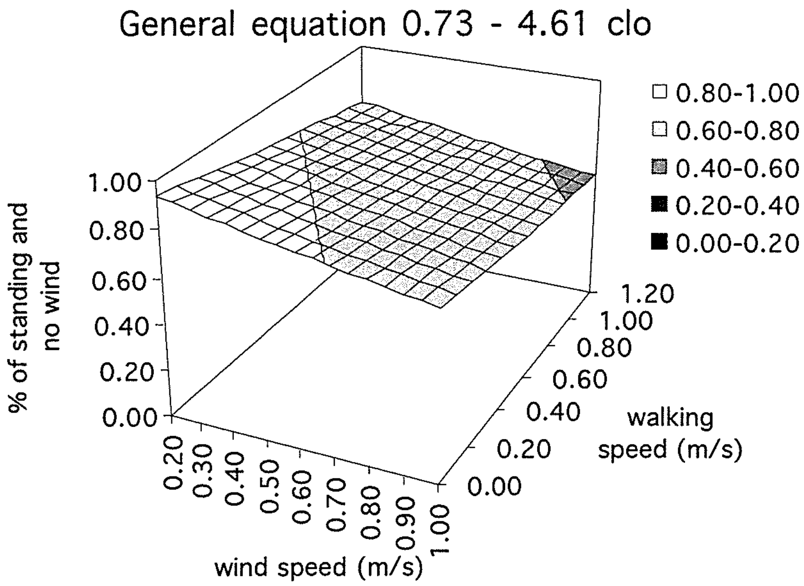

Figure 2. The combined effect of wind and walking speed for TORE while walking at 0 to 1.2 m/s with wind speed from 0.2 to 1.0 m/s. For clothing combinations with 0-3 layers with a total insulation of 0.73- 4.61 clo.

Discussion and Conclusions

The developed and tested method for measurement of dry thermal insulation of clothing combinations gives reliable, relevant and reproducible values. The modifications that have been made of the manikin construction in combination with the walking apparatus and wind tunnel give a practically useful method. The developed method thereby fulfils the demands stated in the preliminary European standard prENV 342:1997.

The clothing insulation is strongly affected by wind and body movements. The combined effect of body movements and wind increases the heat loss from the human body. A reduction of the clothing insulation measured with a static thermal manikin is consequently needed. The insulation is reduced exponentially with increased step frequency (walking speed) and increased wind speed.

A general reduction equation has been developed. The equation makes it possible to calculate the reduction of different activity for most work clothing, if the static clothing insulation is known from measurements or tables. To validate these relationships more measurements on subjects exposed to wind and motion in working life are needed.

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References

ASTM-F1291-96, Standard method for measuring the thermal insulation of clothing using a heated thermal manikin. ASTM, 1996,

Hänel S-E. Anthropometric background for the nordic thermal manikin "Tore". Second International Congress on Physiological Anthropology. Kiel: German Society of Physiological Anthropology, 1994: 308-313.

Hänel S-E. A joint Nordic project to develop an improved thermal manikin for modelling and measuring human heat exchange. In: Aspect médicaux et biphysiques des vêtements de protection. Lyon: Centre de Recherche du Service de Santé des Armées, 1983: 280-282.

ISO-9920, Ergonomics - Estimation of the thermal characteristics of a clothing ensemble . International Standards Organisation, 1993.

Nilsson H O, Gavhed D C E, Holmér I. Effect of step rate on clothing insulation. – Measurement with a moveable thermal manikin. In: Lotens W, Havenith G, ed. Environmental Ergonomics V. Masstricht, Netherlands, 1992

Testing issues at IFP Mölndal

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IFP (The Swedish Institute for Fibre and Polymer Research) formerly known as TEFO (The Swedish Institute for Textile Research) was partner in the development of the Nordic line of TORE-manikins. At IFP the thermal manikin has mainly been used for product testing and development. The most important product categories are protective and sports clothing, sleeping bags and surgeons' gowns. Due to an over-heating the lower part of our Tore has been rebuilt. During that process we separated some heating and measuring zones to give better discrimination when sitting or lying. We have also built a controlled temperature cabinet to facilitate calibration. Within this cabinet we can calibrate Tores temperature sensors to better than 0.05 °C.
We have develop mathematical models to simulate heat and moisture flow from upright or lying persons. Insulation data from Tore measurements and water vapour resistance from the Skin Model measurements are input. The resulting values correlates well with measurements on humans.

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