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Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble

Ergonomie des ambiances thermiques — Détermination de l'isolement thermique et de la résistance à l'évaporation d'une tenue vestimentaire

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9920 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This second edition cancels and replaces the first edition (ISO 9920:1995), which has been technically revised. It includes major changes to the sections on clothing vapour resistance as well as those dealing with the effects of air movement and body motion on clothing insulation and vapour resistance.

Introduction

This International Standard is one of a series of International Standards intended for use in the study of thermal environments. It is a basic document for evaluation of the thermal characteristics of a clothing ensemble (thermal insulation and water vapour resistance). It is necessary to know these values when evaluating the thermal stress or degree of comfort provided by the physical environment according to standardized methods. The thermal characteristics determined in this International Standard are values for steady-state conditions. Properties like "buffering", adsorption of water and similar are not dealt with.

The emphasis in this International Standard is on the estimation of the thermal characteristics. The heat and vapour resistance may also be measured directly, and this is discussed in the annexes.

This International Standard does not deal with the local thermal insulation on different body parts, nor the discomfort due to a non-uniform distribution of the clothing on the body.

Man's thermal balance in neutral, cold and warm environments is influenced by the clothing worn. For evaluating the thermal stress on human beings in the cold (IREQ, see ISO/TR 11079, insulation index), neutral environments (PMV-PPD, see ISO 7730, indices) and the heat (predicted heat strain, see ISO 7933, index), it is necessary to know the thermal characteristics of the clothing ensemble, i.e. the thermal insulation and the water vapour resistance.

Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble

1 Scope

This International Standard specifies methods for estimating the thermal characteristics (resistance to dry heat loss and evaporative heat loss) in steady-state conditions for a clothing ensemble based on values for known garments, ensembles and textiles. It examines the influence of body movement and air penetration on the thermal insulation and water vapour resistance.

This International Standard does not

- deal with other effects of clothing, such as adsorption of water, buffering or tactile comfort,
- take into account the influence of rain and snow on the thermal characteristics,
- consider special protective clothing (water-cooled suits, ventilated suits, heated clothing), or
- deal with the separate insulation on different parts of the body and discomfort due to the asymmetry of a clothing ensemble.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
thermal insulation
I
resistance to dry heat loss between two surfaces, expressed in square metres Kelvin per watt ($m^2 \cdot K \cdot W^{-1}$)

NOTE 1 In this International Standard it is considered as the *equivalent uniform thermal resistance*, or thermal insulation, on a human body. This is the clothing *heat resistance* (thermal insulation) that, when uniformly covering the whole body surface (including hands, face, etc.), would result in the same heat loss as the actual, possibly non-uniform, clothing heat resistance. This heat resistance is the quotient of the temperature gradient between the surfaces (the driving force) over the dry heat loss per unit of body surface area (the flux):

$$I = \frac{\text{temperature gradient}}{\text{heat loss per unit of body surface area}} \quad (1)$$

For the human body, this resistance can be divided into specific layers, as illustrated in Figure 1 (see also Annex F).

NOTE 2 Because of the special definition of thermal insulation in this International Standard, it is usually expressed in clo, the unit of thermal insulation of clothing. Although it can be converted into SI units in similar fashion to the thermal insulation of, for example, textile samples [symbol: R_{ct}; 1 clo = 0,155 ($m^2 \cdot K \cdot W^{-1}$)], the meaning is not the same.

2.1.1
total insulation
I_T
thermal insulation from the body surface to the environment (including all clothing, enclosed air layers and boundary air layer) under reference conditions, static

See Figure 1.

NOTE Based on Equation (1), it is expressed as:

$$I_T = \frac{\bar{t}_{sk} - t_o}{H} \quad (2)$$

where

$\bar{t}_{sk}$ is the mean skin surface temperature, in degrees Celsius;

t_o is the operative temperature, in degrees Celsius (in most cases equal to the air temperature, t_a);

H is the dry heat loss per square metre of skin, in watts per square metre.

2.1.2
basic insulation
intrinsic insulation
I_{cl}
thermal insulation from the skin surface to the outer clothing surface (including enclosed air layers) under reference conditions, static

See Figure 1.

NOTE Based on Equation (1), it is expressed as:

$$I_{cl} = \frac{\bar{t}_{sk} - t_{cl}}{H} \quad (3)$$

where $\bar{t}_{cl}$ is the mean outer clothing surface temperature, in degrees Celsius.

2.1.3
air insulation
I_a
thermal insulation of the boundary (surface) air layer around the outer clothing or, when nude, around the skin surface

See Figure 1.

NOTE 1 Based on Equation (1), it is expressed as

$$I_a = \frac{\bar{t}_{cl} - t_o}{H} \quad (4)$$

NOTE 2 The dry heat loss is composed of radiant and convective heat loss (see Annex G). These heat transfers through the clothing layers are not considered separately in this International Standard; for the air layer, they can be considered separately. The alternative representation is then:

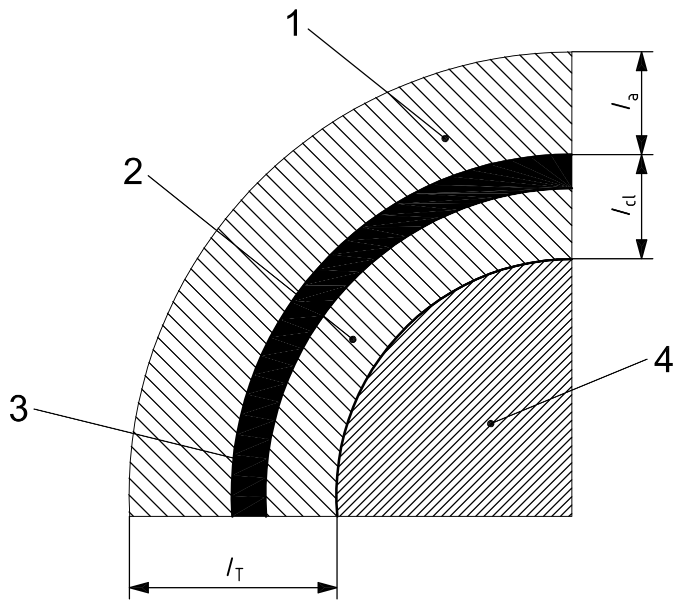
$$I_a = \frac{1}{h_c + h_r} \quad (5)$$

where

h_c is the convective heat transfer coefficient, in watts per square metre Kelvin ($W \cdot m^{-2} \cdot K^{-1}$);

h_r is the radiative heat transfer coefficient, in watts per square metre Kelvin ($W \cdot m^{-2} \cdot K^{-1}$).

NOTE 3 Such values are defined for standardized conditions (static body, wind still, i.e. speed $< 0{,}2\ m \cdot s^{-1}$). When air movement is present, or when the body moves, this will affect the insulation (typically lowering it), in which case, it is referred to as *resultant* or *dynamic heat resistance*.



Key

1 surface (or boundary) air layer

2 enclosed air layer

3 clothing

4 body

Figure 1 — Schematic representation of total, basic and air insulations

2.1.4
clothing area factor
f_{cl}
ratio of the outer surface area of the clothed body to the surface area of the nude body

NOTE 1 The outer surface area of a clothed person, A_{cl}, is greater than the surface area of a nude body, A_{Du}. Their ratio is therefore larger than 1:

$$f_{cl} = \frac{A_{cl}}{A_{Du}} \tag{6}$$

NOTE 2 Basic and air insulation do not simply add up to total insulation. This is explained by the difference in surface area between the outer clothing surface and the skin surface. Owing to this higher surface area, the insulative effect for the body of the air insulation is reduced the thicker the clothing (the larger the outer clothing surface area):

$$I_T = I_{cl} + \frac{I_a}{f_{cl}} \tag{7}$$

2.1.5
resultant total insulation
dynamic total insulation
$I_{T,r}$
actual thermal insulation from the body surface to the environment (including all clothing, enclosed air layers and boundary air layers) under given environmental conditions and activities

NOTE It is the total insulation (I_T) value in actual situations (as opposed to reference conditions), including the effects of movements and wind. Values for I_T given in this International Standard and in most of the literature are obtained on a thermal manikin which remains static in a low wind condition, and such values need to be corrected for wind and movement effects.

2.1.6
resultant basic insulation
dynamic basic insulation
$I_{cl,r}$
actual thermal insulation from the body surface to the outer clothing surface (including enclosed air layers) under given environmental conditions and activities

NOTE It is the basic (intrinsic) insulation (I_{cl}) value in actual situations (as opposed to reference conditions), including the effects of movements and wind.

2.1.7
effective insulation
I_{clu}
increase in insulation provided to a thermal manikin by a single garment compared to the nude manikin insulation

NOTE For insulation of individual garments, the term *effective thermal insulation* is used (I_{clu}). The effective thermal insulation of individual garments making up the ensemble (see Table B.2) is determined on a manikin wearing only that single garment as:

$$I_{clu} = I_T - I_a = \frac{\overline{t}_{sk} - t_o}{H} - I_a \qquad (8)$$

where

I_T is the total thermal insulation of the garment, in square metres Kelvin per watt ($m^2 \cdot K \cdot W^{-1}$) or in clo;

t_o is the operative temperature, in degrees Celsius (equal to the air temperature, t_a, for most measuring conditions in climatic chambers).

2.2
water vapour resistance
evaporative resistance
R_e
resistance to water vapour transfer between two surfaces, expressed in square metres kilopascal per watt

NOTE 1 In this International Standard it is considered as the *equivalent uniform* vapour resistance. This is the resistance that, when uniformly covering the whole body surface (including hands, face, etc.), would result in the same heat loss through evaporation as the actual, possibly non-uniform, vapour resistance. This resistance is the quotient of the vapour pressure gradient between the surfaces (the driving force) over the evaporative heat loss per unit of body surface area:

$$R_e = \frac{\text{vapour pressure gradient}}{\text{evaporative heat loss per unit of body surface area}} \qquad (9)$$

NOTE 2 Similarly to heat resistance, it is divided into specific layers.

2.2.1
total water vapour resistance
$R_{e,T}$
vapour resistance from the body surface to the environment (including all clothing, enclosed air layers and boundary air layers) under reference conditions, static

2.2.2
basic water vapour resistance
$R_{e,cl}$
vapour resistance from the body surface to the outer clothing surface (including enclosed air layers) under reference conditions, static

2.2.3
air water vapour resistance
$R_{e,a}$
vapour resistance of the boundary (surface) air layer around the outer clothing or, when nude, around the skin surface

NOTE In analogy to heat resistance:

$$R_{e,T} = R_{e,cl} + \frac{R_{e,a}}{f_{cl}} \qquad (10)$$

2.2.4
resultant total water vapour resistance
dynamic total water vapour resistance
$R_{e,T,r}$
vapour resistance from the body surface to the environment (including all clothing, enclosed air layers and boundary air layers) under given environmental conditions and activities

NOTE 1 It is the total water vapour resistance ($R_{e,T}$) value in actual situations (as opposed to reference conditions), including the effects of movements and wind.

NOTE 2 Values of $R_{e,T}$ are defined for standardized conditions (static body, wind still, i.e. speed $< 0{,}2\ \mathrm{m \cdot s^{-1}}$). When air movement is present, or when the body moves, this will affect the vapour resistance (typically lowering it), in which case it is referred to as the *resultant* or *dynamic* total water vapour resistance.

2.2.5
resultant basic water vapour resistance
dynamic basic water vapour resistance
$R_{e,cl,r}$
vapour resistance from the body surface to the outer clothing surface (including enclosed air layers) under given environmental conditions and activities

NOTE 1 It is the basic water vapour resistance ($R_{e,cl}$) value in actual situations (as opposed to reference conditions), including the effects of movements and wind.

NOTE 2 Values of $R_{e,cl}$ are defined for standardized conditions (static body, wind still, i.e. speed $< 0{,}2\ \mathrm{m \cdot s^{-1}}$). When air movement is present, or when the body moves, this will affect the vapour resistance (typically lowering it), in which case it is referred to as the *resultant* or *dynamic* basic water vapour resistance.

3 Application of this International Standard

Where possible, the insulation and vapour resistance values of a clothing ensemble should be measured using equipment such as thermal (wetted or sweating) manikins, or by performing experiments involving human subjects. Test procedures for the measurement of heat and vapour resistance are outlined in Annexes D and E. However, given the cost and the need for specialized equipment, actual measurement will most likely be beyond the reach of most users of this International Standard. In that case, the insulation and vapour resistance shall be estimated using the methods specified in the following clauses and Annexes A, B and C.

For guidance, the stepwise approach is schematically represented in the flowcharts of Figure 2, for the determination of heat resistance, and Figure 3, for the determination of vapour resistance. The various options are described.

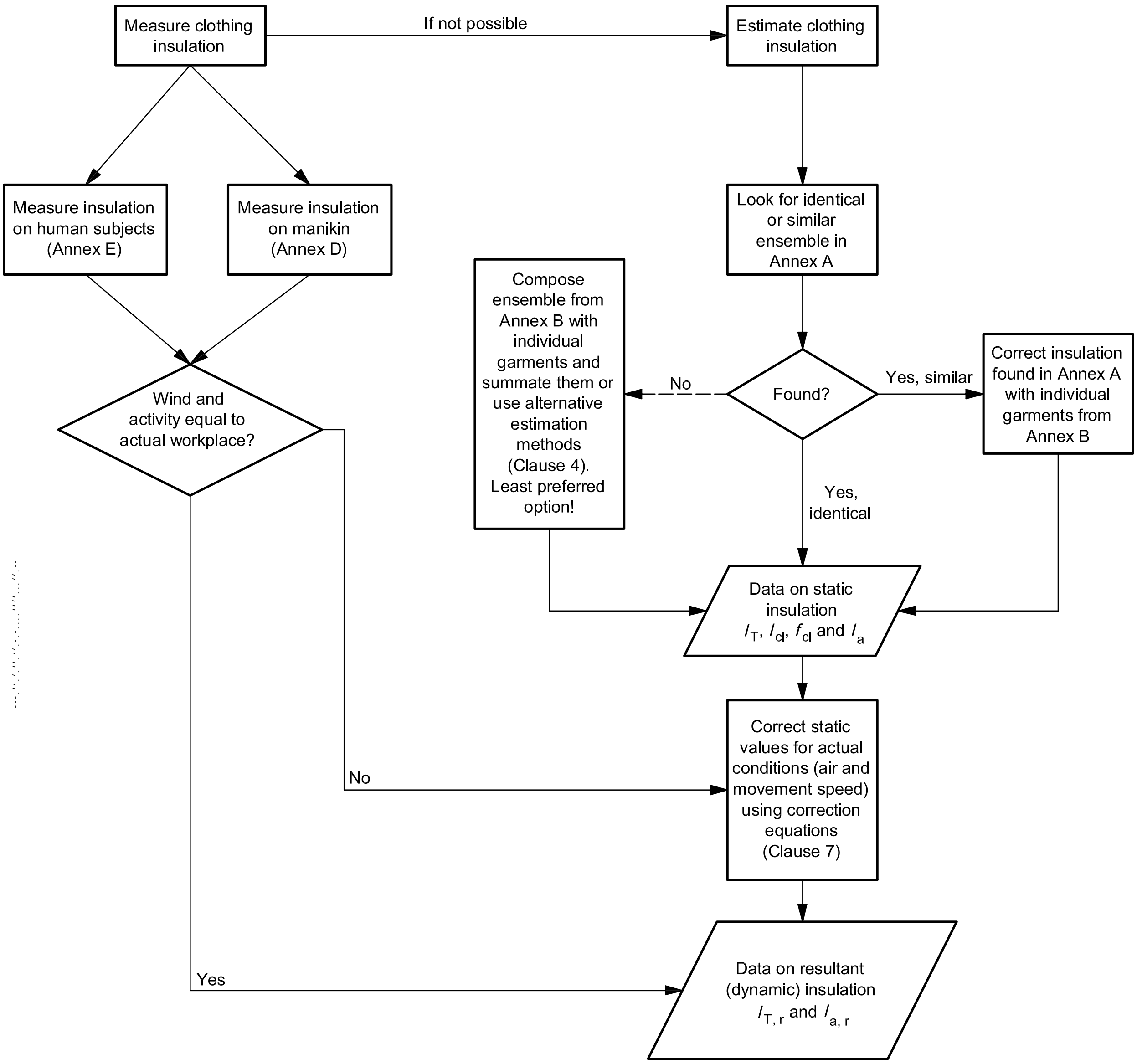


Figure 2 — Determining clothing insulation

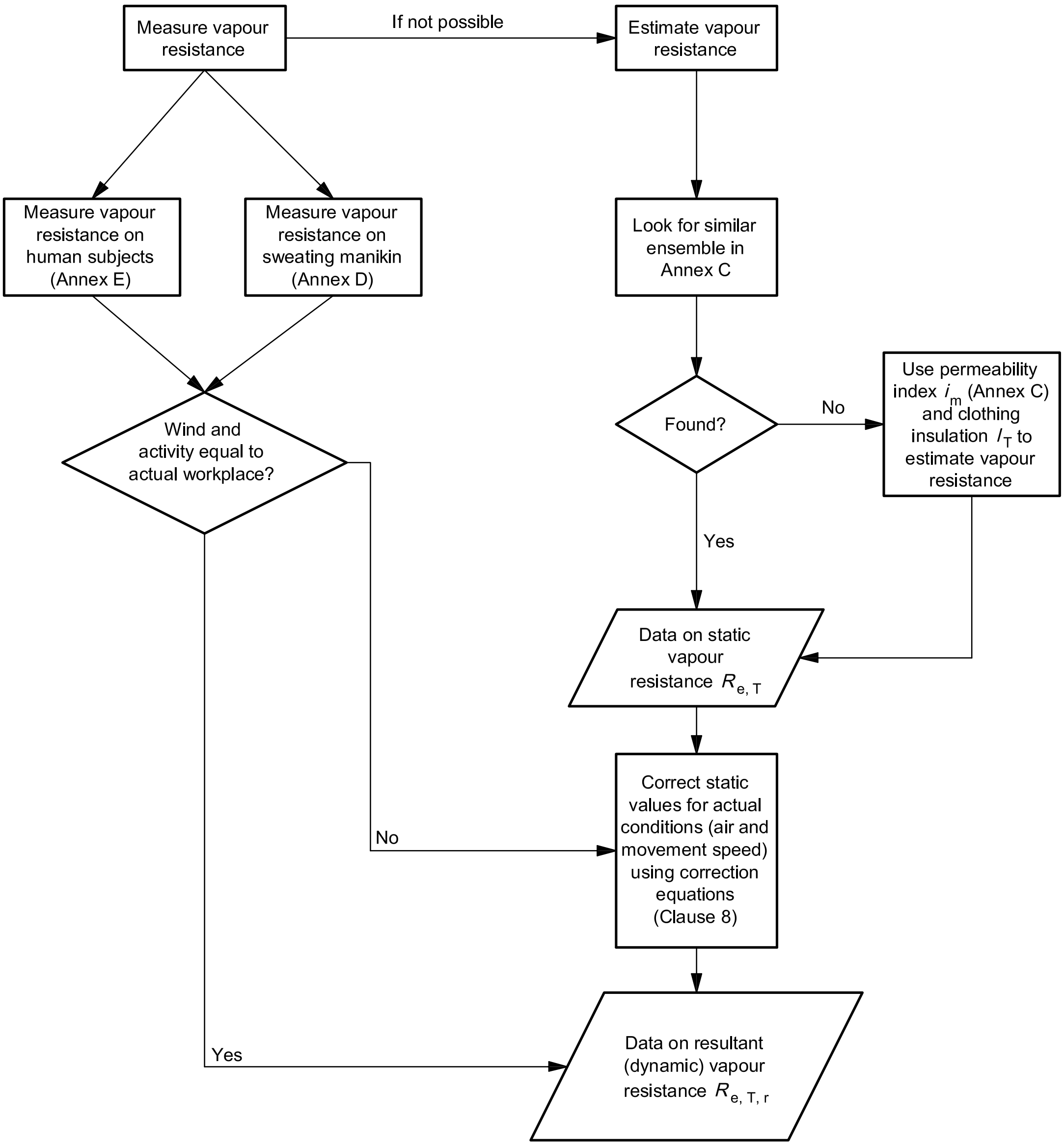


Figure 3 — Determining clothing vapour resistance

4 Estimation of thermal insulation of clothing ensemble based on tables and with values measured on a standing thermal manikin

4.1 General

Tables in this International Standard provide data on the insulation of complete clothing ensembles, as well as insulation values for individual garments that can be added to create complete ensembles. It is advisable to use the tables of complete ensembles to match the actual ensemble, as this will provide a more accurate value for clothing insulation than the summation of individual garments. Interpolation between the thermal insulation of two ensembles may be used and, when an ensemble is found similar to the actual ensemble, small corrections may also be made by adding or subtracting individual garment insulations to achieve the best estimate of the insulation of the actual ensemble. Finally, corrections for movement and air velocity shall be applied.

4.2 Insulation values of complete ensembles

In Annex A, I_T and I_{cl} values are listed for a selection of clothing ensembles. All of the values were measured on a static, standing, thermal manikin in low air movement ($< 0{,}2\ m \cdot s^{-1}$). In Table A.1, a short description of the clothing ensembles is given. Tables A.2 to A.10 present more extended lists that can be used for finding a clothing ensemble that is comparable with the actual clothing ensemble; f_{cl} values are also given. The total clothing mass, where this is given, is based on garments that fit a standard person (European male size 52) and does not include shoes. A number following the listing in the tables of individual garments making up most of the ensembles refers to Annex B, where a more detailed description of the individual garment is presented, including figures.

Annex A can also be used to select clothing for a workplace when the required insulation is known.

4.3 Ensemble thermal insulation values based on individual garments

Instead of using the ensembles in Annex A, the insulation for an ensemble, I_{cl}, expressed in clo, may also be estimated, based on a summation of the insulation of individual garments using the following empirical equation [31], [36]:

$$I_{cl} = 0{,}161 + 0{,}835 \sum I_{clu} \tag{11}$$

expressed in clo.

Or, with slightly reduced accuracy [32], [37]:

$$I_{cl} = \sum I_{clu} \tag{12}$$

expressed in square metres Kelvin per watt, or clo, and where I_{clu} is the effective thermal insulation of the individual garments making up the ensemble, in values of either square metres Kelvin per watt or clo.

Such values are listed in Annex B.

The design of the various garments in Annex B is indicated by a type number, referring to drawings showing a person dressed in various garment designs (Figures B.1 to B.14).

In some cases, the fabrics used are also listed. The type of material, however, has a limited influence on the thermal insulation. Instead, the insulation is mainly influenced by the thickness (indicated in Annex B) and the body surface area covered (indicated on the drawings).

It should be noted that the summations presented in Equations (11) and (12) are based on data with rather uniform insulation distributions over the body. Such summations should not be used for extreme situations (e.g. three layers on lower body and only a thin layer on upper body). The accuracy of the summation was acceptable when actually measured data for the respective garments were used. When the separate garments' insulations were obtained from the tables, the accuracy of the summation was limited. Hence, it is preferable to work with values of full ensembles (see Annex A).

The application range for which these relationships [Equations (11) and (12)] were tested is between 0,2 clo and 1,6 clo.

4.4 Complete ensemble insulation corrected for small differences in composition

The accuracy of the summation of individual garments (4.3) is much less than that of matching the actual ensemble with an ensemble taken from Annex A (4.2). Hence, when an exact match of the actual ensemble with those of the tables of Annex A is not possible, but similar ensembles can be found, it is best to take the similar ensemble insulation value and correct this for the difference in ensemble composition. For example, if the actual ensemble has a different type of sweater, the ensemble insulation may be corrected for the difference in insulation between the actual sweater and that of the sweater in the ensemble description of

Annex A. For this purpose, the effective insulations of both clothing items are compared and the difference used for adjustment of the ensemble value:

$$I_{\text{cl,a}} = I_{\text{cl,A}} + 0{,}835 \times \Delta I_{\text{cl}u} \tag{13}$$

with the result expressed in clo or in m^2·k·w^{-1}, and where $I_{\text{cl,a}}$ is the basic insulation of the actual ensemble, $I_{\text{cl, A}}$ is the basic insulation of the ensemble according to Annex A, and $\Delta I_{\text{cl}u}$ is the correction for the difference in individual garments (negative for subtracting a garment or when replacing with a less insulative garment).

This can be the difference between two garments of the same type (replacing one sweater by another), or the effective insulation of an extra garment, or a negative value in the case where the actual ensemble contains one garment less. The $I_{\text{cl}u}$ values are taken from Annex B.

Corrections should be kept to a minimum, and interpolation between two relevant ensembles is preferred. In adding and removing garments, it should be considered how the insulation is distributed. Adding a thin layer to an already covered part of a cold weather ensemble will have minimal impact, compared with the large impact of adding a thin layer to a nude part in such an ensemble.

4.5 Calculation of thermal insulation for clothing ensembles

As an alternative to the selection of an ensemble from the tables, it is also possible to determine the clothing insulation of an ensemble using the following empirically determined relationship [32], [37]:

$$I_{\text{cl}} = 0{,}919 + 0{,}255 \times m - 0{,}008\,74 \times A_{\text{COV,0}} - 0{,}005\,10 \times A_{\text{COV,1}} \tag{14}$$

where

I_{cl}	is the intrinsic clothing insulation, in clo;
m	is the clothing weight (without shoes), in kilograms;
$A_{\text{COV,0}}$	is the body surface area not covered by clothing, as a percentage of total body surface area;
$A_{\text{COV,1}}$	is the body surface area covered by a single clothing layer, as a percentage of total body surface area.

In effect, Equation (14) assumes a certain multi-layer insulation for a given clothing weight and then subtracts insulation for areas only covered with a single layer and for areas without clothing. The application range for which this relation was tested is between 0,2 clo and 1,8 clo.

Guidance on how to calculate A_{COV} is given in Annex H.

4.6 Calculation of thermal insulation for individual garments

The effective thermal insulation of an individual garment, $I_{\text{cl}u}$ (m^2 · K · W^{-1}), may also be estimated by

$$I_{\text{cl}u} = 0{,}00095 \times A_{\text{COV}} \tag{15}$$

or, if expressed in clo, using

$$I_{\text{cl}u} = 0{,}0061 \times A_{\text{COV}} \tag{16}$$

where A_{COV} is the body surface area covered by clothing (percentage of total skin area).

The values for body surface area covered by clothing are shown for garments in the figures of Annex B. Garment weight on its own is not a good predictor of garment insulation [32].

When the thickness of the fabric used, d_{fab}, expressed in metres, is also known, a more exact estimation of I_{clu} ($m^2 \cdot K \cdot W^{-1}$) may be made using

$$I_{clu} = 0{,}00067\ A_{COV} + 0{,}217 \times d_{fab} \times A_{COV} \tag{17}$$

or, if expressed in clo, using

$$I_{clu} = 0{,}0043\ A_{COV} + 1{,}4 \times d_{fab} \times A_{COV} \tag{18}$$

where d_{fab} is the thickness of the fabric, in metres, measured in accordance with ASTM D1777 using a 7,5 cm diameter pressure foot and 69,1 $N \cdot m^{-2}$ pressure.

NOTE As the formula was derived using the ASTM method, no ISO alternative can be given, as this could affect the relation.

The application range for which this relation [Equation (15)] was tested is between 0,02 clo and 0,5 clo or 5 % to 82 % A_{COV}. For Equation (17), the range was 0,02 clo to 1,05 clo.

5 Estimation of clothing area factor

The outer surface area of a clothed person, A_{cl}, is greater than the surface area of a nude body, A_{Du}. The ratio of these is the clothing area factor, f_{cl} [Equation (6)].

The value of f_{cl} is listed in Annex A for all clothing ensembles. It can be measured by photographic [32], [45], [47] or whole body scanning methods. Pictures from different directions or whole body scans of the nude person/manikin are compared with similar pictures/scans of the clothed person/manikin.

In view of the fact that the surface area increase depends on the clothing ensemble thickness, usually related to its insulation, I_{cl}, the clothing area factor may also be estimated [32], [46], [48] from the following equations:

— If I_{cl} is expressed in square metres Kelvin per watt ($m^2 \cdot K \cdot W^{-1}$):

$$f_{cl} = 1{,}00 + 1{,}81 \times I_{cl} \tag{19}$$

— If I_{cl} is expressed in clo:

$$f_{cl} = 1{,}00 + 0{,}28 \times I_{cl} \tag{20}$$

It should be noted that the correlation between f_{cl} and I_{cl} observed was low, so the estimate has limited reliability, especially for non-western clothing [1]. Determination of f_{cl} based on the table examples in Annex A, or, ideally, by actually measuring it, is therefore preferable, although in general the actual impact of f_{cl} on the overall result for the insulation values is small. The application range for which these relations were tested is between 0,2 clo and 1,7 clo.

6 Estimation of surface (or boundary) air layer insulation

In some cases, it is necessary to know the insulation of the surface air layer I_a (also called “boundary air layer”) — for example, if I_T is known, but I_{cl} is needed, or vice versa. In that case, Equation (7) may be used with I_a and f_{cl}, and either I_T or I_{cl} as input.

The static value of I_a ranges in most studies on which the tables in Annex A were based around 0,7 clo (0,109 $m^2 \cdot K \cdot W^{-1}$) when measured at air velocities around 0,1 $m \cdot s^{-1}$ to 0,15 $m \cdot s^{-1}$. Thus, for static conditions, this value may be used as an estimate. For some cold weather clothing measurements the reference wind speed is set at 0,4 $m \cdot s^{-1}$; see Reference [6].

The insulation provided by the outer surface (boundary layer) thermal insulation (see Figure 1) is disturbed when air movement increases or the person starts to move. The following correction equation [17] shows by how much this reduction takes place, compared to the static, no-wind (v_{ar} = 0,15 m · s^{-1}) I_a value taken from Reference [11]:

$$I_{a,r} = e^{\left[-0{,}533 \times (v_{ar} - 0{,}15) + 0{,}069 \times (v_{ar} - 0{,}15)^2 - 0{,}462 v_w + 0{,}201 v_w^2\right]} \cdot I_{a,static} \quad (21)$$

where

$I_{a,r}$ is the boundary layer thermal insulation, in clo;

v_{ar} is the relative air velocity, in metres per second (minimum = 0,15 m · s^{-1}; maximum = 3,5 m · s^{-1});

v_w is the walking speed, in metres per second (maximum = 1,2 m · s^{-1});

$I_{a,static}$ is the reference value for air insulation (= 0,7 clo).

Alternatively, I_a may be calculated as:

$$I_a = \frac{1}{(h_c + h_r)} \quad (22)$$

where

h_c is the convective heat transfer coefficient, in watt per metre squared per degree Celsius (W·m^{-2}·°C^{-1});

h_r is the radiative heat transfer coefficient, in watt per metre squared per degree Celsius (W·m^{-2}·°C^{-1}).

This does not include a correction for the effect of movement. The convective heat exchange coefficient, h_c, may be estimated as the greatest value from the following:

$$2{,}38 \left|\bar{t}_{sk} - t_a\right|^{0{,}25} \quad (23)$$

$$3{,}5 + 5{,}2\ v_{ar} \quad (24)$$

$$8{,}7\ v_{ar}^{0{,}6} \quad (25)$$

The radiative heat exchange, h_r, may be estimated using:

$$h_r = 5{,}67 \cdot 10^{-8} \varepsilon \times \frac{A_r}{A_{DU}} \times \frac{(t_{cl} + 273)^4 - (t_r + 273)^4}{t_{cl} - t_r} \quad (26)$$

The fraction of skin surface involved in heat exchange by radiation, A_r/A_{DU}, is equal to 0,67 for a crouching subject, 0,70 for a seated subject and 0,77 for a standing subject.

7 Estimation of water vapour resistance

7.1 General

The water vapour resistance, $R_{e,T}$, of a clothing ensemble may be measured in experiments with subjects or with a wetted or sweating thermal manikin. If this is not possible, $R_{e,T}$ may be estimated using existing data, or using a relationship between vapour and heat resistance to derive it from the latter.

7.2 Estimation of vapour resistance of clothing ensembles based on tables with values measured on standing thermal manikin

In Annex C, $R_{e,T}$ and $R_{e,cl}$ values are listed for a selection of clothing ensembles. All of the values were measured on a static, standing thermal manikin in low air movement ($< 0{,}2\ \text{m} \cdot \text{s}^{-1}$). A short description of the clothing ensembles is given and the f_{cl} values are also listed.

A number following the listing in the tables of individual garments making up most of the ensembles refers to Table C.5, where a detailed description of the garment fabric is presented.

7.3 Estimation of vapour resistance of clothing ensemble based on its relation with dry heat resistance

The total water vapour resistance, $R_{e,T}$, in square metre kilopascals per watt ($\text{m}^2 \cdot \text{kPa} \cdot \text{W}^{-1}$) may be estimated on the basis of the thermal insulation of that ensemble, I_T or I_{cl}, by means of the permeability index, i_m, and the Lewis relation (L = 16,5 K · kPa^{-1}):

$$R_{e,T} = \frac{I_T}{i_m L} = \frac{0{,}06}{i_m}\left(\frac{I_a}{f_{cl}} + I_{cl}\right) \tag{27}$$

with I_T, I_a and I_{cl} expressed in $\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$.

Typical values for i_m are given in Annex C, Table C.1. These are not as such related to the clothing's insulation, but to the permeability of the fabric layers. Based on the data for I_T and i_m, it is now possible to estimate $R_{e,T}$.

For an air layer, i_m as defined and used in Equation (27), is around 0,5. For impermeable garments that cover the whole body including hands, feet and head it is close to zero. For many types of one- or two-layer, permeable clothing, the permeability index, i_m, may be set to 0,38 and the equation for vapour resistance ($\text{m}^2 \cdot \text{kPa} \cdot \text{W}^{-1}$) simplified to:

$$R_{e,T} = 0{,}16 \times I_T = 0{,}16\left(\frac{I_a}{f_{cl}} + I_{cl}\right) \tag{28}$$

For the clothing and air layer alone, similar relations apply:

$$R_{e,a} = \frac{0{,}06}{f_{cl} \times h_c} \tag{29}$$

$$R_{e,cl} = 0{,}06 \times \frac{I_{cl}}{i_{m,cl}} \tag{30}$$

where $i_{m,cl}$ is the permeability index for the clothing layer alone.

For many permeable one- or two-layer clothing ensembles, $i_{m,cl}$ may be set to 0,34, giving:

$$R_{e,cl} = 0{,}18 \times I_{cl} \quad \text{m}^2 \cdot \text{kPa} \cdot \text{W}^{-1} \tag{31}$$

Clothing with specific protective properties against chemical, physical or biological agents such as oil, radiant heat or bacteria, may have considerably lower values for i_m. Refer to the tabular values for heat protective clothing given in Annex C.

CAUTION — For the application of ISO 7933 with such special garments, it is recommended that an expert be consulted.

Typical values for the permeation efficiency ratio, or permeability index, i_m, are given in Tables C.1, C.2 and C.3, in which the numbers of the clothing ensembles and garments refer to Annexes A and B.

8 Influence of body movement and air movement on the thermal insulation and vapour resistance of a clothing ensemble

8.1 General

Most types of clothing ensembles have openings (e.g. collars, cuffs) which allow a certain air exchange with the environment. When work is performed, this air exchange can increase, changing the insulation of the clothing. This is called the “pumping effect”. In addition, clothing may be compressed by wind, reducing its thickness, and wind may enter through the fabrics or openings, increasing the air exchange of the microclimate air with the external environment. This would also change the resistance to heat and moisture transfer provided by the clothing.

To estimate the effect of body motion (pumping effect) and wind on the clothing insulation, a movable thermal manikin may be used in simulated wind conditions. The methods given in Annex D can be used. $I_{a,r}$ is then measured with a nude manikin engaged in the appropriate activity (seated, standing, walking, bicycling) and air movement and $I_{cl,r}$ or $I_{T,r}$ on the clothed manikin in the same conditions. From these measurements, corrections of the I_a, I_{cl}, and I_T values measured on the standing manikin can be estimated and used for other clothing ensembles. The pumping effect can also be measured on human subjects: see Annex E.

For vapour resistance, this same procedure can be followed with specialized “sweating manikins”, or with human subjects.

The effect of body motion is only measured on a whole clothing ensemble and not on each single garment.

The influence of wind depends on the air permeability of the outer textile layer and on the types and number of openings, though for many ensembles the effects have been shown to be similar. Based on such measurements, correction equations have been obtained that allow the correction of the values presented in the tables in Annexes A and C, which were derived from measurements on static manikins, without any wind present ($v_{ar} < 0,2\ \text{m}\cdot\text{s}^{-1}$).

8.2 Correction of clothing insulation

Owing to the type of data that are available, the correction equations used to correct static clothing insulation for the effects of air and body movement are based on correction of the total static insulation value, I_T. The following two equations are to be used for the correction of total clothing insulation to obtain the resultant total clothing insulation, $I_{T,r}$, i.e. the actual clothing insulation in the current conditions [17], [18]:

— For a clothed person in normal or light clothing (0,6 clo < I_{cl} < 1,4 clo or 1,2 clo < I_T < 2,0 clo):

$$I_{T,r} = \text{corr}\ I_T \times I_T = e^{\left[-0{,}281 \times (v_{ar} - 0{,}15) + 0{,}044 \times (v_{ar} - 0{,}15)^2 - 0{,}492 v_w + 0{,}176 v_w^2\right]} \cdot I_T \qquad (32)$$

— For a nude person (I_{cl} = 0 clo):

$$I_{T,r} = I_{a,r} = \text{corr}\ I_a \times I_{a,\text{static}} = e^{\left[-0{,}533 \times (v_{ar} - 0{,}15) + 0{,}069 \times (v_{ar} - 0{,}15)^2 - 0{,}462 v_w + 0{,}201 v_w^2\right]} \cdot I_{a,\text{static}} \qquad (33)$$

where

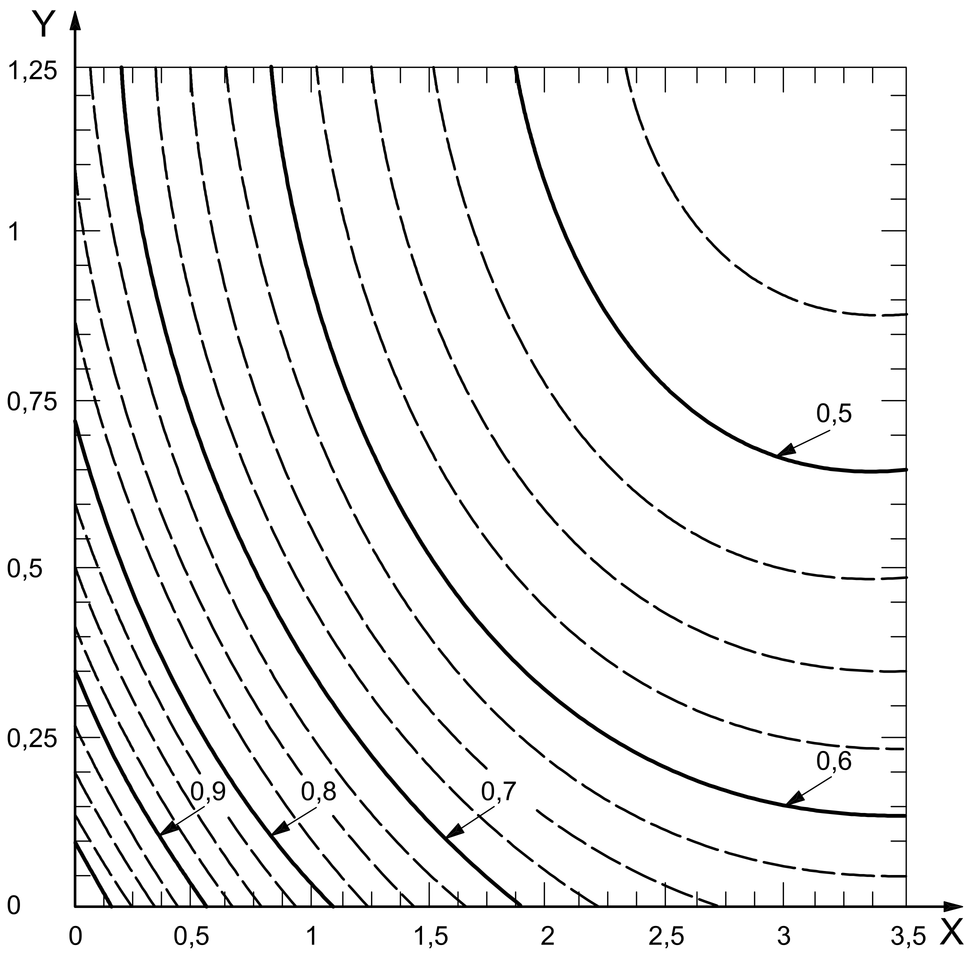
corr I_T is the correction factor for total insulation;

corr I_a is the correction factor for air insulation;

v_{ar} is the air velocity relative to the person, in metres per second, from 0,15 m·s^{-1} to 3,5 m·s^{-1};

v_w is the walking speed, in metres per second, from 0 m·s^{-1} to 1,2 m·s^{-1}.

These corrections for clothed and nude subjects are graphically represented in Figures 4 and 5.



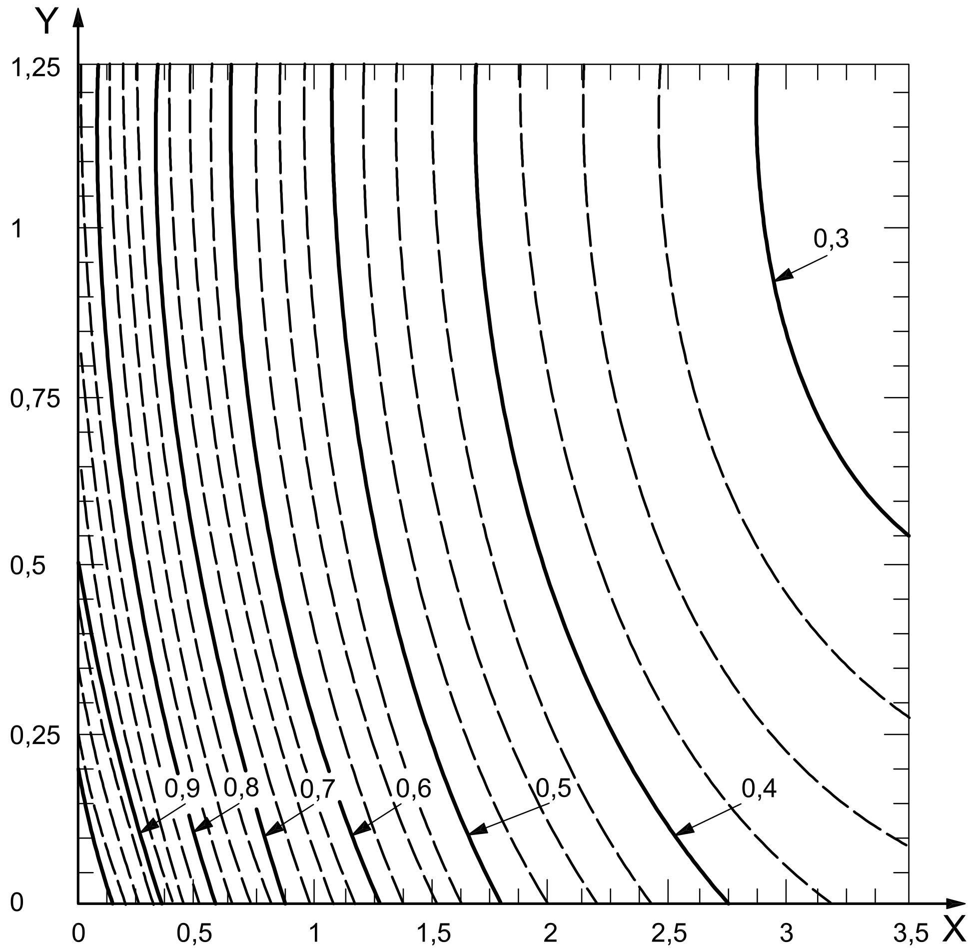
Valid up to 1,2 m·s^{-1} walking speed (v_w) and 3,5 m·s^{-1} relative wind speed (v_{ar}) (from References [17] and [18])

Key

X relative wind speed, m·s^{-1}

Y walking speed, m·s^{-1}

Figure 4 — Correction factor ($I_{T,r}/I_T$) for dressed subjects



Valid up to 1,2 m·s^{-1} walking speed (v_w) and 3,5 m·s^{-1} relative wind speed (v_{ar}) (from Reference [4])

Key

X relative wind speed, m·s^{-1}

Y walking speed, m·s^{-1}

Figure 5 — Correction factor ($I_{a,r}/I_a$) for nude subjects

For very low clothing insulations, i.e. I_{cl} between 0 clo and 0,6 clo, an equation for interpolation between Equations (32) (I_T dressed) and (33) (I_T nude = I_a) was derived [11]:

$$I_{T,r} = \frac{\left[(0{,}6 - I_{cl}) I_{T,r,nude} + I_{cl} \times I_{T,r,dressed}\right]}{0{,}6} \qquad 0 < I_{cl} < 0{,}6 \text{ clo} \qquad (34)$$

For specialized, insulating, cold weather clothing ($I_T > 2$ clo), which typically has low air permeability, and where high wind speeds occur more frequently, the formula for the correction factor to be used is [16], [41]:

$$I_{T,r} = e^{\left\{\left[-0{,}0512 \times (v_{ar} - 0{,}4) + 0{,}794 \times 10^{-3} * (v_{ar} - 0{,}4)^2 - 0{,}0639 \times v_w\right] \times p^{0{,}144}\right\}} \cdot I_T \qquad (35)$$

r^2 = 0,968 and SEE = 0,048

where

v_{ar} is the air velocity relative to the person, in metres per second, from 0,4 m·s^{-1} to 18 m·s^{-1};

v_w is the walking speed, in metres per second, from 0 m·s^{-1} to 1,2 m·s^{-1};

p is the air permeability of outer fabric, in litres per square metre per second, from 1 l·m^{-2} · s^{-1} to 1 000 l·m^{-2} · s^{-1} [low (e.g. coating or laminate) = 1; medium = 50; high (open weave) = 1 000 l·m^{-2} · s^{-1}].

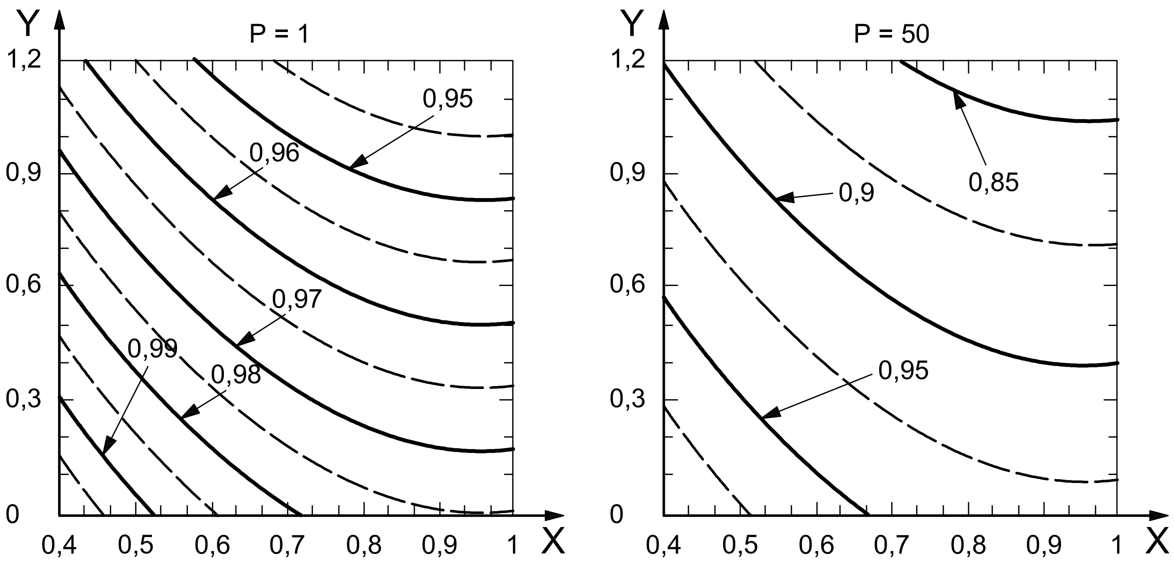
SEE is the standard error of the estimate.

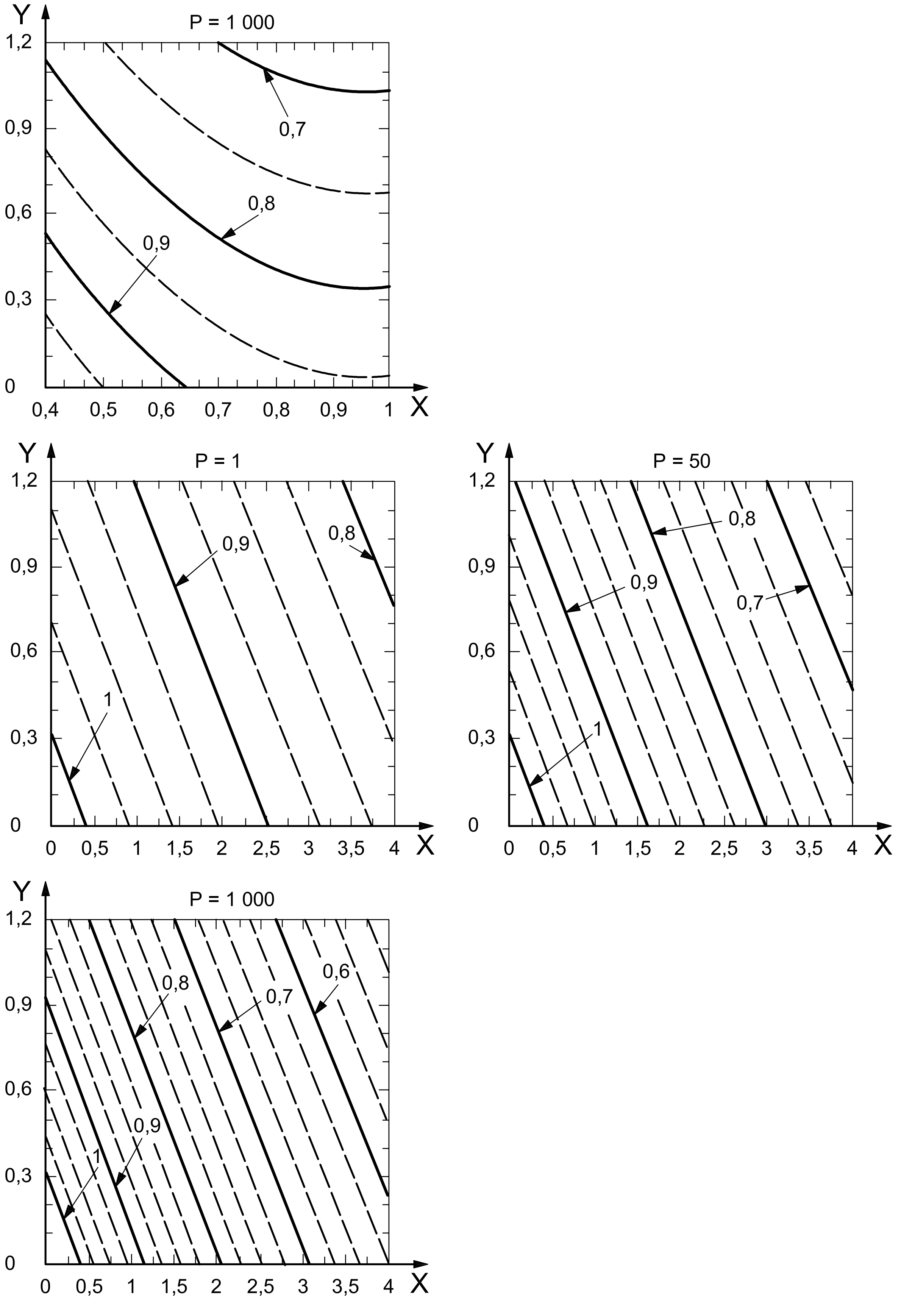
For the lower area of the wind range, better results were obtained in a separate analysis [17], [42]:

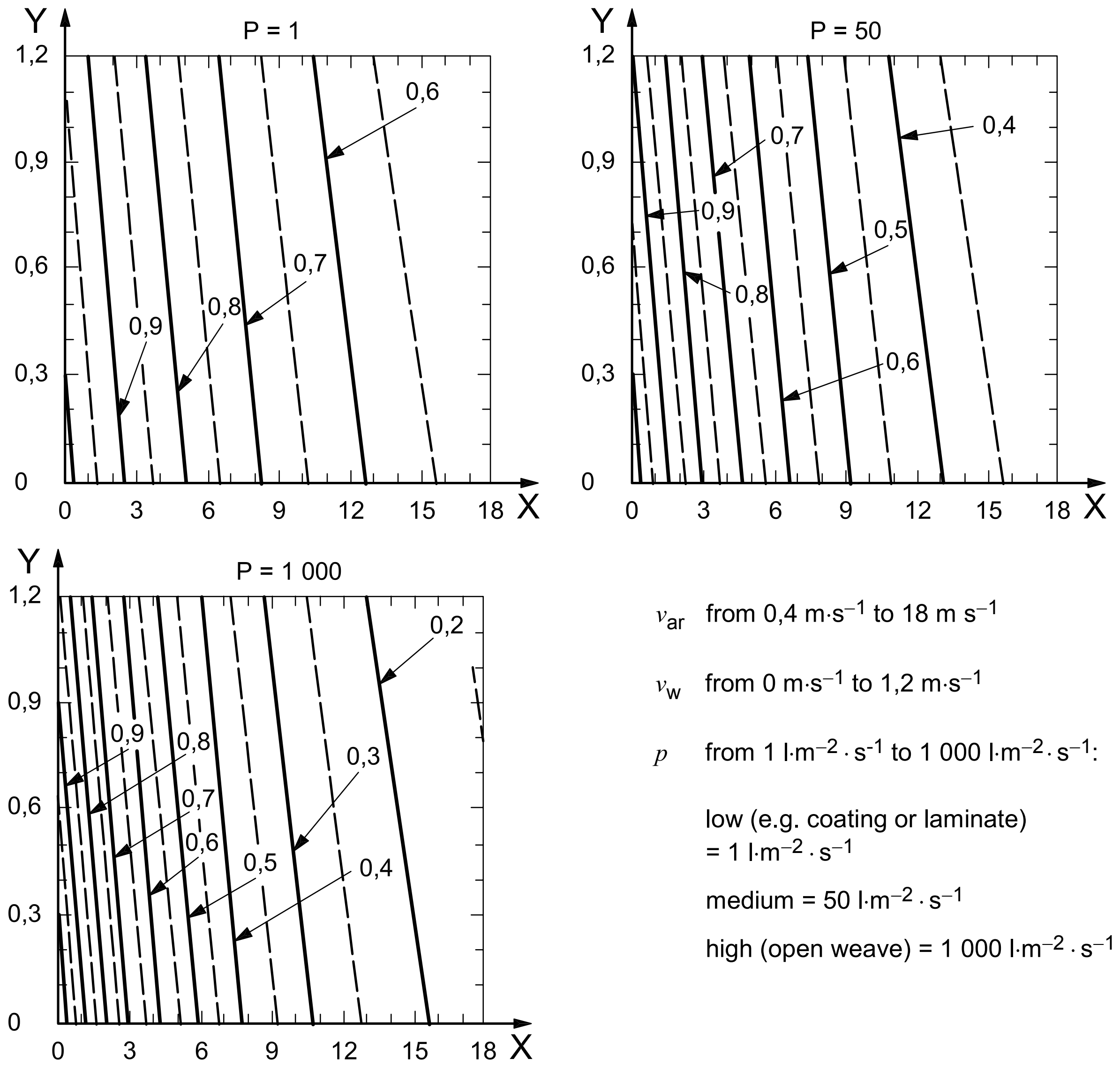
$$I_{T,r} = e^{\left\{\left[-0{,}0881 \times (v_{ar} - 0{,}4) + 0{,}0779 \times (v_{ar} - 0{,}4)^2 - 0{,}0317 \times (w)\right] \times p^{0{,}2648}\right\}} \cdot I_T \qquad (36)$$

with r^2 = 0,931 and SEE = 0,023; 0 m·s^{-1} $<$ walking speed $<$ 1,2 m·s^{-1} and 0,4 m·s^{-1} $<$ wind speed $<$ 1 m·s^{-1} and 1 l·m^{-2} · s^{-1} $< p <$ 1 000 l·m^{-2} · s^{-1}.

Here, it is assumed that the head and hands are covered with a hood or hat and gloves, i.e. the body is totally covered. This relation is presented in Figure 6 for three wind speed ranges and the three permeability levels. Note that the reference wind speed in these data was 0,4 m·s^{-1} [6], [17], [42].




P = 1 000
Y
1,2
0,9
0,6
0,3
0
0,4
0,5
0,6
0,7
0,8
0,9
1
X
0,7
0,8
0,9
P = 1
1
0,9
0,8
0
0,5
1
1,5
2
2,5
3
3,5
4
P = 50
0,8
0,9
0,7
1
P = 1 000
0,8
0,7
0,6
0,9
1



Valid up to 1,2 m·s^{-1} walking speed (v_w) and 18 m·s^{-1} relative wind speed (v_{ar})
(from References [17] and [42])

Key

X relative wind speed, m·s^{-1}

Y walking speed, m·s^{-1}

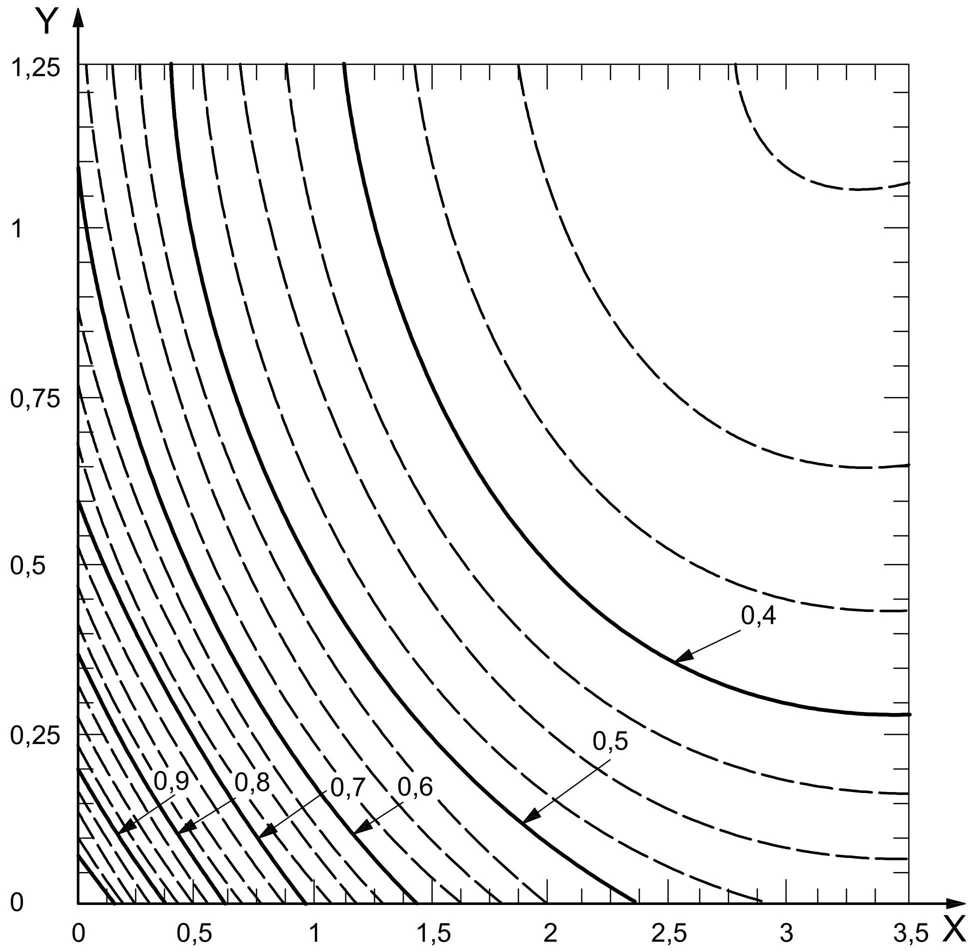
Figure 6 — Correction factor for effects of wind and movement for cold weather clothing ($I_T > 2$ clo)

8.3 Correction of clothing vapour resistance

The reduction of $R_{e,T}$ is shown to be related to the reduction in I_T. Based on the reduction factor for I_T, the resultant vapour resistance in windy and moving conditions, $R_{e,T,r}$, can be calculated as [12], [13]:

$$R_{e,T,r} = (0{,}3 - 0{,}5 \times \text{corr } I_T + 1{,}2 \times \text{corr } I_T^2) \cdot R_{e,T} \quad (37)$$

where corr I_T is the correction factor for clothing insulation [as, for example, in Equation (32)]. This relation is illustrated in Figure 7.



Valid up to 1,2 m·s^{-1} walking speed (v_w) and 3,5 m·s^{-1} relative wind speed (v_{ar})
(from References [12] and [13])

v_{ar} from 0,15 m·s^{-1} to 3,5 m s^{-1}

v_w from 0 m·s^{-1} to 1,2 m·s^{-1}

Key

X relative wind speed, m·s^{-1}

Y walking speed, m·s^{-1}

Figure 7 — Correction factor ($R_{e,T,r}/R_{e,T}$) for reduction in clothing vapour resistance in relation to air and body movements

$R_{e,T,r}$ can also be calculated directly from air and walking speed as [12], [13]:

$$R_{e,T,r} = e^{\left[-0{,}468\times(v_{ar}-0{,}15)+(v_{ar}-0{,}15)^2-0{,}874_{w}+0{,}358 v_w{}^2\right]} \cdot R_{e,T} \qquad (38)$$

where

v_{ar} is the air velocity relative to the person, in metres per second, min. 0,15 m·s^{-1}, max. 3,5 m s^{-1};

v_w is the walking speed, in metres per second, max. 1,2 m·s^{-1}.

NOTE Equations (37) and (38) were derived independantly from the raw data and thus may yield slightly different results.

These equations can be used for garments with a wide range of vapour permeability, as it has been shown that the relative change in vapour resistance due to movement and wind is similar [12], [13].

8.4 Activities other than walking

When, instead of walking, other, less-defined activities are performed (e.g. conveyor belt work), the value for walking speed in the equations may be replaced using:

$$v_{\mathrm{w}} = 0{,}0052 \cdot (M - 58) \qquad (39)$$

where M is the metabolic rate, in watts per square metre ($\mathrm{W \cdot m^{-2}}$), and v_{w} is limited to 0,7 $\mathrm{m \cdot s^{-1}}$.

8.5 Relative air velocity

The wind speed used in Equations (32) to (38) is the air velocity relative to the person, also called “relative air velocity”. When the person walks facing the wind, the relative air velocity for the person is simply the sum of the walking and air velocities. With the wind at back, the relative air velocity is the absolute value of the difference between walking and wind speeds. For all other angles, the relative air velocity may be calculated as [11], [12]:

$$v_{\mathrm{ar}} = \sqrt{\left[v_{\mathrm{w}} - v_{\mathrm{a}} \cdot \cos(\alpha)\right]^2 + \left[v_{\mathrm{\alpha}} \cdot \sin(\alpha)\right]^2} \qquad (40)$$

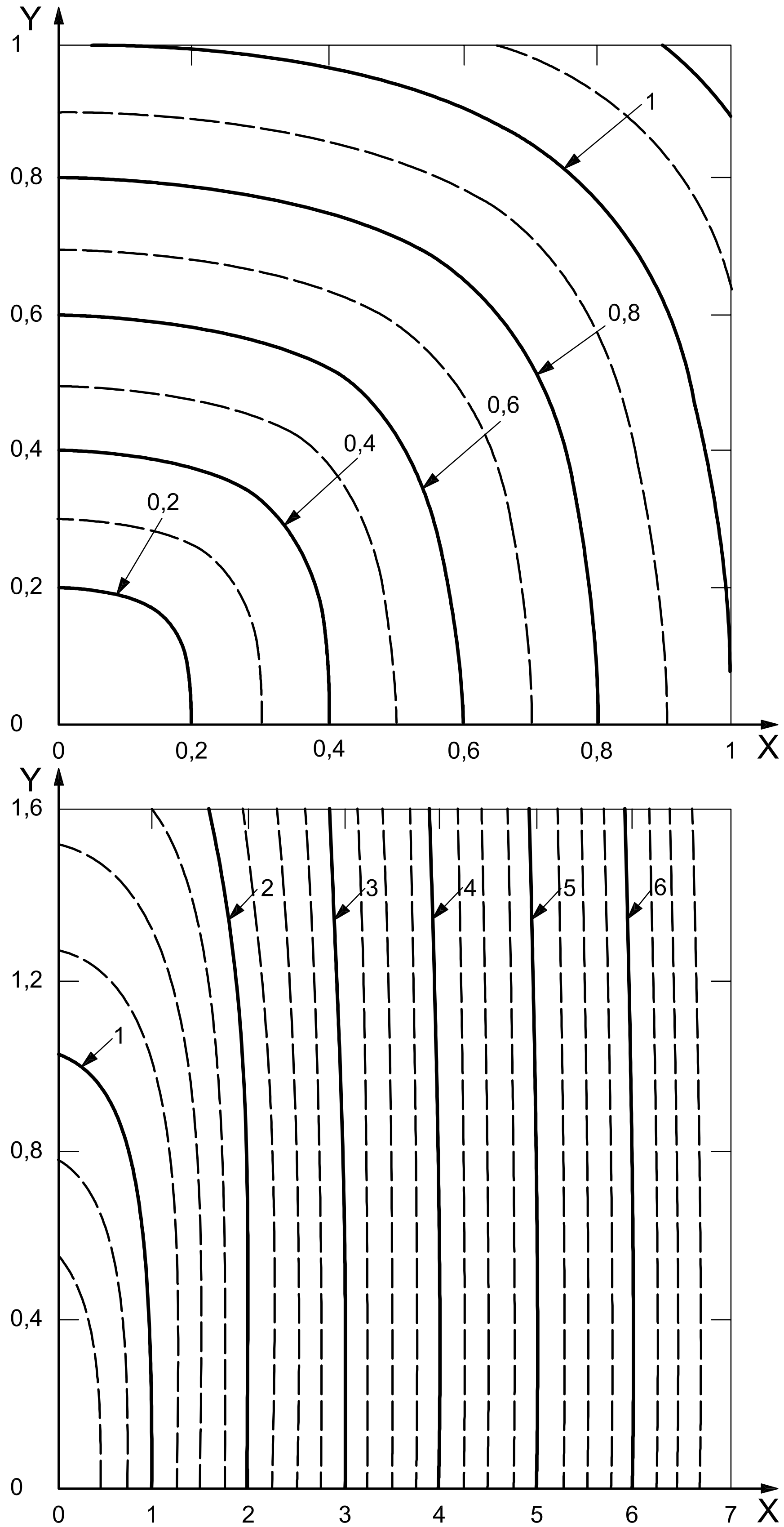
where

v_{a} is the absolute air velocity, in metres per second;

v_{w} is the walking speed, in metres per second;

α is the angle between walking and air velocities (0° if both are in the same direction).

When the air movement is not unidirectional, or when the person’s movement is not in a constant angle relative to the air movement (e.g. moving about a room) the relative airspeed towards the person can be calculated as the average of all possible angles between air and walking directions. These values can be deduced from Figure 8.



Key

X absolute air velocity, m·s^{-1}

Y walking speed, m·s^{-1}

Figure 8 — Values for relative air velocity in relation to walking speed and absolute wind speed for multidirectional movement assuming equal exposures to all wind angles [11]

9 Other factors influencing clothing insulation

9.1 General

Apart from air and body movement, other factors may also influence clothing insulation. The most notable of these are body posture, use of chairs, hypo- or hyperbaric environments and clothing wetting.

9.2 Posture

On the one hand, changes in posture (e.g. sitting) affect the heat exchange surface of the human body, as well as introducing air pockets (knee, hip) which together lead to an increase in the air layer insulation, I_a. On the other hand, the clothing insulation (I_{cl}) usually decreases when a person sits, as the clothing on the back, thighs and buttocks is compressed — I_{cl} typically decreases by 6 % to 18 %, whereas I_a increases by between 10 % and 25 %. The combined effect is therefore dependent on the ratio between the insulation of clothing and air. For nude subjects, insulation typically increases by 10 %, while for thick clothing it decreases by 10 %. These effects do not include the effect of the seat itself.

9.3 Effect of seats

Depending on the type of seat, it may add or reduce the insulation of a person due to the extra insulative material versus the compression of the clothing. For a manikin in 1,36 clo insulation, a standard car seat increases the insulation by 0,25 clo (1,61 clo). Ventilation of the car seat results in decreased insulation. Office chairs produce an increase in insulation of from 0,04 clo to 0,17 clo, depending on the height of the backrest and the thickness of the seat, and a sofa adds approximately 0,21 clo. A net chair and a wooden stool both give a decrease in insulation, by 0,03 clo [38].

9.4 Effect of pressure

A change in air pressure, e.g. a reduction when going to altitude, will affect both dry and evaporative heat transfer. At altitude, air is thinner, which causes a reduction in convective heat transfer and thus an increase in dry insulation. The low pressure will enhance evaporative heat transfer, however. The overall effect depends on the balance between these processes, and on the level of sweating present.

9.5 Wetting

When clothing gets wet it will lose part of its insulation. The liquid will increase the material's conductivity, thereby reducing insulation. The presence of moisture in the clothing will also cause extra evaporation and increase heat loss [30].

9.6 Washing

Washing may change the thermal insulation values. The effect depends on the type of textile, but is normally within the measuring accuracy. Insulation can increase due to contraction of fibres in woven or knitted garments, but mostly decreases due to reduced thickness. In particular, cold protective clothing with polyester batting fillings tends to decrease in thickness and insulation with washing.

Annex A
(normative)

Thermal insulation values for clothing ensembles

See Tables A.1 to A.10.

Table A.1 — Insulation values of typical clothing ensembles

Work clothing	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	Daily wear clothing	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$
Underpants, boiler suit, socks, shoes	0,7	0,11	Panties, T-shirt, shorts, light socks, sandals	0,3	0,05
Underpants, shirt, trousers, socks, shoes	0,75	0,115	Panties, petticoat, stockings, light dress with sleeves, sandals	0,45	0,07
Underpants, shirt, boiler suit, socks, shoes	0,8	0,125	Underpants, shirt with short sleeves, light trousers, light socks, shoes	0,5	0,08
Underpants, shirt, trousers, jacket, socks, shoes	0,85	0,135	Panties, stockings, shirt with short sleeves, skirt, sandals	0,55	0,085
Underpants, shirt, trousers, smock, socks, shoes	0,9	0,14	Underpants, shirt, light-weight trousers, socks, shoes	0,6	0,095
Underwear with short sleeves and legs, shirt, trousers, jacket, socks, shoes	1	0,155	Panties, petticoat, stockings, dress, shoes	0,7	0,105
Underwear with short legs and sleeves, shirt, trousers, boiler suit, socks, shoes	1,1	0,17	Underwear, shirt, trousers, socks, shoes	0,7	0,11
Underwear with long legs and sleeves, thermojacket, trousers, socks, shoes	1,2	0,185	Underwear, track suit (sweater and trousers), long socks, runners	0,75	0,115
Underwear with short sleeves and legs, shirt, trousers, jacket, thermojacket, socks, shoes	1,25	0,19	Panties, petticoat, shirt, skirt, thick knee socks, shoes	0,8	0,12
Underwear with short sleeves and legs, boiler suit, thermojacket and trousers, socks, shoes	1,4	0,22	Panties, shirt, skirt, roundneck sweater, thick knee socks, shoes	0,9	0,14
Underwear with short sleeves and legs, shirt, trousers, jacket, thermojacket and trousers, socks, shoes	1,55	0,225	Underpants, singlet with short sleeves, shirt, trousers, V-neck sweater, socks, shoes	0,95	0,145
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes	1,85	0,285	Panties, shirt, trousers, jacket, socks, shoes	1	0,155
Underwear with short sleeves and legs, shirt, trousers, jacket, heavy quilted outer jacket and overalls, socks, shoes, cap, gloves	2	0,31	Panties, stockings, shirt, skirt, vest, jacket	1	0,155
Underwear with long sleeves and legs, thermojacket and trousers, thermojacket and trousers, socks, shoes	2,2	0,34	Panties, stockings, blouse, long skirt, jacket, shoes	1,1	0,17
Underwear with long sleeves and legs, thermojacket and trousers, parka with heavy quilting, overalls with heavy quilting, socks, shoes, cap, gloves	2,55	0,395	Underwear, singlet with short sleeves, shirt, trousers, jacket, socks, shoes	1,1	0,17
			Underwear, singlet with short sleeves, shirt, trousers, vest, jacket, socks, shoes	1,15	0,18
			Underwear with long sleeves and legs, shirt, trousers, V-neck sweater, jacket, socks, shoes	1,3	0,2
			Underwear with short sleeves and legs, shirt, trousers, vest, jacket, coat, socks, shoes	1,5	0,23

Table A.2 — Additional insulation values of various clothing ensembles — Daily wear clothing [32]

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
Daily wear clothing: trousers, shirt								
100	Briefs 8 T-shirt 30, undershorts 364 calf-length socks 264, athletic shoes 262,		318	1,10	0,33	0,051	0,98	0,151
101	Panties 1, tube top 69 short shorts 99 sandals 272		258	1,07	0,23	0,036	0,89	0,139
102	Briefs 8 short-sleeve shirt 79, shorts 97 calf-length socks 265, shoes 260		622	1,11	0,41	0,064	1,05	0,163
103	Briefs 8 3/4-length-sleeve shirt 66, shorts 97 socks 263, athletic shoes 262		451	1,17	0,52	0,081	1,13	0,175
106	Panties 1 sleeveless blouse 68, fitted trousers 102 sandals 272		523	1,14	0,44	0,068	1,06	0,165
107	Briefs 8 short-sleeve shirt 79, fitted trousers 102 calf-length socks 265, shoes 260		725	1,14	0,50	0,078	1,12	0,174
108	Briefs 8 long-sleeve shirt 75, fitted trousers 102 calf-length socks 265, shoes 260		693	1,19	0,62	0,096	1,22	0,189
112	Briefs 8, T-shirt 30 long-sleeve shirt 76, loose trousers 103 calf-length socks 265, shoes 260		1 072	1,30	0,89	0,138	1,44	0,223
121	Briefs 8 sweater 290, sweat pants 291 calf-length socks 264, athlectic shoes 262		776	1,19	0,77	0,119	1,37	0,212
124	Briefs 8, T-shirt 30 coveralls 114 calf-length socks 264, shoes 260		1 247	1,23	0,72	0,112	1,30	0,201

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass g	f_{cl}	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
200	Underpants 8 long-sleeve shirt 54, fitted trousers 89 calf-length socks 265, shoes 258		924	1,19	0,61	0,095	1,21	0,187
201	Briefs 8 shirt 54, fitted trousers 87 socks 265, shoes 258		911	1,19	0,63	0,098	1,23	0,190
203	Briefs 8 shirt 54, loose trousers 86 socks 265, shoes 258		991	1,30	0,71	0,110	1,26	0,195
204	Briefs 8 shirt 54, walking shorts 85 socks 265, shoes 258		673	1,16	0,53	0,082	1,14	0,177
205	Briefs 8 shirt 54, walking shorts 84 socks 265, shoes 258		895	1,16	0,53	0,082	1,14	0,177
206	Briefs 8 shirt 54, shorts 83 socks 265, shoes 258		820	1,15	0,48	0,074	1,10	0,170
207	Briefs 8 short-sleeve shirt 56, fitted trousers 89 socks 265, shoes 258		846	1,16	0,55	0,085	1,16	0,180
208	Briefs 8 sleeveless blouse 58, fitted trousers 89 socks 265, shoes 258		773	1,14	0,48	0,074	1,10	0,171
209	Briefs 8 turtleneck blouse 60, fitted trousers 89 socks 265, shoes 258		907	1,20	0,63	0,098	1,22	0,189
210	Briefs 8 blouse 61, fitted trousers 89 socks 265, shoes 258		945	1,20	0,63	0,098	1,22	0,189
216	Briefs 8 coveralls 117 socks 265, shoes 258		1 140	1,27	0,70	0,109	1,26	0,195
449	Briefs 23 shirt 74, trousers 103 socks 254, shoes 255		871	1,19	0,73	0,113	1,33	0,206

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	m^2·K·W^{-1}	clo	m^2·K·W^{-1}
Daily wear clothing: trousers, sweater								
104	Briefs 8 short-sleeve shirt 77, shorts 97 V-neck cardigan 136 calf-length socks 265, shoes 260		765	1,13	0,63	0,098	1,26	0,195
105	Panties 1 shirt 75, shorts 98 sleeveless, roundneck sweater 146 knee socks (thick) 267, shoes 260		924	1,17	0,71	0,110	1,32	0,204
109	Briefs 8 short-sleeve shirt 77, fitted trousers 102 V-neck sweater 135 calf-length socks 265, shoes 260		868	1,17	0,72	0,112	1,33	0,206
111	Panties 1 Sleeveless, V-neck sweater 141, short-sleeve, V-neck cardigan 139, fitted trousers 102, shoes 260		643	1,15	0,62	0,096	1,24	0,192
113	Briefs 8, T-shirt 30 shirt 75, loose trousers 103 V-neck sweater 135 calf-length socks 265, shoes 260		1 174	1,27	0,95	0,147	1,51	0,234
114	Briefs 8, T-shirt 30 shirt 75, loose trousers 103 round-neck sweater 142 calf-length socks 265, shoes 260		1 383	1,28	1,01	0,157	1,56	0,243
115	Briefs 8, thermal underpants 27, T-shirt 30 shirt 75, loose trousers 103 sleeveless, round-neck sweater 146 calf-length socks 265, shoes 260		1 470	1,29	1,06	0,164	1,61	0,250

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass g	f_{cl}	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
120	Briefs 8, thermal underpants 27, T-shirt 30 turtleneck sweater (thick) 148, loose trousers 103 calf-length socks 265, shoes 260		1 351	1,28	1,02	0,158	1,57	0,244
447	Briefs 23, T-shirt 31 shirt 78, trousers 96 round-neck cardigan 140 socks 254, shoes 255		1 542	1,27	0,97	0,150	1,53	0,237
Daily wear clothing: trousers, jacket, vest								
110	Briefs 8 shirt 75, fitted trousers 102 suit jacket 156 calf-length socks 265, shoes 260		1 130	1,23	0,96	0,149	1,54	0,238
116	Briefs 8 shirt 75, loose trousers 103, vest 162 calf-length socks 265, shoes 260		1 039	1,29	0,86	0,133	1,41	0,219
117	Briefs 8, T-shirt 30 shirt 75, loose trousers 103, vest 162 suit jacket 157 calf-length socks 265, shoes 260	118 162	1 796	1,33	1,16	0,180	1,69	0,263
118	Briefs 8, T-shirt 30 shirt 75, loose trousers 103 suit jacket 157 calf-length socks 265, shoes 260		1 611	1,32	1,13	0,175	1,67	0,259
119	Panties 1 turtleneck sweater (thin) 147, loose trousers 103 double-breasted suit jacket 159 knee socks (thick) 267, shoes 260		1 568	1,34	1,14	0,177	1,67	0,259
129	Briefs 8, thermal underpants 27, T-shirt 30 shirt 75, loose trousers 103 V-neck sweater 135, suit jacket 157 calf-length socks 265, shoes 260	118 27 135	2 036	1,33	1,30	0,202	1,83	0,284

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
211	Briefs 8 shirt 54, fitted trousers 89 suit jacket 169 socks 265, shoes 258	200 169	1 442	1,23	0,93	0,144	1,51	0,234
212	Briefs 8 shirt 54, fitted trousers 89 suit jacket 171 socks 265, shoes 258	200 171	1 623	1,23	1,01	0,157	1,59	0,246
213	Briefs 8 shirt 54, fitted trousers 89 suit jacket 172 socks 265, shoes 258	200 172	1 718	1,24	0,97	0,150	1,54	0,239
214	Briefs 8 shirt 54, fitted trousers 89, vest 173 Socks 265, shoes 258	200 17	1 131	1,20	0,78	0,121	1,37	0,213
444	Briefs 23, T-shirt 31 shirt 72, trousers 96 jacket 160, vest 162 socks 254, shoes 255		2 080	1,41	1,11	0,172	1,61	0,250
445	Briefs 23, T-shirt 31 shirt 72, trousers 96, vest 162 coat 184, jacket 160 socks 254, shoes 255	444 184	3 900	1,49	1,49	0,231	1,97	0,305
450	Pants 28, undershirt 37 shirt 78, trousers 96 round-neck cardigan 140, jacket 160 socks 256, shoes 255		2 666	1,41	1,37	0,212	1,87	0,290
Daily wear clothing: skirt, shirt								
130	Panties 1, pantyhose 3 short-sleeve shirt 77, skirt 304 sandals 272		451	1,26	0,54	0,084	1,10	0,171
131	Panties 1, full slip 5, pantyhose 3 shirt 75, skirt 304 sandals 272		573	1,29	0,67	0,104	1,22	0,189

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	m²·K·W⁻¹	clo	m²·K·W⁻¹
135	Panties 1, pantyhose 3 3/4-length-sleeve shirt 66, skirt 308 sandals 272		479	1,29	0,57	0,088	1,12	0,174
136	Panties 1, full slip 5 shirt 75, skirt 312 knee socks (thick) 267, shoes 260		912	1,32	0,78	0,121	1,32	0,204
145	Panties 1, pantyhose 3 cap-sleeve blouse 67, skirt 306 sandals 272		373	1,27	0,52	0,081	1,08	0,167
146	Panties 1, pantyhose 3, sleeveless blouse 68, ankle-length skirt 300 sandals 272		511	1,39	0,62	0,096	1,13	0,175
Daily wear clothing: skirt, sweater								
132	Panties 1, half slip 4, pantyhose 3 short-sleeve shirt 77, skirt 304 V-neck cardigan 136 sandals 272		731	1,25	0,78	0,121	1,35	0,209
133	Panties 1, pantyhose 3 sleeveless, V-neck sweater 141, skirt 307 short-sleeve, V-neck cardigan 139 sandals 272		670	1,29	0,64	0,099	1,19	0,185
137	Panties 1 shirt 75, skirt 305 round-neck sweater 142 knee socks (thick) 267, shoes 260		1 020	1,29	0,92	0,143	1,47	0,228
138	Panties 1, half slip 4, pantyhose 3 shirt 75, skirt 305 v-neck sweater 135 shoes 260		847	1,27	0,83	0,129	1,39	0,215
139	Panties 1, full slip 5, pantyhose 3 turtleneck sweater (thick) 148, skirt 309 shoes 260		966	1,29	0,85	0,132	1,40	0,217

Table A.2 (*continued*)

No.	**Ensemble description** (numbers following garments refer to Table B.2)	**Combination**	**Mass** g	f_{cl}	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
141	Panties 1 bow-at-neck blouse 74, skirt 309 sleeveless, round-neck sweater 146 knee socks (thick) 267, shoes 260		961	1,30	0,81	0,126	1,36	0,210
Daily wear clothing: skirt, jacket								
134	Panties 1, pantyhose 3, half slip 4 bow-at-neck blouse 74, skirt 304 suit jacket 156 sandals 272		1 084	1,30	0,81	0,126	1,36	0,210
140	Panties 1, pantyhose 3 bow-at-neck blouse 74, skirt 312 double-breasted suit jacket 159 shoes 260		1 513	1,35	1,05	0,163	1,58	0,244
142	Panties 1, pantyhose 3 shirt 75, skirt 305, vest 162 suit jacket 157 shoes 260		1 404	1,33	1,02	0,158	1,55	0,241
143	Panties 1, half slip 4, pantyhose 3 shirt 75, skirt 305, V-neck sweater 135 suit jacket 157 shoes 260		1 499	1,33	1,12	0,174	1,65	0,256
144	Panties 1, pantyhose 3 shirt 75, skirt 305 suit jacket 157 shoes 260		1 219	1,32	0,97	0,150	1,51	0,234
147	Panties 1, pantyhose 3, bow-at-neck blouse 74, ankle-length skirt 301 suit jacket 157 shoes 260		1 302	1,46	1,10	0,171	1,59	0,246

Table A.2 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
Daily wear clothing: dress								
148	Panties 1, pantyhose 3, full slip 5 short-sleeve dress, belted 333 V-neck cardigan 136, Shoes 260		660	1,21	0,71	0,110	1,30	0,201
149	Panties 1, full slip 5, pantyhose 3 sleeveless dress 336 sandals 272		325	1,15	0,46	0,071	1,08	0,167
150	Panties 1, half slip 4 shirt 75, sleeveless dress 335 knee socks (thick) 267, shoes 260		770	1,26	0,77	0,119	1,33	0,207
151	Panties 1, pantyhose 3, full slip 5 dress 331, round-neck cardigan 143 shoes 260		852	1,25	0,93	0,144	1,50	0,232
217	Bra and panties 44, pantyhose 3 dress 339 shoes 260		1 274	1,22	0,69	0,107	1,27	0,197
Daily wear clothing: sleeping wear, robe								
152	Long gown 351 long wrap robe 374 slippers 261		1 970	1,49	1,71	0,265	2,19	0,339
153	Long pyjamas 360 long wrap robe 371 slippers 261		1 137	1,42	1,25	0,194	1,75	0,271
154	Short-sleeve long pyjamas 361 short wrap robe 375 sandals 272		595	1,33	0,93	0,144	1,46	0,227
155	Sleeveless short gown 356 short robe 378 sandals 272		398	1,31	0,70	0,109	1,24	0,193
156	T-shirt 30 undershorts 364		171	1,07	0,25	0,039	0,91	0,142
157	Short gown 357 short-sleeve short robe 380 sandals 272		325	1,29	0,66	0,102	1,21	0,188

Table A.3 — Insulation values of various clothing ensembles — Work clothing [32]

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
122	Briefs 8, T-shirt 30, work jacket 153 work pants 90, belt Calf-length socks 264, shoes 260		2 050	1,39	0,99	0,153	1,50	0,233
123	Briefs 8, T-shirt 30 shirt 76, fitted trousers 102, belt work jacket 153, work pants 90 calf-length socks 265, shoes 260		2 628	1,40	1,27	0,197	1,78	0,275
125	Briefs 8 shirt 75, fitted trousers 102 coveralls 114 socks 265, shoes 260		1 607	1,25	0,96	0,149	1,53	0,237
126	Briefs 8, thermal undershirt 41 thermal underpants 27 shirt 76, overalls 95 calf-length socks 265, shoes 260		1 691	1,28	1,00	0,155	1,55	0,241
420	Briefs 23, T-shirt 31 shirt 70, trousers 91 coveralls 112 socks 254, shoes 255		2 573	1,31	1,18	0,183	1,72	0,267
421	Briefs 23 shirt 70, overalls 94 jacket 151, coveralls 112 socks 254, shoes 255		3 333	1,40	1,33	0,206	1,84	0,285
422	Briefs 20 shirt 71, overalls 93 jacket 151, coveralls 113 socks 254, shoes 255		2 992	1,40	1,25	0,194	1,76	0,272
423	Briefs 23 shirt 71, trousers 92, jacket 152 socks 254, shoes 255		1 708	1,36	0,79	0,122	1,31	0,203
424	Briefs 23 shirt 71, trousers 92 smock 154 socks 254, shoes 255		1 645	1,40	0,91	0,141	1,42	0,220

Table A.3 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	m²·K·W⁻¹	clo	m²·K·W⁻¹
425	Briefs 23 shirt 71 coveralls 113 socks 254, shoes 255		1 633	1,36	0,81	0,126	1,33	0,206
426	Briefs 23 shirt 71, overalls 93 jacket 152 socks 254, shoes 255		1 858	1,30	0,87	0,135	1,42	0,220
427	Briefs 23 shirt 70, trousers 91 jacket 150 socks 254, shoes 255	434 150	1 783	1,38	0,86	0,133	1,37	0,213
428	Briefs 23, T-shirt 31 shirt 71, trousers 92 coveralls 113 socks 254, shoes 255		2 538	1,31	1,05	0,163	1,59	0,247
429	Briefs 23 shirt 70, trousers 91, jacket 151 socks 254, shoes 255	434 151	1 803	1,29	0,87	0,135	1,42	0,220
430	Bra and panties 44 shirt 73, skirt 311 jacket 167 socks 254, shoes 255		1 018	1,28	0,79	0,122	1,34	0,208
431	Bra and panties 44 shirt 73, trousers 101 jacket 167 socks 254, shoes 255		1 088	1,26	0,90	0,140	1,46	0,227
434	Briefs 23 trousers 91, shirt 70 socks 254, shoes 255		1 105	1,24	0,75	0,116	1,32	0,205
435	Briefs 23, T-shirt 31 shirt 70, trousers 91 jacket 151 socks 254, shoes 255	429 31	1 939	1,29	0,98	0,152	1,53	0,237

Table A.3 (*continued*)

No.	**Ensemble description** (numbers following garments refer to Table B.2)	**Combination**	**Mass** g	f_{cl}	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
470	Undershirt 33, underpants 26 coveralls 120 socks 254, shoes 255		1 344	1,25	0,84	0,130	1,41	0,218
471	Briefs 23 coveralls 120 socks 254, shoes 255		1 031	1,25	0,72	0,112	1,29	0,200
480	Briefs 23, T-shirt 31 coveralls 120 socks 254, shoes 255		1 210	1,30	0,82	0,127	1,37	0,212
481	Undershirt 47, underpants 48 coveralls 120 socks 254, shoes 255		1 300	1,30	0,84	0,130	1,39	0,215
483	Briefs 23, T-shirt 31 shirt 73 coveralls 120 socks 254, shoes 255		1 430	1,30	0,94	0,146	1,49	0,230
500	Briefs 8, T-shirt 32 trousers 104, jacket 164 socks 263, shoes 258		—	1,36	0,93	0,144	1,45	0,225
501	Briefs 8 shirt 52, trousers 108 socks 263, shoes 258		—	1,19	0,65	0,101	1,25	0,193
502	Briefs 8, T-shirt 32 trousers 105, jacket 165 socks 263, shoes 258		—	1,39	1,00	0,155	1,51	0,234
503	Briefs 8 shirt 51, trousers 107 socks 263, shoes 258		—	1,20	0,61	0,095	1,20	0,186
505	Briefs 8 shirt 50, trousers 106 socks 263, shoes 258		—	1,22	0,70	0,109	1,28	0,199
508	Briefs 8 short-sleeve shirt 53, trousers 107 socks 263, shoes 258		—	1,19	0,55	0,085	1,15	0,178
527	Briefs 8, T-shirt 32 coveralls 110 socks 263, shoes 258		—	1,19	0,65	0,101	1,25	0,193

Table A.4 — Insulation values of various clothing ensembles — Cold protective clothing [32]

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
127	Briefs 8, thermal undershirt 41 thermal underpants 27 insulated coveralls 214 calf-length socks 265, shoes 260		1 841	1,25	1,36	0,211	1,93	0,299
128	Briefs 8, T-shirt 30 shirt 76, fitted trousers 102 insulated coveralls 214 calf-length socks 264, shoes 260		2 172	1,27	1,50	0,233	2,06	0,319
400	Undershirt 42, underpants 43 coveralls 115 socks 254, shoes 255		1 286	1,18	1,11	0,172	1,71	0,265
401	Undershirt 42, underpants 43 insulated trousers 201, insulated jacket 225 socks 254, shoes 255		1 363	1,27	1,20	0,186	1,76	0,273
402	Undershirt 42, underpants 43 insulated trousers 201, insulated vest 226 socks 254, shoes 255		1 205	1,22	0,85	0,132	1,43	0,222
404	Undershirt 42, underpants 43 insulated coveralls 210 overtrousers 182, overjacket 183 socks 256, clogs 257		2 564	1,40	1,88	0,291	2,39	0,370
405	Undershirt 42, underpants 43 insulated trousers 201, insulated jacket 225 overtrousers 182, overjacket 183 socks 256, clogs 257		2 641	1,42	2,13	0,330	2,63	0,408
406	Undershirt 42, underpants 43 insulated trousers 201, insulated jacket 225 overtrousers 182, overjacket 183 socks 254, shoes 255		2 490	1,42	2,41	0,374	2,91	0,451
407	Undershirt 42, underpants 43 insulated trousers 200, insulated jacket 221 socks 254, shoes 255		2 449	1,22	1,40	0,217	1,98	0,307

Table A.4 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
408	Undershirt 42, underpants 43 insulated trousers 200, insulated jacket 222 socks 254, shoes 255		2 445	1,22	1,38	0,214	1,96	0,304
409	Undershirt 42, underpants 43 insulated trousers 200, insulated jacket 222 overtrousers 182, overjacket 183 socks 256, clogs 257		2 631	1,42	2,22	0,344	2,72	0,422
410	Undershirt 42, underpants 43 insulated trousers 200, insulated jacket 221 overtrousers 182, overjacket 183 socks 256, clogs 257		2 884	1,42	2,17	0,336	2,67	0,414
411	Undershirt 42, underpants 43 insulated trousers 201, insulated jacket 225 overtrousers 182, overjacket 183 socks 256, shoes 255		2 566	1,42	2,16	0,335	2,66	0,412
436	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 insulated jacket 228, insulated trousers 203 socks 256, clogs 257		2 618	1,36	1,53	0,237	2,05	0,318
438	Briefs 23, T-shirt 31 shirt 70, trousers 91 jacket 151, insulated jacket 228 socks 256, shoes 255		2 326	1,30	0,18	0,183	0,73	0,113
439	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 insulated trousers 203, insulated jacket 228 socks 256, shoes 255	438 203	2 618	1,35	1,46	0,226	1,99	0,308
482	Undershirt 47, underpants 48 insulated trousers 204, insulated jacket 229 coveralls 120 socks 254, shoes 255	481 204 229	1 970	1,32	1,43	0,222	1,97	0,305

Table A.4 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
441	Briefs 23, T-shirt 31 shirt 70, trousers 91 jacket 151, insulated jacket 225 socks 256, shoes 255	435 225	2 404	1,36	1,23	0,191	1,75	0,272
442	Briefs 23, T-shirt 31 shirt 70, trousers 91 jacket 151, insulated jacket 225 insulated trousers 201 socks 256, shoes 255	441 201	2 726	1,35	1,54	0,239	2,07	0,320
472	Briefs 23, T-shirt 31 shirt 70 insulated jacket 228, insulated trousers 203 overtrousers 180, overjacket 198 socks 254, shoes 255, gloves 251, cap 259		3 257	1,45	2,26	0,350	2,75	0,426
473	Briefs 23, T-shirt 31 shirt 70 insulated jacket 228, insulated trousers 203 overtrousers 180, overjacket 188 socks 254, shoes 255, gloves 251, hat 259		3 697	1,48	2,30	0,357	2,78	0,431
474	Briefs 23, T-shirt 31 shirt 70 insulated jacket 228, insulated trousers 203 overtrousers 180, overjacket 189 socks 254, shoes 255, gloves 251, cap 259		3 697	1,49	2,48	0,384	2,96	0,458
475	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 overtrousers 180, overjacket 189 socks 254, shoes 255, gloves 251, cap 259		4 405	1,49	2,15	0,333	2,63	0,407
476	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 overjacket 188, overtrousers 180 socks 254, shoes 255, gloves 251, cap 259	477 251 259	3 783	1,42	1,86	0,288	2,36	0,366

Table A.4 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass g	f_{cl}	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
477	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 overjacket 188, overtrousers 180 socks 254, shoes 255		4 223	1,45	1,87	0,290	2,36	0,366
478	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 overjacket 198, overtrousers 180 socks 254, shoes 255, cap 259, gloves 251	251 259 259	3 965	1,45	2,02	0,313	2,51	0,389
479	Briefs 23, T-shirt 31 shirt 70, trousers 91, jacket 151 overjacket 198, overtrousers 180 socks 254, shoes 255	435 190 198	3 783	1,42	1,86	0,288	2,36	0,366
484	Briefs 23, T-shirt 31 coveralls 120 insulated trousers 204, insulated jacket 229 socks 254, shoes 255	480 204 229	1 780	1,35	1,42	0,220	1,95	0,302
491	Undershirt 47, underpants 48 coveralls 120 overjacket 188 socks 254, shoes 255, cap 259, gloves 251	481 188 251 259	2 920	1,43	1,63	0,253	2,13	0,330
492	Undershirt 47, underpants 48 coveralls 120, overjacket 188, overtrousers 180 gloves 251, cap 259 socks 254, shoes 255	491 190	3 720	1,49	2,34	0,363	2,82	0,437
493	Undershirt 47, underpants 48 insulated trousers 204, insulated jacket 229 overtrousers 180, overjacket 188 socks 254, shoes 255, cap 259, gloves 251		4 390	1,48	2,55	0,395	3,03	0,470
494	Briefs 23, T-shirt 31 shirt 73, trousers 96, jacket 160 overjacket 188 cap 259, gloves 251, socks 254, shoes 255		3 552	1,43	1,60	0,248	2,10	0,325

Table A.4 (*continued*)

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
495	Briefs 23, T-shirt 31 shirt 73, trousers 96, jacket 160 overtrousers 180, overjacket 188 cap 259, gloves 251, socks 254, shoes 255	494 190	4 352	1,48	2,36	0,366	2,84	0,440

Table A.5 — Insulation values of various clothing ensembles — Cold protective clothing — With dynamic insulation values for walking (no wind), body surface area covered (BSAC) and mass of clothing without shoes and belts [29]

No.	Ensemble description	BSAC	Mass	f_{cl}	I_{cl} clo		I_T clo	
		%	g		Static	Dynamic	Static	Dynamic
601	Extreme cold weather expedition suit with hood (down-filled, one-piece suit), thermal long underwear top and bottoms, mittens with fleece liners, thick socks, insulated waterproof boots	98,9	2 804	1,5	3,67	3,21	4,12	3,54
602	One-piece ski suit, thermal long underwear top and bottoms, knited head/ear band, goggles, insulated ski gloves, thin knee-length ski socks, insulated waterproof boots	97,1	2 357	1,28	1,6	1,13	2,13	1,51
603	One-piece fibrefill ski suit with hood, thermal long underwear top and bottoms, goggles, insulated ski gloves, thin knee-length ski socks, insulated waterproof boots	98,8	2 494	1,27	1,97	1,53	2,51	1,92
604	Ski jacket with detachable fibrefill liner, thermal long underwear bottoms, knited turtleneck sweater, fibrefill ski pants, knited hat, goggles, mitten shell with fleece glove inserts, thin knee-length ski socks, insulated waterproof boots	98,5	2 943	1,34	2,3	1,75	2,81	2,12
604a	No. 604 without jacket liner	98,5	2 683	1,32	1,77	1,3	2,29	1,67
605	Extreme cold weather down-filled parka with hood, shell pants, fibrefill pants liner, thermal long underwear top and bottoms, sweatshirt, mitten shell with inner fleece gloves, thick socks, insulated waterproof boots	98,8	2 916	1,47	3,28	2,53	3,74	2,86
606	Knee-length down-filled coat, thermal long underwear bottoms, jeans, T-shirt, long-sleeve flannel shirt, hat with fleece liner and ear flaps, insulated ski gloves, thick socks, low-cut leather work boots	97,8	3 322	1,52	2,45	1,5	2,90	1,82
607	Fibrefill jacket, jeans, T-shirt, thermal long underwear bottoms, long-sleeve flannel shirt, baseball cap, thick socks, low-cut leather work boots	91	2 283	1,4	1,68	1,3	2,17	1,65

Table A.5 (*continued*)

No.	Ensemble description	BSAC %	Mass g	f_{cl}	I_{cl} clo		I_T clo	
					Static	Dynamic	Static	Dynamic
608	Down-filled vest, jeans, briefs, long-sleeve knited rugby shirt, baseball cap, athletic socks, athletic shoes	91	1 707	1,25	1,12	0,83	1,66	1,22
609	Fleece long-sleeve shirt, fleece pants, briefs, athletic socks, athletic shoes	88,1	913	1,29	1,19	0,86	1,72	1,24
610	Fleece long-sleeve shirt, fleece pants, briefs, thermal long underwear top and bottoms, athletic socks, athletic shoes	88,1	1 370	1,29	1,34	1,04	1,87	1,42
611	Lightweight jacket, briefs, thermal long underwear top and bottoms, shell pants, athletic socks, athletic shoes	88,1	1 665	1,36	1,24	0,73	1,74	1,09
612	Lightweight jacket, briefs, long-sleeve fleece shirt, fleece pants, shell pants, athletic socks, athletic shoes	88,1	1 990	1,37	1,67	1,16	2,17	1,52
613	Lightweight jacket, briefs, thermal long underwear top and bottoms, long-sleeve fleece shirt, fleece pants, shell pants, athletic socks, athletic shoes	88,1	2 466	1,37	1,81	1,34	2,31	1,70
614	Insulated coverall, thermal long underwear top and bottoms, knited work gloves, athletic socks, low-cut leather work boots	92,7	1 833	1,27	1,51	1,16	2,05	1,55
615	Shell windbreaker jacket, briefs, long-sleeve T-shirt, bib overalls, baseball cap, knited work gloves, athletic socks, low-cut leather work boots	95,6	1 940	1,26	1,15	0,8	1,69	1,19
616	Heavy fibrefill hunting jacket with detachable liner, matching hunting bib overalls, briefs, knited turtleneck sweater, jeans, hat with fleece liner and ear flaps, fibrefill gloves, thick socks, insulated waterproof boots	97,8	4 386	1,5	2,98	2,32	3,43	2,65
616a	No. 616 without liner	97,8	3 683	1,48	2,13	1,56	2,59	1,89
617	Windproof, waterproof jogging suit (shell jacket and pants), T-shirt, briefs, running shorts, athletic socks, athletic shoes	88,1	1 024	1,25	1,03	0,71	1,57	1,10
618	Double-breasted trench coat with detachable liner, T-shirt, briefs, dress socks, long-sleeve dress shirt, tie, men’s business suit, belt on trousers, leather street shoes	88,1	2 954	1,46	1,63	0,87	2,10	1,21
619	Belted, double-breasted trench coat with detachable liner, long-sleeve oxford shirt, knee length A-line skirt, long-sleeve, crewneck sweater, pantyhose, vinyl street shoes	77	2 568	1,42	1,33	0,85	1,81	1,20
620	Women’s knee-length dress coat, long-sleeve blouse, knee-length A-line skirt, cardigan sweater, pantyhose, vinyl street shoes	72,7	2 435	1,41	1,22	0,81	1,70	1,16
621	Women’s below-knee-length wool cape, long-sleeve blouse, knee-length A-line skirt, pantyhose, vinyl street shoes	78,5	1 960	1,53	1,1	0,53	1,54	0,85
622	Casual lightweight jacket, T-shirt, briefs, thick turtleneck wool sweater, chino trousers, dress socks, leather street shoes	88,1	1 774	1,31	1,19	0,81	1,71	1,18

Table A.6 — Insulation values of various clothing ensembles — Heat protective clothing

No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
488	Briefs 23, T-shirt 31 coveralls 120 overtrousers 194, overjacket 195 socks 254, shoes 255	480 194 195	2 710	1,45	1,48	0,229	1,97	0,305
489	Briefs 23, T-shirt 31 coveralls 120 overtrousers 191, overjacket 193 shoes 255, socks 254	480 191 193	4 630	1,50	1,55	0,240	2,02	0,314
510	Briefs 8 shirt 52, trousers 108 socks 263, leggings 270, shoes 258	501 266	—	1,24	0,82	0,127	1,39	0,216
512	Briefs 8 shirt 52, trousers 108 arm protectors 271 socks 263, shoes 258	501 267	—	1,30	0,86	0,133	1,41	0,218
513	Briefs 8 shirt 52, trousers 108 arm protectors 268 socks 263, shoes 258	501 268	—	1,28	0,77	0,119	1,32	0,205
514	Briefs 8 shirt 52, trousers 108 apron 269 socks 263, shoes 258	501 265	—	1,26	0,77	0,119	1,33	0,207
524	Briefs 8 shirt 52, trousers 108 aluminized hip-length coat 179 socks 263, shoes 258	501 179	—	1,34	1,36	0,211	1,89	0,293
525	Briefs 8 shirt 52, trousers 108 aluminized calf-length coat 199 socks 263, shoes 258	501 199	—	1,58	1,74	0,270	2,19	0,339

Table A.7 — Insulation values of chemical protective clothing

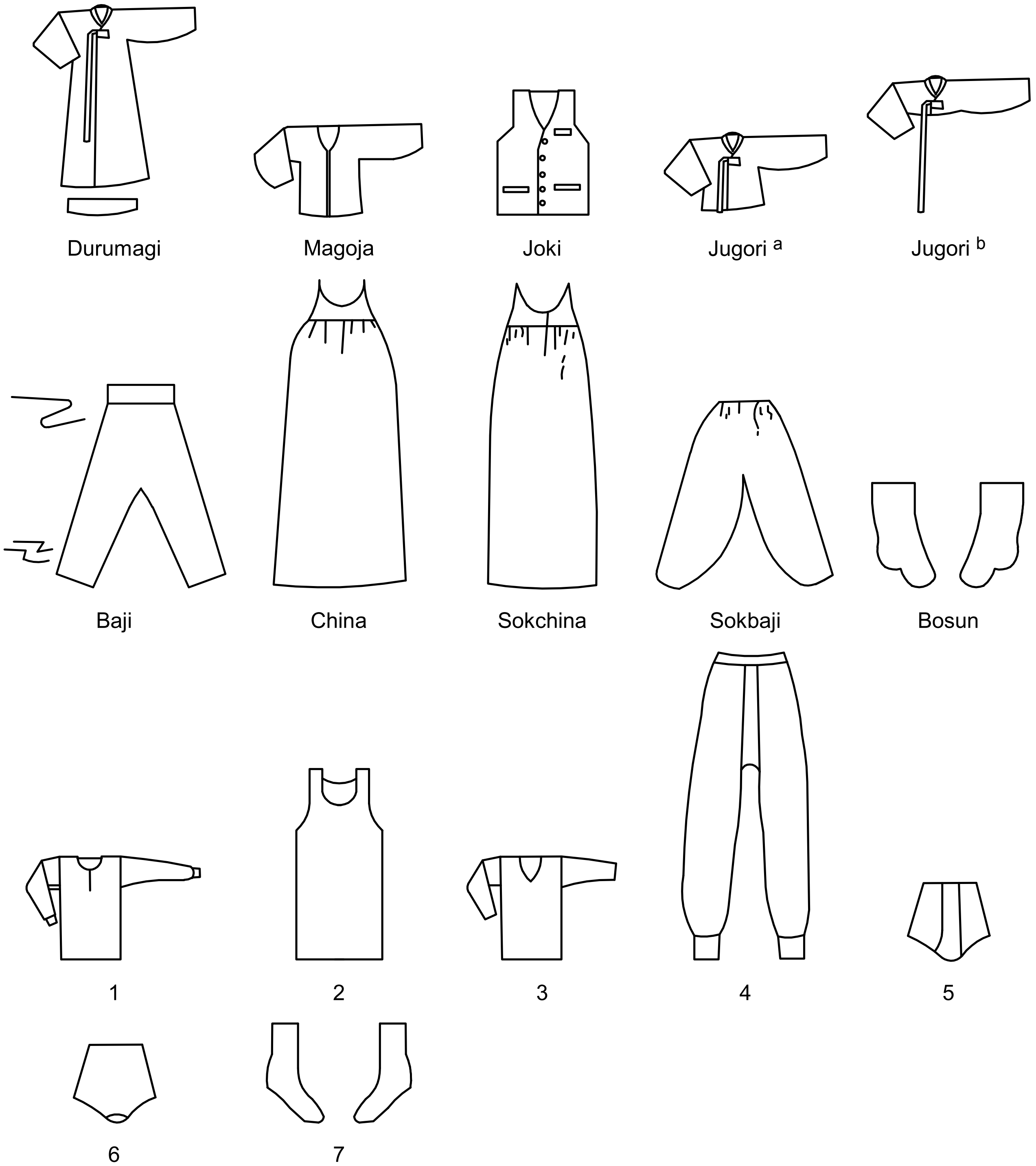
No.	Ensemble description (numbers following garments refer to Table B.2)	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
490	Undershirt 47, underpants 48 coveralls 120, coveralls 121 socks 254, shoes 255	481 121	2640	1,45	1,42	0,220	1,91	0,296

Table A.8 — Insulation values of nuclear power plant clothing [21]

No.	Ensemble description	Combination	Mass	f_{cl}	I_{cl}		I_T	
			g		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
651	Polypropylene coverall, hood, shoes, shoe cover, cotton glove, latex glove, short-sleeve undershirt, briefs, socks	—	—	—	0,84	0,129	1,28	0,198
652	PET65/Rayon35 coverall, hood, shoes, shoe cover, cotton glove, latex glove, short-sleeve undershirt, briefs, socks	—	—	—	0,81	0,126	1,25	0,195
653	PVC coverall over PET65/Rayon35 coverall, hood, shoes, shoe cover, cotton glove, latex glove, short-sleeve undershirt, briefs, socks	—	—	—	1,21	0,187	1,65	0,256

Table A.9 — Insulation values for various clothing ensembles — Korean clothing (see Figure A.1) [5]

Ensemble type	Ensemble description	Mass	BSAC	f_{cl}	I_{cl}		I_T	
		g	%		clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
Male, winter (outdoor)	Durumagi, magoja, joki, jugori, baji, long-sleeve undershirt, long underwear, briefs, calf-length socks	3 341	88	1,37	1,55	0,240	2,05	0,318
Male, winter	Magoja, joki, jugori, baji, long-sleeve undershirt, long underwear, briefs, calf-length socks	2 088	86	1,29	1,27	0,197	1,08	0,167
Male, summer	Joki, jugori, baji, sleeveless undershirt, briefs, calf-length socks	740	86	1,29	0,79	0,122	1,32	0,205
Female, winter (outdoor)	Durumagi, jugori, chima, sokchima, sokbaji, bosun, 3/4-length-sleeve undershirt, panties	2 656	87	1,53	1,83	0,284	2,27	0,352
Female, winter	Jugori, chima, sokchima, sokbaji, bosun, 3/4-length-sleeve undershirt, panties	1 539	85	1,58	1,45	0,225	1,88	0,291
Female, summer	Jugori, chima, sokchima, sokbaji, bosun, panties	1 067	85	1,55	1,08	0,167	1,52	0,236



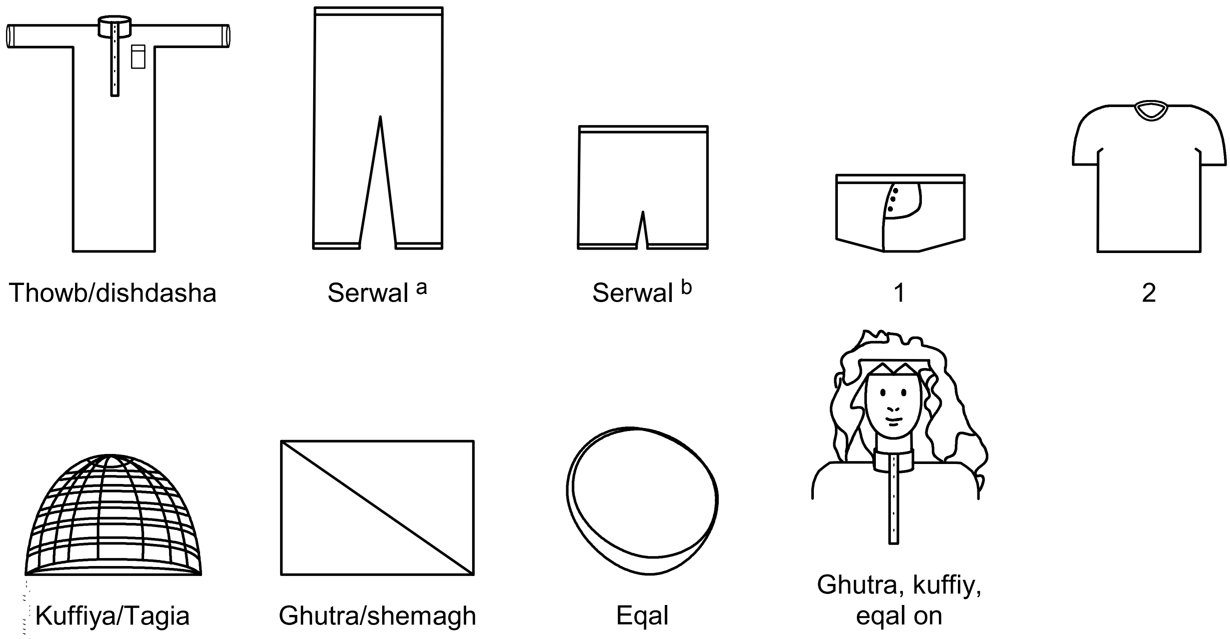
Key

1 undershirt, long-sleeve
2 undershirt, sleeveless
3 undershirt, 3/4-length-sleeve
4 long underwear
5 briefs
6 panties
7 socks
a Male.
b Female.

Figure A.1 — Korean garments

Table A.10 — Insulation values for Gulf region male clothing ensembles (see Figure A.2) [1]

Ensemble type	Ensemble description	f_{cl}	I_a clo	I_a $m^2 \cdot K \cdot W^{-1}$	I_{cl} clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
Male summer clothing	T-shirt with 1/3 sleeves, short serwal, thowb and sandals	1,30	0,594	0,092	0,59	0,092	1,05	0,163
	T-shirt with 1/3 sleeves, short serwal, thowb, kuffiya, white ghutra, eqal, sandals	1,35	0,594	0,092	0,69	0,107	1,13	0,175
	T-shirt with 1/3 sleeves, short serwal, long serwal, thowb, kuffiya, white ghutra, eqal, sandals	1,36	0,594	0,092	0,79	0,123	1,23	0,191
Male winter clothing	T-shirt with 1/3 sleeves, short serwal, long cotton serwal, thowb, kuffiya, ghutra shemagh, eqal, shoes.	1,46	0,594	0,092	0,84	0,131	1,25	0,194
	T-shirt with 1/3 sleeves, short serwal, long cotton serwal, thowb, ghutra shemagh, eqal, jacket, shoes.	1,45	0,594	0,092	1,29	0,200	1,70	0,264



Key

1 pants

2 T-shirt

a Long.

b Short.

Figure A.2 — Gulf region garments

Annex B
(normative)

Thermal insulation values for individual garments

B.1 Lists of garments and their values

The thermal insulation values refer to the whole body surface (as if the subject wears only this garment). Table B.1 lists the most typical values. Table B.2 presents detailed information where

— the type numbers refer to the figures following the tables showing the different garment designs, in which the body surface area covered A_{cov} is also indicated, and

— the fabric numbers refer to Table B.3, which gives a more detailed description of the fabric.

Washing may change the thermal insulation values. This effect depends on the type of textile, but is normally within the measuring accuracy. The measurements were performed in accordance with the description in Annex D, and operating temperature, mean skin temperature and mean heat loss from the manikin were recorded.

Table B.1 — Insulation values of various typical garments

Garment	I_{cl} clo
Underwear	
Panties	0,03
Underpants with long legs	0,1
Singlet	0,04
T-shirt	0,09
Shirt with long sleeves	0,12
Panties and bra	0,03
Shirts, blouses	
Short sleeves	0,15
Lightweight, long sleeves	0,2
Normal, long sleeves	0,25
Flannel shirt, long sleeves	0,3
Lightweight blouse, long sleeves	0,15
Trousers	
Shorts	0,06
Lightweight	0,2
Normal	0,25
Flannel	0,28

Table B.1 (*continued*)

Garment	I_{cl} clo
Dresses, skirts	
Light skirt (summer)	0,15
Heavy skirt (winter)	0,25
Light dress, short sleeves	0,2
Winter dress, long sleeves	0,4
Boiler suit	0,55
Sweaters	
Sleeveless vest	0,12
Thin sweater	0,2
Sweater	0,28
Thick sweater	0,35
Jackets	
Light summer jacket	0,25
Jacket	0,35
Smock	0,3
Highly insulating, fibre-pelt	
Boiler suit	0,9
Trousers	0,35
Jacket	0,4
Vest	0,2
Outdoor clothing	
Coat	0,6
Down jacket	0,55
Parka	0,7
Fibre-pelt overalls	0,55
Sundries	
Socks	0,02
Thick ankle socks	0,05
Thick long socks	0,1
Nylon stockings	0,03
Shoes (thin-soled)	0,02
Shoes (thick-soled)	0,04
Boots	0,1
Gloves	0,05

Table B.2 — Insulation values of various garments

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
Underwear — Pants						
1	Panties	7	25	27	0,03	0,005
3	Pantyhose	8	—	39	0,02	0,003
6	Briefs	2	51	67	0,04	0,006
7	Pants, short-legged	3	51	70	0,04	0,006
8	Briefs	2	24	65	0,04	0,006
9	Pants, 1/2-long-legged	4	51	137	0,06	0,009
10	Pants, long-legged	6	51	198	0,12	0,019
20	Briefs	2	52	66	0,03	0,005
22	Pants, long-legged	6	52	162	0,08	0,012
23	Briefs	2	50	80	0,04	0,006
25	Pants, 3/4-long-legged	5	50	186	0,08	0,012
26	Pants, long-legged	6	50	193	0,1	0,016
27	Pants, long-legged, thermal	6	23	210	0,15	0,023
28	Pants, long-legged	6	53	221	0,1	0,016
43	Pants, long-legged	6	54	165	0,13	0,02
44	Bra and panties	6,7	57	87	0,04	0,006
46	Pants, long-legged	6	55	270	0,22	0,034
48	Pants, long-legged	6	56	155	0,07	0,011
Underwear — Shirts						
2	Bra	6	—	44	0,01	0,002
4	Half slip	7	26	65	0,14	0,022
5	Full slip	8	26	82	0,16	0,025
13	Shirt, sleeveless	1	50	150	0,06	0,009
29	Shirt, sleeveless	1	52	106	0,05	0,008
30	T-shirt	2	27	105	0,08	0,012
31	T-shirt	2	50	180	0,1	0,016
32	T-shirt	2	—	—	0,12	0,019
33	Shirt, long sleeves	3	50	200	0,12	0,019
36	T-shirt	2	53	196	0,09	0,014
37	Shirt, long sleeves	3	53	236	0,16	0,025
41	Shirt, long sleeves, thermal	3	23	200	0,2	0,031
42	Shirt, long sleeves	4	54	182	0,16	0,025
45	Shirt, long sleeves	3	55	360	0,25	0,039
47	Shirt, long sleeves	3	56	195	0,11	0,017

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
Shirts						
50	Long sleeves, shirt collar	2	35	—	0,33	0,051
51	Long sleeves, shirt collar	2	36	—	0,31	0,048
52	Long sleeves, shirt collar	2	37	—	0,28	0,043
53	Short sleeves, shirt collar	3	36	—	0,25	0,039
54	Long sleeves, shirt collar	2	91	362	0,33	0,051
55	Long sleeves, shirt collar	2	93	846	0,33	0,051
56	Short sleeves, shirt collar	3	91	284	0,24	0,037
57	Short sleeves, shirt collar	3	93	651	0,25	0,039
58	Sleeveless, scoop neck	7	91	210	0,18	0,028
59	Sleeveless, scoop neck	7	93	470	0,17	0,026
60	Long-sleeve, turtleneck	9	91	344	0,34	0,053
61	Long-sleeve blouse, bow tied	1	91	382	0,33	0,051
66	3/4-length sleeves, boat neck	5	1	142	0,27	0,042
67	Cap sleeves, boat neck	6	1	113	0,21	0,033
68	Sleeveless, scoop neck	7	1	117	0,13	0,02
69	Tube top	8	4	67	0,06	0,009
70	Long sleeves, shirt collar	2	59	370	0,29	0,045
71	Long sleeves, shirt collar	2	60	360	0,21	0,033
72	Long sleeves, shirt collar	2	—	190	0,15	0,023
73	Long sleeves, shirt collar	2	—	220	0,18	0,028
74	Long sleeves, bow at neck	1	1	206	0,25	0,039
75	Long sleeves, shirt collar	2	1	196	0,25	0,039
76	Long sleeves, shirt collar	2	2	309	0,34	0,053
77	Short sleeves, shirt collar	3	1	156	0,19	0,029
78	Long sleeves, shirt collar	2	-	245	0,26	0,04
79	Short sleeves, sport shirt	4	3	228	0,17	0,026
Trousers						
83	Short shorts	4	93	342	0,08	0,012
84	Walking shorts	3	93	416	0,11	0,017
85	Walking shorts	3	91	195	0,11	0,017
86	Straight, loose	2	92	513	0,22	0,034
87	Straight, fitted	1	95	433	0,22	0,034
88	Straight, fitted	1	93	658	0,17	0,026
89	Straight, fitted	1	92	446	0,18	0,028
90	Work pants	6	11	832	0,24	0,037

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} $m^2 \cdot K \cdot W^{-1}$
91	Straight, loose	2	59	640	0,26	0,04
92	Straight, loose	2	60	605	0,2	0,031
93	Overalls	7	60	755	0,24	0,036
94	Overalls	7	59	910	0,28	0,043
95	Overalls	7	12	854	0,3	0,047
96	Straight, fitted	1	—	542	0,19	0,029
97	Walking shorts	3	9	195	0,08	0,012
98	Walking shorts	3	10	251	0,17	0,026
99	Short shorts	4	9	164	0,06	0,009
100	Straight, fitted	1	10	404	0,24	0,037
101	Straight, loose	2	58	320	0,23	0,036
102	Straight, fitted	1	9	298	0,15	0,023
103	Straight, loose	2	10	459	0,28	0,043
104	Straight, loose	2	38	—	0,21	0,033
105	Straight, loose	2	39	—	0,24	0,037
106	Straight, fitted	1	35	—	0,19	0,029
107	Straight, fitted	1	40	—	0,16	0,025
108	Straight, fitted	1	41	—	0,19	0,029
109	Straight, loose	2	9	354	0,2	0,031
Coveralls						
110	Work	3	35	—	0,5	0,078
111	Work	3	42	—	0,52	0,081
112	Work	3	59	1 260	0,52	0,081
113	Work	3	60	1 140	0,49	0,076
114	Work	3	13	995	0,49	0,076
115	Daily wear, belted	2	91	579	0,49	0,076
116	Daily wear, belted	2	92	891	0,46	0,071
117	Daily wear, belted	2	93	1 331	0,49	0,076
120	Work	3	—	890	0,51	0,079
121	Chemical protective	1	—	1 340	0,6	0,093
Sweaters						
135	Long sleeves, V-neck	1	6	215	0,25	0,039
136	Long-sleeve, V-neck cardigan	2	6	215	0,23	0,036
137	Short sleeves, V-neck	3	6	188	0,2	0,031
138	Long sleeves, turtleneck	11	—	815	0,54	0,084
139	Short-sleeve, V-neck cardigan	4	6	188	0,17	0,026

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
140	Long-sleeve, round-neck cardigan	7	—	460	0,29	0,045
141	Sleeveless, V-neck	5	6	130	0,13	0,02
142	Long sleeves, round neck	6	7	424	0,36	0,056
143	Long-sleeve, round-neck cardigan	7	7	424	0,31	0,048
144	Short sleeves, round neck	8	7	355	0,28	0,043
145	Short-sleeve, round-neck cardigan	9	7	355	0,22	0,034
146	Sleeveless, round neck	10	7	301	0,22	0,034
147	Long sleeves, turtleneck (thin)	11	8	231	0,26	0,04
148	Long sleeves, turtleneck (thick)	11	7	459	0,37	0,057
Jackets, vests and smocks						
150	Jacket, no buttons	6	60	640	0,26	0,04
151	Work jacket	8	59	652	0,26	0,04
152	Work jacket	8	60	610	0,21	0,033
153	Work jacket	3	11	885	0,39	0,06
154	Work smock, above knee length	5	—	547	0,34	0,053
155	Work smock, below knee length	7	—	575	0,36	0,056
156	Single-breasted suit jacket	1	9	518	0,36	0,056
157	Single-breasted suit jacket	1	10	652	0,44	0,068
158	Double-breasted suit jacket	2	9	562	0,42	0,065
159	Double-breasted suit jacket	2	10	702	0,48	0,074
160	Single-breasted, fitted suit jacket	1	—	850	0,32	0,05
161	Vest	4	9	160	0,1	0,016
162	Vest	4	10	185	0,17	0,026
163	Suit-vest	4	—	185	0,07	0,011
164	Long-sleeve shirt-jacket	1	33	—	0,34	0,053
165	Long-sleeve shirt-jacket	1	34	—	0,39	0,06
167	Work jacket, female	3	58	400	0,24	0,037
169	Single-breasted, fitted suit jacket	1	92	725	0,4	0,062
170	Single-breasted suit jacket	1	93	1 076	0,4	0,062
171	Single-breasted suit jacket	1	95	699	0,45	0,07
172	Single-breasted suit jacket	1	92	794	0,46	0,071
173	Suit-vest	4	92	214	0,13	0,02
174	Suit-vest	4	95	—	0,13	0,02

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} $m^2 \cdot K \cdot W^{-1}$
Coats, overjackets and overtrousers						
179	Heat-reflective, hip-length coat, aluminized	6	44	—	0,63	0,098
180	Trousers, loose	6	60	745	0,19	0,029
181	Jacket, above knee length	3	60	942	0,28	0,043
182	Trousers, loose	6	61	452	0,46	0,071
183	Jacket, above knee length	3	61	945	0,69	0,107
184	Coat, below knee length	5	—	1 820	0,65	0,101
185	Down-jacket	4	—	880	0,55	0,085
186	Down-vest	1	—	620	0,3	0,047
187	Coat, below knee length	5	—	650	0,56	0,087
188	Parka-coat, multicomponent	3	—	1 440	0,67	0,104
189	Parka-coat, multicomponent with hat	3	—	1 440	0,79	0,122
190	Overalls, multicomponent	7	—	800	0,52	0,081
191	Heat-protective felt trousers	6	—	1 300	0,33	0,051
192	Jacket, multicomponent	3	—	1 350	0,69	0,107
193	Heat-protective felt jacket	6	—	1 620	0,42	0,065
194	Heat-reflective, aluminized trousers	6	—	670	0,33	0,051
195	Heat-reflective, aluminized coat	6	—	830	0,42	0,065
196	Rain-protective trousers	6	—	250	0,17	0,026
197	Rain-protective jacket	6	—	500	0,31	0,048
198	Jacket, multicomponent	2	—	1 000	0,36	0,056
199	Heat-reflective, calf-length coat, aluminized	5	43	—	0,94	0,146
Highly-insulating trousers						
200	Trousers, fibre-pelt	5	62	341	0,4	0,062
201	Trousers, multicomponent	5	63	322	0,3	0,047
203	Trousers, multicomponent	5	64	292	0,32	0,05
204	Trousers, multicomponent	5	—	360	0,31	0,048
205	Trousers, multicomponent	5	65	225	0,35	0,054
Highly-insulating coveralls						
210	Coverall, multicomponent	1	63	615	0,8	0,124
211	Coverall, multicomponent, filling	4	—	1 500	1,03	0,16
212	Coverall	1	—	1 302	0,32	0,205
213	Coverall, fibre-pelt	1	62	1 215	1,13	0,175
214	Coverall, multicomponent	4	14	1 313	0,96	0,149

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
Highly-insulating jackets						
220	Jacket, lining at wrist and hip, fibre-pelt	5	62	417	0,39	0,06
221	Jacket, lining at wrists, fibre-pelt	3	62	437	0,43	0,067
222	Jacket, fibre-pelt on outside	2	62	434	0,4	0,062
224	Jacket, fibre-pelt, head covered	7	62	472	0,37	0,057
225	Jacket, multicomponent, extra back length	4	63	370	0,39	0,06
226	Vest, multicomponent	1	63	212	0,2	0,031
228	Jacket, multicomponent	4	64	292	0,38	0,059
229	Jacket, multicomponent	3	—	310	0,32	0,05
230	Jacket, multicomponent	3	65	225	0,37	0,057
231	Jacket, multicomponent	3	—	270	0,34	0,053
232	Jacket, multicomponent	3	—	365	0,45	0,07
233	Jacket, multicomponent	3	—	270	0,4	0,062
Socks, shoes, gloves, hats, etc.						
251	Thick gloves, fibre-pelt	4	70	82	0,08	0,012
252	Thick socks, calf-length, fibre-pelt	2	70	113	0,11	0,017
253	Thick socks, ankle-length, fibre-pelt	1	70	77	0,05	0,008
254	Socks, ankle-length	1	—	61	0,02	0,003
255	Suede shoes, rubber sole	6	—	—	0,02	0,003
256	Thick socks, ankle-length	1	—	112	0,05	0,008
257	Clogs	7	—	—	0,03	0,005
258	Shoes	—	—	—	0,05	0,008
259	Cap	12	—	100	0,01	0,002
260	Hard-soled street shoes, vinyl	6	—	1 006	0,03	0,003
261	Slippers, quilted fleece	10	—	186	0,03	0,005
262	Soft-soled athletic shoes, canvas	11	—	812	0,02	0,003
263	Ankle-length athletic socks	1	—	49	0,02	0,003
264	Calf-length athletic socks	2	31	82	0,03	0,005
265	Calf-length dress socks	2	32	53	0,03	0,005
266	Knee socks (thin)	3	30	32	0,03	0,005
267	Knee socks (thick)	3	29	68	0,06	0,009
268	Arm protectors, upper-arm-to-wrist, flame-retardant	16	45	—	0,05	0,008
269	Apron, knee-length, flame-retardant	13	46	—	0,12	0,019
270	Leggings, flame-retardant	14	46	—	0,08	0,012
271	Arm protectors, shoulder to wrist, aluminized	15	44	—	0,11	0,017
272	Thongs/sandals, vinyl	9	—	346	0,02	0,003

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
Sportswear						
280	Sweater, cardigan	12	68	467	0,37	0,057
281	Trousers	5	68	351	0,3	0,047
282	Sweater, cardigan	12	69	496	0,3	0,047
283	Trousers	2	69	447	0,28	0,043
284	Sweater, V-neck	1	66	417	0,36	0,056
285	Trousers	5	66	359	0,32	0,05
286	Sweater, cardigan	12	—	386	0,33	0,051
287	Trousers	2	—	323	0,25	0,039
288	Sweater, cardigan, close-fitting	12	—	457	0,23	0,036
289	Trousers, close-fitting	1	—	344	0,14	0,022
290	Sweater	6	5	284	0,34	0,053
291	Sweat pants	5	5	345	0,28	—
Skirts						
300	A-line, ankle-length	1	09	284	0,23	0,036
301	A-line, ankle-length	1	10	378	0,28	0,043
302	A-line, 0,15 m below knee	2	09	288	0,18	0,028
303	A-line, 0,15 m above knee	3	09	179	0,1	0,016
304	A-line, knee-length	4	09	229	0,14	0,022
305	A-line, knee-length	4	10	305	0,23	0,036
306	Straight, knee-length, with slit	5	09	194	0,14	0,022
307	Bias flair, knee-length	6	09	286	0,13	0,02
308	Full gathered, knee-length	7	09	271	0,14	0,022
309	Full gathered, knee-length	7	10	359	0,22	0,034
310	Knife pleated, knee-length	8	09	410	0,16	0,025
311	A-line, knee-length	4	58	250	0,15	0,023
312	Knife pleated, knee-length	8	10	539	0,26	0,04
313	Straight, knee-length	5	93	437	0,17	0,026
314	A-line, knee-length	4	93	519	0,17	0,026
315	A-line, knee-length	4	95	330	0,19	0,029
316	Full gathered, knee-length	7	93	612	0,18	0,028
Dresses						
330	Long sleeves, shirt collar, A-line	1	1	254	0,32	0,05
331	Long sleeves, shirt collar, A-line	1	10	280	0,47	0,073
332	Long sleeves, shirt collar, A-line, belt	2	1	283	0,35	0,054
333	Short sleeves, shirt collar, A-line, belt	3	1	237	0,29	0,045

Table B.2 (*continued*)

No.	Garment	Type no.	Fabric no.	Garment mass g	I_{clu} clo	I_{clu} m²·K·W⁻¹
334	Sleeveless, scoop neck, A-line	4	1	153	0,23	0,036
335	Sleeveless, scoop neck, A-line	4	10	141	0,27	0,042
336	Sleeveless, scoop neck, gathered waistline	5	1	177	0,26	0,04
337	Long sleeves, shirt collar, A-line	1	91	470	0,41	0,064
338	Long sleeves, shirt collar, A-line	1	92	732	0,4	0,062
339	Long sleeves, shirt collar, A-line	1	93	1 099	0,39	0,06
Sleepwear						
350	Long-sleeve, long gown	1	15	260	0,29	0,045
351	Long-sleeve, long gown	1	16	435	0,46	0,071
352	Long-sleeve, short gown	2	15	180	0,24	0,037
353	Long-sleeve, short gown	2	16	305	0,39	0,06
354	Short-sleeve, long gown	3	15	239	0,25	0,039
355	Short-sleeve, short gown	4	15	157	0,21	0,033
356	Sleeveless, short gown	6	15	138	0,18	0,028
357	Thin-strap, short gown	8	15	94	0,15	0,023
358	Hospital gown	9	17	270	0,31	0,048
359	Long-sleeve, long pyjamas	10	1	327	0,48	0,074
360	Long-sleeve, long pyjamas	10	16	447	0,57	0,088
361	Short-sleeve, long pyjamas	11	1	297	0,42	0,065
362	Long pyjama trousers	12	1	149	0,17	0,026
363	Body sleeper with feet	13	18	599	0,72	0,112
364	Undershorts	14	1	66	0,1	0,016
Robes						
370	Long sleeves, wrap, long	1	1	363	0,44	0,068
371	Long sleeves, wrap, long	1	19	690	0,53	0,082
372	Long sleeves, wrap, long	1	20	1 196	0,68	0,105
373	Long sleeves, wrap, long	1	21	783	0,77	0,119
374	Long sleeves, wrap, long	1	22	1 535	1,02	0,158
375	Long sleeves, wrap, short	2	1	298	0,41	0,064
376	Long sleeves, wrap, short	2	19	556	0,46	0,071
377	Long sleeves, button front, long	4	19	586	0,49	0,076
378	Long sleeves, button front, short	5	1	260	0,4	0,062
379	Long sleeves, button front, short	5	19	472	0,45	0,07
380	Short sleeves, button front, short	6	1	231	0,34	0,053

Table B.3 — Characteristics of various clothing materials used in garments listed in Table B.2

Code	Type/construction	Fibre content	Thickness[a] mm	Fabric insulation[b] $m^2 \cdot K \cdot W^{-1}$	Fabric surface density $g \cdot m^{-2}$	Air permeability [c] $l \cdot m^2 \cdot s^{-1}$
01	Broadcloth/plain weave	65 % polyester, 35 % cotton	0,38	0,029	110	426
02	Flannel/plain weave	80 % cotton, 20 % polyester	1,08	0,045	150	355
03	Double knit/weft knit	100 % cotton	0,96	—	—	426
04	Double knit/weft knit	100 % polyester	1,06	0,022	—	1 453
05	Fleece-backed double knit	50 % polyester, 38 % cotton, 12 % viscose	2,23	—	—	1 072
06	Jersey/weft knit	100 % acrylic	1,62	—	—	1 407
07	Jersey/weft knit	85 % wool, 15 % nylon	3,55	—	—	1 631
08	Double knit/weft knit	50 % cotton, 50 % polyester	1,1	—	—	1 727
09	Denim/twill weave	100 % cotton	0,8	0,023	206	246
10	Tweed/plain weave	50 % wool, 50 % polyester	1,27	0,04	310	899
11	Duck/twill weave	100 % cotton	1,16	—	467	25
12	Denim/twill weave	64 % cotton, 36 % polyester	1,17	—	480	123
13	Gabardine/twill weave	100 % cotton	0,91	—	390	50
14	Multicomponent fabric shell: gabardine: lining: quilted	65 % polyester, 35 % cotton, 100 % nylon	4,32	—	—	126
15	Tricot/warp knit	100 % nylon	0,31	0,009	90	26
16	Flannel/plain weave	100 % cotton	0,99	0,039	141	610
17	Print cloth/plain weave	100 % cotton	0,48	—	126	447
18	Fleece-backed double knit	100 % acrylic	3,34	—	241	1 661
19	Velour/brushed warp knit	80 % triacetate, 20 % nylon	1,47	0,037	200	1 433
20	Terry cloth/warp slack tension plain weave	88 % cotton, 12 % polyester	3,13	0,071	335	681
21	Quilted multicomponent fabric	Face: 50 % polyester, 50 % viscose Fill: 100 % polyester Back: 100 % nylon	3,03	0,113	206	1 113
22	Fleece/pile jersey knit	Pile: 50 % polyester, 50 % acrylic Back: 100 % polyester	5,91	0,153	467	1 311
23	Waffle knit	50 % cotton, 50 % polyester	1,54	—	—	2 057
24	Jersey/weft knit	100 % cotton	0,9	—	—	1 534
25	Tricot/warp knit	100 % nylon	0,3	—	—	3 327
26	Tricot/warp knit	100 % nylon	0,32	—	—	2 946
27	Jersey/weft knit	100 % cotton	0,95	—	—	1 067
28	Lining/plain weave	100 % polyester	0,09	0,009	80	276
29	Weft knit	80 % acrylic, 20 % nylon	2,5	—	—	—
30	Weft knit	100 % nylon	0,9	—	—	—

Table B.3 (*continued*)

Code	Type/construction	Fibre content	Thickness[a] mm	Fabric insulation[b] $m^2 \cdot K \cdot W^{-1}$	Fabric surface density $g \cdot m^{-2}$	Air permeability [c] $l \cdot m^2 \cdot s^{-1}$
31	Weft knit	85 % acrylic, 15 % nylon	2,3	—	—	—
32	Weft knit	75 % acrylic, 25 % nylon	2	—	—	—
33	Satin weave, flame-retardant	100 % cotton	0,76	—	375	—
34	Twill weave, flame-retardant	100 % cotton	0,89	—	448	—
35	Twill weave, antistatic acid-resistant	100 % SEF, modacrylic	0,53	—	231	—
36	Plain weave, durable press, soil release	65 % polyester, 35 % cotton	0,33	—	153	—
37	Twill weave	65 % polyester, 35 % cotton	0,38	—	136	—
38	Twill weave, flame-retardant	100 % cotton	0,86	—	468	—
39	Twill weave, flame-retardant	100 % cotton	0,94	—	451	—
40	Twill weave, durable press	65 % polyester, 35 % cotton	0,48	—	254	—
41	Twill weave	65 % polyester, 35 % cotton	0,61	—	248	—
42	Twill weave	100 % cotton	0,81	—	356	—
43	2 × 2 basket weave aluminized coating	100 % PFR viscose	1,19	—	634	—
44	2 × 2 basket weave aluminized coating	100 % PFR viscose	1,32	—	644	—
45	Plain weave, flame-retardant	100 % cotton	1,04	—	505	—
46	Satin weave, flame-retardant	100 % cotton	0,84	—	305	—
50	—	Cotton	1,5	0,028	153	1 741
51	—	Wool	2	0,043	215	1 432
52	—	Cotton, polyester	—	—	—	—
53	—	Cotton, wool	—	—	—	—
54	—	Polypropylene	2,1	0,038	189	1 382
55	—	Wool, polyester, polyamide	—	—	—	—
56	—	Modal, cotton	—	—	—	—
57	—	Nylon	—	—	—	—
58	—	35 % cotton, 65 % polyester	0,8	0,01	221	139
59	—	Cotton	1,4	0,023	339	32
60	—	35 % cotton, 65 % polyester	0,9	0,011	295	80
61	Highly insulating	Polyester, polyamide	11,6	0,252	255	24

Table B.3 (*continued*)

Code	Type/construction	Fibre content	Thickness[a] mm	Fabric insulation[b] $m^2 \cdot K \cdot W^{-1}$	Fabric surface density $g \cdot m^{-2}$	Air permeability [c] $l \cdot m^2 \cdot s^{-1}$
62	Fibre-pelt	Polyamide	12,9	0,254	297	1 588
63	Highly insulating	Polyester, polyamide	7,5	0,137	234	1 577
64	Highly insulating	Polyester, polyamide	6,7	—	160	204
65	Highly insulating	Polyester, polyamide	7,8	0,155	172	221
66	—	Cotton	2,1	0,029	260	366
67	—	52 % cotton, 48 % polyester	1,8	0,025	245	400
68	—	37 % cotton, 63 % polyester	1,6	0,021	260	325
69	—	40 % cotton, 60 % polyester	1,7	0,022	290	308
70	—	Polyamide	—	—	—	—
91	Twill weave	Cotton	0,7	0,04	206	241
92	Twill weave	Cotton	1,0	0,038	322	84
93	Twill weave	Cotton	1,2	0,038	498	18
94	Plain weave	35 % cotton, 65 % polyester	0,3	0,034	111	370
95	Plain weave	80 % wool, 20 % nylon	1,5	0,056	306	973

[a] Thickness: Fabric codes 1 to 46 were measured in accordance with ASTM D1777 using a 75 mm diameter presser foot and 0,07 kPa pressure. The thickness of sock fabric codes 29 to 39 was estimated from circumference measurements taken on the manikin. Fabric codes 50 to 95 were measured in accordance with ISO 9073-2 with 0,0069 kPa pressure.

[b] Insulation: Fabric codes 1 to 46 were measured in accordance with ASTM D1518. The insulation provided by the air, 0,62 clo, is not included in the values in the table. Fabric codes 50 to 95 were measured in accordance with BS 4745.

[c] Air permeability: Fabric codes 1 to 46 were measured in accordance with ASTM D737 at 1,7 kPa pressure. Fabric codes 50 to 95 were measured in accordance with ISO 9237.

B.2 Illustrations of garments

Figures B.1 to B.14 illustrate the garment types listed in Table B.2.

The number of each individual drawing corresponds to the type number given for that garment in Table B.2, while the percentage below each drawing represents the percentage of body surface area covered by the particular item of clothing (BSAC).

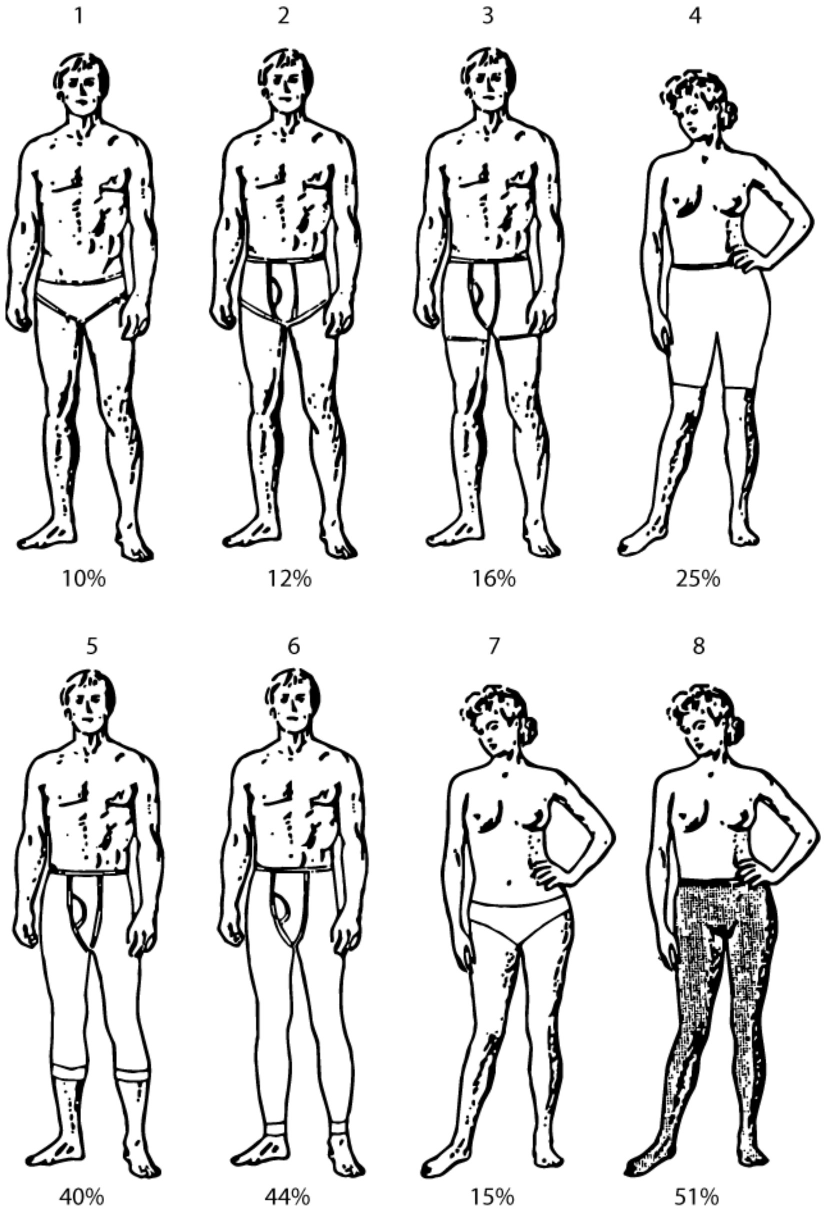


Figure B.1 — Underwear — Pants

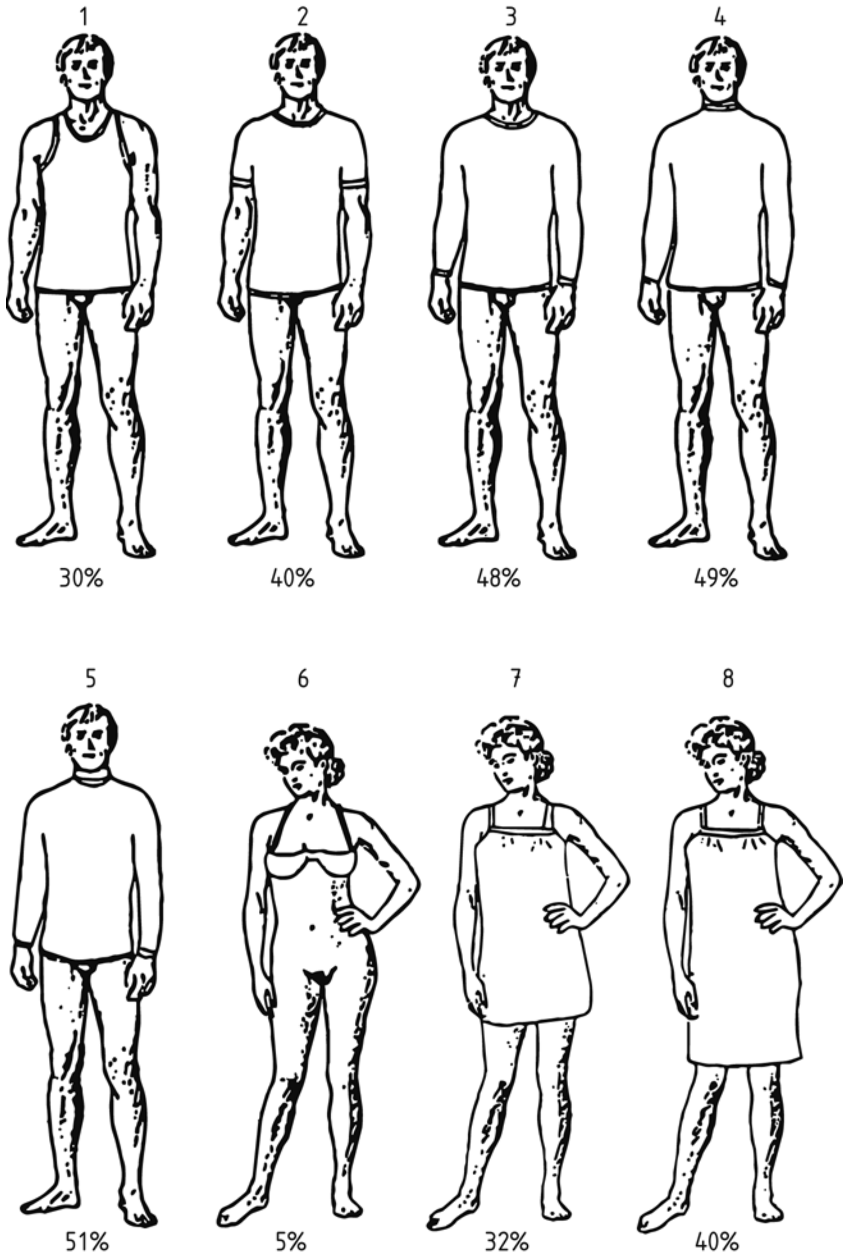


Figure B.2 — Underwear — Shirts

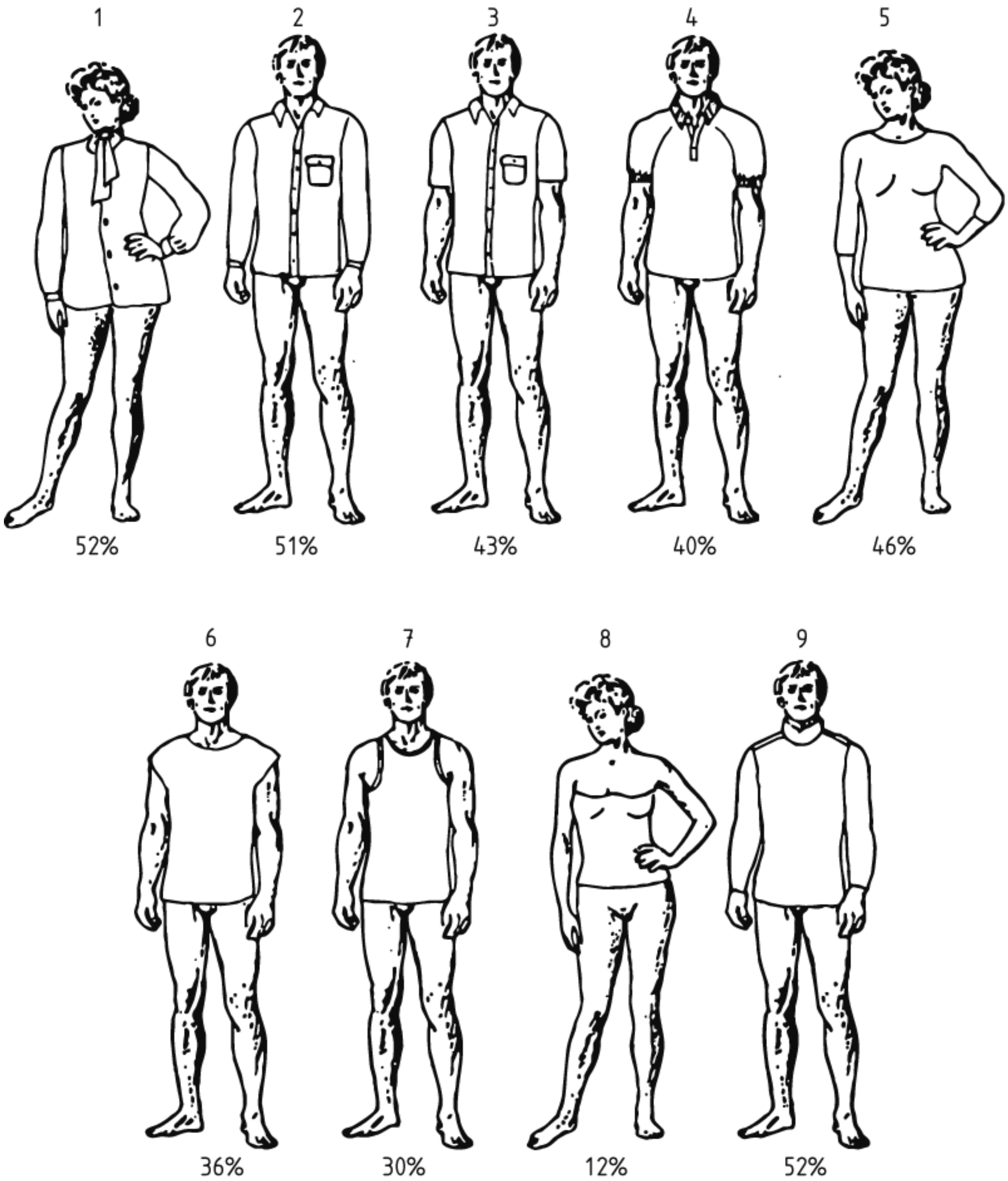


Figure B.3 — Shirts

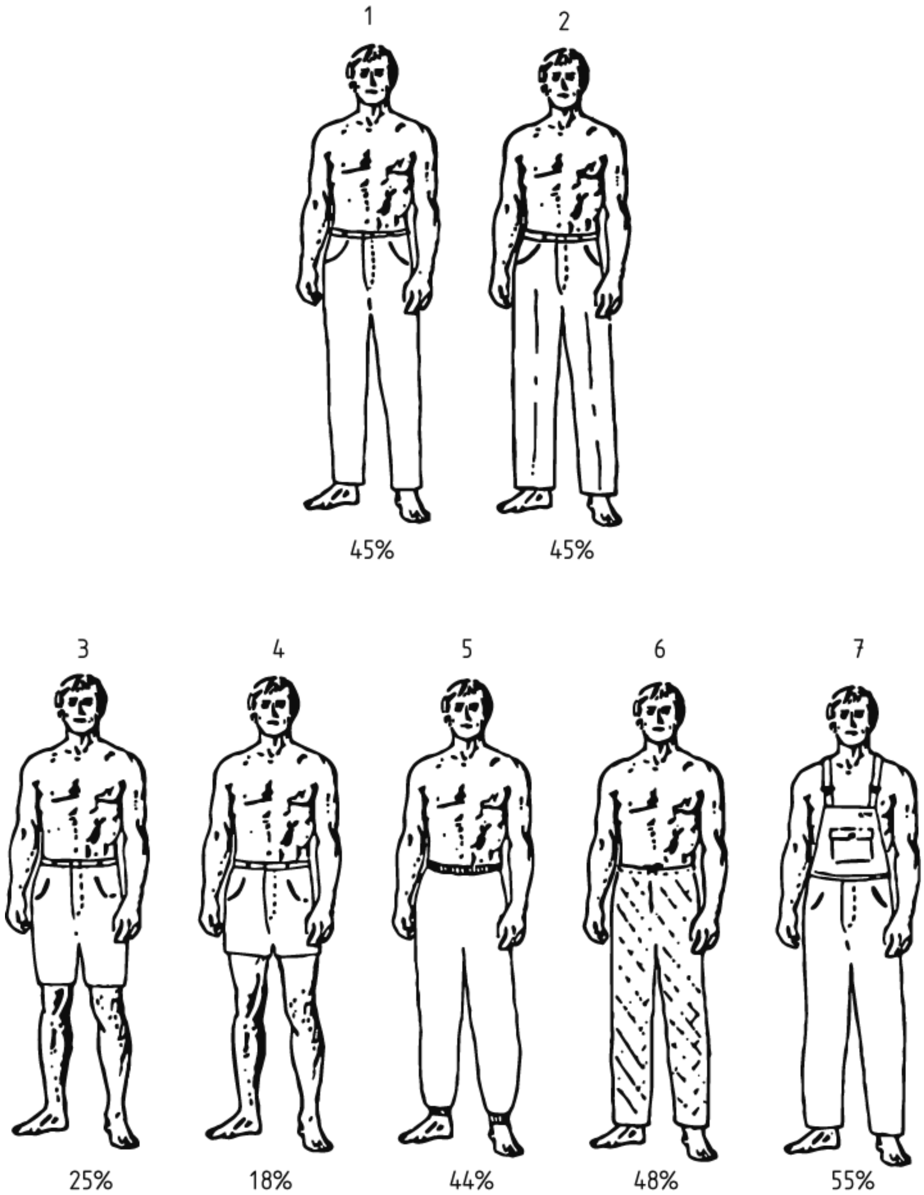


Figure B.4 — Trousers

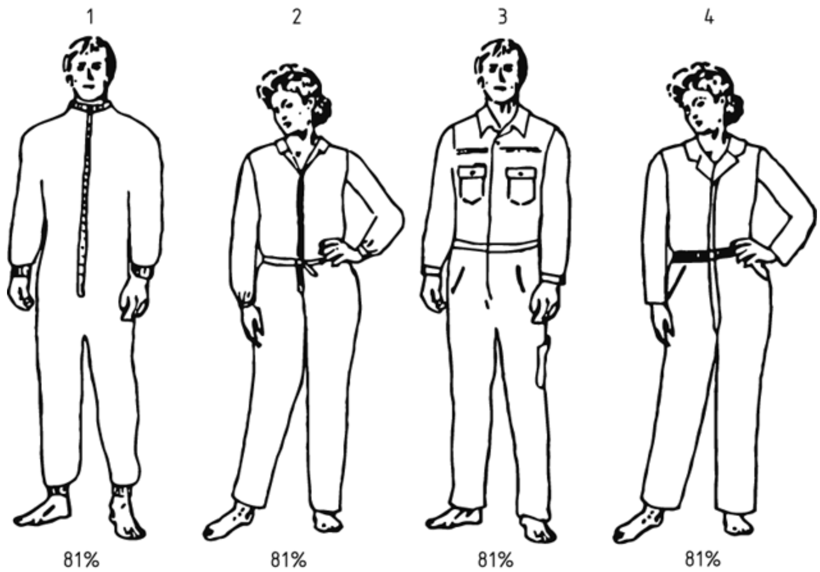


Figure B.5 — Coveralls

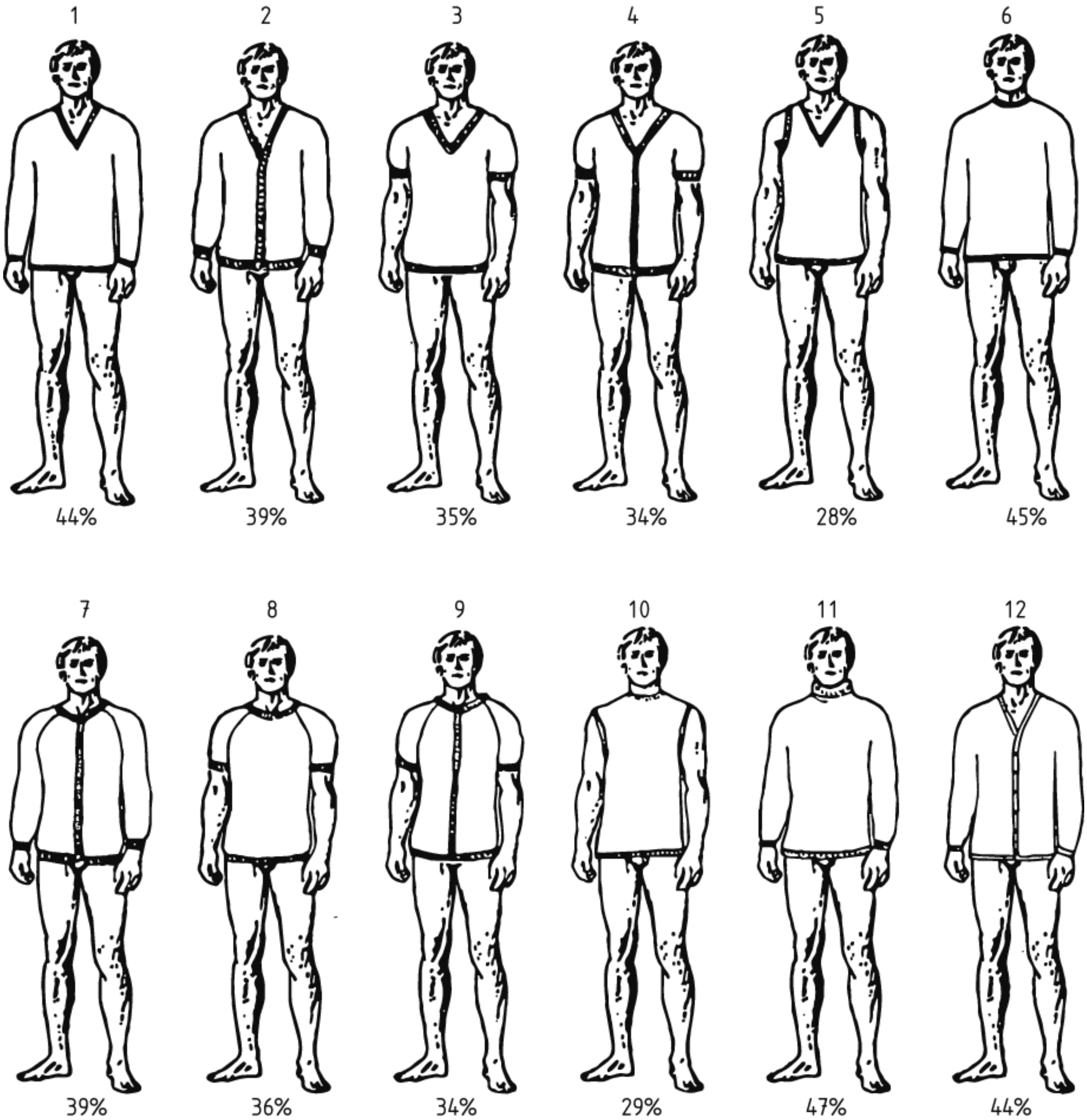


Figure B.6 — Sweaters

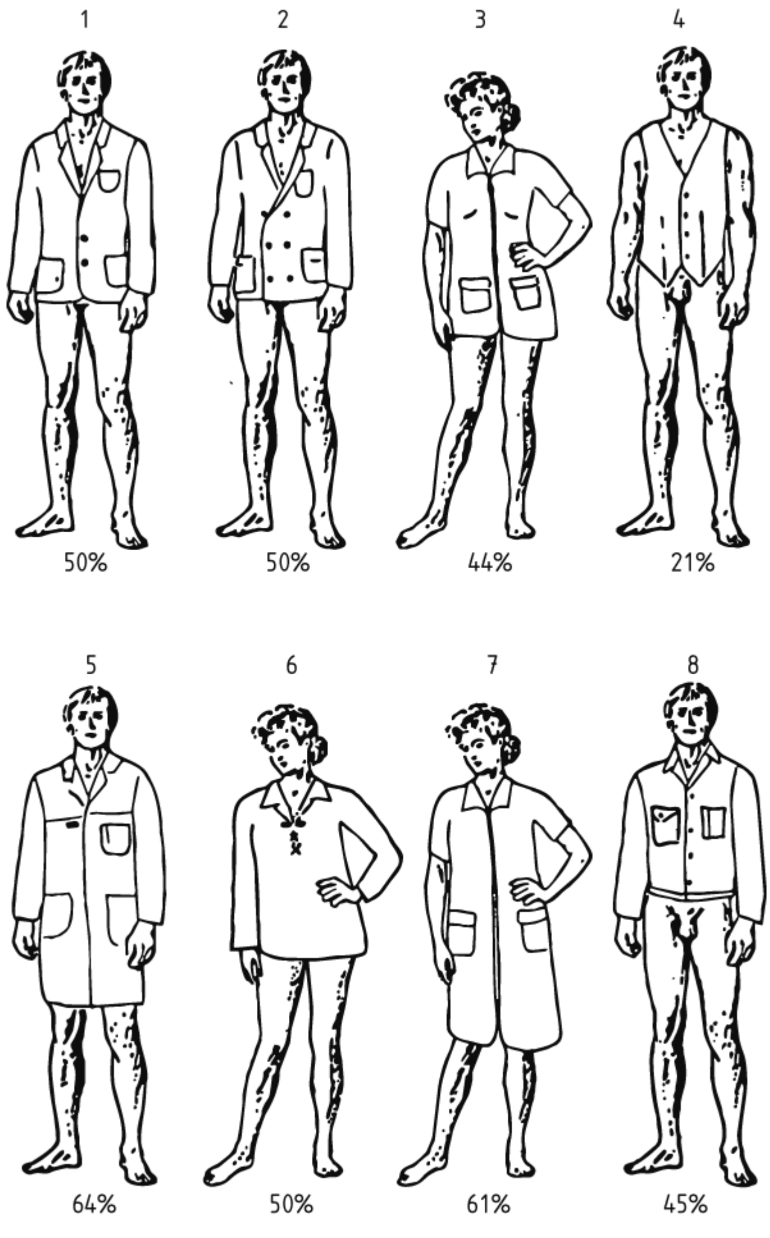


Figure B.7 — Jackets, vests, smocks

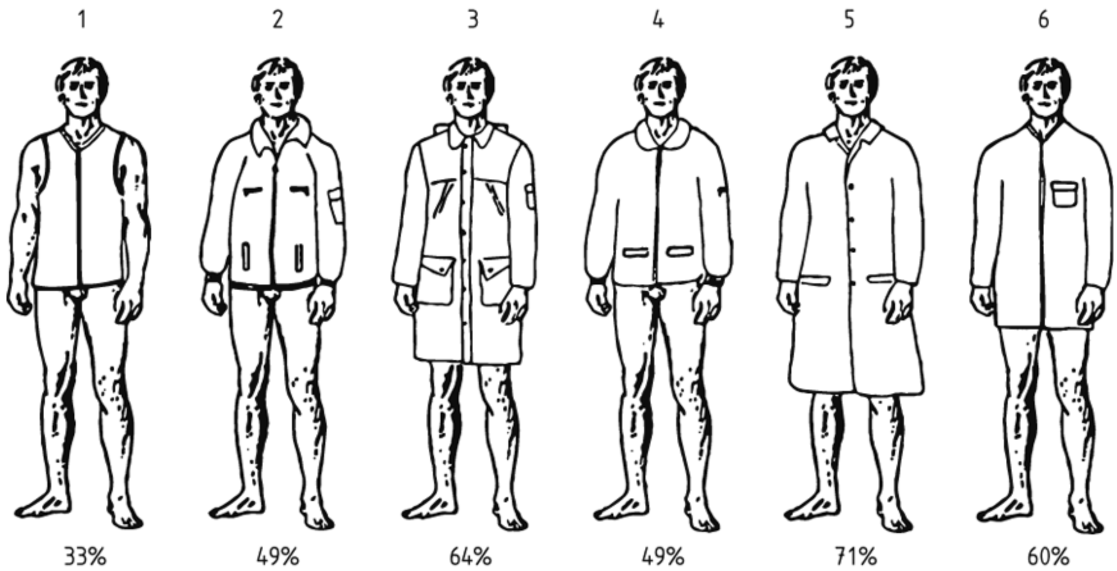


Figure B.8 — Overjackets, coats

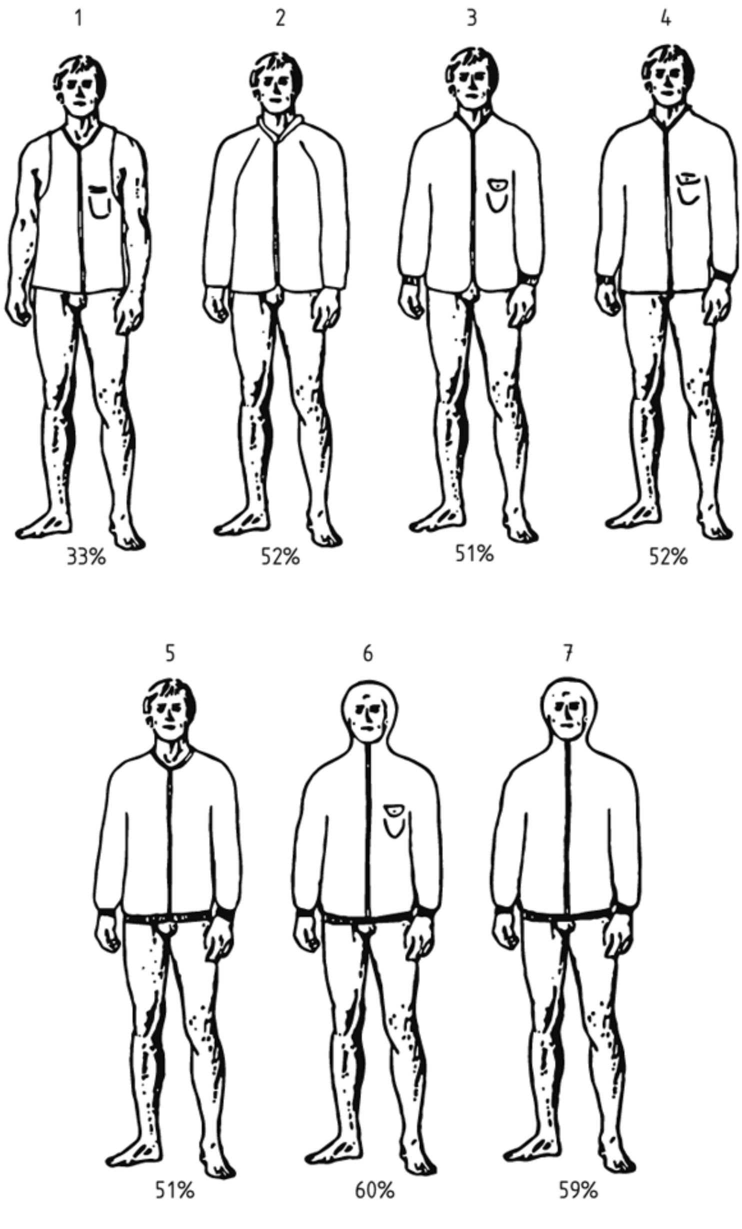


Figure B.9 — Highly-insulating jackets

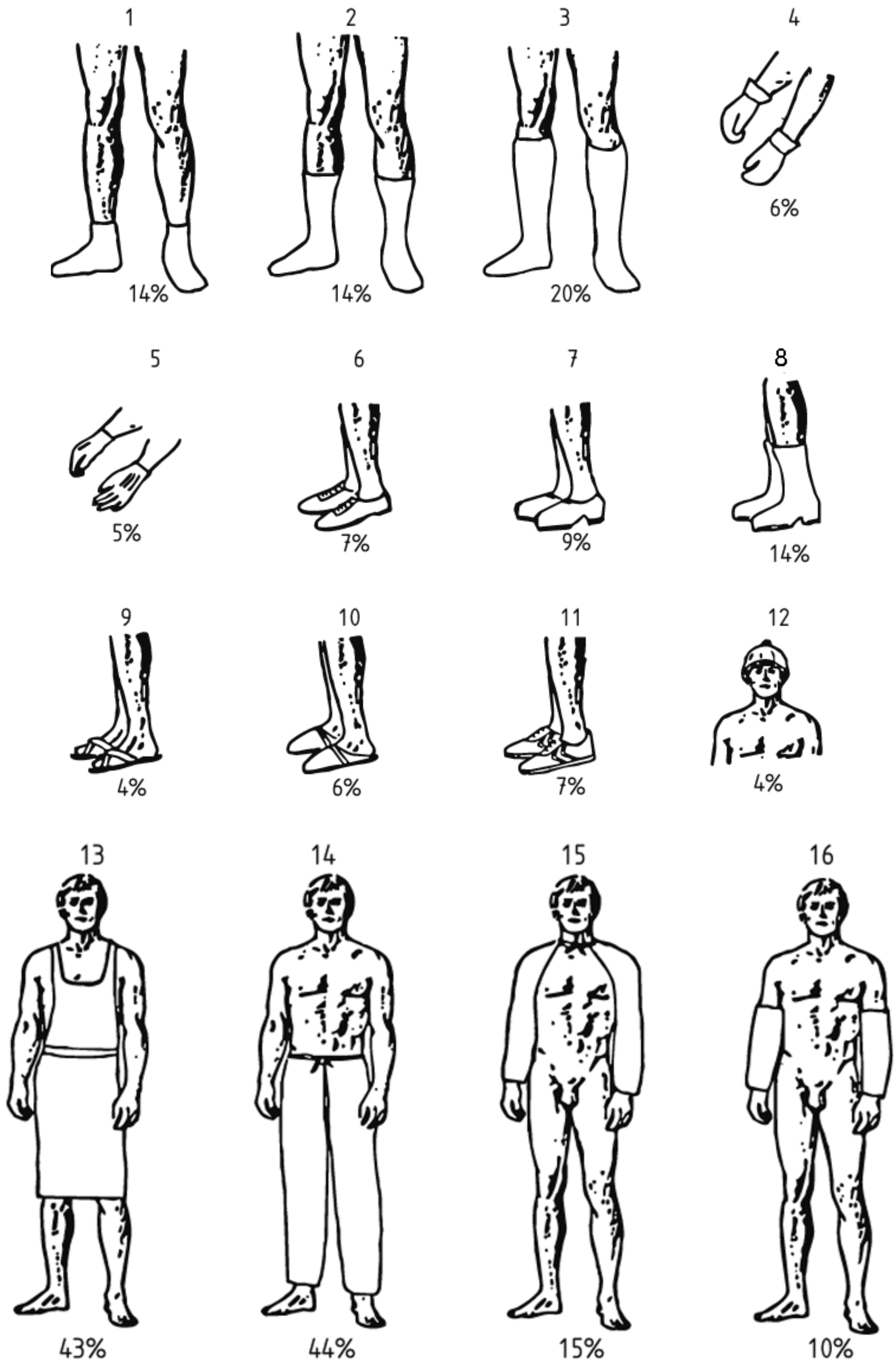


Figure B.10 — Socks, shoes, gloves, hats, etc.

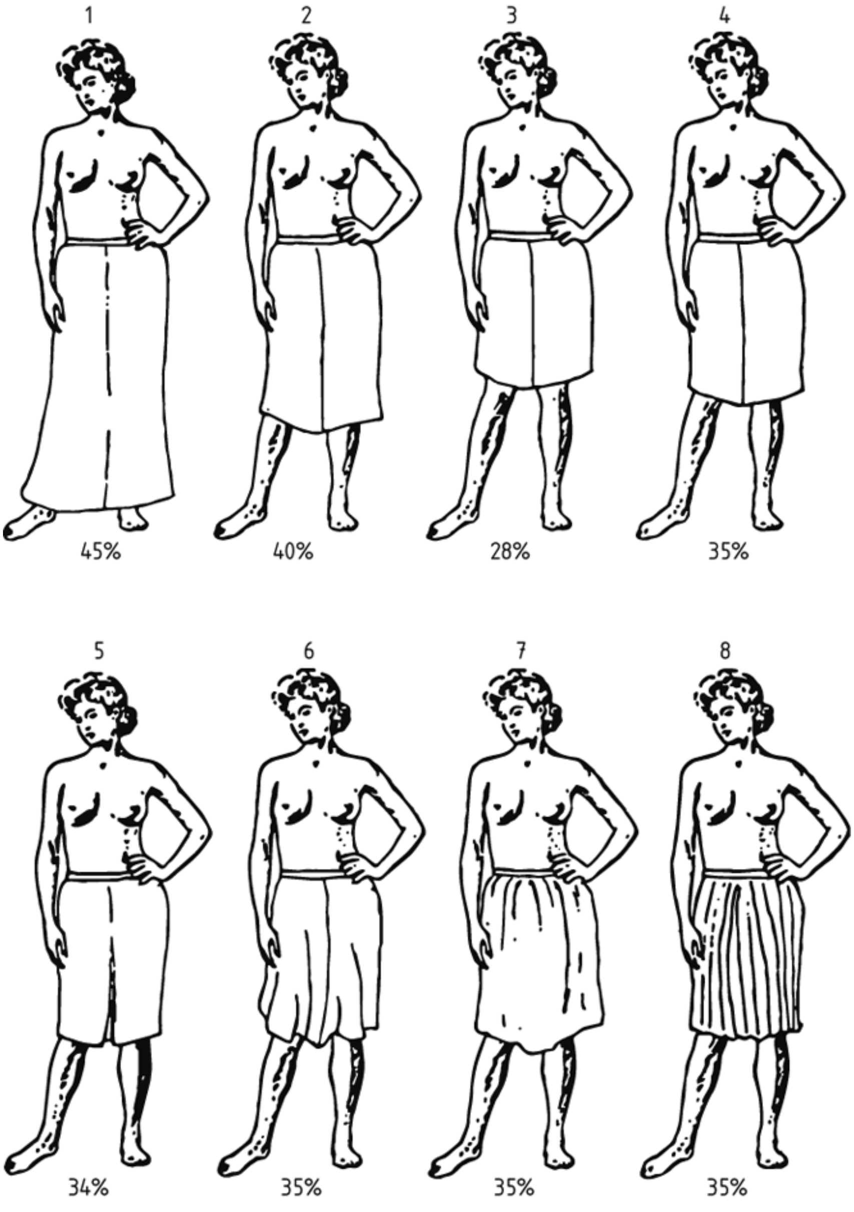


Figure B.11 — Skirts

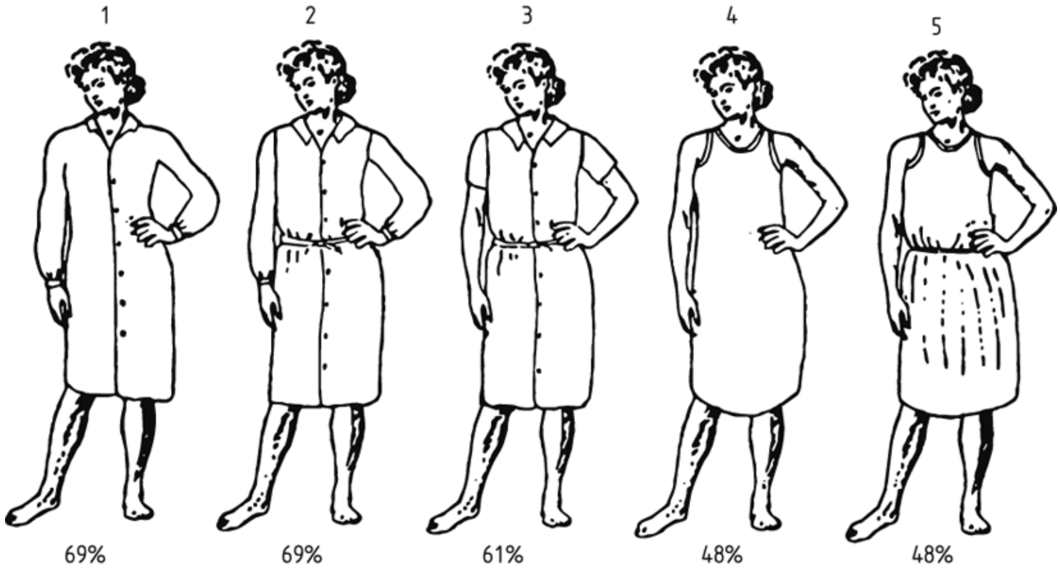


Figure B.12 — Dresses

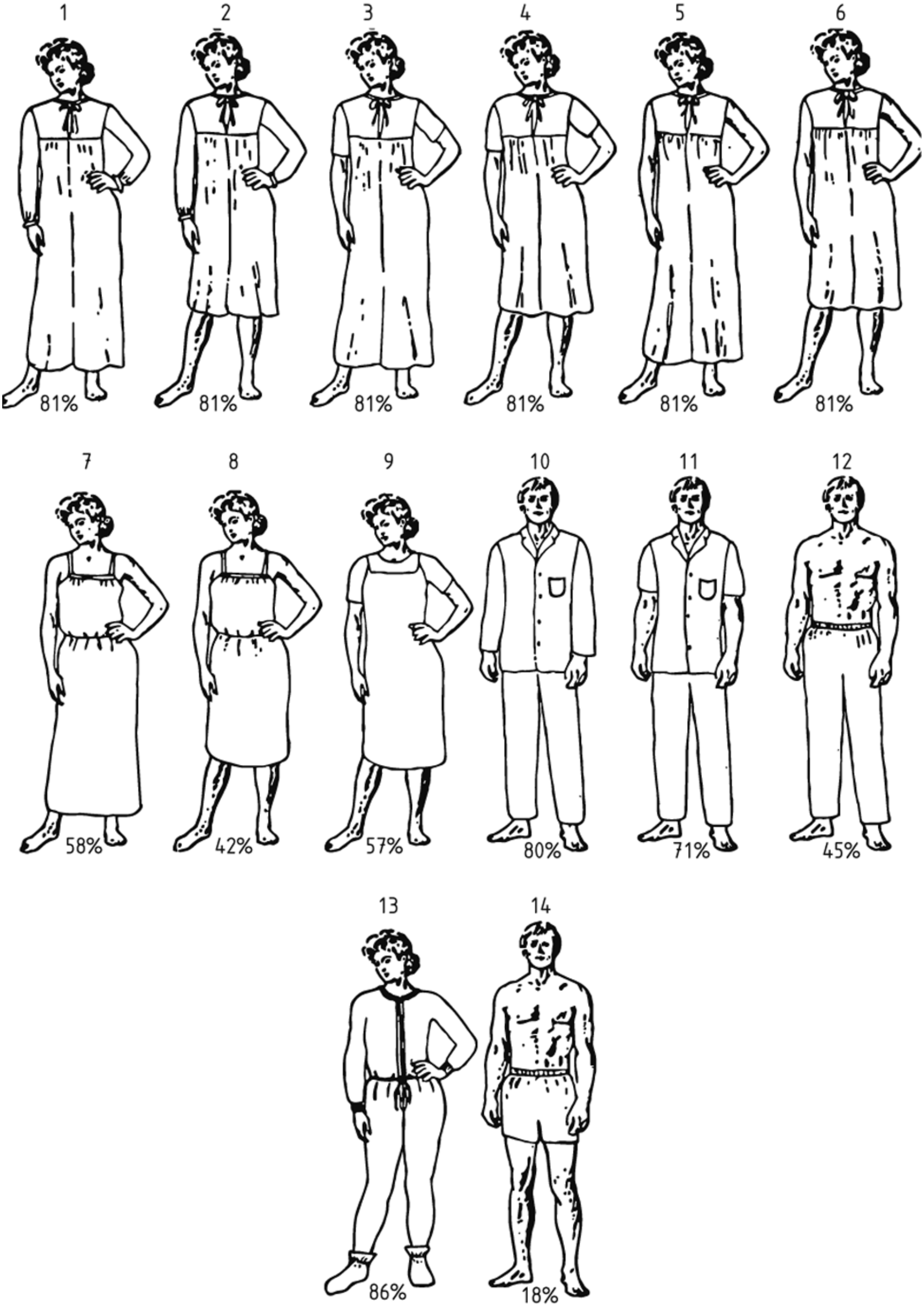


Figure B.13 — Sleepwear

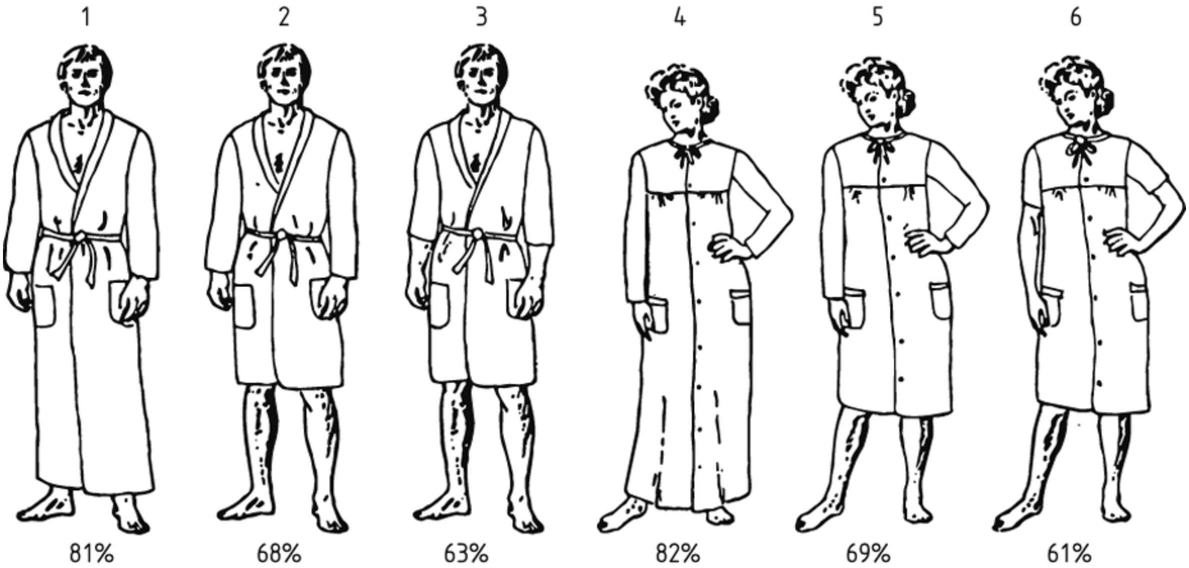


Figure B.14 — Robes

Annex C
(normative)

Vapour permeability index values for clothing ensembles

Table C.1 — Example data for estimation of the static clothing permeability index (i_m) using the description of the clothing type

	Clothing description	Estimated static i_m < 15 °C	Estimated static i_m > 30 °C
1	Nude	0,5	
2	Normal, permeable clothing, regardless of number of layers	0,38	
3	As 2, with tightly woven jacket	0,34	
4	As 2, with aluminized coat *or* trousers	0,31	
5	As 2, with two piece semi-permeable overgarment	0,17	0,15
6	As 2, with one piece semi-permeable overgarment	0,14	0,13
7	As 2, with two piece impermeable overgarment	0,12	0,07
8	As 2, with one piece impermeable overgarment	0,1	0,06
9	As 2, with one piece impermeable overgarment, covered head except face, gloves, openings sealed (e.g. immersion suit)	0,06	0,02
10	Completely encapsulating suit, all openings sealed, no skin exposed	0,05	0,0

The difference between the two temperatures is related to the occurrence of condensation at or close to the outer clothing surface, which will increase evaporative heat loss from the skin despite low or no permeability of the outer layers. Intermediate values may be interpolated as:

$i_m = (\alpha \times i_m 15 + (1 - \alpha) \times i_m 30)$ with $\alpha = [(30 - \text{air temperature})/15]$ (from Reference [13]).

Table C.2 — Vapour resistance values of various clothing ensembles — Daily wear clothing [36]

No.	Ensemble	Combination	I_T m²·K·W⁻¹	f_{cl}	I_{cl} m²·K·W⁻¹	$R_{e,T}$ m²·kPa·W⁻¹	i_m	$R_{e,cl}$ m²·kPa·W⁻¹	$i_{m,cl}$
1	**Men's business suit** 02 briefs 02 t-shirt 22 long-sleeve shirt, shirt collar 51A suit jacket, single-breasted 51B vest 31 long trousers 90 belt 81 calf-length dress socks 92 hard-soled street shoes 00 necktie	—	0,262	1,32	0,177	0,044	0,37	0,033	0,32
2	**Women's business suit** 04 panties 04 half slip, knee-length 21 long-sleeve blouse 51A, B lined suit jacket, double-breasted 51A, B skirt, straight, knee-length 83 pantyhose 92 hard-soled street shoes	—	0,248	1,3	0,162	0,039	0,4	0,028	0,35
3	**Men's summer casual** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes	—	0,186	1,15	0,089	0,027	0,43	0,015	0,36

Table C.2 (*continued*)

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
4	**Jeans and shirt** 02 briefs 26 long-sleeve shirt, rugby, heavy 33 jeans 82 calf-length athletic socks 93 soft-soled athletic shoes	—	0,197	1,22	0,105	0,031	0,4	0,02	0,32
5	**Summer shorts and shirt** 02 briefs 27 short-sleeve shirt, tab-front 35 shorts 82 calf-length athletic socks 93 soft-soled athletic shoes	—	0,158	1,1	0,056	0,023	0,42	0,01	0,34
6	**Women's casual** 24 long-sleeve shirt 36 straight-legged slacks 83 pantyhose 92 hard-soled street shoes	—	0,188	1,2	0,095	0,026	0,45	0,014	0,41
7	**Women's shorts and tank top** 04 panties 28 sleeveless tank top 37 shorts 97 sandals/thongs	—	0,144	1,08	0,040	0,022	0,4	0,009	0,27

Table C.2 (*continued*)

No.	Ensemble	Combination	I_T m²·K·W⁻¹	f_{cl}	I_{cl} m²·K·W⁻¹	$R_{e,T}$ m²·kPa·W⁻¹	i_m	$R_{e,cl}$ m²·kPa·W⁻¹	$i_{m,cl}$
8	**Athletic sweat suit** 04 panties 11 long-sleeve sweatshirt 11 sweat pants 82 athletic socks 93 soft-soled athletic shoes	—	0,209	1,19	0,115	0,029	0,45	0,017	0,41
9	**Sleepwear and robe** 12 long sleeve pyjama top 12 long pyjama trousers 13 short 3/4 sleeve wrap robe 96 slippers	—	0,233	1,32	0,148	0,035	0,41	0,024	0,37

Table C.3 — Vapour permeability values of various clothing ensembles — Work clothing [36]

No.	Ensemble	Combination	I_T m²·K·W⁻¹	f_{cl}	I_{cl} m²·K·W⁻¹	$R_{e,T}$ m²·kPa·W⁻¹	i_m	$R_{e,cl}$ m²·kPa·W⁻¹	$i_{m,cl}$
10	**Overalls and shirt** 02 briefs 02 t-shirt 25 long-sleeve shirt, shirt collar 34 bib overalls 82 athletic socks 94 work shoes/boots	—	0,226	1,27	0,138	0,035	0,4	0,024	0,35

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
11	**Insulated coverall and long underwear** 05 thermal long-sleeve underwear top 05 thermal long underwear bottoms 82 athletic socks 62 A, B insulated coverall 94 work shoes/boots	—	0,302	1,26	0,213	0,048	0,39	0,037	0,35
12	**Work shirt and trousers** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 61 polyester/cotton coverall	—	0,236	1,18	0,141	0,037	0,4	0,025	0,34
13	**Cleanroom coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 63 polyester coverall	—	0,240	1,26	0,151	0,039	0,38	0,028	0,32

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T m²·K·W⁻¹	f_{cl}	I_{cl} m²·K·W⁻¹	$R_{e,T}$ m²·kPa·W⁻¹	i_m	$R_{e,cl}$ m²·kPa·W⁻¹	$i_{m,cl}$
14	**Wool coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 64 wool coverall	—	0,260	1,26	0,171	0,042	0,38	0,031	0,33
15	**Firestop cotton coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 65 firestop cotton coverall	—	0,248	1,26	0,159	0,038	0,4	0,027	0,35
16	**Modacrylic coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 66 SEF modacrylic coverall	—	0,251	1,26	0,162	0,038	0,41	0,027	0,36

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
17	**Tyvek[1] coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 67 Tyvek disposable coveralls	—	0,237	1,26	0,148	0,045	0,33	0,034	0,26
18	**Goretex[2] two piece suit** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 78A, B, C light-weight Goretex jacket 78A, B Goretex trousers	—	0,268	1,28	0,181	0,044	0,38	0,033	0,33

1) Tyvek® is the trade name of a product supplied by Dupont. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

2) Goretex® is the trade name of a product supplied by W.L. Gore and Associates. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T m²·K·W⁻¹	f_{cl}	I_{cl} m²·K·W⁻¹	$R_{e,T}$ m²·kPa·W⁻¹	i_m	$R_{e,cl}$ m²·kPa·W⁻¹	$i_{m,cl}$
19	**Nomex[3] coverall** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 68 Nomex aramid coverall	—	0,251	1,26	0,162	0,039	0,4	0,028	0,35
20	**PVC/Polyester knit acid suit** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 75 acid suit jacket 75 acid suit trousers	—	0,253	1,28	0,166	0,105	0,15	0,094	0,11

3) Nomex® is the trade name of a product supplied by Dupont. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
21	**PVC and vinyl acid suit** 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 73 PVC and Vinyl acid splash jacket with hood 73 PVC and Vinyl acid splash overall	—	0,262	1,28	0,175	0,126	0,13	0,115	0,09
22	**Neoprene/nylon suit** 4) 02 briefs 22 short-sleeve shirt, shirt collar 32 long trousers 96 belt 81 calf-length dress socks 92 hard-soled street shoes 71 Neoprene/nylon jacket with hood 71 Neoprene/nylon overall	—	0,264	1,28	0,177	0,12	0,14	0,109	0,1

4) Neoprene is the trade name of a product supplied by Dupont. This information is given for the convenience of users of this International Standard and does not constitute an endorsement by ISO of the product named. Equivalent products may be used if they can be shown to lead to the same results.

Table C.3 (*continued*)

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
500	Underpants 8, T-shirt 32 trousers 104, jacket 164 socks 263, shoes 258	—	0,104	1,36	0,144	0,018	0,34	—	—
502	Underpants 8, T-shirt 32 trousers 105, jacket 165 socks 263, shoes 258	—	0,104	1,39	0,155	0,020	0,32	—	—
503	Underpants 8 shirt 51, trousers 107 socks 263, shoes 258	—	0,108	1,2	0,095	0,017	0,38	—	—
505	Underpants 8 shirt 50, trousers 106 socks 263, shoes 258	—	0,108	1,22	0,109	0,017	0,38	—	—
508	Underpants 8 short-sleeve shirt 53, trousers 107 socks 263, shoes 258	—	0,107	1,19	0,085	0,017	0,38	—	—
527	Underpants 8, T-shirt 32 coveralls 110 socks 263, shoes 258	—	0,109	1,19	0,101	0,017	0,39	—	—
501	Underpants 8 shirt 52, trousers 108 socks 263, shoes 258	—	0,109	1,19	0,101	0,017	0,39	—	—

Table C.4 — Vapour permeability values of various clothing ensembles — Heat-protective clothing [36]

No.	Ensemble	Combination	I_T $m^2 \cdot K \cdot W^{-1}$	f_{cl}	I_{cl} $m^2 \cdot K \cdot W^{-1}$	$R_{e,T}$ $m^2 \cdot kPa \cdot W^{-1}$	i_m	$R_{e,cl}$ $m^2 \cdot kPa \cdot W^{-1}$	$i_{m,cl}$
510	Underpants 8 shirt 52 trousers 108, socks 263 hip leggings 270, shoes 258	501 270	0,110	1,24	0,127	0,016	0,4	—	—
512	Underpants 8 shirt 52, trousers 108 arm protectors 268 socks 263, shoes 271	501 271	0,107	1,3	0,133	0,021	0,31	—	—
513	Underpants 8 shirt 52, trousers 108 arm protectors 258 socks 263, shoes 258	501 268	0,106	1,28	0,119	0,017	0,37	—	—
514	Underpants 8 shirt 52, trousers 108 apron 269 socks 263, shoes 258	501 269	0,107	1,26	0,119	0,016	0,4	—	—
524	Underpants 8 shirt 52, trousers 108 aluminized hip-length coat 179 socks 263, shoes 258	501 179	0,116	1,34	0,211	0,021	0,33	—	—
525	Underpants 8 shirt 52, trousers 108 aluminized hip-length coat 179 socks 263, shoes 258	501 199	0,112	1,58	0,270	0,023	0,3	—	—

Table C.5 — Fabric characteristics and thermal resistance values of garments listed in Tables C.2 and C.3, for ensemble numbers < 100[36]

Fabric code	Description	Thickness	Intrinsic fabric insulation R_f		Water vapour resistance or fabric $R_{e,f}$	Water vapour permeability index of fabric $i_{m,cl}$
		mm	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot kPa \cdot W^{-1}$	
02	Jersey single knit, 100 % cotton	1,270	0,036	0,230	0,004 0	0,541
04	Tricot, warp knit, 100 % nylon	0,356	0,011	0,068	0,001 4	0,472
05	Rib knit, 50 % cotton, 50 % polyester	2,184	0,055	0,357	0,006 0	0551
11	Fleece-backed knit, 50 % cotton, 50 % polyester	3,658	0,103	0.665	0,010 6	0,584
12	Broadcloth, plain weave, 60 % cotton, 40 % polyester	0,584	0,024	0,155	0,002 4	0,601
13	Velour brushed, warped knit, 80 % triacetate, 20 % nylon	1,727	0,049	0,049	0,004 6	0,640
21	Plain weave, 100 % polyester	0,152	0,011	0,070	0,000 9	0,734
22	Broadcloth, plain weave, 65% polyester, 35 % cotton	0,533	0,025	0,162	0,002 4	0,626
24	Oxford cloth, basket weave 60 % cotton, 40 % polyester	0,660	0,024	0,154	0,002 7	0,534
25	Flannel, napped, plain weave, 80 % cotton, 20 % polyester	1,422	0,047	0,306	0,005 2	0,543
26	Single knit, 100 % cotton	1,575	0,036	0,233	0,005 2	0,416
27	Double knit, 65 % polyester, 35 % cotton	1,118	0,039	0,249	0,003 9	0,601
28	Jersey single knit, 50 % cotton, 50 % polyester	1,194	0,043	0,280	0,004 2	0,615
31	Pinwheel corduroy, 75 % cotton, 25 % polyester	1,880	0,041	0,261	0,006 5	0,379
32	Poplin, 60 % cotton, 40 % polyester	0,787	0,026	0,169	0,004 1	0,381
33	Denim, 100 % cotton,	1,778	0,037	0.236	0,006 6	0,337
34	Denim, 64 % cotton, 36 % polyester	1,422	0,034	0,222	0,005 5	0371

Table C.5 (*continued*)

Fabric code	Description	Thickness	Intrinsic fabric insulation R_f		Water vapour resistance or fabric $R_{e,f}$	Water vapour permeability index of fabric $i_{m,cl}$
		mm	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot kPa \cdot W^{-1}$	
35	Plain weave, 100 % cotton	0,965	0,025	0,163	0,004 4	0,341
36	Even twill weave, 100 % polyester	0,889	0,020	0,128	0,003 0	0400
37	Single knit, 65 % polyester, 35 % cotton	1,727	0,046	0,295	0,005 9	0,468
51A	A tweed plain weave, 50 % woof, 50 % polyester	1,727	0,049	0,314	0,005 5	0,535
51B	Lining, plain weave, 100 % polyester	0,102	0,008	0,052	0,001 8	0,267
61	Gabardine, twill weave, 65 % polyester, 35 % cotton	0,762	0,024	0,157	0,004 4	0,328
62A	Gabardine, twill weave, 65 % polyester, 35 % cotton	0,864	0,033	0,214	0,004 0	0,495
62B	Batting quilted to plain weave fabric 100 % nylon, 100 % polyester fibrefil	6,706	0,158	0,158	0,015 2	0,624
63	Herringbone, twill weave, 100 % polyester	0,229	0,012	0,076	0,005 5	0,131
64	Napped plain weave, 100 % wool	2,464	0,061	0,394	0,007 9	0464
65	Sateen, 100 % Firestop cotton	1,372	0,034	0,218	0,005 3	0,385
66	Sateen, 100 % SEF modacrylic	0,838	0,034	0,216	0,003 8	0537
67	Non-woven, spunbonded, 100 % Tyvek olefin	0,330	0,027	0,177	0,016 3	0,099
68	Plain weave, 100 % Nomex aramid	0,787	0,030	0,192	0,003 5	0,515
71	Coated plain weave, neoprene coated nylon	0,559	0,052	0,335	0,354 2	0,009
73	Coated plain weave, 100 % PVC vinyl coated on both sides of nylon	0,457	0,016	0,105	0,348 9	0,003
75	Coated filling knit, PVC coated polyester	0,559	0,024	0.156	0,357 5	0,004
78A	Plain weave, 100 % polyester laminated with Goretex	0,229	0,011	0,068	0,005 2	0,127

Table C.5 (*continued*)

Fabric code	Description	Thickness	Intrinsic fabric insulation R_f		Water vapour resistance or fabric $R_{e,f}$	Water vapour permeability index of fabric $i_{m,cl}$
		mm	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot kPa \cdot W^{-1}$	
78B	Taffeta, plain weave, 100 % nylon	0,152	0,017	0,108	0,004 7	0,217
78C	Open mesh, 100 % nylon	0,305	0,013	0,083	0,000 7	
81	Dress socks, rib knit, 75 % hi-bulk, Orlon acrylic, 25 % stretch nylon	3,353	0,086	0,556	0,008 3	0,622
82	Athletic socks, rib knit, 80 % cotton, 8 % acrylic, 7 % nylon, 5 % elastic	3,480	0,070	0,454	0,007 6	0,553
92	Street shoes, vinyl	2,700			0,079	0,050
93	Athletic shoes, woven fabric, vinyl, knit	3,500			0,052	0,100
94	Work shoe-boots, leather	3,200			0,047	0,100
96	Slippers, vinyl, foam, knit	3,500			0,103	0,050
97	Sandals, vinyl	4,300			0,126	0,050

Thickness was measured according to ASTM D1777 using a 3 in (7,6 cm) diameter presser foot and 0,01 psi (0,07 kPa) pressure. The thickness of sock fabrics were measured in the stretched state. Fabric insulation and water vapour resistance were measured using a guarded hot plate. The insulation provided by the air, 0,043 $m^2 \cdot K \cdot W^{-1}$ (0,277 clo), and the water vapour resistance provided by the air layer and liquid barrier, 0,0039 $m^2 \cdot kPa \cdot W^{-1}$, are not included in the values in the table. Data for the shoes are estimated from average thickness values and by estimating relative values for i_m.

Annex D
(informative)

Measurement of thermal insulation and water vapour resistance of clothing ensembles on a thermal manikin

D.1 Heat resistance

D.1.1 General

The most common tool used to measure the thermal insulation of a garment or an ensemble is the thermal manikin. This is a full-size manikin with standard measures and equipped with facilities for heating and simulation of the dry-heat loss from a human. The standing manikin is dressed in the ensemble or garment to be tested and placed in an environmental chamber. When the thermal insulation of a clothing ensemble is measured, it is necessary to record mean skin temperature, heat loss from the manikin and the operative temperature and, for the calculation of I_{cl}, to estimate the clothing area factor. It is also necessary to perform a measurement with the nude manikin, in order to estimate the surface insulation between the ensemble and the environment. When measuring the thermal insulation of a garment, however, it is not necessary to estimate the clothing area factor. The measurements are performed under the following conditions:

Air velocity	$< 0{,}15\ \text{m}\cdot\text{s}^{-1}$ (EN 342 [6] works with $0{,}4\ \text{m}\cdot\text{s}^{-1}$ for cold weather clothing; ISO 15831 [22] also $0{,}4\ \text{m}\cdot\text{s}^{-1}$)
Difference between air and mean radiant temperature	$< \lvert 1 \rvert$ °C
Relative humidity (steady state)	30 % to 70 %, preferably 50 %
Heat loss from thermal manikin	more than $20\ \text{W}\cdot\text{m}^{-2}$ for each segment (typically $40\ \text{W}\cdot\text{m}^{-2}$ to $80\ \text{W}\cdot\text{m}^{-2}$)
Mean skin temperature of thermal manikin	32 °C to 34 °C (uniform over body)
Room operative temperature	typically > 12 °C below mean skin temperature

Power to the heaters is electronically controlled to produce a uniform mean skin temperature near to that of a human being in a thermally neutral indoor environment.

Power, skin temperature and operative temperature measurements made under equilibrium conditions (equilibrium present for at least 20 min) are combined, as in the following formula, to determine the total thermal insulation, I_T ($\text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$), which is the thermal insulation for the ensemble including the surface resistance surrounding the ensemble (I_a):

$$I_T = \frac{\bar{t}_{sk} - t_o}{H} \tag{D.1}$$

where

$\bar{t}_{sk}$ is the mean skin surface temperature in degrees Celsius;

t_o is the operative temperature in degrees Celsius;

H is the dry heat loss per square metre of skin area in watts per square metre ($\text{W}\cdot\text{m}^{-2}$).

To determine the basic thermal insulation, I_{cl}, of the ensemble, it is necessary to subtract from the total resistance the contribution due to the surface resistance between the ensemble and the environment. The surface resistance, I_{a}, is obtained by operating the manikin nude and using Equation (D.1) to find I_{a} at various values of $(\bar{t}_{\text{sk}} - t_{\text{o}})$. When the manikin is clothed, the temperature at the outer surface of the clothing, $\bar{t}_{\text{cl}}$, is lower than $\bar{t}_{\text{sk}}$. Thus, since I_{a} can be a function of the temperature difference, the thermal resistance of the boundary layer over the clothing should be evaluated at the temperature difference $(\bar{t}_{\text{cl}} - t_{\text{o}})$, rather than $(\bar{t}_{\text{sk}} - t_{\text{o}})$.

Operate the manikin nude and obtain the relationship between the heat loss, H, and I_{a}. This depends on air velocity and flow pattern in the test chamber, and needs to be done only once for unchanged test conditions in the same environmental chamber.

Carry out one of the following procedures, as applicable.

a) If I_{a} is constant, i.e. independent of H and thus also independent of $(\bar{t}_{\text{cl}} - t_{\text{o}})$, then the thermal insulation, I_{cl} ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$), of the ensemble is calculated as follows:

$$I_{\text{cl}} = I_{\text{T}} - \frac{I_{\text{a}}}{f_{\text{cl}}} \quad \text{(D.2)}$$

b) if I_{a} varies with H and thus with $(\bar{t}_{\text{cl}} - t_{\text{o}})$, then I_{a} is estimated from the obtained relationship between the heat loss from the manikin and I_{a}. Nevertheless, the heat loss used to estimate I_{a} is the measured heat loss in the test with clothing [Equation (D.1)], divided by the clothing area factor, i.e. H/f_{cl}. The thermal insulation is estimated from Equation (D.2).

Use this method for measurement on ensembles. Before making the measurement, it is necessary to evaluate or measure the f_{cl} values directly, in accordance with Clause 5.

When the effective thermal insulation of a single garment is measured, use the same procedure but without taking f_{cl} into account:

$$I_{\text{clu}} = I_{\text{T}} - I_{\text{a}} \quad \text{(D.3)}$$

D.1.2 Calculation of insulation from manikin measurement

Manikins differ in the number of their segments and segment layout. Some variation exists in the way insulation is measured on the manikin. Originally, settings with equal skin temperature over the body were used, but in some cases it was deemed more realistic to set a constant heat loss, resulting in lower temperatures for uncovered parts (e.g. hands).

Three calculation methods are in use, based on different models.

a) The general formula for defining whole body resistance, best fitting the insulation definition of this International Standard is:

$$I_{\text{T}} = \frac{\overline{t_{\text{sk}}} - t_{\text{a}}}{H_{\text{sk}}} = \frac{\sum \alpha_i \cdot t_i - t_{\text{a}}}{\sum (\alpha_i \cdot H_i)} = \frac{\sum \alpha_i \cdot (t_i - t_{\text{a}})}{\sum (\alpha_i \cdot H_i)} \quad \text{(D.4)}$$

with $\alpha_i = \dfrac{\text{surface area of segment } i}{\text{total surface area of manikin}}$ and where

$\overline{t_{\text{sk}}}$ is the average skin temperature;

t_i is the temperature of segment i;

t_a is the air temperature;

H_i is the heat loss of segment i.

This calculation is according to the so-called *global model*.

b) For two specific conditions of temperature or heat loss distribution, Equation (D.4) can be simplified. If the assumption is made that skin temperature is uniform over the body, i.e. $t_i = t_{sk}$ = constant, then the equation becomes:

$$I_T = \frac{\bar{t}_{sk} - t_a}{\sum(\alpha_i \cdot H_i)} \tag{D.5}$$

or

$$\frac{1}{I_T} = \frac{\sum \alpha_i \cdot H_i}{\bar{t}_{sk} - t_a} = \sum \alpha_i \cdot \left(\frac{H_i}{\bar{t}_{sk} - t_a} \right) = \sum \alpha_i \cdot \frac{1}{I_{T,i}} \tag{D.6}$$

This is adding up resistance according to a *parallel model*, used in ASTM F1291, this International Standard and ISO 15831.

c) If the assumption is made that local heat flux is uniform over the body, i.e. $H_i = H_{sk}$ = constant, then Equation (D.4) becomes:

$$I_T = \frac{\sum \alpha_i.(t_i - t_a)}{\sum(\alpha_i.H_i)} = \frac{\sum \alpha_i.(t_i - t_a)}{H_{sk}} = \sum \alpha_i.\frac{t_i - t_a}{H_{sk}} = \sum \alpha_i.I_{T,i} \tag{D.7}$$

This equation is adding up resistances according to a *serial model*, used in EN 13537 and ISO 15831.

With uneven distribution of insulation (e.g. nude hands and head in cold weather clothing), the serial method will produce higher total insulation values than the parallel method and, if used in total body heat balance models, the serial-method-based insulation values will give unrealistic results in such cases.

If the user is in any doubt about which of the above three equations to choose, Equation (D.4) shall be used, as this is the general form [9], [46].

For a more detailed description of manikin measurements and the relevant calculations, see References [2], [6], [7] and [22].

A comparison of the four methods is given in Table D.1. An important difference between them is the reference air velocity used. In interpreting the data this should be taken into account. The data presented in this International Standard are almost exclusively obtained at air velocities below 0,2 m·s^{-1} – realistic for office environments.

Table D.1 — Comparison of clothing insulation standards (adapted and updated from Reference [34])

	ASTM F 1291-05	This International Standard	EN 13537	ISO 15831
Scope	Garments, clothing ensembles	Garments, clothing ensembles	Sleeping bags	Clothing ensembles
Manikin height	170 ± 10 cm	Full size	1,5–2,0 m	170 ± 15 cm
Manikin surface area	1,8 ± 0,3 m^2	Not stated	1,5–2,0 m^2	1,7 ± 0,3 m^2
Position of thermal manikin during test	Standing	Standing	Supine	Standing and walking 45 ± 2 double steps/min
Mean skin temperature	35 °C	32–34 °C	25–40 °C	34 °C
Temperature of body segments	All shall be 35 °C	All at same temperature	Not specified	All shall be 34 °C
Air temperature	⩾ 12 °C below mean skin	⩾ 12 °C below mean skin	⩾ 15 °C below mean skin	⩾ 12 °C below mean skin
Heat loss from manikin	⩾ 20 ± 10 $W{\cdot}m^{-2}$	⩾ 40 $W{\cdot}m^{-2}$	20–120 $W{\cdot}m^{-2}$	⩾ 20 $W{\cdot}m^{-2}$
Relative humidity	30–70 % preferably 50 %	30–70 % preferably 50 %	40–80 %	30–70 % preferably 50 %
Air velocity	0,4 $m{\cdot}s^{-1}$ or level appropriate for end use	< 0,2 $m{\cdot}s^{-1}$	< 0,5 $m{\cdot}s^{-1}$	0,4 $m{\cdot}s^{-1}$
Test period	30 min	Stability for > 20 min	Stability for > 15 min	Stability for ⩾ 20 min
Parameter measured (symbol and definition)	R_t in $m^2{\cdot}°C{\cdot}W^{-1}$ or I_T (in clo)	I_T (total thermal insulation)	I_T (total thermal insulation; symbol R_c in standard)	I_T (total thermal insulation) and $I_{T,r}$ (resultant total thermal insulation)
Method of calculation	Parallel	Parallel, global	Serial	Parallel or serial or mean of both
Determination of basic or intrinsic clothing insulation	Standard refers to ISO 9920: $I_{cl} = I_T - I_a/f_{cl}$	$I_{cl} = I_T - I_a/f_{cl}$ Garments: $I_{clu} = I_T - I_a$	N/A	$I_{cl} = I_t - I_a/f_{cl}$ $I_{cl,r} = I_{t,r} - I_{a,r}/f_{cl}$
Units	$m^2{\cdot}°C{\cdot}W^{-1}$ or clo	$m^2{\cdot}K{\cdot}W^{-1}$ or clo	$m^2{\cdot}K{\cdot}W^{-1}$	$m^2{\cdot}K{\cdot}W^{-1}$

D.2 Vapour resistance

D.2.1 General

Vapour resistance can be measured on a so-called "sweating manikin". This is a manikin with a similar technical specification to that described in D.1, but with an additional facility to create a wet skin from which moisture can evaporate. Several systems are in use, the simplest being a wicking, tight-fitting skin covering the manikin, which is wetted with distilled water before the manikin is dressed. This avoids excessive dripping, but the measurement needs to be concluded before this layer (partially) dries out. It has been demonstrated that using this method a steady state in weight loss can be reached for up to 45 min for clothing of normal permeability [19]. For less permeable clothing, the steady state in mass loss lasts for more than 1 h. Both are sufficient for reaching a stable measurement if the manikin is warmed up before wetting and has sufficient power to reach a steady state quickly after wetting. More complex systems combine the wicking skin with a water supply system, or even with “sweat glands” that supply water built into the skin. The latter would allow differential sweat rates for different body areas. In all models, a wicking layer on the surface will spread the liquid. Some manikins cover this wet layer with a semi-permeable membrane to avoid moisture wicking into the clothing.

Problems with sweating manikins relate to the regulation of sweating, with the need to keep the skin fully wet but not unrealistically dripping. So far, most sweating manikins have been able to provide comparable results in terms of ranking garments, but limited in absolute data.

NOTE A full description of sweating manikin measurements is given in ASTM F2370-05. No ISO equivalent is as yet available.

D.2.2 Calculation of evaporative resistance from the manikin

The evaporative resistance can be calculated either from the increase in heat loss of the manikin when the skin is wet compared to that when it is dry, or from the evaporation rate of the moisture from the manikin–clothing assembly. The first is determined from the manikin’s power consumption; the second from the weight loss rate.

It should be noted that both methods do not necessarily produce the same results, as not all moisture evaporating from the skin may leave the clothing ensemble, but could well cool the manikin (evaporation–condensation cycle [19], [30]).

Apart from these two methods, two environmental conditions can also be used: isothermal and non-isothermal environments. In the isothermal method, the ambient temperature is equal to the skin temperature of the manikin, thus preventing any dry heat loss, as no temperature gradient is present. In non-isothermal conditions, the climate relevant to the application shall be used. In isothermal conditions, the real evaporative resistance is determined; while in non-isothermal conditions the “apparent vapour resistance” is determined, which includes changes to dry heat loss as well as any condensation effects and will be affected by the ambient temperature [10], [19].

a) Using manikin dry and wet heat losses

The parallel method of calculating the total evaporative resistance shall be used, where the area-weighted temperatures of all the sweating body segments are summed and averaged, the power levels to all body segments are summed, and the areas are summed before the total resistance is calculated.

Calculate the total evaporative resistance of the ensemble using:

$$R_{\mathrm{e,T}} = \frac{(P_{\mathrm{s}} - P_{\mathrm{a}})A}{H_{\mathrm{e}} - \dfrac{(T_{\mathrm{s}} - T_{\mathrm{a}})A}{I_{\mathrm{T}}}} \quad \text{(D.8)}$$

where

$R_{\mathrm{e,T}}$ is the total evaporative resistance of the clothing ensemble, including the surface air layer ($\mathrm{m^2 \cdot kPa \cdot W^{-1}}$),

P_{s} is the water vapour pressure at the manikin’s sweating surface (kPa);

P_{a} is the water vapour pressure in the air flowing over the clothing (kPa);

A is the area of the manikin’s surface that is sweating ($\mathrm{m^2}$);

H_{e} is the power required for sweating areas (W);

T_{s} is the temperature at the manikin surface (°C);

T_a is the temperature in the air flowing over the clothing (°C);

I_T is the total insulation of the clothing ensemble, including the surface air layer ($m^2 \cdot K \cdot W^{-1}$).

The value for I_T in Equation (D.8) shall be measured with a dry manikin as described in D.1.

b) Using evaporative mass loss

The parallel method of calculating the total evaporative resistance shall be used, where the area-weighted temperatures of all the sweating body segments are summed and averaged, the total evaporation is determined, and the areas are summed before the total resistance is calculated. Calculate the total evaporative resistance of the ensemble using:

$$R_{e,t} = \frac{(P_s - P_a)A}{\lambda \frac{dm}{dt}} \quad \text{(D.9)}$$

where

$R_{e,T}$ is the total evaporative resistance of the clothing ensemble and surface air layer ($kPa \cdot m^2 \cdot W^{-1}$);

P_s is the saturated water vapour pressure at the manikin's sweating surface (kPa);

P_a is the water vapour pressure in the air flowing over the clothing (kPa);

A is the area of the manikin's surface that is sweating (m^2);

λ is the heat of vaporization of water at the measured surface temperature ($J \cdot g^{-1}$);

dm/dt is the evaporation rate of moisture leaving the manikin's sweating surface ($g \cdot s^{-1}$), and shall not include any water that drips from the surface of the manikin or from the clothing or water absorbed by the clothing.

D.3 Conclusion

Both determinations of heat and vapour resistance shall be replicated three times, ideally with different specimens of the same garments, or, if these are not available, the manikin should be redressed from nude with the same garments three times. Replications should be within 10 % of the mean value of the three replications. If this is not the case, additional tests are required and the outlier should be replaced.

Interlaboratory tests have shown a good repeatability of measurements within the same institution, but substantial variability (especially for vapour resistance) between institutions. For this reason, manikins should be calibrated using the available reference clothing ensembles [2], [3], [22].

Annex E
(informative)

Measurement of thermal insulation and water vapour resistance of a clothing ensemble on human subjects

The thermal properties of a clothing ensemble can be studied on subjects by the use of a total heat balance for the body and indirect calorimetry.

The heat balance equation is written as:

$$S = M - W - R - C - E - E_{\text{res}} - C_{\text{res}} \tag{E.1}$$

where

S is the heat storage in the body;

M is the metabolism;

W is the external work;

R is the radiant heat loss;

C is the convective heat loss;

E is the evaporative heat loss from skin;

E_{res} is the evaporative heat loss from respiration;

C_{res} is the convective heat loss from respiration.

Heat exchange by respiration (E_{res} + C_{res}) is small and can be estimated using known formulas.

For more details on the heat balance equation and those formulas, see ISO 7933.

M, W, E and S can be estimated directly by physiological or physical measurements, and the heat exchange by radiation (R) and convection (C) is then estimated as

$$R + C = M - S - W - E - E_{\text{res}} - C_{\text{res}} \tag{E.2}$$

Knowing the mean skin temperature $\bar{t}_{\text{sk}}$ and the operative temperature t_{o}, the total resultant thermal insulation $I_{\text{T,r}}$ (m^2 ·K·W^{-1}) can be estimated as:

$$I_{\text{T,r}} = \frac{(\bar{t}_{\text{sk}} - t_{\text{o}})}{M - W - E - E_{\text{res}} - C_{\text{res}} - S} \tag{E.3}$$

The water vapour resistance, $R_{\text{e,T,r}}$, can also be estimated on subjects by means of the following equation:

$$R_{\text{e,T,r}} = \frac{P_{\text{sk}} - P_{\text{a}}}{E} \tag{E.4}$$

where

P_{sk} is the water vapour pressure over the skin surface;

P_a is the water vapour pressure in ambient air;

E is the evaporative heat loss from the skin.

Evaporative heat loss from the skin, E, can be obtained from measurements of body mass loss, corrected for respiratory water loss and metabolic weight change (see ISO 9886). The mass loss from the clothed body might not fully represent evaporative heat losses from the skin, as evaporative losses from the skin can lead to condensation in the clothing. This would transport heat away from the skin without it being visible as mass loss from the clothed person [19].

It is assumed that all evaporation takes place at the skin surface. Some sweat can be absorbed by the clothing and then evaporate. It is then necessary to measure the water vapour pressure between clothing and skin surface (P_{sk}) and in the ambient air (P_a). The water vapour pressure between skin and clothing can be difficult to measure and has to be measured as a mean for several positions.

Studies on human subjects are normally performed under realistic circumstances, with the effect of activity and air velocity taken into account. Insulation values, for example, can be compared directly to calculated, required insulation values on the IREQ scale (see ISO/TR 11079).

Annex F
(informative)

Different expressions for the thermal insulation of clothing

F.1 The total insulation, I_T ($m^2 \cdot K \cdot W^{-1}$), is the insulation from the skin surface to the environment, including the effect of the increased surface area, f_{cl}, and the resistance at the surface of the clothed body, I_a:

$$I_T = \frac{\bar{t}_{sk} - t_o}{H} \quad (F.1)$$

where

$\bar{t}_{sk}$ is the mean skin surface temperature in degrees Celsius;

t_o is the operative temperature in °C (usually equal to the air temperature, t_a);

H is the dry heat loss per square metre of skin area in watts per square metre ($W \cdot m^2$).

F.2 The intrinsic or basic clothing insulation, I_{cl} ($m^2 \cdot K \cdot W^{-1}$), is the insulation from the skin to the clothing surface:

$$I_{cl} = I_T - \frac{I_a}{f_{cl}} = \frac{\bar{t}_{sk} - t_o}{H} - \frac{I_a}{f_{cl}} \quad (F.2)$$

where f_{cl} is the clothing area factor.

F.3 For some applications, where the determination of f_{cl} is not practical, a different definition of clothing insulation is used: the effective clothing insulation, I_{cle}. This is the additional insulation the clothing provides compared to the nude situation:

$$I_{cle} = I_T - I_a \quad (F.3)$$

The effective clothing insulation is not a physical concept, as in that sense it does not exist. It neglects the effect of the greater surface area on the outside of the clothing, which reduces the effectivity of the outer surface air layer for insulation. However, for some applications, the empirical use of I_{cle} has been shown to simplify the calculations. The following provides the relationship between basic, I_{cl}, and effective, I_{cle}, clothing insulation:

$$I_{cl} = I_{cle} + I_a \left(1 - \frac{1}{f_{cl}}\right) \quad (F.4)$$

This relationship is important when comparing data from different studies. Thermal insulation for clothing ensembles shall not be compared without specifying whether they refer to the total, effective or basic clothing insulation.

In this International Standard, the thermal insulation of a clothing ensemble is expressed as basic insulation, I_{cl}, expressed in $m^2 \cdot K \cdot W^{-1}$ or clo. The thermal insulation of a garment is expressed as effective insulation, which for a single garment has the symbol I_{clu} ($m^2 \cdot K \cdot W^{-1}$ or clo).

F.4 The effective thermal insulation ($m^2 \cdot K \cdot W^{-1}$ or clo) of a single garment, I_{clu}, can be measured on a manikin wearing only that garment, by measuring the nude I_a and the clothed I_T:

$$I_{clu} = I_T - I_a = \frac{\overline{t}_{sk} - t_0}{H} - I_a \qquad \text{(F.5)}$$

Once more, it needs to be emphasized that this is an empirical concept, used to simplify some of the equations for summation of single garments to whole ensembles [11], [37]:

$$I_{cl} = 0{,}161 + 0{,}835 \sum I_{clu} \quad \text{in clo} \qquad \text{(F.6)}$$

where I_{cl} is the thermal insulation of the ensemble.

Or, with slightly reduced accuracy [37]:

$$I_{cl} = \sum I_{clu} \quad \text{in } m^2 \cdot K \cdot W^{-1} \text{ or clo} \qquad \text{(F.7)}$$

NOTE In earlier literature, other formulas for estimating the thermal insulation of an ensemble based on the insulation of individual garments can be found. In Equations (F.2), (F.4), (F.6) and (F.7), the insulation of each garment is given as “effective” insulation, which is always higher than the “basic” insulation. This explains why the formulas from the earlier literature which use the basic insulation of individual garments are different:

$$I_{cl} = 0{,}82 \sum I_{cl} \quad \text{in } m^2 \cdot K \cdot W^{-1} \text{ or clo} \qquad \text{(F.8)}$$

F.5 Total, basic and effective clothing insulation are defined for standardized (static, standing body, wind still; speed $< 0{,}2\ m \cdot s^{-1}$) conditions. When air movement is present, or when the body moves, this will affect all thermal resistance discussed here (typically lowering it). When sitting, insulation typically increases, due to posture effects and insulating effects of chairs. In these cases, it is referred to as the resultant or dynamic insulation as defined in Clause 2.

Annex G
(informative)

Estimation of the heat exchanges for reflective clothing

G.1 General

The formulas in this annex are taken from ISO 7933.

In the case of specialized reflective clothing, the effective thermal insulation of the boundary air layer, and thus also the value for I_T, changes when radiant heat sources are present, i.e. when $\overline{t}_r - t_a$ increases. In these cases, the dry heat exchanges can be estimated using the following expressions:

$$\text{DRY} = C + R = f_{cl}\left[h_{c,dyn}\ (\overline{t}_{cl} - t_a) + h_r\ (\overline{t}_{cl} - t_r)\right] \quad \text{(G.1)}$$

describes the heat exchanges between the clothing and the environment; and

$$C + R = (\overline{t}_{sk} - \overline{t}_{cl}) / I_{cl,r} \quad \text{(G.2)}$$

describes the heat exchanges between the skin and the clothing surface.

The dynamic convective heat exchange, $h_{c,dyn}$, can be estimated as the greatest value of

$$2{,}38\left|t_{sk} - t_a\right|\ 0{,}25 \quad \text{(G.3)}$$

$$3{,}5 + 5{,}2\ v_{ar} \quad \text{(G.4)}$$

$$8{,}7\ v_{ar}^{0{,}6} \quad \text{(G.5)}$$

The radiative heat exchange, h_r, can be estimated using:

$$h_r = 5{,}67 \times 10^{-8} \times \varepsilon \times \frac{A_r}{A_{DU}} \times \frac{(\overline{t}_{cl} + 273)^4 - (\overline{t}_r + 273)^4}{\overline{t}_{cl} - \overline{t}_r} \quad \text{(G.6)}$$

where

ε is the emission or absorption coefficient of the clothing surface (see Table G.1);

$\overline{t}_{cl}$ is the mean skin temperature;

$\overline{t}_r$ is the mean radiant temperature.

The fraction of skin surface involved in heat exchange by radiation, A_r/A_{DU}, is equal to 0,67 for a crouching subject, 0,70 for a seated subject and 0,77 for a standing subject.

Where reflective clothing is worn, h_r should be corrected by a factor, $F_{cl,R}$, given by:

$$F_{cl,R} = (1 - A_p)\ 0{,}97 + A_p \times F_r \quad \text{(G.7)}$$

Values for F_r and A_p are given in Tables G.1 and G.2.

Both expressions for calculating $C + R$ should be solved iteratively in order to derive t_{cl}.

G.2 Reflection of thermal radiation

Table G.1 gives the absorption coefficients (F_r) for different special materials coated with aluminium to reflect thermal radiation. Colour can also have an effect on visible light radiation. The effect is minimal or absent for longer wavelength radiation. Fibres of the same colour, but of different materials, can also differ. This is related to the surface properties of the fibres (shiny versus matt).

Table G.1 — Absorption coefficients (F_r) for different special materials

Material	Treatment	F_r
Cotton	With aluminium paint	0,42
Viscose	With glossy aluminium foil	0,19
Aramid (Kevlar)	With glossy aluminium foil	0,14
Wool	With glossy aluminium foil	0,12
Cotton	With glossy aluminium foil	0,04
Viscose	Vacuum metallized with aluminium	0,06
Aramid	Vacuum metallized with aluminium	0,04
Wool	Vacuum metallized with aluminium	0,05
Cotton	Vacuum metallized with aluminium	0,05
Glass fibre	Vacuum metallized with aluminium	0,07

This reduction only occurs for that part of the body surface area covered by the reflective clothing. Table G.2 provides information for estimating the fraction (A_p) of the area of the body concerned.

Table G.2 — Ratio between area of part of body and total body surface

Area	A_p
Head and face	0,07
Thorax and abdomen	0,175
Back	0,175
Arms	0,14
Hands	0,05
Thighs	0,19
Lower Legs	0,13
Feet	0,07

Annex H
(informative)

Guidance on the determination of the covered body surface area

For the calculation of clothing insulation based on the body surface area covered with clothing, as given in Equation (14) [32].

$$I_{\text{cl}} = 0{,}919 + 0{,}255 \times 10^{-3} \times m - 0{,}008\,74 \times A_{\text{COV},0} - 0{,}005\,10 \times A_{\text{COV},1} \quad \text{clo} \qquad \text{(H.1)}$$

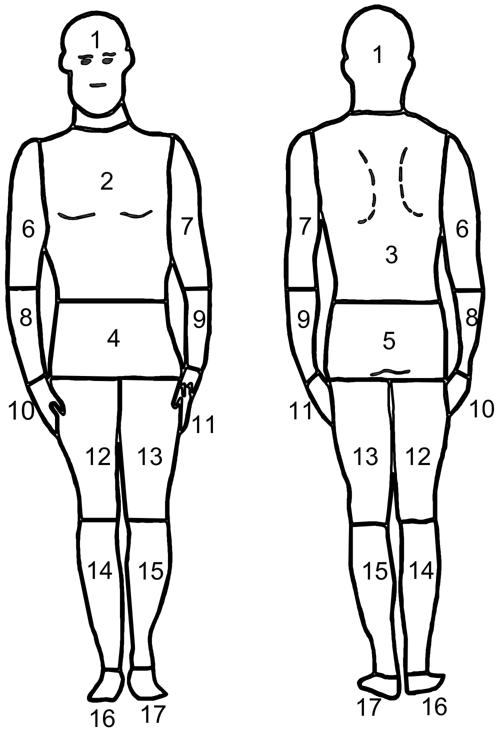
where

m is the mass of the clothing, without shoes, in grams;

$A_{\text{COV},1}$ is the body surface area covered by a single clothing layer, expressed as a percentage of the total body surface area;

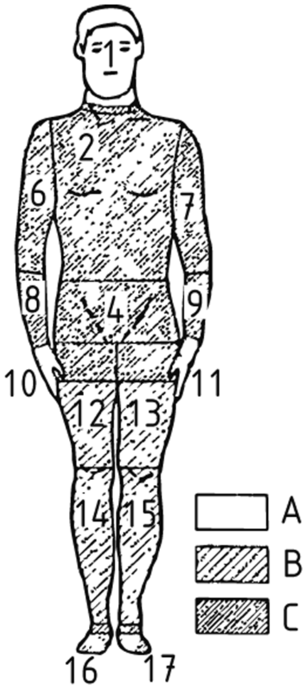
$A_{\text{COV},0}$ is the body surface area not covered by clothing, expressed as a percentage of the total body surface area.

Here, the template presented in Figure H.1 can be used. By drawing the clothing on this template, discriminating between no clothing, a single clothing layer and more than one clothing layer, the data required for the formula can be determined. Figure H.2 presents an example.



Segment		% total area
1	Head + neck	8,7
2	Chest	10,2
3	Back	9,2
4	Abdomen	6,1
5	Buttocks	6,6
6	Right upper arm	5,0
7	Left upper arm	5,0
8	Right lower arm	3,1
9	Left lower arm	3,1
10	Right hand	2,5
11	Left hand	2,5
12	Right thigh	9,2
13	Left thigh	9,2
14	Right calf	6,1
15	Left calf	6,1
16	Right foot	3,7
17	Left foot	3,7
Total		100

Figure H.1 — Template for estimation of body surface area covered by one or more layers of clothing and nude areas [32]



No.	Segment	% total area	% segment		% total body surface area	
			Nude (A)	1 layer (B)	Nude (A)	1 layer (B)
1	Head + neck	8,7	90		7,6	
2	Chest	10,2				
3	Back	9,2				
4	Abdomen	6,1				
5	Buttocks	6,6				
6	Right upper arm	5,0				
7	Left upper arm	5,0				
8	Right lower arm	3,1				
9	Left lower arm	3,1				
10	Right hand	2,5	100		2,5	
11	Left hand	2,5	100		2,5	
12	Right thigh	9,2		70		6,5
13	Left thigh	9,2		70		6,5
14	Right calf	6,1		90		5,5
15	Left calf	6,1		90		5,5
16	Right foot	3,7				
17	Left foot	3,7				
Total		100			12,6	24,0

A no clothing

B single clothing layer

C more than one clothing layer

$$I_{cl} = 0,919 + 0,255 \times 10^{-3} \times m - 0,008\,74 \times A_{COV,0}(\%) - 0,005\,10 \times A_{COV,1}(\%)$$

$$= 0,919 + 0,255 \times 10^{-3} \times 1700 - 0,008\,74 \times 12,6 - 0,005\,10 \times 24,0 = 1,12 \text{ clo}$$

Figure H.2 — Example of use of template for a clothing ensemble — Mass (m) = 1 700 grams [8]

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