

Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble (ISO 9920:2007, Corrected version 2008-11-01)

ICS 13.180; 61.020

National foreword

This British Standard is the UK implementation of EN ISO 9920:2009. It is identical to ISO 9920:2007, corrected version 2008-11-01. It supersedes BS EN ISO 9920:2007 which is withdrawn.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Ergonomie der thermischen Umgebung - Abschätzung der
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Foreword

The text of ISO 9920:2007, corrected version 2008-11-01 has been prepared by Technical Committee ISO/TC 159 "Ergonomics" of the International Organization for Standardization (ISO) and has been taken over as EN ISO 9920:2009 by Technical Committee CEN/TC 122 "Ergonomics" the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by December 2009, and conflicting national standards shall be withdrawn at the latest by December 2009.

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Endorsement notice

The text of ISO 9920:2007, corrected version 2008-11-01 has been approved by CEN as a EN ISO 9920:2009 without any modification.

Contents

Page

Foreword.....	v
Introduction	vi
1 Scope	1
2 Terms and definitions.....	1
3 Application of this International Standard	5
4 Estimation of thermal insulation of clothing ensemble based on tables and with values measured on a standing thermal manikin.....	7
4.1 General.....	7
4.2 Insulation values of complete ensembles.....	8
4.3 Ensemble thermal insulation values based on individual garments	8
4.4 Complete ensemble insulation corrected for small differences in composition	8
4.5 Calculation of thermal insulation for clothing ensembles	9
4.6 Calculation of thermal insulation for individual garments	9
5 Estimation of clothing area factor.....	10
6 Estimation of surface (or boundary) air layer insulation.....	10
7 Estimation of water vapour resistance.....	12
7.1 General.....	12
7.2 Estimation of vapour resistance of clothing ensembles based on tables with values measured on standing thermal manikin.....	12
7.3 Estimation of vapour resistance of clothing ensemble based on its relation with dry heat resistance	12
8 Influence of body movement and air movement on the thermal insulation and vapour resistance of a clothing ensemble	13
8.1 General.....	13
8.2 Correction of clothing insulation	13
8.3 Correction of clothing vapour resistance	18
8.4 Activities other than walking	20
8.5 Relative air velocity	20
9 Other factors influencing clothing insulation.....	22
9.1 General.....	22
9.2 Posture.....	22
9.3 Effect of seats	22
9.4 Effect of pressure	22
9.5 Wetting.....	22
9.6 Washing	22
Annex A (normative) Thermal insulation values for clothing ensembles	23
Annex B (normative) Thermal insulation values for individual garments.....	46
Annex C (normative) Vapour permeability index values for clothing ensembles	73
Annex D (informative) Measurement of thermal insulation and water vapour resistance of clothing ensembles on a thermal manikin	88
Annex E (informative) Measurement of thermal insulation and water vapour resistance of a clothing ensemble on human subjects	94
Annex F (informative) Different expressions for the thermal insulation of clothing.....	96
Annex G (informative) Estimation of the heat exchanges for reflective clothing.....	98

Annex H (informative) Guidance on the determination of the covered body surface area..... 100

Bibliography 102

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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

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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.

This corrected version of ISO 9920:2007 incorporates the following corrections.

- A value and a symbol missing from Equation (38) have been reinstated.
- In Equation (15), the multiplication symbol has been substituted for an (incorrect) asterisk.
- In Figure A.1, traditional Korean garments erroneously captioned “China” and “Sokchina” have been corrected to read *Chima* and *Sokchima*.
- In Equation (F.8), the subscript of the second representation of “ I_{cl} ” has been changed to I_{cli} .
- In the description of symbol H given with Equation (F.1), the minus sign missing from the superscript attached to the unit $W \cdot m^{-2}$ has been inserted.
- “Mean skin temperature”, given as the description for $\bar{t}_{cl}$ with Equation (G.6), has been corrected to “mean outer clothing surface temperature”.
- In a number of instances, “weight” has been changed to the accepted ISO term, *mass*.
- Values in Table A.2, No. 134 for I_{cl} and I_T have been corrected.
- Introductory text similar to that present in the first edition has been reinstated in Annex A, and a new introductory text has been added to Annex C.
- Some minor editorial corrections and additions have been made.

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 ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$)

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 ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$)], 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:

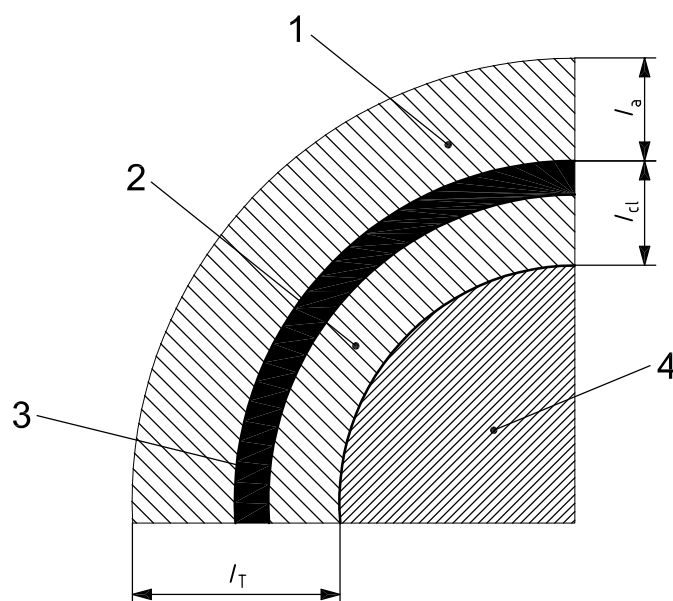
$$I_a = \frac{1}{h_c + h_r} \quad (5)$$

where

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

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

NOTE 3 Such values are defined for standardized conditions (static body, wind still, i.e. speed $< 0,2 \text{ m} \cdot \text{s}^{-1}$). 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:

$$f_{cl} = \frac{A_{cl}}{A_{Du}} \quad (6)$$

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):

$$I_T = I_{cl} + \frac{I_a}{f_{cl}} \quad (7)$$

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:

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

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:

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

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:

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

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 $< 0,2 \text{ m} \cdot \text{s}^{-1}$). 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 $< 0,2 \text{ m} \cdot \text{s}^{-1}$). 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.

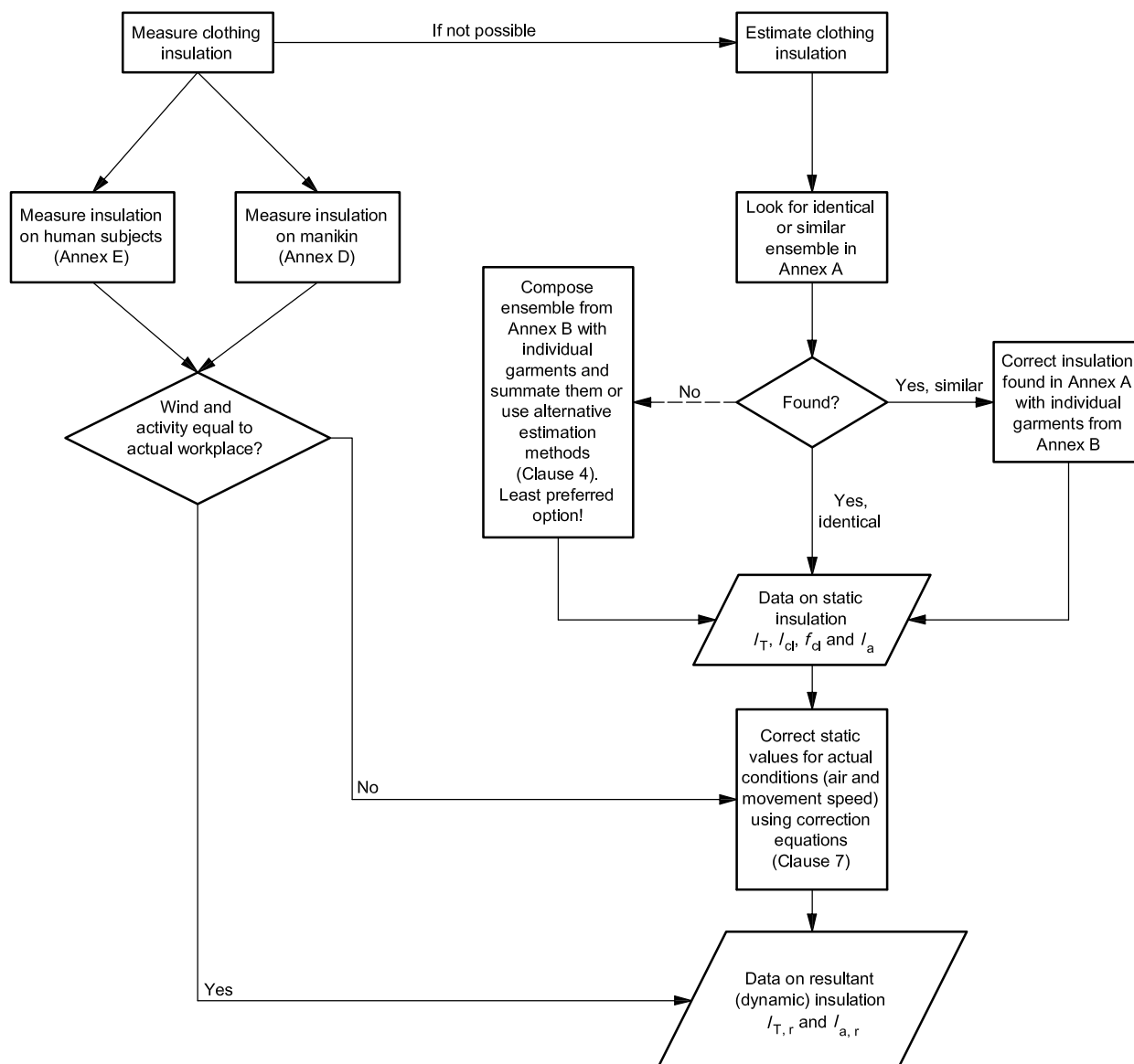


Figure 2 — Determining clothing insulation

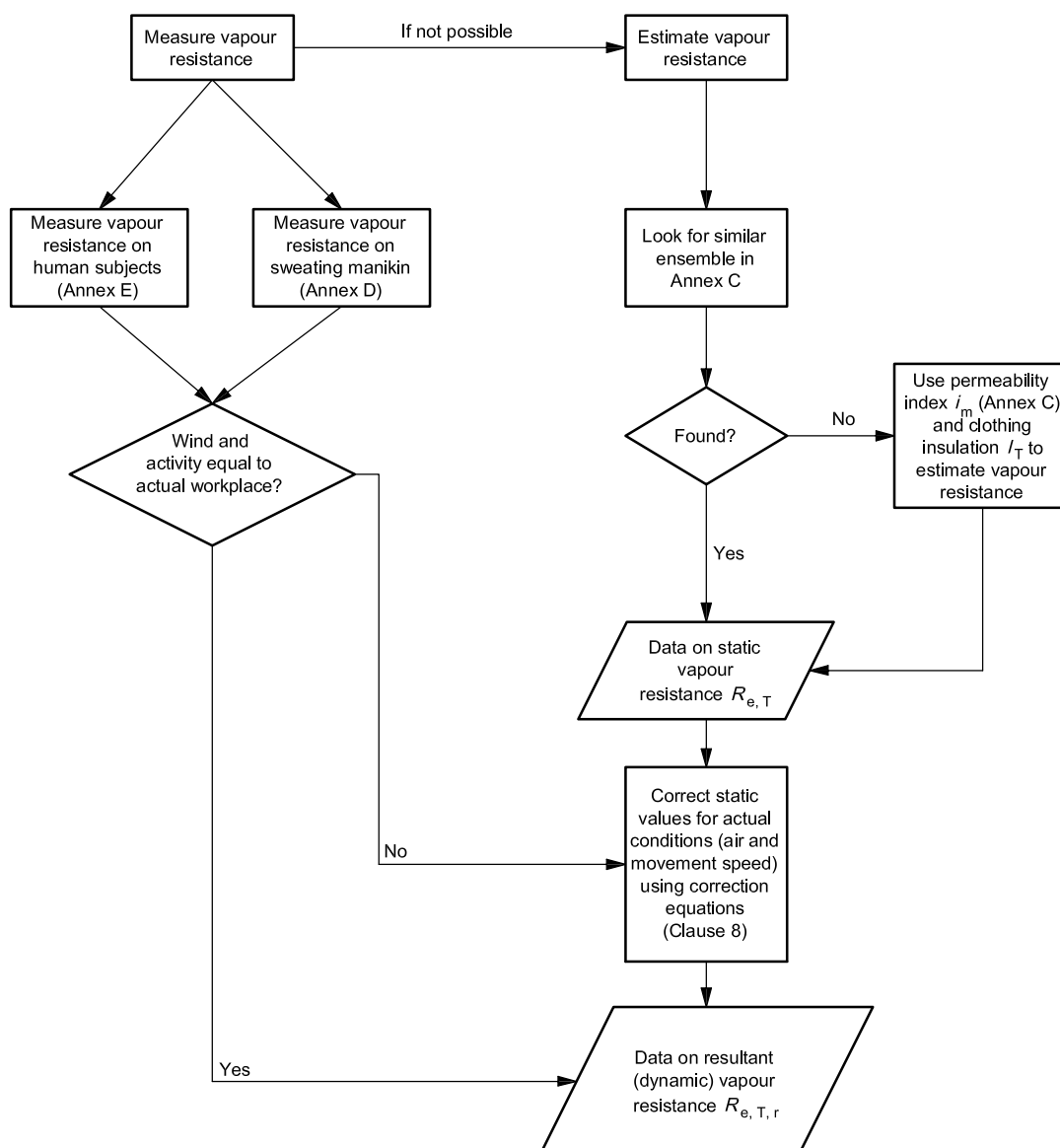


Figure 3 — Determining clothing vapour resistance

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 ($< 0,2 \text{ m} \cdot \text{s}^{-1}$). 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]:

$$I_{cl} = 0,161 + 0,835 \sum I_{clu} \quad (11)$$

expressed in clo.

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

$$I_{cl} = \sum I_{clu} \quad (12)$$

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:

$$I_{cl,a} = I_{cl,A} + 0,835 \times \Delta I_{clu} \quad (13)$$

with the result expressed in clo or in $\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$, and where $I_{cl,a}$ is the basic insulation of the actual ensemble, $I_{cl,A}$ is the basic insulation of the ensemble according to Annex A, and ΔI_{clu} 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_{clu} 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]:

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

where

I_{cl} is the intrinsic clothing insulation, in clo;

m is the clothing mass (without shoes), in kilograms;

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

$A_{COV,1}$ 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 mass 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_{clu} ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$), may also be estimated by

$$I_{clu} = 0,00095 \times A_{COV} \quad (15)$$

or, if expressed in clo, using

$$I_{clu} = 0,0061 \times A_{COV} \quad (16)$$

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 mass 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} ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$) may be made using

$$I_{\text{clu}} = 0,00067 A_{\text{COV}} + 0,217 \times d_{\text{fab}} \times A_{\text{COV}} \quad (17)$$

or, if expressed in clo, using

$$I_{\text{clu}} = 0,0043 A_{\text{COV}} + 1,4 \times d_{\text{fab}} \times A_{\text{COV}} \quad (18)$$

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 · 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 ($\text{m}^2 \cdot \text{K} \cdot \text{W}^{-1}$):

$$f_{\text{cl}} = 1,00 + 1,81 \times I_{\text{cl}} \quad (19)$$

— If I_{cl} is expressed in clo:

$$f_{\text{cl}} = 1,00 + 0,28 \times I_{\text{cl}} \quad (20)$$

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 ($0,109 \text{ m}^2 \cdot \text{K} \cdot \text{W}^{-1}$) when measured at air velocities around $0,1 \text{ m} \cdot \text{s}^{-1}$ to $0,15 \text{ m} \cdot \text{s}^{-1}$. 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 $0,4 \text{ m} \cdot \text{s}^{-1}$; 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 ($v_{ar} = 0,15 \text{ m} \cdot \text{s}^{-1}$) 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 = $0,15 \text{ m} \cdot \text{s}^{-1}$; maximum = $3,5 \text{ m} \cdot \text{s}^{-1}$);

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

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

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 ($\text{W} \cdot \text{m}^{-2} \cdot ^\circ\text{C}^{-1}$);

h_r is the radiative heat transfer coefficient, in watt per metre squared per degree Celsius ($\text{W} \cdot \text{m}^{-2} \cdot ^\circ\text{C}^{-1}$).

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 ($L = 16,5 \text{ K} \cdot \text{kPa}^{-1}$):

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

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:

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

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

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

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

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:

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

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 ($0,6 \text{ clo} < I_{cl} < 1,4 \text{ clo}$ or $1,2 \text{ clo} < I_T < 2,0 \text{ clo}$):

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

— For a nude person ($I_{cl} = 0 \text{ clo}$):

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

where

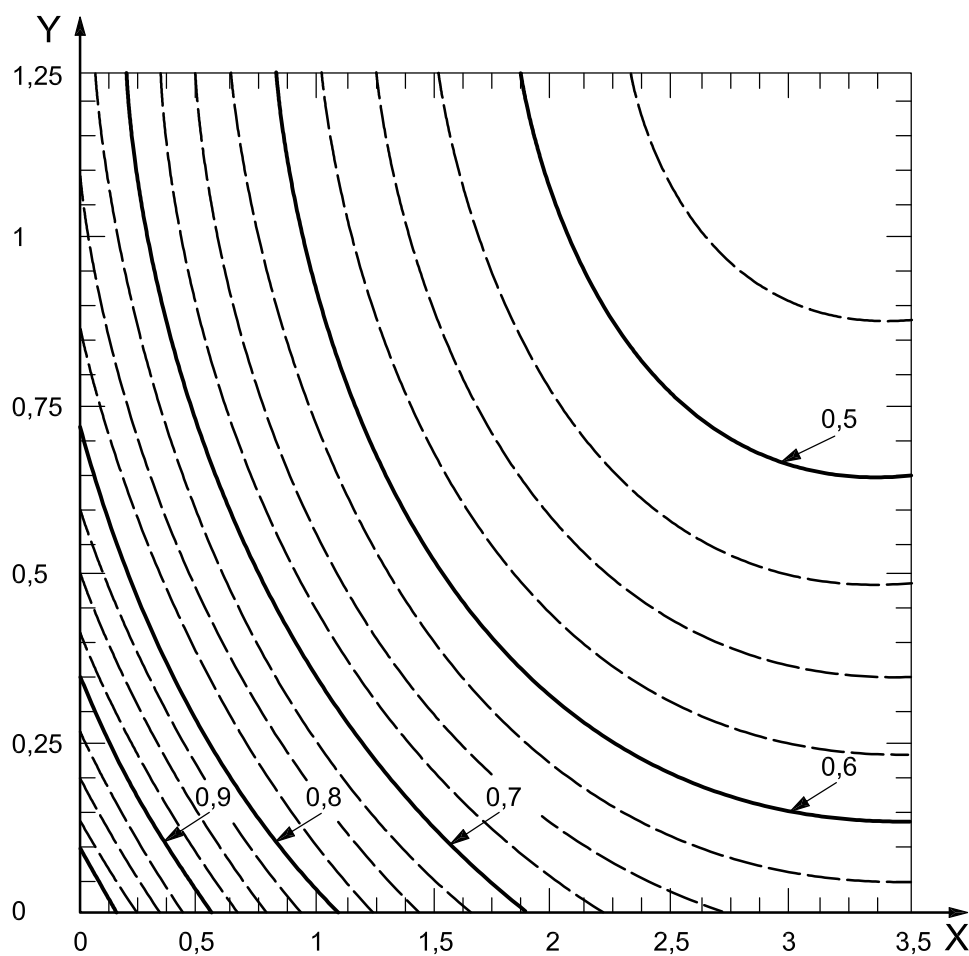
$\text{corr } I_T$ is the correction factor for total insulation;

$\text{corr } I_a$ is the correction factor for air insulation;

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

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

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



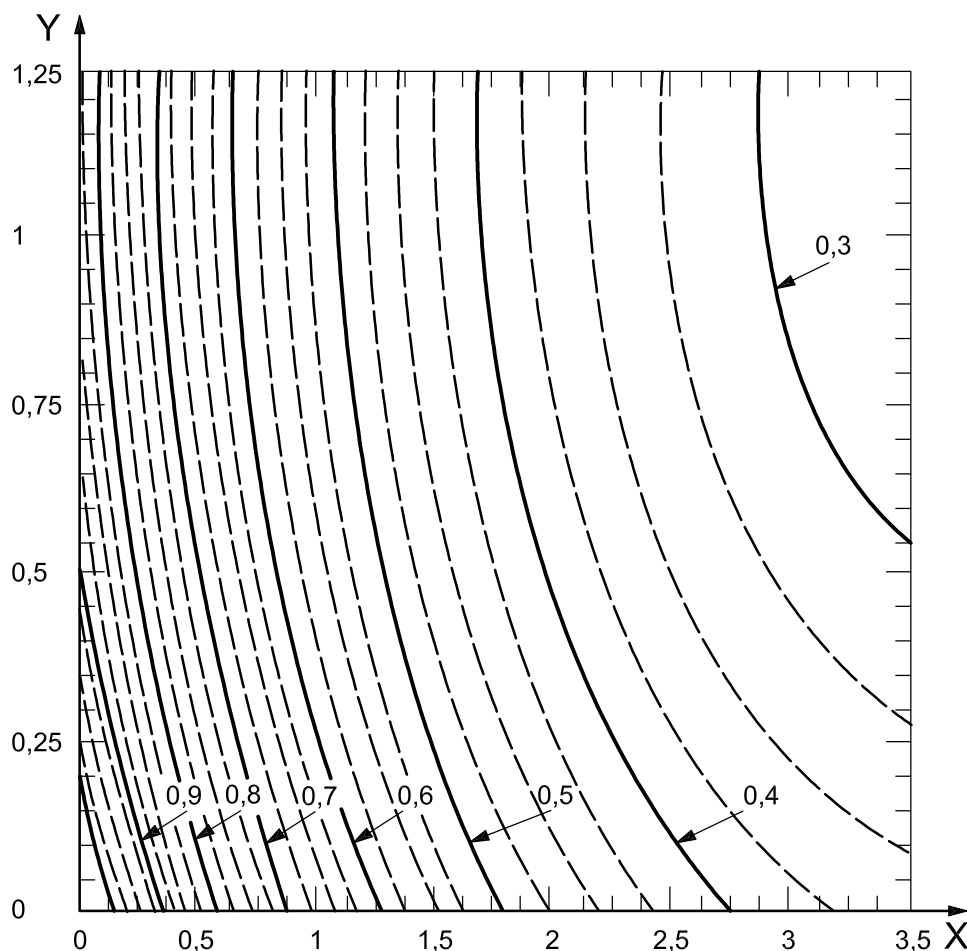
Valid up to $1,2 \text{ m}\cdot\text{s}^{-1}$ walking speed (v_w) and $3,5 \text{ m}\cdot\text{s}^{-1}$ relative wind speed (v_{ar}) (from References [17] and [18])

Key

X relative wind speed, $\text{m}\cdot\text{s}^{-1}$

Y walking speed, $\text{m}\cdot\text{s}^{-1}$

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



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

Key

X relative wind speed, $\text{m}\cdot\text{s}^{-1}$
Y walking speed, $\text{m}\cdot\text{s}^{-1}$

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]:

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

For specialized, insulating, cold weather clothing ($I_T > 2 \text{ clo}$), 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]:

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

$r^2 = 0,968$ and $\text{SEE} = 0,048$

where

- v_{ar} is the air velocity relative to the person, in metres per second, from $0,4 \text{ m}\cdot\text{s}^{-1}$ to $18 \text{ m}\cdot\text{s}^{-1}$;
- v_w is the walking speed, in metres per second, from $0 \text{ m}\cdot\text{s}^{-1}$ to $1,2 \text{ m}\cdot\text{s}^{-1}$;
- p is the air permeability of outer fabric, in litres per square metre per second, from $1 \text{ l}\cdot\text{m}^{-2} \cdot \text{s}^{-1}$ to $1\,000 \text{ l}\cdot\text{m}^{-2} \cdot \text{s}^{-1}$ [low (e.g. coating or laminate) = 1; medium = 50; high (open weave) = $1\,000 \text{ l}\cdot\text{m}^{-2} \cdot \text{s}^{-1}$].

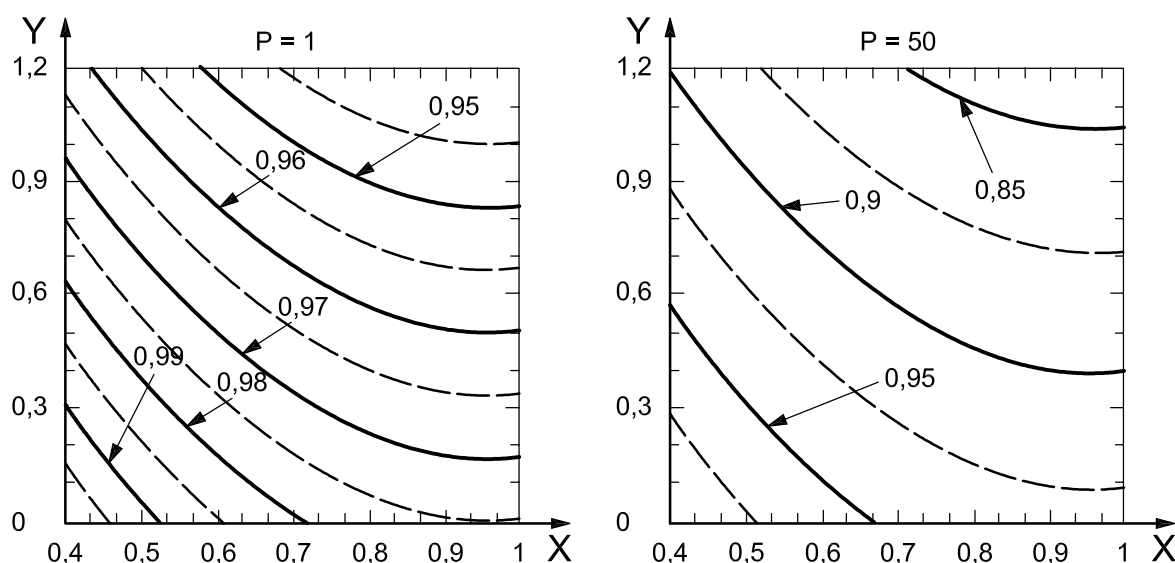
SEE is the standard error of the estimate.

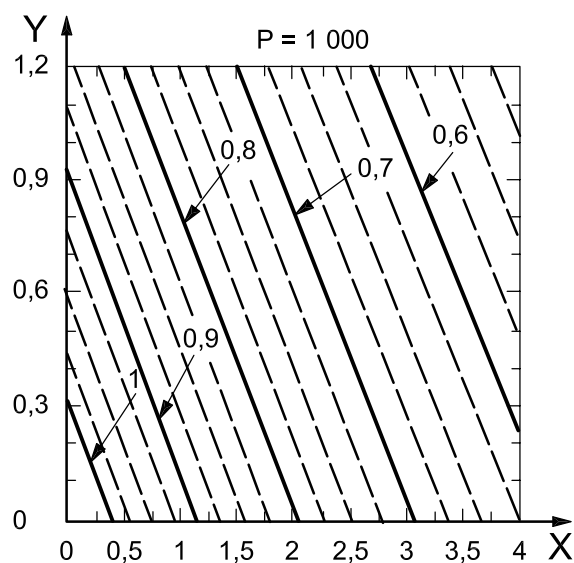
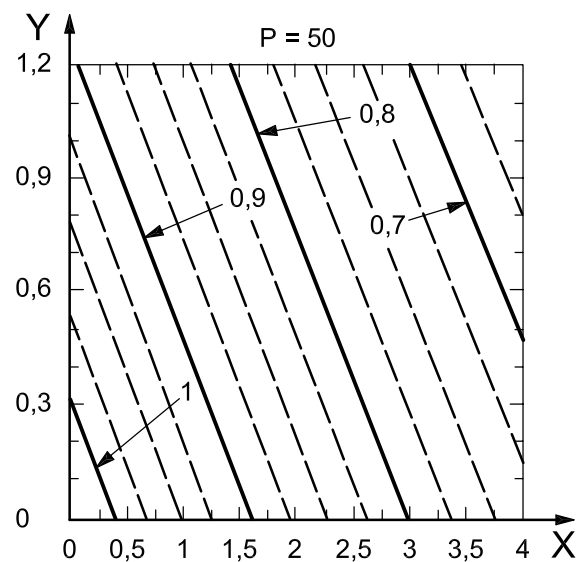
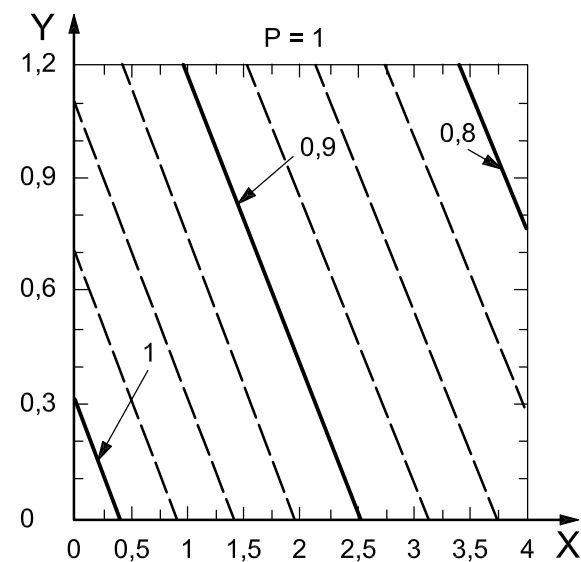
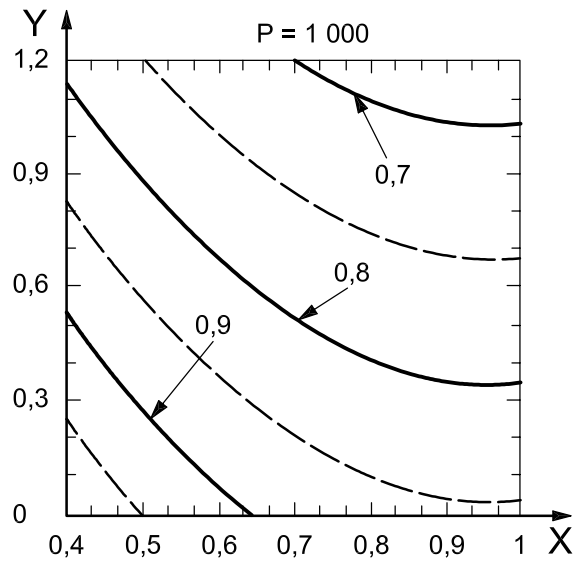
For the lower area of the wind range, better results were obtained in a separate analysis [17], [42]:

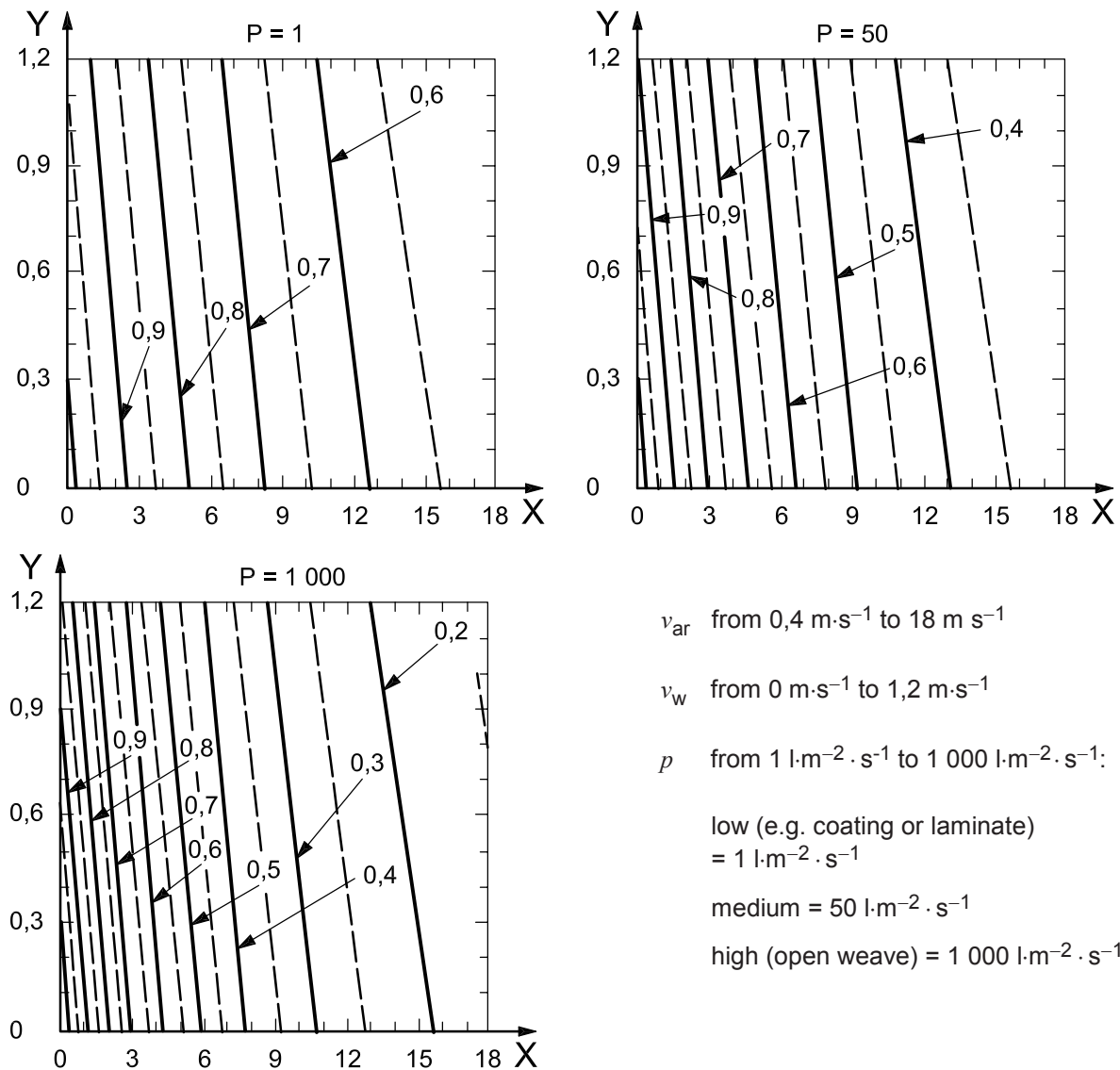
$$I_{T,r} = e^{\left\{ \left[-0,0881 \times (v_{ar} - 0,4) + 0,0779 \times (v_{ar} - 0,4)^2 - 0,0317 \times (w) \right] \times p^{0,2648} \right\}} \cdot I_T \quad (36)$$

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

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 $0,4 \text{ m}\cdot\text{s}^{-1}$ [6], [17], [42].







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

Key

X relative wind speed, $\text{m}\cdot\text{s}^{-1}$
 Y walking speed, $\text{m}\cdot\text{s}^{-1}$

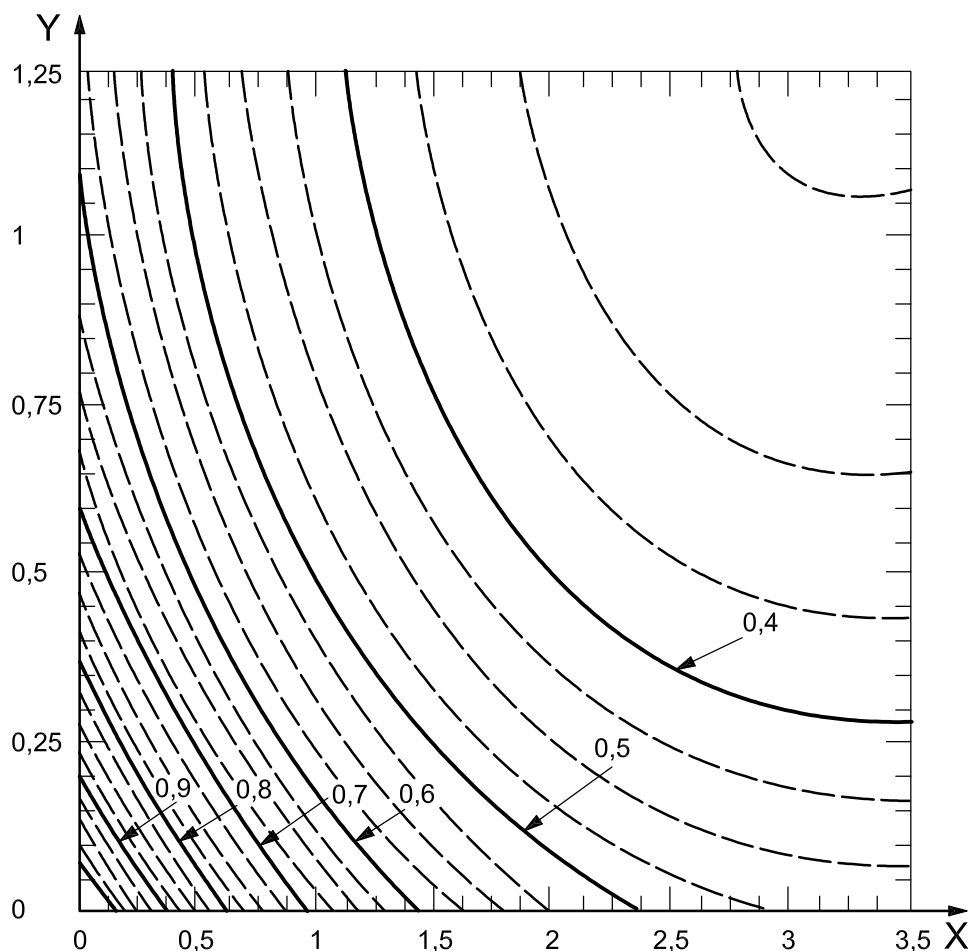
Figure 6 — Correction factor for effects of wind and movement for cold weather clothing ($I_{\text{T}} > 2 \text{ clo}$)

8.3 Correction of clothing vapour resistance

The reduction of $R_{\text{e},\text{T}}$ 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, $R_{\text{e},\text{T},\text{r}}$, can be calculated as [12], [13]:

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

where $\text{corr } I_{\text{T}}$ is the correction factor for clothing insulation [as, for example, in Equation (32)]. This relation is illustrated in Figure 7.



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

v_{ar} from $0,15 \text{ m}\cdot\text{s}^{-1}$ to $3,5 \text{ m}\cdot\text{s}^{-1}$

v_w from $0 \text{ m}\cdot\text{s}^{-1}$ to $1,2 \text{ m}\cdot\text{s}^{-1}$

Key

X relative wind speed, $\text{m}\cdot\text{s}^{-1}$

Y walking speed, $\text{m}\cdot\text{s}^{-1}$

**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]:

$$R_{e,T,r} = e^{\left[-0,468 \times (v_{ar} - 0,15) + 0,080 \times (v_{ar} - 0,15)^2 - 0,874 v_w + 0,358 v_w^2 \right]} \cdot R_{e,T} \quad (38)$$

where

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

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

NOTE Equations (37) and (38) were derived independently 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:

$$v_w = 0,0052 \cdot (M - 58) \quad (39)$$

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

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]:

$$v_{\text{ar}} = \sqrt{[v_w - v_a \cdot \cos(\alpha)]^2 + [v_a \cdot \sin(\alpha)]^2} \quad (40)$$

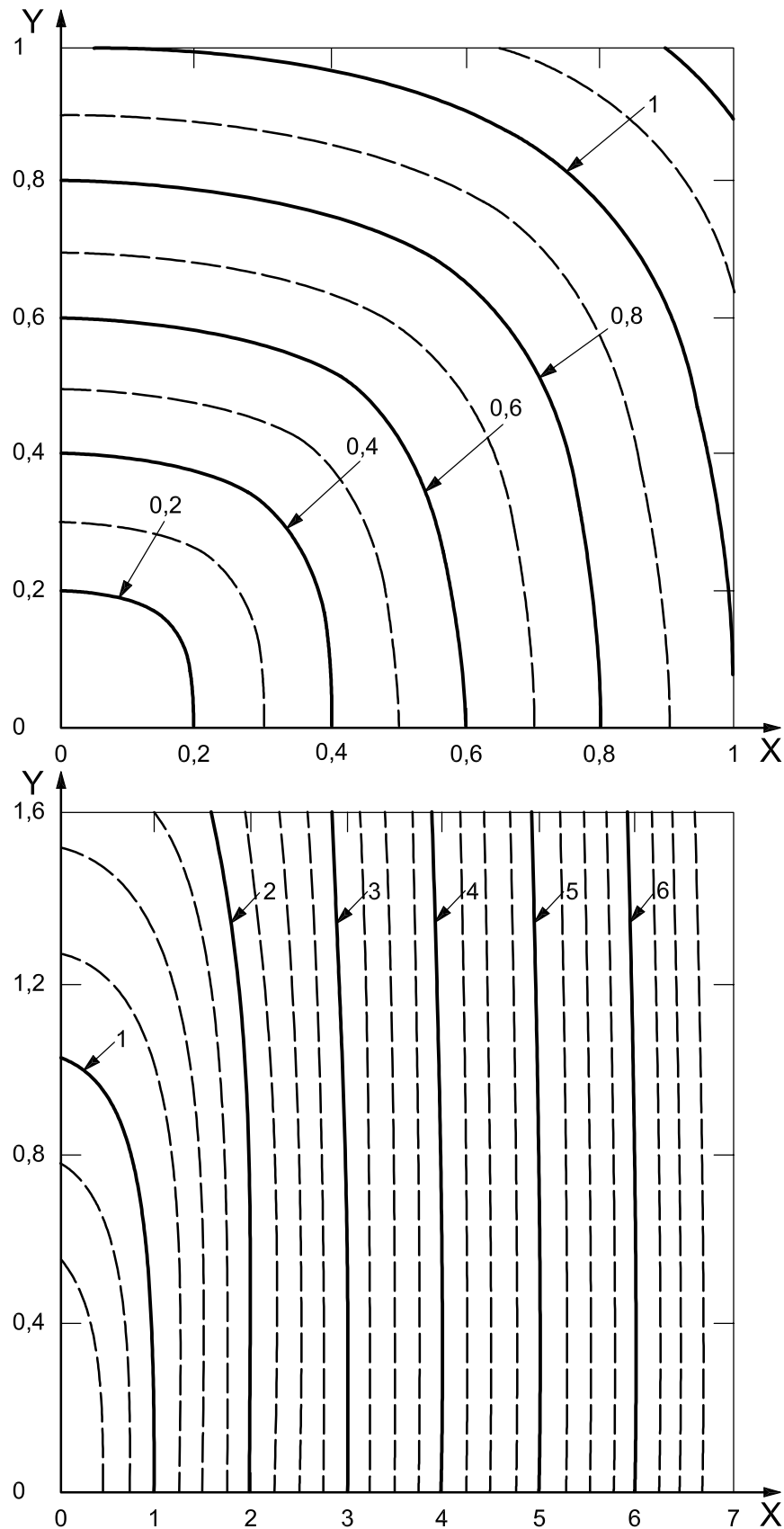
where

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, $\text{m}\cdot\text{s}^{-1}$
Y walking speed, $\text{m}\cdot\text{s}^{-1}$

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

The values are from measurements on a standing thermal manikin, with air movement below $0,2 \text{ m}\cdot\text{s}^{-1}$.

Table A.1 presents values for typical clothing ensembles. Tables A.2 to A.7 list detailed compound ensembles and combinations, while Tables A.8 to A.10 present information on special-application and regional ensembles. The numbers for the individual garments refer to the garments presented in Annex B. The mass does not include shoes. The number of the ensemble is given in the “No.” column of Tables A.2 to A.7. The number of the individual garment making up the ensemble is given immediately after its name. The name and number are those appearing in Annex B. The “Combination” column indicates which other ensemble forms the basis of the ensemble concerned, and also lists the clothing items that were added to obtain the ensemble concerned.

Washing can 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: operative temperature, mean skin temperature and mean heat loss from the manikin were recorded.

Table A.1 — Insulation values of typical clothing ensembles

Work clothing	I_{cl}		Daily wear clothing	I_{cl}	
	clo	m ² ·K·W ⁻¹		clo	m ² ·K·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, lightweight 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 g	f_{cl}	clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T clo	I_T $m^2 \cdot K \cdot W^{-1}$
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, athletic 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}		I_T	
					clo	$m^2 \cdot K \cdot W^{-1}$	clo	$m^2 \cdot K \cdot W^{-1}$
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 g	f_{cl}	clo	I_{cl} $m^2 \cdot K \cdot W^{-1}$	I_T $m^2 \cdot K \cdot W^{-1}$
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