
**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

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.

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.

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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:

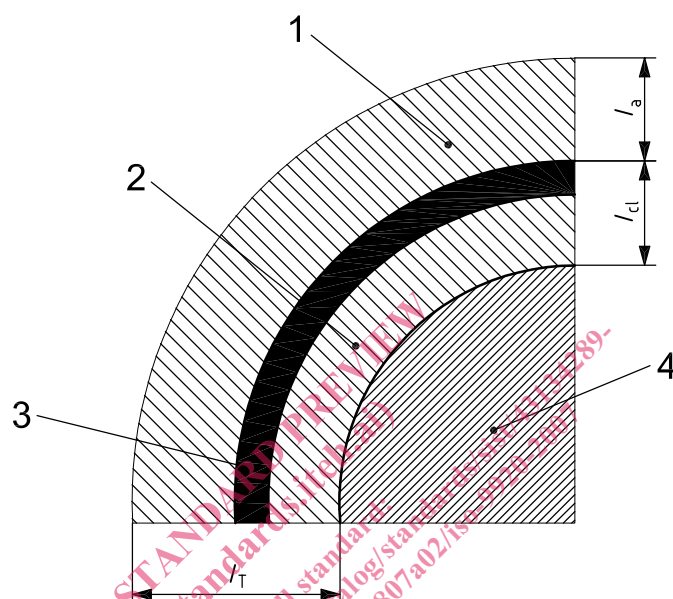
$$I_a = \frac{1}{h_c + h_r} \quad (5)$$

where

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

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

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

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:

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

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.

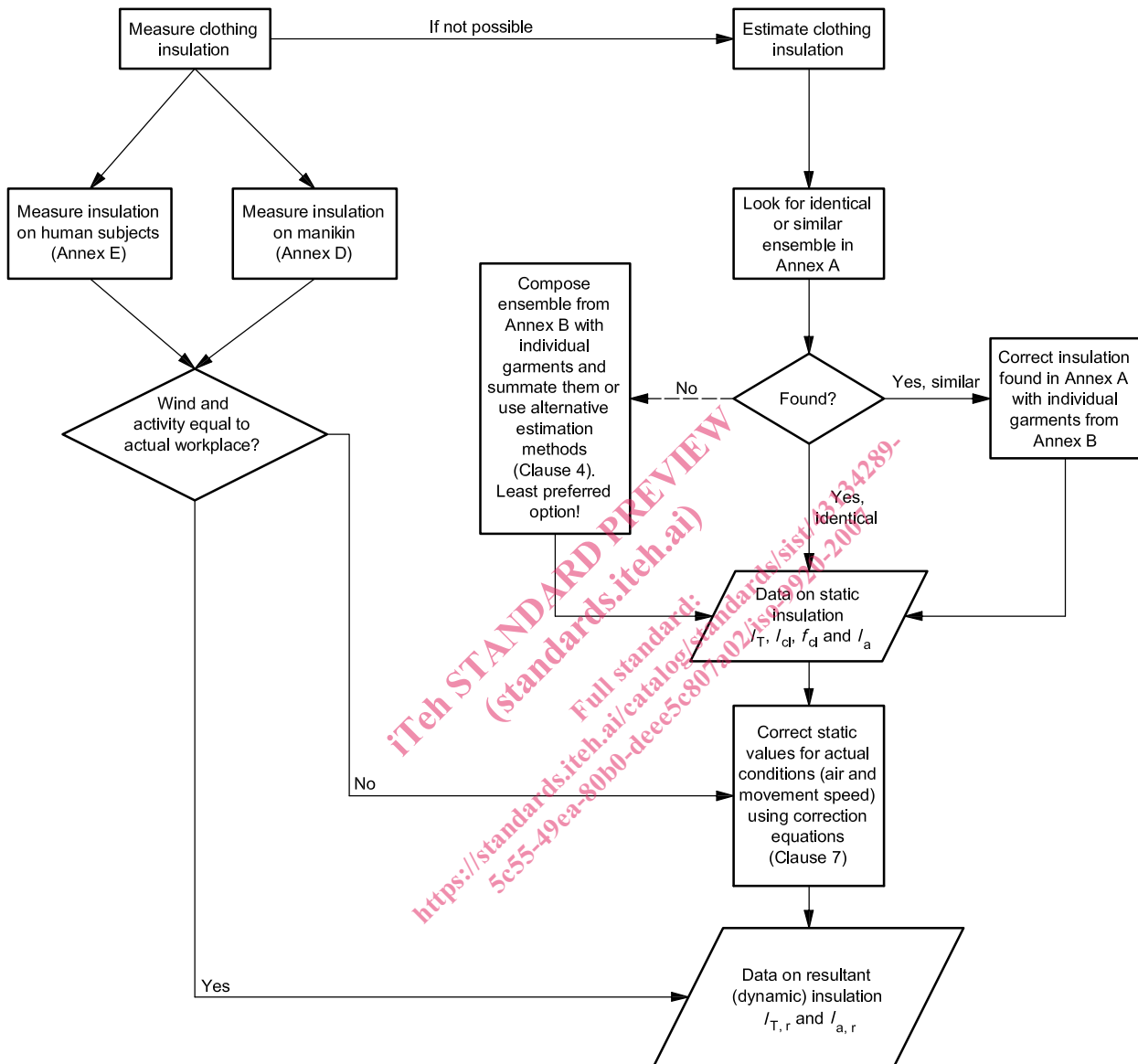


Figure 2 — Determining clothing insulation

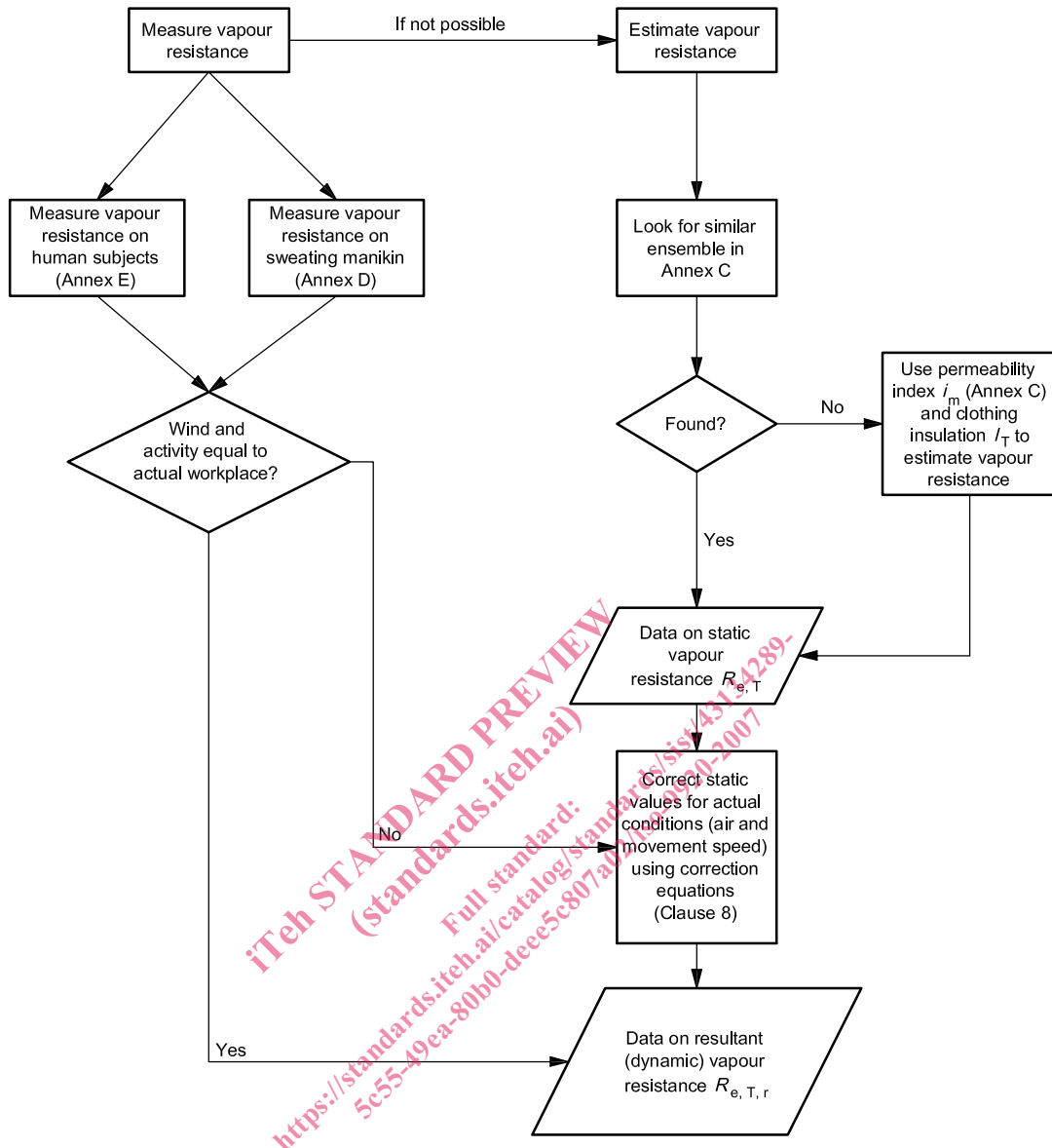


Figure 3 — Determining clothing vapour resistance

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.