SLOVENSKI STANDARD
SIST EN ISO 9920:2004

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Ergonomija toplotnega okolja – Ocena toplotne izolativnosti in izparilne odpornosti oblačil (ISO 9920:1995)

Ergonomics of the thermal environment - Estimation of the thermal insulation and evaporative resistance of a clothing ensemble (ISO 9920:1995)

Ergonomie des Umgebungsklimas - Abschätzung der Wärmeisolation und des Verdunstungswiderstandes einer Bekleidungskombination (ISO 9920:1995)

Ergonomie des ambiances thermiques - Détermination de l'isolement thermique et de la résistance a l'évaporation d'une tenue vestimentaire (ISO 9920:1995)

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Ergonomics of the thermal environment - Estimation of the thermal insulation and evaporative resistance of a clothing ensemble (ISO 9920:1995)

Ergonomie des ambiances thermiques - Détermination de l'isolement thermique et de la résistance à l'évaporation d'une tenue vestimentaire (ISO 9920:1995)

Ergonomie des Umgebungsklimas - Abschätzung der Wärmeisolation und des Verdunstungswiderstandes einer Bekleidungskombination (ISO 9920:1995)

This European Standard was approved by CEN on 7 August 2003.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

The text of ISO 9920:1995 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 9920:2003 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of an identical text or by endorsement, at the latest by February 2004, and conflicting national standards shall be withdrawn at the latest by February 2004.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

Endorsement notice

The text of ISO 9920:1995 has been approved by CEN as EN ISO 9920:2003 without any modifications.

INTERNATIONAL STANDARD

ISO 9920

First edition
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Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative 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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Contents

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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.

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.

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

Annexes A and B form an integral part of this International Standard. Annexes C, D, E and F are for information only.

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 evaporative 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, etc., are not dealt with.

This International Standard does not deal with the local thermal insulation on different body parts, nor the discomfort due to a nonuniform 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 man in the cold [IREQ (see ISO/TR 11079) insulation index], neutral [PMV-PPD (see ISO 7730) indices] and heat [required sweat rate (see ISO 7933) index], it is necessary to know the thermal characteristics of the clothing ensemble, i.e. the thermal insulation (I_{cl}) and the evaporative resistance (R_T).

Until now, very few data are available on the evaporative resistance of a clothing ensemble. This International Standard mainly deals with the estimation of the thermal resistance to dry heat loss.

Ergonomics of the thermal environment — Estimation of the thermal insulation and evaporative 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.

The influence of body movement and air penetration on the thermal insulation and evaporative resistance is discussed.

This International Standard

— does not deal with other effects of clothing, such as adsorption of water, buffering, tactile comfort;

— does not take into account the influence of rain and snow on the thermal characteristics;

— does not consider special protective clothing (water-cooled suits, ventilated suits, heated clothing);

— does not deal with the separate insulation on different parts of the body and discomfort due to the asymmetry of a clothing ensemble.

2 Principles and general definitions

In this International Standard, the thermal insulation (resistance to dry heat loss from the body) of a clothing ensemble is expressed as the basic clothing insulation, I_{cl}, expressed in square metre degrees Celsius per watt (m²·°C/W), which is the insulation from the skin to the clothing surface:

$$I_{cl} = \frac{\bar{t}_{sk} - \bar{t}_{cl}}{H} \qquad \ldots (1)$$

where

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

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

$\bar{t}_{cl}$ is the mean surface temperature of the clothed person, in degrees Celsius.

This definition of clothing insulation also includes the uncovered parts of the body like head and hands, i.e. the mean surface temperature of the clothed person is not only influenced by clothing surface temperature, but also by the skin temperature of the unclothed parts of the body.

Due to this special definition of the thermal insulation including also unclothed parts, it is convenient to use the clo unit for the thermal insulation of a clothing (1 clo = 0,155 m²·°C/W).

The equations in this International Standard are mainly given in SI units. For information, the same equations may also be given using the clo-unit for thermal insulation. Annexes C and D describe how the thermal insulation can be measured.

The dry heat loss from the body (convection, radiation, conduction) takes place from the skin surface through the clothing to the clothing surface. The resistance to this heat flow is expressed by the thermal insulation, I_{cl}.

Then the dry heat loss is transferred from the clothing/skin surface to the environment. The resistance to this heat flow is expressed by the surface resistance between clothing/skin and environment, I_a, expressed in square metre degrees Celsius per watt (m^2·°C/W).

$$I_a = 1/(h_c + h_r) \qquad \ldots (2)$$

where

h_c is the convective heat loss coefficient, in watts per square metre degree Celsius;

h_r is the radiant heat loss coefficient, in watts per square metre degree Celsius.

I_a is influenced by air velocity, clothing/skin surface temperature, air temperature and mean radiant temperature.

Clause 3 presents procedures for estimating the thermal insulation, I_{cl}, for a clothing ensemble based on existing values measured by a standing thermal manikin.

When measuring the thermal insulation value I_{cl} or when estimating the heat loss from the human body, it is necessary to know the clothing area factor, f_{cl}, defined as the ratio of the surface area of the clothed body, A_{cl} (including unclothed parts) to the surface of the nude body, A_{Du} (Du Bois area):

$$f_{cl} = A_{cl}/A_{Du} \quad (f_{cl} \geqslant 1) \qquad \ldots (3)$$

A photographic method for estimating f_{cl} is described in clause 4 together with a simplified equation for estimating it.

The posture and body movements of the wearer (pumping effect) and the penetration of air through the clothing due to increased air velocity will change the thermal insulation of a clothing ensemble. This influence of activity and air velocity is discussed in clause 5.

A thermal manikin is often used to measure the thermal insulation of clothing and in annex C, a test procedure is outlined. A more complex method, which is described in annex D, allows the thermal insulation of clothing to be measured directly on subjects.

In this International Standard, the thermal insulation of ensembles and garments (annexes A and B) is also given in the clo-unit. This is because this unit is more commonly used than the SI-unit (m^2·°C/W). The clo-unit is also special in that it defines thermal insulation of clothing referring to the whole body surface.

3 Estimation of the thermal insulation of a clothing ensemble based on tables with values measured on standing thermal manikin

3.1 General

In annex A, I_{cl} values are listed for a selection of clothing ensembles. All of the values were measured on a standing thermal manikin. A short description of the clothing ensembles is given and the f_{cl} values are also listed. The total clothing mass is based on garments which fit a standard person (European male size 52), and it does not include shoes.

Table A.2 is used for finding a clothing ensemble which is comparable with the actual clothing ensemble. Interpolation between the thermal insulation of two ensembles may be used. Annex A can also be used to predict which types of clothing can be used to obtain a given thermal insulation.

A number is listed for each of the individual garments making up most of the ensembles. This number refers to annex B, where a more detailed description of the individual garments is presented.

The insulation for the entire clothing, I_{cl} (in m^2·°C/W or clo), may also be estimated using the following empirical equation:

$$I_{cl} = \sum I_{clu} \qquad \ldots (4)$$

where I_{clu} is the thermal insulation of various individual garments making up the ensemble, in square metre degrees Celsius per watt or in clo.

3.2 Thermal insulation values for individual garments

See annex B.

The thermal insulation, I_{clu}, (in m^2·°C/W or clo), of individual garments making up the ensemble (see table B.2) is given by

$$I_{clu} = I_T - I_a = \frac{\bar{t}_{sk} - t_o}{H} - I_a \qquad \ldots (5)$$

where

I_T is the total thermal insulation, in square metre degrees Celsius per watt or in clo, of the garment;

t_o is the operative temperature, in degrees Celsius.

NOTE 1 In ISO 7730 and other literature, the thermal insulation of individual garments may be given as basic thermal insulation:

$$I_{cli} = I_T - I_a/f_{cl}$$

giving a summation equation for estimating the insulation of a whole ensemble

$$I_{cl} = 0{,}82 \sum I_{cli}$$

The design of the various garments is indicated by a type number referring to the numbered drawings showing a person dressed in various garment designs.

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 body area covered (indicated on the drawings).

3.3 Calculation of the thermal insulation for individual garments

The thermal insulation, I_{clu} (in m^2·°C/W), of an individual garment may also be estimated using the following equation:

$$I_{clu} = 0{,}095 \times 10^{-2} A_{cov} \quad \ldots (6)$$

or, if it is expressed in clo, using the equation

$$I_{clu} = 0{,}61 \times 10^{-2} A_{cov} \quad \ldots (7)$$

where A_{cov} is the body surface area covered by clothing, expressed as a percentage.

The values for body surface area covered are shown for garments in the figures in annex B.

When the thickness of the fabric used, H_{fab}, expressed in metres, is also known, a more exact estimation of I_{clu} (in m^2·°C/W) can be made using

$$I_{clu} = 0{,}067 \times 10^{-2} A_{cov} + 0{,}217 \times H_{fab} \times A_{cov} \quad \ldots (8)$$

or, if it is expressed in clo, using

$$I_{clu} = 0{,}43 \times 10^{-2} A_{cov} + 1{,}4 \times H_{fab} \times A_{cov} \quad \ldots (9)$$

where H_{fab} is the thickness of fabric, in metres (measured in accordance with ASTM D 1777[1]) using a 7,5 cm diameter presser foot and 69,1 N/m^2 pressure).

4 Estimation of the clothing area factor

The 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 called the clothing area factor, f_{cl}:

$$f_{cl} = A_{cl}/A_{Du}$$

The value of f_{cl} is listed in annex A for all clothing ensembles. It can be measured by a photographic method. Pictures of the nude person/manikin from different directions are compared with pictures of the clothed person/manikin from the same directions and distance.

The projected area of a standing, clothed person/manikin is compared with the projected area of a nude person/manikin. The projected area is measured from six directions: altitudes 0° (horizontal) and 60°, and at each altitude, three azimuth angles 0° (front), 45° and 90° (profile). The projected area is estimated for nude, A_{ni} and clothed, A_{cli}, and for each direction the clothing area factor is estimated using the following equation:

$$f_{cli} = \frac{A_{cli}}{A_{ni}} \quad \ldots (10)$$

where i designates the direction considered.

Then the clothing area factor, f_{cf} is estimated as

$$f_{cl} = \frac{f_{cl1} + f_{cl2} + \ldots + f_{cl6}}{6} \quad \ldots (11)$$

It is very important that the position and posture (standing) of the person/manikin in relation to the camera is exactly the same when clothed as when nude.

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

— if I_{cl} is expressed in m^2·°C/W:

$$f_{cl} = 1{,}00 + 1{,}97 I_{cl} \quad \ldots (12)$$

— if I_{cl} is expressed in clo:

$$f_{cl} = 1{,}00 + 0{,}31 I_{cl} \quad \ldots (13)$$

NOTE 2 In ISO 7730, the following equations have been used based on older and more limited results.

$$f_{cl} = 1{,}00 + 1{,}290\ I_{cl} \text{ for } I_{cl} \leqslant 0{,}078 \text{ m}^2\text{·C/W}$$

$$f_{cl} = 1{,}00 + 0{,}645\ I_{cl} \text{ for } I_{cl} \geqslant 0{,}078 \text{ m}^2\text{·C/W}$$

1) ASTM D 1777-64 (Reapproved 1975), *Standard Method for Measuring Thickness of Textile Materials*.

5 Influence of body movements and wind on the thermal insulation of a clothing ensemble

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 may increase and change the insulation of the clothing.

This effect is called the "pumping effect". To estimate the effect of body motion (pumping effect) on the clothing insulation, a movable thermal manikin may be used. The same methods as in annex C may be used. Now, I_a is measured with a nude manikin engaged in the appropriate activity (seated, standing, walking, bicycling). From these measurements, corrections of the I_{cl} value measured on the standing manikin may be estimated and used for other clothing ensembles. The pumping effect may also be measured on human subjects (annex D).

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

The pumping effect may reduce the resulting thermal insulation of a clothing ensemble between 5 % and 50 % depending on the number of openings and the type of textile (i.e. permeability, stiffness).

If a clothing ensemble is exposed to increased air velocity, some of the air may penetrate through the fabrics and thus change the thermal resistance. In addition, an increased air velocity will decrease I_a.

This effect may also be measured by means of a thermal manikin using the same method as described in annex C. Measurements on the nude and clothed manikin are necessary to be able to estimate the change in I_{cl} and I_a separately. Measurements on human subjects are also possible (annex D).

The influence of wind depends on the air permeability of the outer textile layer and on the types and number of openings.

For the time being, a reduction by 20 % is recommended, when metabolic rate is greater than 100 W/m^2 and 10 % for values between 60 W/m^2 and 100 W/m^2. More research is required to establish quantitative correction factors for the combined action of wind and body movements.

6 Estimation of the evaporative resistance

The evaporative resistance, R_T, of a clothing ensemble may be measured in experiments with subjects or with a sweating thermal manikin.

The evaporative resistance may also be calculated on the basis of clothing insulation and permeation properties in relation to water vapour.

The evaporative resistance, R_T, expressed in square metre kilopascals per watt (m^2·kPa/W), can be defined as the sum of the evaporative resistance of the external air layer, R_a and that of the clothing layers, R_{cl}:

$$R_T = R_a + R_{cl} \qquad \ldots (14)$$

The evaporative resistance will also be influenced by body movements and air penetration. It is recommended to apply the same corrections as for thermal insulation values.

Equations for estimating R_T are given in annex F.

Annex A
(normative)

Thermal insulation values for clothing ensembles

The values are from measurements on a standing thermal manikin. Table A.1 is for typical clothing ensembles. Tables A.2 to A.7 list detailed compound ensembles and combinations. The numbers for the individual garments refer to the garment 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.

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 C, and operative temperature, mean skin temperature and mean heat loss from the manikin were recorded.

Table A.1

Work clothing	I_{cl}		**Daily wear clothing**	I_{cl}	
	clo	$m^2 \cdot °C/W$		clo	$m^2 \cdot °C/W$
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	0,8
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, 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

Work clothing	I_{cl}		Daily wear clothing	I_{cl}	
	clo	m²·°C/W		clo	m²·°C/W
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, outer 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	1,17
—	—	—	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

No.	Clothing ensemble	Combination	Mass g	f_{cl}	I_{cl} clo	 m²·°C/W
	DAILY WEAR CLOTHING **Trousers, shirt**					
100	Briefs 8 T-shirt 30, undershorts 364 Calf-length socks 264, athletic shoes 262		318	1,1	0,33	0,051
101	Panties 1, tube top 69 Short shorts 99 Sandals 272		258	1,07	0,23	0,036
102	Briefs 8 Short-sleeve shirt 79, shorts 97 Calf-length socks 265, shoes 260		622	1,11	0,41	0,064
103	Briefs 8 3/4-length-sleeve shirt 66, shorts 97 Socks 263, athletic shoes 262		451	1,17	0,52	0,081
106	Panties 1 Sleeveless blouse 68, fitted trousers 102 Sandals 272		523	1,14	0,44	0,068
107	Briefs 8 Short-sleeve shirt 79, fitted trousers 102 Calf-length socks 265, shoes 260		725	1,14	0,5	0,078
108	Briefs 8 Shirt 75, fitted trousers 102 Calf-length socks 265, shoes 260		693	1,19	0,62	0,096
112	Briefs 8, T-shirt 30 Shirt 76, loose trousers 103 Calf-length socks 265, shoes 260		1 072	1,3	0,89	0,138
121	Briefs 8 Sweatshirt 290, sweat pants 291 Calf-length socks 264, shoes 262		776	1,19	0,77	0,119
124	Briefs 8, T-shirt 30 Coveralls 114 Calf-length socks 264, shoes 260		1 247	1,23	0,72	0,112
200	Underpants 8 Shirt 54, fitted trousers 89 Socks 265, shoes 258		924	1,19	0,61	0,095
201	Underpants 8 Shirt 54, fitted trousers 87 Socks 265, shoes 258		911	1,19	0,63	0,098
203	Underpants 8 Shirt 54, loose trousers 86 Socks 265, shoes 258		991	1,3	0,71	0,11
204	Underpants 8 Shirt 54, walking shorts 85 Socks 265, shoes 258		673	1,16	0,53	0,082