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# Ergonomics of the thermal environment — Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects

*Ergonomie des ambiances thermiques — Détermination et interprétation de la contrainte liée au froid en utilisant l'isolement thermique requis du vêtement (IREQ) et les effets du refroidissement local*

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# Foreword

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ISO 11079 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 5, *Ergonomics of the physical environment*.

This first edition of ISO 11079 cancels and replaces the ISO/TR 11079:1993, of which it constitutes a technical revision.


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## Introduction

Wind chill is commonly encountered in cold climates, but it is low temperatures that first of all endanger body heat balance. By proper adjustment of clothing, human beings can often control and regulate body heat loss, to balance a change in the ambient climate. The method presented here is based therefore on the evaluation of the clothing insulation required to maintain the thermal balance of the body in equilibrium. The heat balance equation used takes into account the most recent scientific findings concerning heat exchanges at the surface of the skin as well as the clothing.


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# Ergonomics of the thermal environment — Determination and interpretation of cold stress when using required clothing insulation (IREQ) and local cooling effects

## 1 Scope

This International Standard specifies methods and strategies for assessing the thermal stress associated with exposure to cold environments. These methods apply to continuous, intermittent as well as occasional exposure and type of work, indoors and outdoors. They are not applicable to specific effects associated with certain meteorological phenomena (e.g. precipitation), which are assessed by other methods.

## 2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7726, *Ergonomics of the thermal environment — Instruments for measuring physical quantities*

ISO 8996, *Ergonomics of the thermal environment — Determination of metabolic rate*

ISO 9237, *Textiles — Determination of permeability of fabrics to air*

ISO 9920, *Ergonomics of the thermal environment — Estimation of thermal insulation and water vapour resistance of a clothing ensemble*

ISO 13731, *Ergonomics of the thermal environment — Vocabulary and symbols*

ISO 13732-3, *Ergonomics of the thermal environment — Methods for the assessment of human responses to contact with surfaces — Part 3: Cold surfaces*

ISO 15831, *Clothing — Physiological effects — Measurement of thermal insulation by means of a thermal manikin*

EN 511, *Protective gloves against cold*

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# 3 Terms, definitions and symbols

For the purposes of this document, the terms and definitions given in ISO 13731 and the following terms, definitions and symbols apply.

## 3.1 Terms and definitions

**3.1.1**
**cold stress**
climatic conditions under which the body heat exchange is just equal to or too large for heat balance at the expense of significant and sometimes uncompensable physiological strain (heat debt)

**3.1.2**
**heat stress**
climatic conditions under which the body heat exchange is just equal to or too small for heat balance at the expense of significant and sometimes uncompensable physiological strain (heat storage)

**3.1.3**
**IREQ**
required clothing insulation for the preservation of body heat balance at defined levels of physiological strain

**3.1.4**
**thermoneutral zone**
temperature interval within which the body maintains heat balance exclusively by vasomotor reactions

**3.1.5**
**wind chill temperature**
temperature related to the cooling effect on a local skin segment

## 3.2 Symbols

| | |
|---|---|
| $A_{\mathrm{Du}}$ | Dubois body surface area, m$^2$ |
| ap | air permeability, l · m$^{-2}$ · s$^{-1}$ |
| $C$ | convective heat flow (exchange), W · m$^{-2}$ |
| $c_{\mathrm{e}}$ | water latent heat of vaporization, J · kg$^{-1}$ |
| $c_{\mathrm{p}}$ | specific heat of dry air at constant pressure, J · kg$^{-1}$ · K$^{-1}$ |
| $C_{\mathrm{res}}$ | respiratory convective heat flow (loss), W · m$^{-2}$ |
| $D_{\mathrm{lim}}$ | duration limited exposure, h |
| $D_{\mathrm{rec}}$ | recovery time, h |
| $E$ | evaporative heat flow (exchange) at the skin, W · m$^{-2}$ |
| $E_{\mathrm{res}}$ | respiratory evaporative heat flow (loss), W · m$^{-2}$ |
| $f_{\mathrm{cl}}$ | clothing area factor, dimensionless |
| $h_{\mathrm{c}}$ | convective heat transfer coefficient, W · m$^{-2}$ · K$^{-1}$ |
| $h_{\mathrm{r}}$ | radiative heat transfer coefficient, W · m$^{-2}$ · K$^{-1}$ |
| $I_{\mathrm{a}}$ | boundary layer thermal insulation, m$^2$ · K · W$^{-1}$ |
| $I_{\mathrm{a,r}}$ | resultant boundary layer thermal insulation, m$^2$ · K · W$^{-1}$ |


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$I_{cl}$ basic clothing insulation, $m^2 \cdot K \cdot W^{-1}$

$I_{cl,r}$ resultant clothing insulation, $m^2 \cdot K \cdot W^{-1}$

$I_T$ basic total insulation, $m^2 \cdot K \cdot W^{-1}$

$I_{T,r}$ resultant total insulation, $m^2 \cdot K \cdot W^{-1}$

$i_m$ moisture permeability index, dimensionless

IREQ required clothing insulation, $m^2 \cdot K \cdot W^{-1}$

$IREQ_{min}$ minimal required clothing insulation, $m^2 \cdot K \cdot W^{-1}$

$IREQ_{neutral}$ neutral required clothing insulation, $m^2 \cdot K \cdot W^{-1}$

$K$ conductive heat flow (exchange), $W \cdot m^{-2}$

$M$ metabolic rate, $W \cdot m^{-2}$

$p_a$ water vapour partial pressure, kPa

$p_{ex}$ saturated water vapour pressure at expired air temperature, kPa

$p_{sk}$ water vapour pressure at skin temperature, kPa

$p_{sk,s}$ saturated water vapour pressure at the skin surface, kPa

$Q$ body heat gain or loss, $kJ \cdot m^{-2}$

$Q_{lim}$ limit value for $Q$, $kJ \cdot m^{-2}$

$R$ radiative heat flow (exchange), $W \cdot m^{-2}$

$R_{e,T}$ total evaporative resistance of clothing and boundary air layer, $m^2 \cdot kPa \cdot W^{-1}$

$S$ body heat storage rate, $W \cdot m^{-2}$

$t_a$ air temperature, °C

$t_{cl}$ clothing surface temperature, °C

$t_{ex}$ expired air temperature, °C

$t_o$ operative temperature, °C

$t_r$ radiant temperature

$t_{sk}$ local skin temperature, °C

$\bar{t}_{sk}$ mean skin temperature, °C

$t_{WC}$ wind chill temperature, °C

$V$ respiratory ventilation rate, kg air $\cdot s^{-1}$

$v_{10}$ wind speed measured 10 m above ground level, $m \cdot s^{-1}$

$v_a$ air velocity, $m \cdot s^{-1}$

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

$W$ effective mechanical power, $W \cdot m^{-2}$

$w$ skin wettedness, dimensionless

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$W_a$ humidity ratio of inhaled air, kg water/kg dry air

$W_{ex}$ humidity ratio of exhaled air, kg water/kg dry air

$\sigma$ Stefan-Boltzmann constant

$\varepsilon_{cl}$ emissivity of clothing surface, dimensionless

# 4 Principles of methods for evaluation

Cold stress is evaluated in terms of both general cooling of the body and local cooling of particular parts of the body (e.g. extremities and face). The following types of cold stress are identified.

**a) General cooling**

For general cooling, an analytical method is presented in Clause 5 for the evaluation and interpretation of the thermal stress. It is based on a calculation of the body heat exchange, the required clothing insulation (IREQ) for the maintenance of thermal equilibrium and the insulation provided by clothing ensemble in use or anticipated to be used.

**b) Local cooling**

1) convective cooling (wind chill)

2) conductive cooling

3) extremity cooling

4) airway cooling

For local cooling, methods are proposed in Clause 6. Criteria and limit values are also given in Clause 6 and Annex B.

In the following sections, the main steps of evaluation are described.

# 5 General cooling

## 5.1 Overview

A general equation for body heat balance is defined. In this equation clothing thermal properties, body heat production and physical characteristics of the environment are the determinant factors. The equation is solved for the required clothing insulation (IREQ) for maintained heat balance under specified criteria of physiological strain. IREQ is subsequently compared with the protection (insulation) offered by the worker's clothing. If worn insulation is less than required, a duration limited exposure ($D_{lim}$) is calculated on the basis of acceptable levels of body cooling. Detailed formulas, coefficients and criteria are proposed in Annexes A and B.

The method involves the following steps, outlined schematically in Figure 1:

— measurements of the thermal parameters of the environment;

— determination of activity level (metabolic rate);

— calculation of IREQ;

— comparison of IREQ with resultant insulation provided by clothing in use;

— evaluation of the conditions for thermal balance and calculation of the recommended maximal exposure time ($D_{lim}$).


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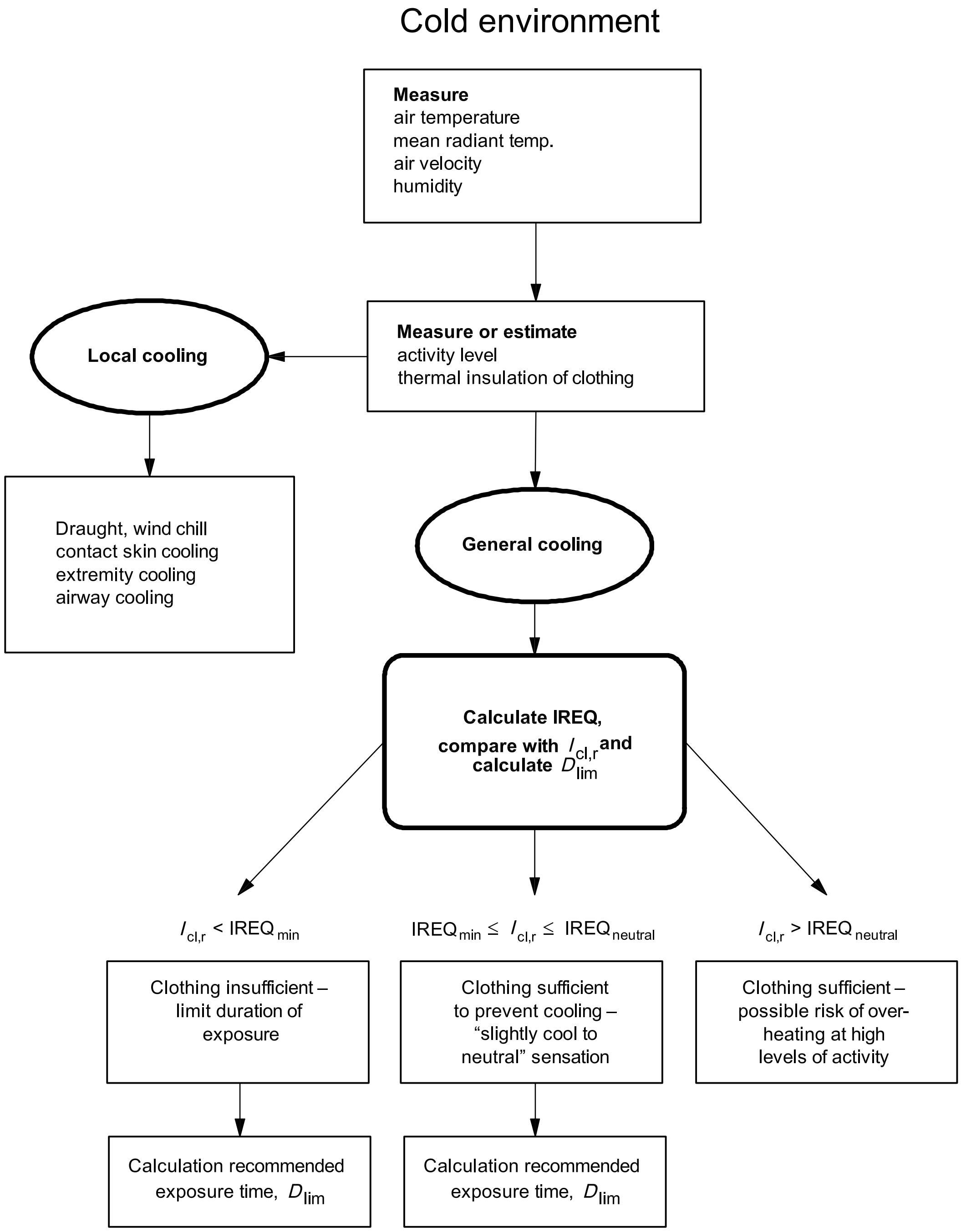


**Figure 1 — Procedure for evaluation of cold environments**



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## 5.2 Definition of required clothing insulation, IREQ

IREQ is the resultant clothing insulation required in the actual environmental conditions to maintain the body in a state of thermal equilibrium at acceptable levels of body and skin temperatures.

IREQ is

a) a measure of cold stress integrating the effects of air temperature, mean radiant temperature, relative humidity and air velocity for defined levels of metabolic rate,

b) a method for the analysis of effects of the thermal environment and metabolic rate on the human body,

c) a method for specification of clothing insulation requirements and the subsequent selection of clothing to be used under the actual conditions, and

d) a method for evaluation of changes in heat balance parameters as measures for improvement of design and planning of work time and work regimes under cold conditions.

## 5.3 Derivation of IREQ

### 5.3.1 General heat balance equation

Calculation of IREQ is based on a rational analysis of a human being's heat exchange with the environment. The following subclauses review the general principles for calculation of the various factors affecting IREQ.

The general heat balance equation [Equation (1)] is as follows:

$$M - W = E_{\mathrm{res}} + C_{\mathrm{res}} + E + K + R + C + S \tag{1}$$

where the left-hand side of the equation represents the internal heat production, which is balanced by the right-hand side which represents the sum of heat exchanges in the respiratory tract, heat exchanges on the skin and the heat storage accumulating in the body. Variables of Equation (1) are defined in the following. For the meaning of symbols, see also 3.2.

### 5.3.2 Metabolic rate

$M$ is the metabolic rate and is evaluated in accordance with ISO 8996.

### 5.3.3 Effective mechanical power

$W$ is the effective mechanical power. In most industrial situations this is small and can be neglected. See also information in ISO 8996.

### 5.3.4 Respiratory heat exchange

Heat is lost from the respiratory tract by warming and saturating inspired air, and is the sum of convective heat loss ($C_{\mathrm{res}}$) and evaporative heat loss ($E_{\mathrm{res}}$), determined, respectively, by

$$C_{\mathrm{res}} = c_{\mathrm{p}} \cdot V(t_{\mathrm{ex}} - t_{\mathrm{a}}) / A_{\mathrm{Du}} \tag{2}$$

$$E_{\mathrm{res}} = c_{\mathrm{e}} \cdot V(W_{\mathrm{ex}} - W_{\mathrm{a}}) / A_{\mathrm{Du}} \tag{3}$$


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### 5.3.5 Evaporative heat exchange

The evaporative heat exchange, $E$, is defined by

$$E = (p_{sk} - p_a)/R_{e,T} \tag{4}$$

### 5.3.6 Conductive heat exchange

Conductive heat exchange, $K$, is related to the area of body parts in direct contact with external surfaces. Although it may be of significant importance for local heat balance, conductive heat exchange is mostly small and can be accounted for by the expressions for convective and radiation heat exchange.

### 5.3.7 Radiative heat exchange

The radiative heat exchange, $R$, between the clothing surface including uncovered skin and the environment is defined by

$$R = f_{cl} \cdot h_r \cdot (t_{cl} - \bar{t}_r) \tag{5}$$

### 5.3.8 Convective heat exchange

The convective heat exchange, $C$, between the clothing surface including uncovered skin and the environment is defined by

$$C = f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \tag{6}$$

### 5.3.9 Heat exchange through clothing

Heat exchange through clothing takes place by conduction, convection and radiation and by the transfer of evaporated sweat. The effect of clothing on latent heat exchange is accounted for by Equation (4). The effect of clothing on dry heat exchange is determined by the thermal insulation of the clothing ensemble and the skin-to-clothing surface temperature gradient. Dry heat flow to the clothing surface is equivalent to the heat transfer between the clothing surface and the environment. Heat exchange through clothing, therefore, is expressed by the resultant, thermal insulation of clothing:

$$\frac{\bar{t}_{sk} - t_{cl}}{I_{cl,r}} = R + C = M - W - E_{res} - C_{res} - E - S \tag{7}$$

## 5.4 Calculation of IREQ

On the basis of Equations (1) to (7), in steady state and using the hypothesis made concerning heat flow by conduction, the required clothing insulation, IREQ, is calculated on the basis Equation (8):

$$\text{IREQ} = \frac{\bar{t}_{sk} - t_{cl}}{R + C} \tag{8}$$

Equations (7) and (8) express the dry heat exchange at the clothing surface when the body is in thermal equilibrium and state the relationship between $I_{cl,r}$ and IREQ. $I_{cl,r}$ is the value of clothing insulation corrected for the effects of wind penetration and activity, taking into account the air permeability of the outer garment layer. IREQ is the thermal insulation required for the maintenance of thermal equilibrium.

Equation (8) contains two unknown variables (IREQ and $t_{cl}$). Therefore, Equation (8) is solved for $t_{cl}$ as follows

$$t_{cl} = \bar{t}_{sk} - \text{IREQ} \cdot (M - W - E_{res} - C_{res} - E) \tag{9}$$

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This expression replaces $t_{cl}$ in the computation formulas for the variables in Equation (8), where the formulas for $R$ and $C$ contain $t_{cl}$ [see Equations (5) and (6)]. The value of IREQ that satisfies Equation (8) is then calculated by iteration. A computer program is referenced in Annex F for this purpose. IREQ is expressed in square metre degrees Kelvin per watt ($m^2 \cdot K \cdot W^{-1}$). It may also be expressed in clo[1)].

## 5.5 Interpretation of IREQ

### 5.5.1 IREQ as a cold index

IREQ is a measure of the thermal stress presented by the combined effects of internal heat production and heat exchange with the environment. The greater the cooling power of the environment, the higher the value of IREQ at any given activity level. At any given set of climatic conditions, cold stress and thereby IREQ is reduced with increasing activity due to the extra demand for dissipation of metabolic heat.

### 5.5.2 IREQ and physiological strain

Thermal equilibrium can be achieved at different levels of thermoregulatory strain, defined in terms of values for mean skin temperature, sweating (skin wettedness) and change in body temperature.

IREQ is defined at the following two levels of physiological strain.

a) $IREQ_{min}$ defines a minimal thermal insulation required to maintain body thermal equilibrium at a subnormal level of mean body temperature. The minimal IREQ represents some body cooling, in particular of peripheral parts of the body. With prolonged exposures extremity cooling may become a limiting factor for duration of exposure.

b) $IREQ_{neutral}$ is defined as the thermal insulation required to provide conditions of thermal neutrality, i.e. thermal equilibrium maintained at a normal level of mean body temperature. This level represents none or minimal cooling of the human body.

The relevant physiological criteria are presented in Annex B.

### 5.5.3 IREQ and clothing insulation

IREQ is a resultant clothing insulation value that is required for the actual conditions. It may, therefore, serve as a basis for the evaluation of the protection provided by clothing in use or as a guideline for the selection of appropriate clothing. The IREQ value is compared with the resultant insulation value of the selected clothing ensembles. This evaluation is described in 5.6.

### 5.5.4 IREQ and design of work

Any of the parameters of the heat balance equation can be changed and the calculated value of IREQ will indicate the relative importance of this particular factor.

## 5.6 Comparison of IREQ and selected clothing insulation

The primary purpose of the IREQ method is to analyse whether or not the selected clothing provides insulation that is sufficient to establish a defined level of heat balance. The most commonly reported insulation value of a clothing ensemble is its basic insulation value, $I_{cl}$ (see ISO 9920). In order to use this information for a comparison with IREQ, the value must be corrected for several factors. The corrected value, $I_{cl,r}$, is not readily available, as it depends on the user conditions. Therefore it needs to be determined on the basis of available information for the actual clothing (basic insulation, air permeability) wind and activity level.

1) 1 clo = 0,155 $m^2 \cdot K \cdot W^{-1}$.


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Values for basic insulation of clothing ensembles and air permeability shall be determined in accordance with ISO 9920. Examples of values are provided in Annex C. The final correction algorithms are given in Annex A.

$I_{cl,r}$ is compared with the calculated IREQ for the given conditions and criteria. The following interpretation is made:

| | |
|---|---|
| $I_{cl,r} > IREQ_{neutral}$ | warm, overheating zone — clothing insulation shall be reduced |
| $IREQ_{min} \leqslant I_{cl,r} \leqslant IREQ_{neutral}$ | neutral, regulatory zone — no action required |
| $I_{cl,r} < IREQ_{min}$ | cold, cooling zone — clothing insulation shall be increased or $D_{lim}$ calculated (see 5.7). |

The interval between $IREQ_{min}$ and $IREQ_{neutral}$ may be regarded as a clothing regulatory zone, in which each individual chooses the appropriate protection level. With insulation values lower than $IREQ_{min}$ there is a risk of progressive body cooling. With values higher than $IREQ_{neutral}$ conditions will be considered warm and overheating can occur. In the final evaluation, the result can also be presented in terms of basic insulation needed for the given conditions (see Annex E).

## 5.7 Definition and calculation of duration limited exposure, $D_{lim}$

When the corrected value of a selected or used clothing ensemble is less than the calculated required insulation (IREQ), exposure has to be time limited to prevent progressive body cooling. A certain reduction in body heat content ($Q$) is acceptable during an exposure of a few hours and can be used to calculate the duration of exposure when the rate of heat storage is known.

Duration limited exposure ($D_{lim}$) to cold is defined as the recommended maximum time of exposure with available or selected clothing. $D_{lim}$ is calculated using Equation (10):

$$D_{lim} = \frac{Q_{lim}}{S} \tag{10}$$

where $Q_{lim}$ is the limit value of $Q$ (see Annex B) and $S$ is calculated from

$$S = M - W - E_{res} - C_{res} - E - R - C \tag{11}$$

Equation (11) contains unknown $t_{cl}$. Therefore, it is solved by mathematical iteration:

$$t_{cl} = \bar{t}_{sk} - I_{cl,r} \cdot (M - W - E_{res} - C_{res} - E - S) \tag{12}$$

Equation (12) is similar to Equation (9), the difference being that Equation (9) is used in steady state to calculate IREQ and Equation (12) in the actual conditions when clothing insulation is known.

$D_{lim}$ shall be calculated from $IREQ_{neutral}$ (default) (see 5.5.2). Other values for thermal sensation can be selected [see 5.5.2., b)]. If the worker at the onset of exposure has adopted a certain heat debt, the exposure time shall be reduced accordingly.

After an exposure with body cooling, a recovery period shall be allowed to restore normal body heat balance. Recovery time ($D_{rec}$) is calculated in the same way as $D_{lim}$, substituting the “cold conditions” with the exposure conditions during the recovery period. In other words:

$$D_{rec} = Q_{lim}/S \tag{13}$$

where $S$ is the rate of body heat storage (positive) calculated from Equation (11) for the exposure conditions during the recovery period.

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Since recovery is supposed to start when the body has achieved a certain heat debt, the value of $Q_{lim}$ shall be the same when calculating $D_{rec}/D_{lim}$. The calculation of $D_{rec}$ requires a new determination if clothing is changed during the recovery period, as $S$ will change with different clothing.

The physiological criteria to be used are presented in Annex B and examples of the application of $D_{lim}$ and $D_{rec}$ in Annex E.

# 6 Local cooling

## 6.1 General

Local cooling of any part of the body with emphasis on hands, feet and head may produce discomfort, deterioration of manual and physical performance and cold injury. The amount of knowledge on responses to local cooling is insufficient for the development of a single evaluation method. Several approaches are proposed and more research work is encouraged on the subject.

The indoor cold environment is relatively easy to modify by engineering techniques. Light, stationary work makes a person more prone to unpleasant effects of local cooling, caused by for example draught or radiation heat loss to cold surfaces. Particular attention should be paid to the evaluation of discomfort.

The outdoor cold environment is determined by weather and climate, and protective measures mostly comprise adjustment of clothing or control of exposure. All types of local cold stress may occur, simultaneously or independently.

## 6.2 Convective cooling

The combination of low temperature and wind accelerates heat loss from warm surfaces. Accordingly, unprotected parts of the body, such as face and sometimes hands, may cool very quickly and reach low temperatures with considerable risk of injury. Local convective cold stress is evaluated with a general equation [Equation (14)] for convective and radiative heat loss of a bare skin surface:

$$R + C = h_r \cdot (t_{sk} - \overline{t}_r) + h_c \cdot (t_{sk} - t_a) \tag{14}$$

The wind chill temperature, $t_{WC}$, is a temperature that describes a cooling effect on the skin. It is derived from Equation (14), which is solved for $t_a$ for combinations of wind and heat losses.

The expression to be used for the evaluation of $t_{WC}$ is presented in Annex D.

## 6.3 Conductive cooling

The contact of cold surfaces produces an immediate heat exchange between warm skin and cold surface. The risk of incurring unpleasant tissue cooling or at worst a local cold injury shall be assessed in accordance with ISO 13732-3.

## 6.4 Extremity cooling

Even at thermoneutral conditions the extremities, the hands in particular may suffer unwanted cooling. This depends to a large extent on the local climatic conditions, local protection and heat input by blood circulation. The latter factor is much dependent on the overall thermal balance. If the heat balance is negative, as for example when protective clothing does not match IREQ, extremity blood flow is reduced due to vasoconstriction. This may reduce heat input to very low levels. Extremities, in particular fingers and toes, will gradually cool down and reach unacceptably low temperatures.

Extremity cooling is prevented or reduced by putting on adequate protection, e.g. insulative hand and footgear. Test methods for determination of thermal insulation of hand-wear shall be in accordance with EN 511. Required insulation for various wear conditions are also given in EN 511.


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Hand cooling shall be evaluated by the methods and procedures specified in EN 511.

Extremity cooling can also be evaluated by direct skin temperature measurements. Recommended criteria and temperature levels are given in Annex B.

### 6.5 Airway cooling

Inhalation of air at low temperatures cools the membranes of the airway walls and can be harmful to the tissues. Cooling is more pronounced when the ventilated air volume is high (e.g. at high physical activity).

Recommendations for lowest temperatures of inspired air is given in Annex B.

## 7 Practical assessment of cold environments and interpretation

### 7.1 General

Procedures for the practical determination of IREQ, $D_{lim}$ and local cooling effects are described in the following subclauses.

### 7.2 Procedure for determination of IREQ and $D_{lim}$

The procedure for the assessment of cold environments is specified in steps a) to g), below, and described schematically in Figure 1.

NOTE A link to a computer program is provided in Annex F for a complete evaluation of the steps from c) to f).

a) Measure or estimate the following climate parameters in accordance with ISO 7726:

- air temperature;
- mean radiant temperature;
- air velocity;
- humidity.

The operative temperature may replace the air temperature and mean radiant temperature when it is calculated as a weighted average of the two using the convective and radiative heat transfer coefficients, respectively. Water content of air at low temperature is very small, so a standard value of 50 % relative humidity may be used below −5 °C.

b) Determine the metabolic rate in accordance with ISO 8996. Values for selected examples of physical activity are given in Annex C.

c) Determine external work rate. For most types of manual work and movements on the ground, the work rate can be set to 0.

d) Determine the basic clothing insulation of the cold protective clothing in use in accordance with ISO 15831 or from the corresponding tables given in ISO 9920 and Annex C. The program provided in Annex F can be used to calculate the resultant clothing insulation value, $I_{cl,r}$ (see Annex C).

e) Calculate IREQ from Equation (8). With intermittent exposure or activity (e.g. fixed work–rest regimens), IREQ is calculated for each different work and rest period, and the time-weighted average for a minimum of 1 h then calculated. The individual period may depend on the organization and nature of the work but should be at least 15 min.

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f) Evaluate the conditions for heat balance by comparison of IREQ with the corrected clothing insulation value, $I_{cl,r}$.

Three cases apply:

1) $I_{cl,r} > IREQ_{neutral}$

The selected clothing ensemble provides more than sufficient insulation. Too much insulation can increase the risk of overheating, excessive sweating and moisture absorption by clothing and a prospective risk of progressive hypothermia. Clothing insulation shall be reduced.

2) $IREQ_{min} \leqslant I_{cl,r} \leqslant IREQ_{neutral}$

Selected clothing ensemble provides adequate insulation. The level of physiological strain may vary from high to low and the thermal conditions are perceived as “slightly cold” to “neutral”. No action is required, except for further evaluation of local cooling effects.

3) $I_{cl,r} < IREQ_{min}$

The selected clothing ensemble does not provide adequate insulation to prevent body cooling. There is an increasing risk of hypothermia with progressive exposure:

i) clothing insulation shall be increased;

ii) a time limited exposure shall be selected and $D_{lim}$ calculated [see g) below].

g) Determine the duration limited exposure time ($D_{lim}$) and the required recovery time ($D_{rec}$) if $I_{cl,r}$ is less than $IREQ_{neutral}$. If the clothing is changed during recovery, a new calculation shall be made. $D_{lim}$ and $D_{rec}$ are by default calculated for neutral conditions.

The IREQ index applies to cool and cold environments. It is recommended that the index be used within the following limits of the main parameters:

$t_a \leqslant 10$ °C;

$0{,}4\ \text{m}\cdot\text{s}^{-1} \leqslant v_a \leqslant 18\ \text{m}\cdot\text{s}^{-1}$;

$I_{cl} > 0{,}078\ \text{m}^2\cdot\text{K}\cdot\text{W}^{-1}$ (0,5 clo).

## 7.3 Local cooling

In cold environments there is always a risk of local cold stress. This problem is dealt with according to the following:

— convective cooling (see Annex D);

— conductive cooling (see ISO 13732-3);

— extremity cooling (see EN 511);

— airway cooling (see Annex B).


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# Annex A
(normative)

# Computation of thermal balance

## A.1 General

The formulas, coefficients and values for the calculation of the various forms of heat exchange presented in this annex should only be applied within the limit values of the main parameters. They are based on the most recent and accepted experimental investigations available in the literature (see the Bibliography). The symbols and units given in 3.2 apply.

## A.2 Determination of respiratory heat exchange

Respiratory heat loss is related to $M$ and is calculated from the formulas for convective and evaporative respiratory heat loss presented below.

$$E_{\text{res}} = 0{,}017\,3 \cdot M \cdot \left(p_{\text{ex}} - p_{\text{a}}\right) \tag{A.1}$$

$$C_{\text{res}} = 0{,}001\,4 \cdot M \cdot \left(t_{\text{ex}} - t_{\text{a}}\right) \tag{A.2}$$

$$t_{\text{ex}} = 29 + 0{,}2 \cdot t_{\text{a}} \tag{A.3}$$

It is assumed that expired air is saturated and has a temperature ($t_{\text{ex}}$), that is related to inspired (ambient) temperature ($t_{\text{a}}$) using Equation (A.3).

## A.3 Determination of evaporative heat exchange

Skin evaporative heat exchange ($E$) is determined by

$$E = w \cdot (p_{\text{sk,s}} - p_{\text{a}}) / R_{\text{E,T}} \tag{A.4}$$

The skin wettedness factor may be regarded as the wetted fraction of the skin, participating in evaporative heat exchange. The factor, $w$, can vary approximately from 0,06, when skin diffusion is the only form of evaporation, to 1,0, when evaporation is maximal and the skin is fully wet. The saturated water vapour pressure at the skin surface, $p_{\text{sk,s}}$, is calculated from the mean skin temperature by

$$p_{\text{sk,s}} = 610{,}78 \cdot \text{e}^{\frac{(17{,}27 \cdot t_{\text{sk}})}{(t_{\text{sk}} + 23{,}3)}} \tag{A.5}$$

The mean skin temperature is determined automatically as a function of the metabolic rate (see Annex C).



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## A.4 Determination of evaporative resistance

The value of $R_{e,T}$ is calculated on the basis of clothing insulation and permeation properties to water vapour. Due to the limited contribution from evaporative heat loss in the cold for defined levels of physiological strain, it is sufficient with the following approximate estimation of $R_{e,T}$:

$$R_{e,T} = \frac{0{,}06}{i_m} \cdot \left( \frac{I_{a,r}}{f_{cl}} + I_{cl,r} \right) \quad \text{(A.6)}$$

The expression within brackets is the total insulation value. $I_{a,r}$ is calculated using Equation (A.13). A limited number of values for $R_{e,T}$ and $i_m$ are available in the literature (see ISO 9920). For common (vapour permeable) clothing, an $i_m$ of 0,38 is assumed and Equation (A.6) becomes

$$R_{e,T} = 0{,}16 \cdot \left( \frac{I_{a,r}}{f_{cl}} + I_{cl,r} \right) \quad \text{(A.7)}$$

## A.5 Determination of the clothing area factor

In all calculations, $f_{cl}$ is calculated with

$$f_{cl} = 1{,}0 + 1{,}97 \cdot I_{cl} \quad \text{(A.8)}$$

## A.6 Determination of the convective heat transfer coefficient

$h_c$ is calculated with

$$h_c = \frac{f_{cl}}{I_{a,r}} - h_r \quad \text{(A.9)}$$

For $0{,}4\ \text{m} \cdot \text{s}^{-1} \leqslant v_a \leqslant 18\ \text{m} \cdot \text{s}^{-1}$ and $0\ \text{m} \cdot \text{s}^{-1} \leqslant v_w \leqslant 1{,}2\ \text{m} \cdot \text{s}^{-1}$; $I_{a,r}$ is determined using Equation (A.13).

## A.7 Determination of radiation heat transfer coefficient

In environments with a predominantly low temperature radiation, $h_r$ is approximated by

$$h_r \approx \sigma \cdot \varepsilon_{cl} \cdot \frac{(t_{cl} + 273)^4 - (t_r + 273)^4}{t_{cl} - t_r} \quad \text{(A.10)}$$

where $\sigma$ is the Stefan-Boltzmann constant, equal to $(5{,}67 \times 10^{-8})\ \text{W} \cdot \text{m}^{-2} \cdot \text{K}^{-4}$, $\varepsilon_{cl}$ is the emissivity of the clothing.

The emissivity of the clothing depends on the temperature of the radiation source.

With low temperature radiation, emissivity is independent of the colour of clothing and shall be 0,97.

With high temperature radiation (e.g. sunshine), the colour of clothing is important and an appropriate value shall be chosen. A completely dark outer surface layer may absorb up to $100\ \text{W} \cdot \text{m}^{-2}$ more than a white surface.


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## A.8 Determination of resultant clothing insulation

The basic insulation value ($I_{cl}$) of a selected clothing ensemble is corrected for the effects of wind penetration and activity, taking into account the air permeability of the outer garment layer. Air permeability shall be determined in accordance with ISO 9237. This correction gives a resultant insulation value ($I_{cl,r}$) that is more realistic for a comparison with IREQ.

$I_{cl,r}$ is calculated using Equation (A.11) from corrected values of total insulation [Equation (A.12)] and boundary layer thermal insulation [Equation (A.13)]. This value of $I_{cl,r}$ is used for the calculation of $D_{lim}$ (see 5.7).

$$I_{cl,r} = I_{T,r} - \frac{I_{a,r}}{f_{cl}} \quad (A.11)$$

$$I_{T,r} = I_T \cdot \left[0{,}54 \cdot e^{(0{,}075 \cdot \ln(ap) - 0{,}15 \cdot v_a - 0{,}22 \cdot v_w)} - 0{,}06 \cdot \ln(ap) + 0{,}5\right] \quad (A.12)$$

The relationship for air layer reduction calculations is derived from Equation (A.12) by inserting $ap$ = 10 000 l · m$^{-2}$ · s$^{-1}$ and replacing $I_T$ by $I_a$ = 0,085 m$^2$ · K · W$^{-1}$. The formula then becomes:

$$I_{a,r} = 0{,}092 \cdot e^{(0{,}15 \cdot v_a - 0{,}22 \cdot v_w)} - 0{,}004\,5 \quad (A.13)$$

Equations (A.12) and (A.13) apply for 0,4 m · s$^{-1}$ $\leqslant v_a \leqslant$ 18 m · s$^{-1}$ and 0 m · s$^{-1}$ $\leqslant v_m \leqslant$ 1,2 m · s$^{-1}$, and for the conditions of Equation (A.14).

If walking speed is unknown or not applicable (stationary work), the movement generated, increased air velocity around the body, can be calculated by

$$v_w = 0{,}005\,2 \cdot (M - 58) \quad (A.14)$$

The effect of body movement is limited to values lower than 0,7 m · s$^{-1}$.

Equation (A.15) shall be used to determine the required $I_{cl}$ as a function of the previous equations. This provides a complementary evaluation of required insulation. The necessary corrections are made by the program and the result is a required $I_{cl}$ value that can be compared directly with information from tables (see Annex C) or static manikin data.

$I_{cl}$ required is determined by replacing $I_{cl,r}$ in Equation (A.15) with the IREQ value:

$$I_{cl} = \frac{I_{cl,r} + \left[0{,}092 \cdot e^{(0{,}15 \cdot v_a - 0{,}22 \cdot v_w)} - 0{,}004\,5\right] / f_{cl}}{\left[0{,}54 \cdot e^{(0{,}075 \cdot \ln(ap) - 0{,}15 \cdot v_a - 0{,}22 \cdot v_w)}\right] - 0{,}06 \cdot \ln(ap) + 0{,}5} - 0{,}085 / f_{cl} \quad (A.15)$$

Examples of basic insulation values are given in Annex C.

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# Annex B
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# Physiological criteria in cold exposure

## B.1 General cooling

Two sets of physiological criteria are defined to identify

a) *low physiological strain*, characterized by a neutral thermal state of the body, corresponding to a “neutral” thermal sensation, and

b) *high physiological strain*, characterized by peripheral vasoconstriction and no regulatory sweating, and corresponding to a thermal sensation of “cold”.

The low level of strain corresponds to thermoneutral conditions. Heat balance is maintained at a minimum of thermoregulatory load for given conditions. In such conditions, a person wishes to be neither warmer nor cooler. Comprehensive investigations under indoor conditions have provided sets of comfort criteria that may be used to physiologically define thermal neutrality. Equations for prediction of mean skin temperature conform with results from cold environments. A modified set of “comfort criteria” in terms of skin wettedness is used for the calculations. Values for proposed criteria are given in Table B.1.

The high level of strain corresponds to conditions under which heat balance is maintained only with vasoconstriction of skin and extremities. In such conditions, a person would perceive a thermal sensation of “cold”. This condition is reached when heat balance cannot be maintained at the low level of strain. On start of exposure there is an initial cooling period of 20 min to 40 min, when heat content of body tissues, preferably skin and extremities, is reduced. Thermal equilibrium is then restored for the high strain values of mean skin temperature and skin wettedness given in Table B.1. This corresponds to a heat debt of approximately 140 kJ · m$^{-2}$ compared to the low level strain. Heat balance under these cold conditions is maintained with no regulatory sweating. Evaporative heat exchange takes place by skin diffusion only ($w$ = 0,06). This state of the body coincides with a subjective thermal sensation of “cold” and is tolerated (though not comfortable) for extended exposures.

## B.2 Duration limited exposure

Two levels of strain also apply for the calculation of $D_{\text{lim}}$.

When the resultant insulation of selected or used clothing ($I_{\text{cl,r}}$) is less than $\text{IREQ}_{\text{neutral}}$, the body cannot maintain equilibrium under defined levels of strain during long exposure. The difference between $I_{\text{cl,r}}$ and $\text{IREQ}_{\text{neutral}}$ results in a negative heat storage rate (see 5.7). $D_{\text{lim}}$ for low strain conditions is calculated and corresponds to the time to lose 144 kJ · m$^{-2}$ of body heat content.

For high strain conditions, $D_{\text{lim}}$ is calculated on the basis of the difference between $I_{\text{cl,r}}$ and $\text{IREQ}_{\text{min}}$. The starting condition assumes that the body is already slightly cooled and mean skin temperature is lowered (see Table B.1, column 2). From these conditions, an additional drop in body heat content (144 kJ · m$^{-2}$) occurs.


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**Table B.1 — Suggested physiological criteria for determination of IREQ, $D_{lim}$ and local cooling**

| General cooling | "High strain" | "Low strain" |
|---|---|---|
| IREQ | Minimal | Neutral |
| $t_{sk}$ (°C) | $t_{sk} = 33{,}34 - 0{,}035\,4 \cdot M$ | $t_{sk} = 35{,}7 - 0{,}028\,5 \cdot M$ |
| $w$ (dimensionless) | 0,06 | $w = 0{,}001 \cdot$ M |
| $D_{lim}$ | Long | Short |
| $Q_{lim}$ (kJ · m$^{-2}$) | 144 | 144 |
| Local cooling | "High strain" | "Low strain" |
| Wind chill temperature, $t_{wc}$ | –30 | –15 |
| Finger temperature (°C) | 15 | 24 |
| Respiratory tract: | | |
| Low activity ($M \leqslant 115$ W · m$^{-2}$) | $t_a = -40$ | $t_a = -20$ |
| High activity ($M > 115$ W · m$^{-2}$) | $t_a = -30$ | $t_a = -15$ |

## B.3 Local cooling

Values for proposed criteria are given in Table B.1 for two levels of strain.

For convective cooling, two values are given for the effective cooling temperature ($t_{WC}$) determined according to Annex D.

Conductive cooling is assessed on the basis of ISO 13732-3.

Extremity cooling is evaluated by finger skin temperature.

Airway cooling is evaluated as a lowest temperature of air recommended for inhalation. At temperatures below –15 °C, respiratory protection is recommended for high activity levels (with increased ventilation volume). At temperatures below –30 °C, respiratory protection is strongly recommended.

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# Annex C
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# Metabolic rate and thermal properties of clothing

## C.1 Metabolic heat production

Methods for determination of metabolic heat production are given in ISO 8996. Table C.1 depicts examples of activities and the associated values for metabolic heat production.

**Table C.1 — Classification of metabolic rate for kinds of activities** (modified from ISO 8996)

| **Class** [a] | $m$<br>$\mathrm{W \cdot m^{-2}}$ | **Examples** |
|---|---|---|
| Resting | 65 | Resting, sitting |
| Very low metabolic rate | 80 | Light manual work (writing, typing, drawing); inspection, assembly or sorting of very light materials) |
| Low metabolic rate | 100 | Hand work (small bench tools); arm work (driving vehicle in normal conditions, operating foot switch or pedal); machining with low power tools; light strolling |
| Low-to-moderate metabolic rate | 140 | Hand and arm work at moderate pace; mounting and assembling light pieces of material |
| Moderate metabolic rate | 165 | Sustained hand and arm work (hammering in nails, filing); work with light equipment and tools; arm and leg work (off-road operation of lorries, tractors or construction equipment |
| Moderate-to-high metabolic rate | 175 | Arm and trunk work; work with pneumatic hammer; intermittent handling of moderately heavy material; pushing or pulling light-weight carts or wheelbarrows; walking at a speed of 4 km/h to 5 km/h; snowmobile driving |
| High metabolic rate | 230 | Intense arm and trunk work; carrying heavy material; shovelling; sledgehammer work; cutting trees by chainsaw; hand mowing; digging; walking at a speed of 5 km/h to 6 km/h; pushing or pulling heavily loaded handcarts or wheelbarrows; chipping castings; concrete block laying; snowmobile in heavy terrain |
| Very high metabolic rate | 290 | Very intense activity at fast to maximum pace; working with an axe; intense shovelling or digging; climbing stairs, ramp or ladder; walking quickly with small steps; running; walking at a speed greater than 6 km/h; walking in deep loose snow |
| Very, very high metabolic rate (up to 1 h to 2 h) | 400 | Very intense activity sustained without breaks; emergency and rescue work at high intensity |

[a] Indicated metabolic rate refers to the average of 60 min over a shift's continuous work.

## C.2 Basic and resultant insulation

Basic insulation specifies the insulation value under standardized (static, wind-still) conditions. Most insulation values available in the literature are basic insulation values ($I_{cl}$) and have been measured with a standing, static thermal manikin. ISO 9920 compiles a large variety of such data. Values of $I_{cl}$ for selected ensembles are presented here in Table C.2.

Resultant insulation defines the factual insulation provided by clothing under given conditions. Body movements and wind disturb still air layers and reduce clothing insulation. The effect depends on the air permeability of the fabrics, on the design and construction of garments, on the type of activity and how the clothing is worn. Garments made of windproof fabrics are less affected by wind. IREQ determined according to the present method is a resultant insulation value.

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$I_{cl}$ and its variation with, for example, body movements and wind, are inherent properties of a clothing ensemble and must be determined or estimated before a comparison can be made with IREQ. Measurements of clothing insulation on a movable thermal manikin under the influence of wind will provide more reliable information about the effective protection (resultant insulation) provided by the actual clothing in a real situation and whether or not it corresponds to IREQ.

NOTE EN 342 describes a method for determination of insulation values under walking conditions.

For the interpretation of IREQ, the $I_{cl}$ of selected clothing must be corrected for wind, walking and air permeability of the outer layer (see Annex A). The corrected value, $I_{cl,r}$, is used for comparison with the calculated IREQ value.

It needs to be emphasized that calculated IREQ is assumed to be evenly distributed over the body surface. IREQ refers to whole body thermal equilibrium, which does not necessarily mean that extremities are always kept warm. Local climate and protection influence the heat balance of hands and feet, for example, and must often be considered separately.

NOTE EN 511 describes methods for evaluation of cold protective gloves.

## C.3 Air permeability

Values for the air permeability of different outer layer fabrics are given in ISO 9920. Most types of outer garments for outdoor use are made of windproof fabrics and for these cases a standard value of 8 $l \cdot m^{-2} \cdot s^{-1}$ can be used.

## C.4 Moisture absorption

Too much clothing insulation compared to the required value ($IREQ_{neutral}$), particularly in combination with high activity, causes overheating. The associated sweating, sweat absorption and progressive wetting of clothing layers impair the insulation properties and can endanger an adequate body heat balance during prolonged stay in the cold. Under such conditions persons must have access to extra clothing for replacement and/or heated shelter for rest and pause.

## C.5 Individual behaviour and clothing requirements

Calculation of IREQ and the concomitant evaluation of heat balance apply to the average person. The interpretation of IREQ in terms of a required clothing insulation may only serve as a guideline for the individual. The individual variation in terms of physiological capacities, clothing behaviour and subjective demand is great. Preferably, the final choice and adjustment of clothing to the environment are to be made by the individual, according to his and her experiences, needs and preferences.

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**Table C.2 — Basic insulation values ($I_{cl}$) of selected garment ensembles measured with a thermal manikin** (based on ISO 9920)

| Clothing ensemble | $I_{cl}$ | |
|---|---|---|
| | $m^2 \cdot K \cdot W^{-1}$ | clo |
| 1. Briefs, short-sleeve shirt, fitted trousers, calf length socks, shoes | 0,08 | 0,5 |
| 2. Underpants, shirt, fitted trousers, socks, shoes | 0,10 | 0,6 |
| 3. Underpants, coverall, socks, shoes | 0,11 | 0,7 |
| 4. Underpants, shirt, coverall, socks, shoes | 0,13 | 0,8 |
| 5. Underpants, shirt, trousers, smock, socks, shoes | 0,14 | 0,9 |
| 6. Briefs, undershirt, underpants, shirt, overalls, calf length socks, shoes | 0,16 | 1,0 |
| 7. Underpants, undershirt, shirt, trousers, jacket, vest, socks, shoes | 0,17 | 1,1 |
| 8. Underpants, shirt, trousers, jacket, coverall, socks, shoes | 0,19 | 1,3 |
| 9. Undershirt, underpants, insulated trousers, insulated jacket, socks, shoes | 0,22 | 1,4 |
| 10. Briefs, T–shirt, shirt, fitted trousers, insulated coveralls, calf length socks, shoes | 0,23 | 1,5 |
| 11. Underpants, undershirt, shirt, trousers, jacket, overjacket, hat, gloves, socks, shoes | 0,25 | 1,6 |
| 12. Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes | 0,29 | 1,9 |
| 13. Underpants, undershirt, shirt, trousers, jacket, overjacket, overtrousers, socks, shoes, hat, gloves | 0,31 | 2,0 |
| 14. Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes | 0,34 | 2,2 |
| 15. Undershirt, underpants, insulated trousers, insulated jacket, overtrousers, overjacket, socks, shoes, hat, gloves | 0,40 | 2,6 |
| 16. Arctic clothing systems | 0,46 to 0,70 | 3 to 4,5 |
| 17. Sleeping bags | 0,46 to 1,4 | 3 to 9 |


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# Annex D
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## Determination of wind cooling

The wind causes a cooling effect on the skin. This effect may be expressed as a wind chill temperature. The wind chill temperature ($t_{WC}$) defines the ambient temperature, which at a wind speed of 4,2 km · h$^{-1}$ produces the same cooling power (sensation) as the actual environmental conditions. The wind chill temperature (in degrees Celsius) is determined by the following formula:

$$t_{WC} = 13{,}12 + 0{,}621\,5 \cdot t_a - 11{,}37 \cdot v_{10}^{0{,}16} + 0{,}396\,5 \cdot t_a v_{10}^{0{,}16} \quad \text{(D.1)}$$

Wind velocity ($v_{10}$) is defined as the standard meteorological value measured 10 m above ground level. This value is obtained from weather stations and weather forecasts. If the local wind velocity ($v_a$) at ground level is measured, it must be multiplied by 1,5 before it is inserted in Equation (D.1).

Calculated values for $t_{WC}$ and criteria associated with the evaluation of the risk of cold injury based on the index are given in Tables D.1 and D.2.

**Table D.1 — Cooling power of wind on exposed flesh expressed as a comparative wind chill temperature ($t_{WC}$) at a defined wind speed of 4,2 km · h$^{-1}$**

| $v_{10}$ | | $t_a$ °C | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| km·h$^{-1}$ | m·s$^{-1}$ | **0** | **–5** | **–10** | **–15** | **–20** | **–25** | **–30** | **–35** | **–40** | **–45** | **–50** |
| **5** | **1,4** | –2 | –7 | –13 | –19 | –24 | –30 | –36 | –41 | –47 | –53 | –58 |
| **10** | **2,8** | –3 | –9 | –15 | –21 | –27 | –33 | –39 | –45 | –51 | –57 | –63 |
| **15** | **4,2** | –4 | –11 | –17 | –23 | –29 | –35 | –41 | –48 | –54 | –60 | –66 |
| **20** | **5,6** | –5 | –12 | –18 | –24 | –31 | –37 | –43 | –49 | –56 | –62 | –68 |
| **25** | **6,9** | –6 | –12 | –19 | –25 | –32 | –38 | –45 | –51 | –57 | –64 | –70 |
| **30** | **8,3** | –7 | –13 | –20 | –26 | –33 | –39 | –46 | –52 | –59 | –65 | –72 |
| **35** | **9,7** | –7 | –14 | –20 | –27 | –33 | –40 | –47 | –53 | –60 | –66 | –73 |
| **40** | **11,1** | –7 | –14 | –21 | –27 | –34 | –41 | –48 | –54 | –61 | –68 | –74 |
| **45** | **12,5** | –8 | –15 | –21 | –28 | –35 | –42 | –48 | –55 | –62 | –69 | –75 |
| **50** | **13,9** | –8 | –15 | –22 | –29 | –35 | –42 | –49 | –56 | –63 | –70 | –76 |
| **55** | **15,3** | –9 | –15 | –22 | –29 | –36 | –43 | –50 | –57 | –63 | –70 | –77 |
| **60** | **16,7** | –9 | –16 | –23 | –30 | –37 | –43 | –50 | –57 | –64 | –71 | –78 |
| **65** | **18,1** | –9 | –16 | –23 | –30 | –37 | –44 | –51 | –58 | –65 | –72 | –79 |
| **70** | **19,4** | –9 | –16 | –23 | –30 | –37 | –44 | –51 | –59 | –66 | –73 | –80 |
| **75** | **20,8** | –10 | –17 | –24 | –31 | –38 | –45 | –52 | –59 | –66 | –73 | –80 |
| **80** | **22,2** | –10 | –17 | –24 | –31 | –38 | –45 | –52 | –60 | –67 | –74 | –81 |
| The shaded areas refer to the different classes of risk according to Table D.2. | | | | | | | | | | | | |

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**Table D.2 — Wind chill temperature ($t_{WC}$) and freezing time of exposed skin**

| Classification of risk | $t_{WC}$<br>°C | Effect |
|---|---|---|
| 1 | −10 to −24 | Uncomfortably cold |
| 2 | −25 to −34 | Very cold,<br>risk of skin freezing |
| 3 | −35 to −59 | Bitterly cold,<br>exposed skin may freeze in 10 min |
| 4 | −60 and colder | Extremely cold,<br>exposed skin may freeze within 2 min |


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# Annex E
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# Examples of evaluation of IREQ

## E.1 General

As previously mentioned, different procedures apply to the determination of IREQ and $D_{lim}$ when exposure to cold is continuous or intermittent. For extreme exposures with insufficient clothing insulation, a duration limited exposure ($D_{lim}$) and a required recovery time ($D_{rec}$) is calculated. Examples are given for both minimal and neutral “criteria”. IREQ values are given in clo[2)].

## E.2 Continuous exposure

$IREQ_{min}$ and $IREQ_{neutral}$ as a function of activity level (metabolic rate) and operative temperature are illustrated in Figures E.1 and E.2. In Figure E.3, minimal and neutral levels of IREQ are calculated for four activity levels as function of operative temperature. The area between the lines may be regarded as a “clothing regulatory zone”, in which an insulation level corresponding to various degrees of thermal strain and sensation may be selected. Values are given for a wind velocity of 0,4 $m \cdot s^{-1}$.

The effect of wind depends on the air permeability of the selected clothing ensemble, in particular the outer layer. A value of 8 $l \cdot m^{-2} \cdot s^{-1}$ is a typical value for many outdoor clothing materials. The effect of wind on such a garment assembly at an activity level of 90 $W \cdot m^{-2}$ is given in Figure E.4. The required insulation is expressed as the basic insulation value (cf. Table C.2).

A continuous work at 175 $W \cdot m^{-2}$ in –10 °C and calm wind gives an $IREQ_{neutral}$ of 1,6 clo (Figure E.1) or an $IREQ_{min}$ of 1,3 clo (Figure E.2). This corresponds to a basic insulation value ($I_{cl}$) of approx. 1,7 clo and 1,4 clo, respectively, calculated using Equation (A.15).

## E.3 Intermittent exposure

Work is often organized in more or less fixed work–rest regimens. An evaluation of cold stress is based on an analysis of the following.

a) The “coldest” interval, defined either by the lowest activity or the lowest temperature. The basic insulation value of the selected clothing determines whether heat balance can be maintained or calculates a recommended exposure time ($D_{lim}$).

b) The “warmest” interval, defined either by the highest activity or the highest temperature. The basic insulation value of selected clothing, as in a), determines whether heat balance can be maintained (usually the case) or calculates a recommended exposure time ($D_{lim}$).

Clothing that permits adjustments within this range of required insulation/exposure time is required. Outer layers are required to be easy to open and close and to don and doff. Removal of an insulated outer garment can correspond to a decrease in basic insulation by 1 clo or more.

2) 1 clo = 0,155 $m^2 \cdot K \cdot W^{-1}$.

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EXAMPLE 1 A worker operates a forklift in a cold store at −25 °C. He transports goods from the store room to an adjacent packing room with an air temperature at +5 °C, spending approximately an equal amount of time in the two conditions. His activity level is estimated at 115 W · m$^{-2}$. $IREQ_{neutral}$ for −25 °C and +5 °C is 3,6 clo and 1,5 clo, respectively (Figure E.1). Due to driving wind speed the selected clothing must provide a basic insulation value of at least 4,3 clo and 2,0 clo, respectively, with windproof outer layer (cf. Table C.2). These values are calculated using Equation (A.15). The available clothing provides 3,5 clo, which is likely to be a sufficient compromise between the two requirements.

EXAMPLE 2 In the same workplace as in Example 1, a worker is placing orders of frozen food in containers for the forklift driver. His activity is estimated at about 175 W · m$^{-2}$. His clothing provides a basic insulation of 3,5 clo (same as for the driver). $IREQ_{neutral}$ is determined at 2,2 clo (Figure E.1), requiring a basic insulation of at least 2,7 clo (Table C.2). This value is calculated using Equation (A.12). His clothing meets the insulation requirements and ought to be, in fact, a little bit too warm for this activity level. Reduction of insulation must be made by the worker himself by means of opening the garment and/or removing insulative under layers.

NOTE In both examples, clothing needs to be flexible and allow for easy adjustment and doffing during breaks and pauses in heated rooms.

## E.4 Duration limited exposure

At very low temperatures and low activity levels IREQ becomes high, indicating a high level of cold stress. A subject cannot sustain this cold stress, since available clothing for work under these conditions does not normally provide such a high insulation level. When $I_{cl}$ of available clothing is known, a recommended maximal exposure time ($D_{lim}$) can be calculated. Figures E.5 to E.8 depict calculated $D_{lim}$ values for several activity and insulation levels, expressed in terms of the basic insulation value ($I_{cl}$).

EXAMPLE A person working at 115 W·m$^{-2}$ at −15 °C (IREQ ≈ 2,9 clo), dressed in a garment assembly providing an $I_{cl}$ value of 2,0 clo is not permitted to work for a period longer than about 1 h and 20 min applying low strain criterion (Figure E.6). Increasing available garment insulation to 2,5 clo increases $D_{lim}$ to about 4 h. The corresponding required recovery time ($D_{rec}$) calculated for 1,5 clo at 90 W · m$^{-2}$ in a room at 25 °C, 0,2 m · s$^{-1}$ and 50 % r.h. (relative humidity) is 54 min.

The operative temperature is the integrated value of the air temperature and mean radiant temperature weighted according to values of the convective and radiation heat transfer coefficients, respectively. It is used for environmental temperature in the following figures.


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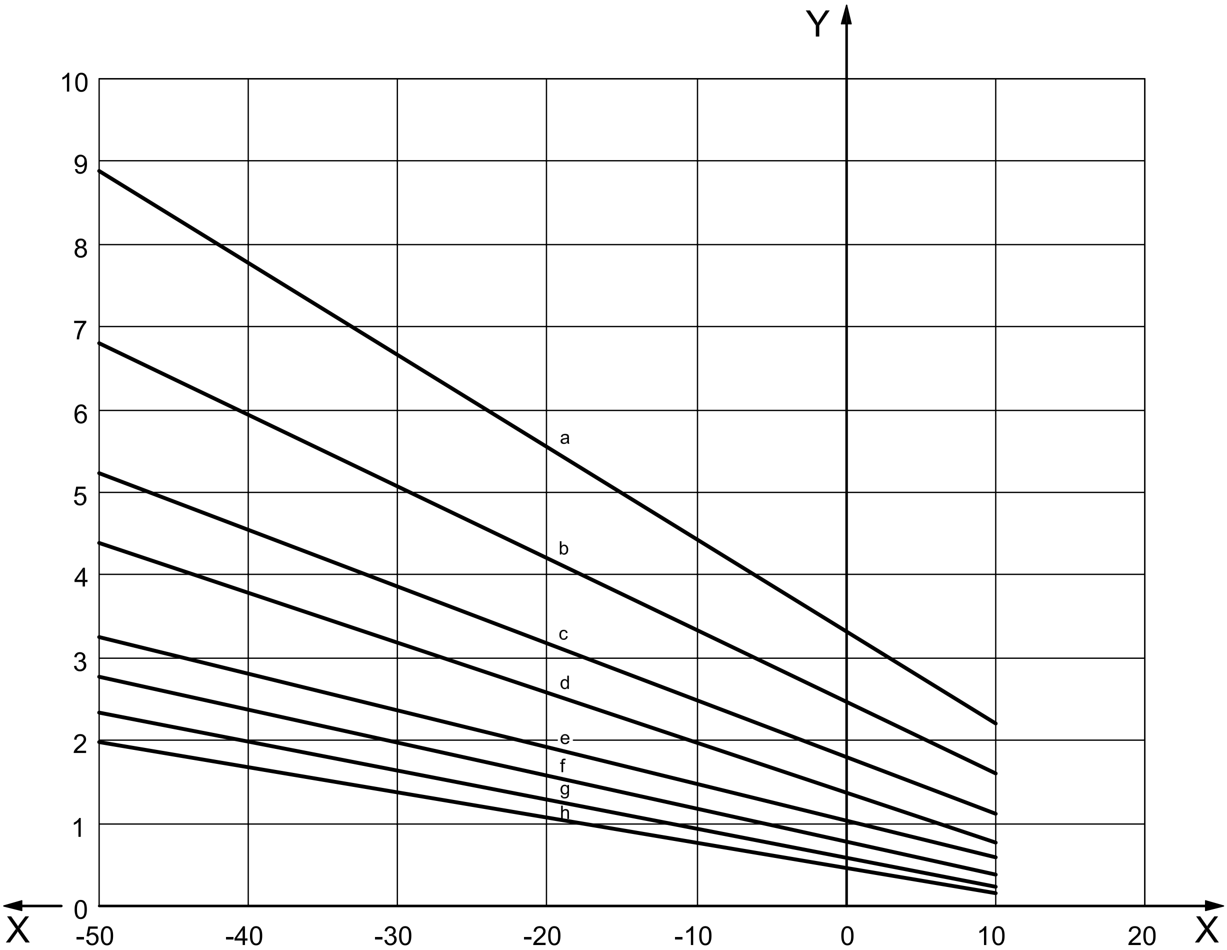


**Key**

X operative temperature, $t_o$, °C

Y IREQ, clo

Air velocity: 0,4 m·s$^{-1}$

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 70 W · m$^{-2}$

b 90 W · m$^{-2}$

c 115 W · m$^{-2}$

d 145 W · m$^{-2}$

e 175 W · m$^{-2}$

f 200 W · m$^{-2}$

g 230 W · m$^{-2}$

h 260 W · m$^{-2}$

**Figure E.1 — IREQ$_{neutral}$ as function of operative temperature at eight levels of metabolic rate**

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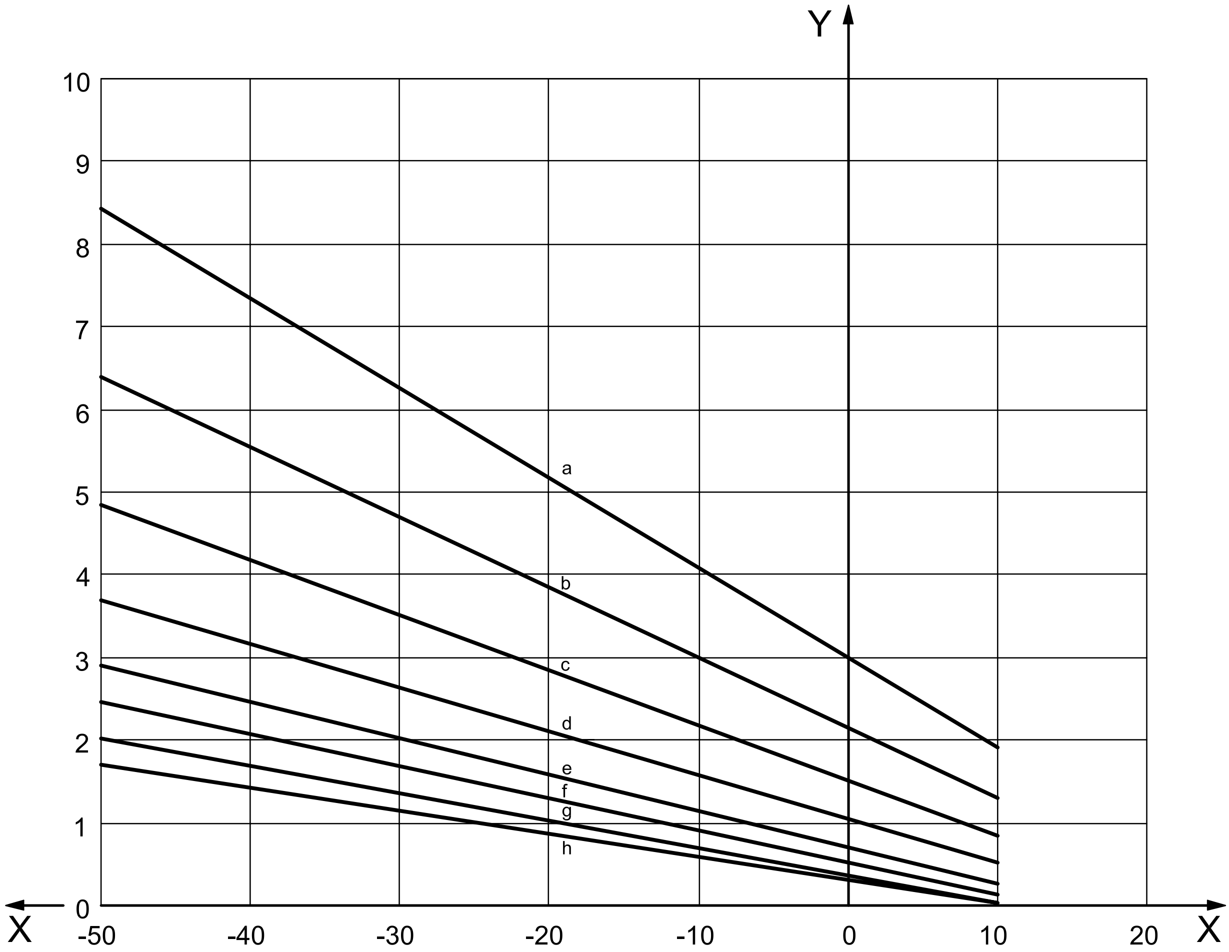


**Key**

X operative temperature, $t_o$, °C

Y IREQ, clo

Air velocity: 0,4 m·s$^{-1}$

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 70 W · m$^{-2}$

b 90 W · m$^{-2}$

c 115 W · m$^{-2}$

d 145 W · m$^{-2}$

e 175 W · m$^{-2}$

f 200 W · m$^{-2}$

g 230 W · m$^{-2}$

h 260 W · m$^{-2}$

**Figure E.2 — IREQ$_{min}$ as function of operative temperature at eight levels of metabolic rate**



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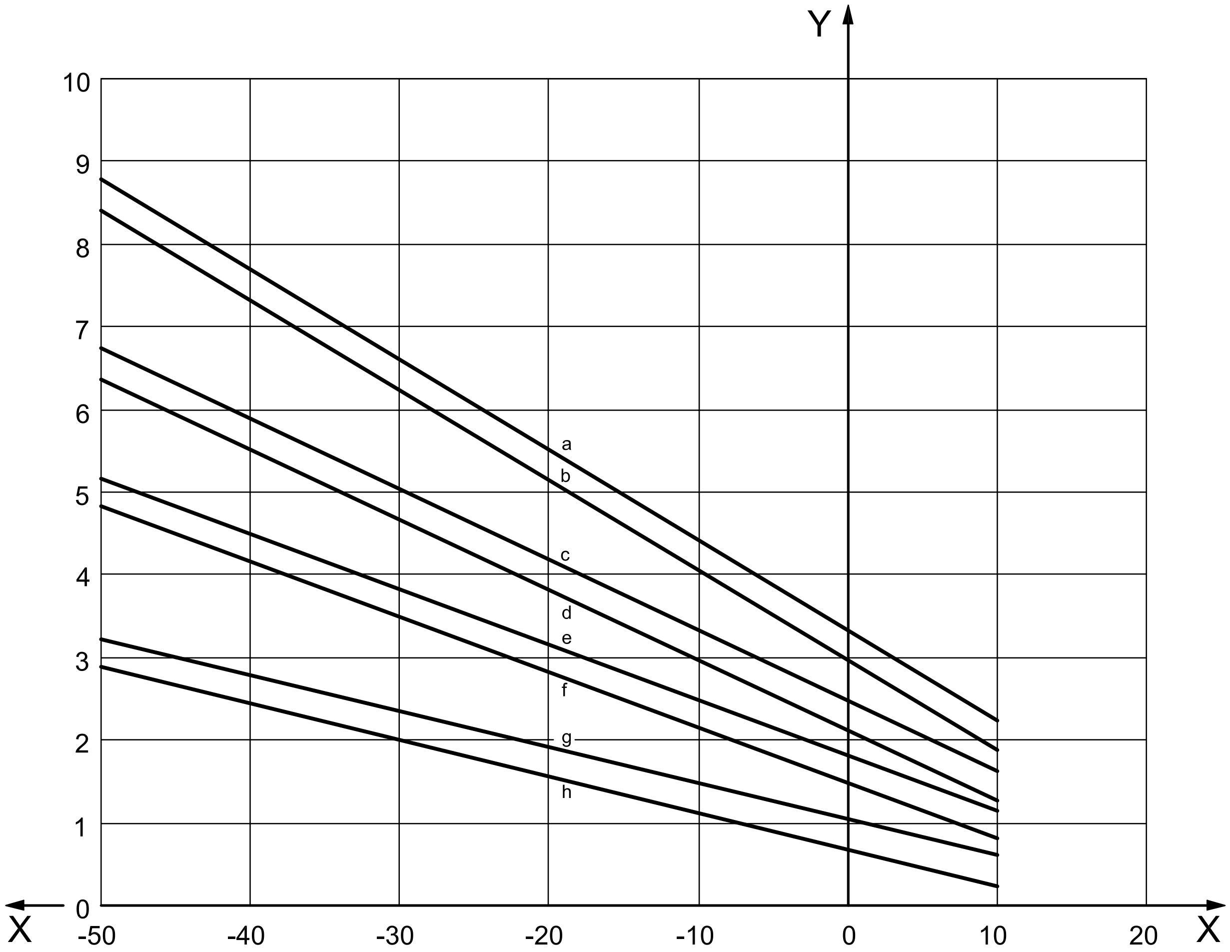


**Key**

X operative temperature, $t_o$, °C

Y IREQ, clo

Air velocity: 0,4 m·s$^{-1}$

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

| | | |
|---|---|---|
| a | 70 W · m$^{-2}$ | $IREQ_{neutral}$ |
| b | 70 W · m$^{-2}$ | $IREQ_{min}$ |
| c | 90 W · m$^{-2}$ | $IREQ_{neutral}$ |
| d | 90 W · m$^{-2}$ | $IREQ_{min}$ |
| e | 115 W · m$^{-2}$ | $IREQ_{neutral}$ |
| f | 115 W · m$^{-2}$ | $IREQ_{min}$ |
| g | 175 W · m$^{-2}$ | $IREQ_{neutral}$ |
| h | 175 W · m$^{-2}$ | $IREQ_{min}$ |

**Figure E.3 — Comparison of $IREQ_{min}$ and $IREQ_{neutral}$ at four levels of metabolic rate**

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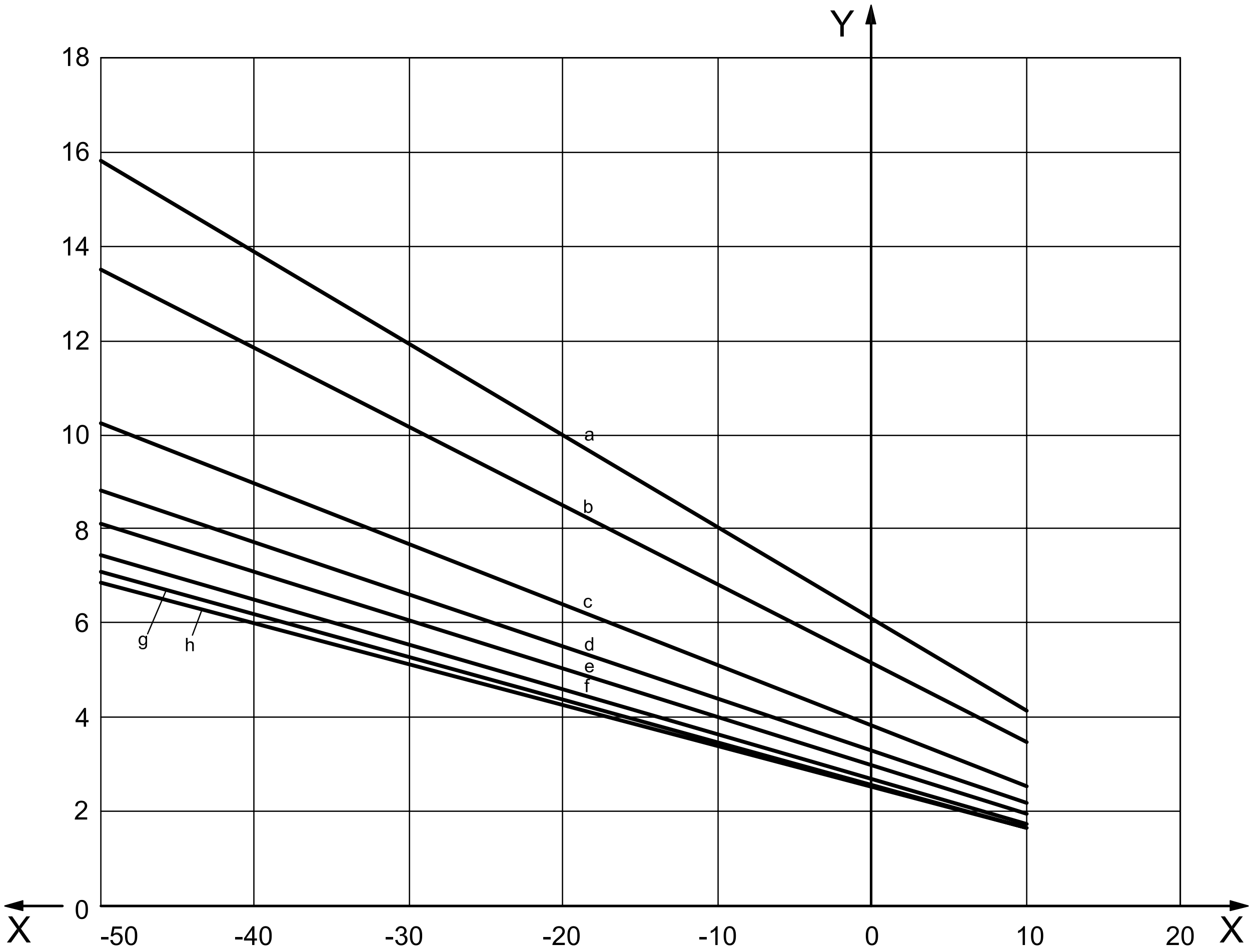


**Key**

X operative temperature, $t_o$, °C

Y IREQ, clo

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 15 m/s

b 10 m/s

c 5 m/s

d 3 m/s

e 2 m/s

f 1 m/s

g 0,5 m/s

h 0,2 m/s

**Figure E.4 — Effect of wind on the required basic insulation value to be provided at an activity of 90 W · m$^{-2}$ by an ensemble with an outer layer of medium air permeability**


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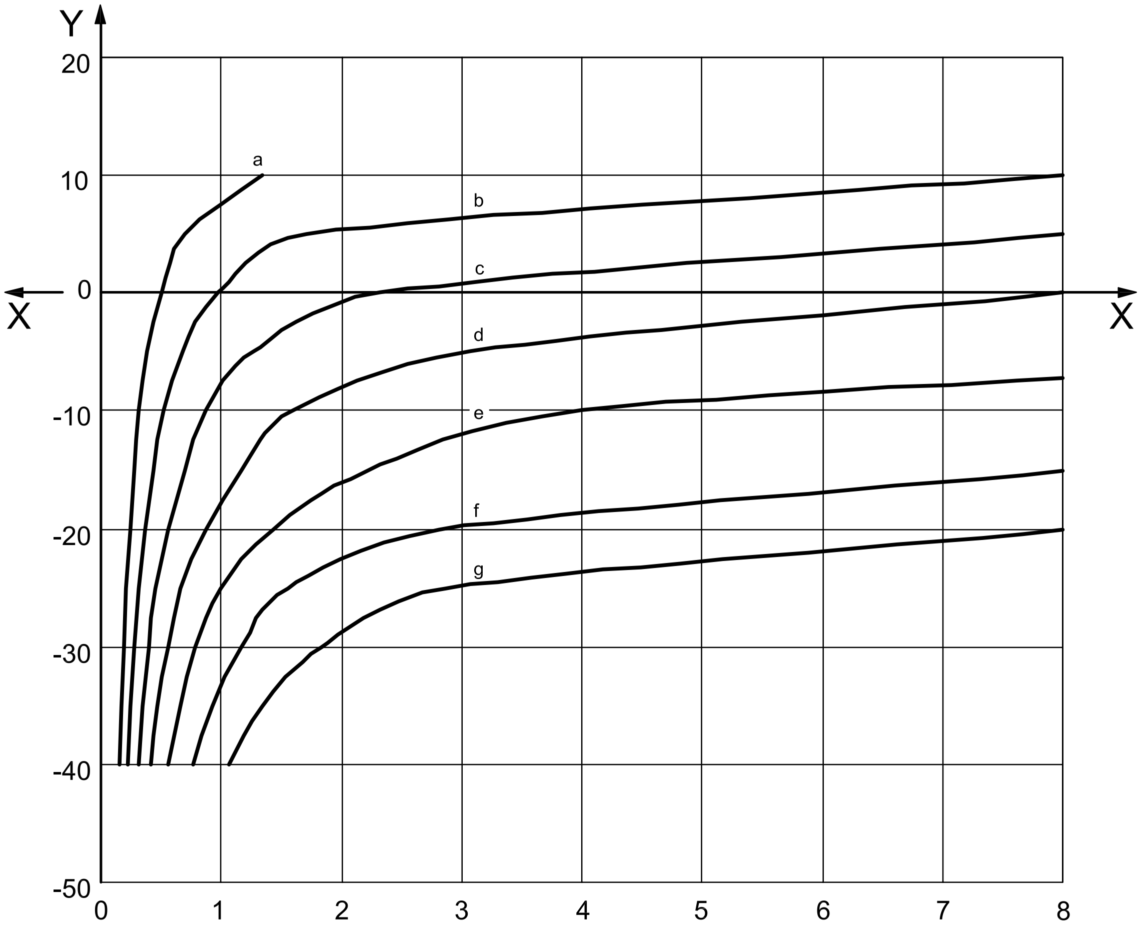


**Key**

X $D_{lim}$, h

Y operative temperature, $t_o$, °C

Air velocity: 0,4 m/s

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 0,5 clo

b 1 clo

c 1,5 clo

d 2 clo

e 2,5 clo

f 3 clo

g 3,5 clo

**Figure E.5 — Recommended duration limited exposure ($D_{lim}$) for low strain (neutral) at an activity of 90 W · m$^{-2}$ for seven basic clothing insulation values** (cf. Table C.2)

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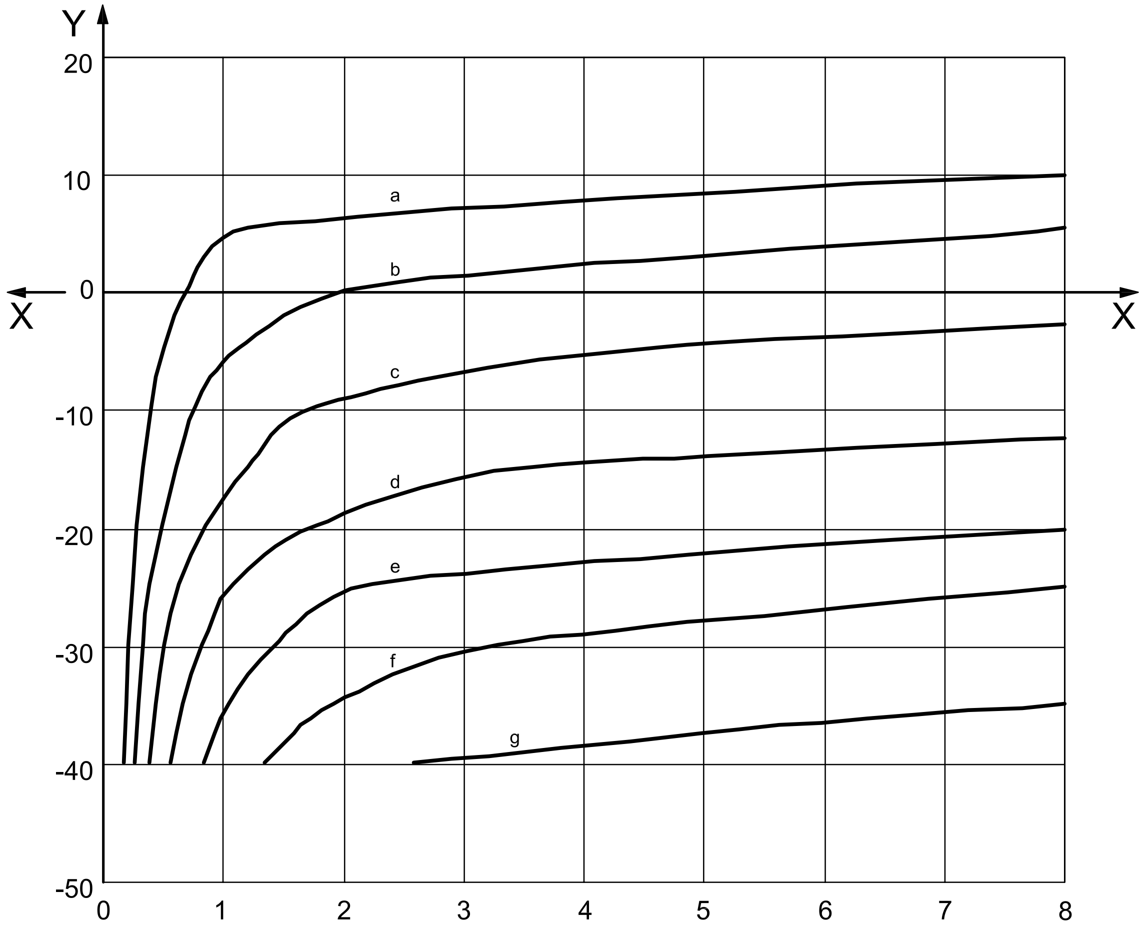


**Key**

X $D_{lim}$, h

Y operative temperature, $t_o$, °C

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 0,5 clo

b 1 clo

c 1,5 clo

d 2 clo

e 2,5 clo

f 3 clo

g 3,5 clo

**Figure E.6 — Recommended duration limited exposure ($D_{lim}$) for low strain (neutral) at an activity level of 115 W · m$^{-2}$ for seven basic clothing insulation values** (cf. Table C.2)


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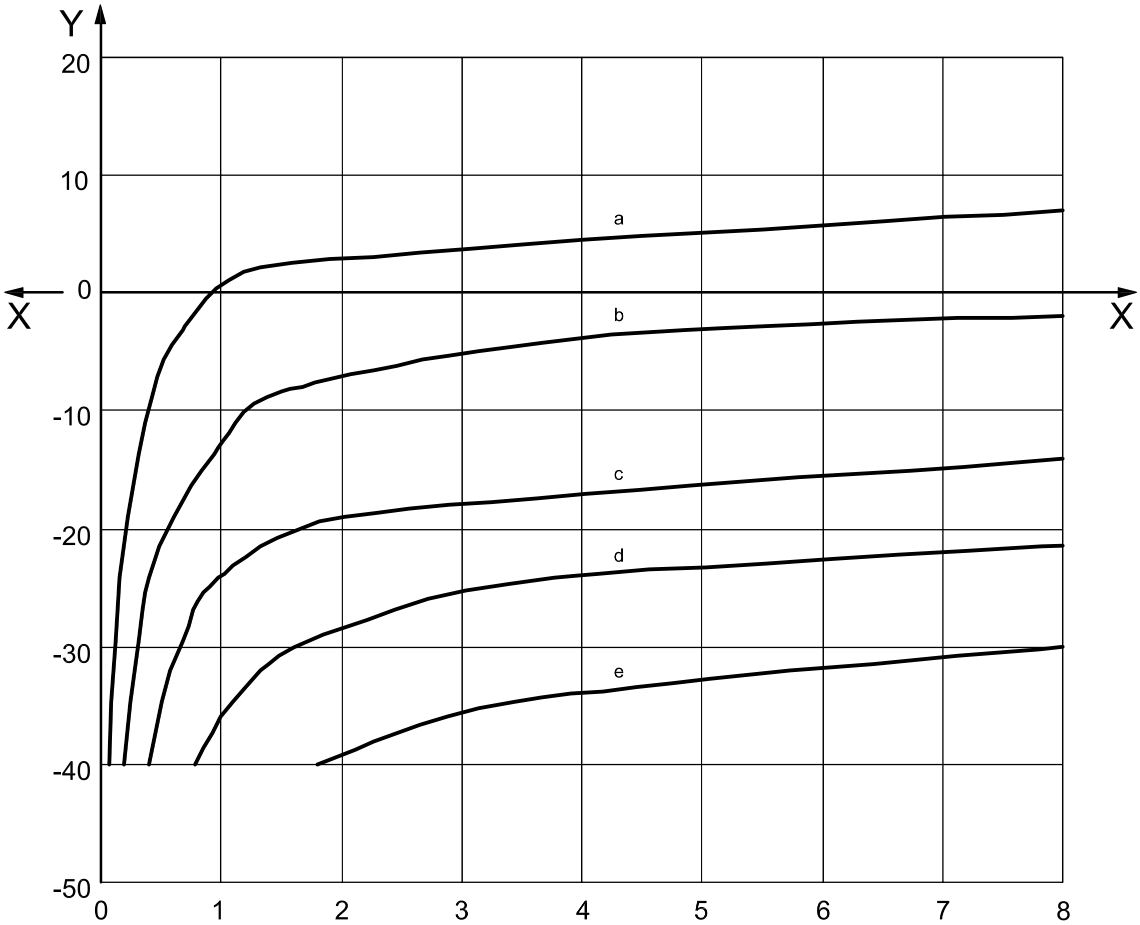


**Key**

X $D_{lim}$, h

Y operative temperature, $t_o$, °C

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 1 clo

b 1,5 clo

c 2 clo

d 2,5 clo

e 3 clo

**Figure E.7 — Recommended duration limited exposure ($D_{lim}$) for low strain (neutral) at an activity level of 145 W · m$^{-2}$ for five basic clothing insulation values** (cf. Table C.2)

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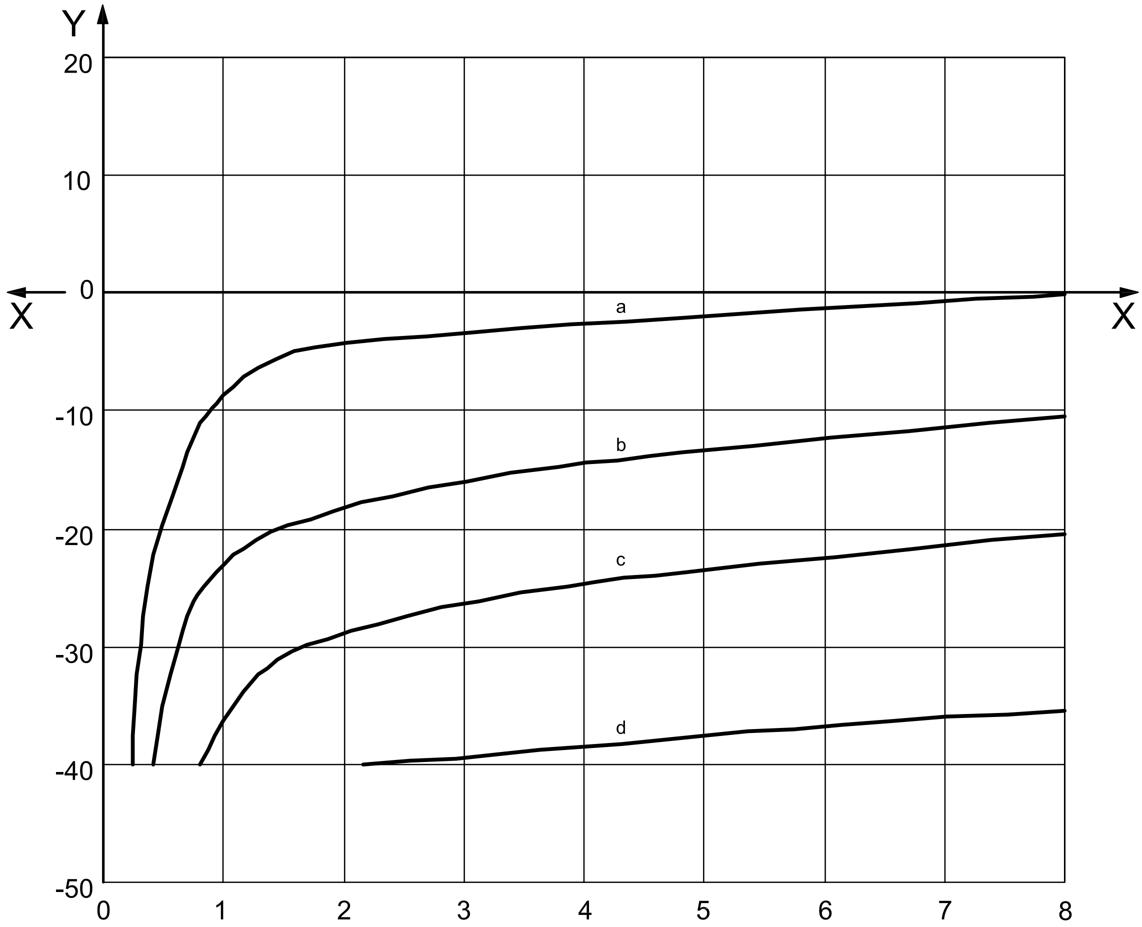


**Key**

X $D_{lim}$, h

Y operative temperature, $t_o$, °C

Air permeability of outer layer: 8 l · m$^{-2}$ · s$^{-1}$

a 1 clo

b 1,5 clo

c 2 clo

d 2,5 clo

**Figure E.8 — Recommended duration limited exposure ($D_{lim}$) for low strain (neutral) at an activity level of 175 W · m$^{-2}$ for four basic clothing insulation values** (cf. Table C.2)


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# Annex F
(informative)

## Computer program for calculating IREQ

The internet site whose address is given below provides a fully operational program for calculation of IREQ and $D_{lim}$. The same site offers a downloadable copy of the program that can be run on any personal computer with javascript installed. Always check for the latest version at this address:

http://wwwold.eat.lth.se/Forskning/Termisk/Termisk_HP/Klimatfiler/IREQ2002alfa.htm

Table F.1 presents calculation examples.

**Table F.1 — Calculation examples**

| Input values | | | | | Calculated values | | |
|---|---|---|---|---|---|---|---|
| **Air temperature**<br>°C | **Mean radiant temperature**<br>°C | **Wind**<br>$m \cdot s^{-1}$ | **Metabolic rate**<br>$W \cdot m^{-2}$ | **Basic thermal insulation of used clothing**<br>clo | $IREQ_{neutral}$<br>clo | **Required basic thermal insulation**<br>clo | **Duration limited exposure** $D_{lim}$<br>h |
| 0 | 0 | 2 | 90 | 2,5 | 2,6 | 3,1 | 2,3 |
| 0 | 0 | 2 | 145 | 2,5 | 1,5 | 1,8 | >8 |
| −10 | −10 | 2 | 90 | 2,5 | 3,5 | 4,4 | 0,7 |
| −10 | 0 | 2 | 145 | 2,4 | 1,9 | 2,4 | >8 |
| −20 | −20 | 2 | 115 | 4,2 | 3,4 | 4,2 | >8 |
| −20 | −20 | 7 | 115 | 4,2 | 3,5 | 5,9 | 1,1 |
| −30 | −30 | 2 | 115 | 4,2 | 4,0 | 5,0 | 2,2 |
| −30 | −30 | 5 | 175 | 4,2 | 2,6 | 4,0 | >8 |
| Rate of mechanical work, $W = 0$<br>Relative humidity in all examples: 85 %<br>Air permeability of clothing: $8\ l \cdot m^{-2} \cdot s^{-1}$ | | | | | | | |

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