INTERNATIONAL STANDARD

ISO 7345
Second edition
1987-12-01

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION
ORGANISATION INTERNATIONALE DE NORMALISATION
МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ

Thermal insulation — Physical quantities and definitions

Isolation thermique — Grandeurs physiques et définitions

Reference number
ISO 7345 : 1987 (E)

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.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council. They are approved in accordance with ISO procedures requiring at least 75 % approval by the member bodies voting.

International Standard ISO 7345 was prepared by Technical Committee ISO/TC 163, *Thermal insulation*.

This second edition cancels and replaces the first edition (ISO 7345 : 1985); clauses 0 and 3 are new.

Users should note that all International Standards undergo revision from time to time and that any reference made herein to any other International Standard implies its latest edition, unless otherwise stated.

Printed in Switzerland

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Thermal insulation — Physical quantities and definitions

0 Introduction

This International Standard forms part of a series of vocabularies related to thermal insulation.

The series will include

ISO 7345, *Thermal insulation — Physical quantities and definitions.*

ISO 9251, *Thermal insulation — Heat transfer conditions and properties of materials — Vocabulary.*

ISO 9346, *Thermal insulation — Mass transfer — Physical quantities and definitions.*

ISO 9229, *Thermal insulation — Thermal insulating materials and products — Vocabulary.*[1]

ISO 9288, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions.*[1]

1 Scope and field of application

This International Standard defines physical quantities used in the field of thermal insulation, and gives the corresponding symbols and units.

NOTE — Because the scope of this International Standard is restricted to thermal insulation, some of the definitions given in clause 2 differ from those given in ISO 31/4, *Quantities and units of heat*. To identify such differences an asterisk has been inserted before the term concerned.

2 Physical quantities and definitions	Quantity	Unit
2.1 heat; quantity of heat	Q	J
2.2 heat flow rate: Quantity of heat transferred to or from a system divided by time: $\Phi = \frac{dQ}{dt}$	Φ	W
2.3 density of heat flow rate: Heat flow rate divided by area: $q = \frac{d\Phi}{dA}$ NOTE — The word "density" should be replaced by "surface density" when it may be confused with "linear density" (2.4).	q	W/m^2

1) In preparation.

	Quantity	Unit
2.4 linear density of heat flow rate: Heat flow rate divided by length:	q_l	W/m

$$q_l = \frac{d\Phi}{dl}$$

	Quantity	Unit
2.5 thermal conductivity: Quantity defined by the following relation:	λ	W/(m·K)

$$\vec{q} = -\lambda \text{ grad } T$$

NOTE — A rigorous treatment of the concept of thermal conductivity is given in the annex, which also deals with the application of the concept of thermal conductivity to porous isotropic or anisotropic materials and the influence of temperature and test conditions.

	Quantity	Unit
2.6 thermal resistivity: Quantity defined by the following relation:	r	(m·K)/W

$$\text{grad } T = -r\vec{q}$$

NOTE — A rigorous treatment of the concept of thermal resistivity is given in the annex.

	Quantity	Unit
2.7 *thermal resistance:[1] Temperature difference divided by the density of heat flow rate in the steady state condition:	R	$(m^2 \cdot K)/W$

$$R = \frac{T_1 - T_2}{q}$$

NOTES

1 For a plane layer for which the concept of thermal conductivity applies, and when this property is constant or linear with temperature (see the annex):

$$R = \frac{d}{\lambda}$$

where d is the thickness of the layer.

These definitions assume the definition of two reference temperatures, T_1 and T_2, and the area through which the density of heat flow rate is uniform.

Thermal resistance can be related either to the material, structure or surface. If either T_1 or T_2 is not the temperature of a solid surface, but that of a fluid, a reference temperature must be defined in each specific case (with reference to free or forced convection and radiation from surrounding surfaces, etc.).

When quoting values of thermal resistance, T_1 and T_2 must be stated.

2 "Thermal resistance" should be replaced by "surface thermal resistance" when it may be confused with "linear thermal resistance" (2.8).

	Quantity	Unit
2.8 *linear thermal resistance:[1] Temperature difference divided by the linear density of heat flow rate in the steady state condition:	R_l	(m·K)/W

$$R_l = \frac{T_1 - T_2}{q_l}$$

NOTE — This assumes the definition of two reference temperatures, T_1 and T_2, and the length along which the linear density of heat flow rate is uniform.

If within the system either T_1 or T_2 is not the temperature of a solid surface, but that of a fluid, a reference temperature must be defined in each specific case (with reference to free or forced convection and radiation from surrounding surfaces, etc.).

When quoting values of linear thermal resistance, T_1 and T_2 must be stated.

1) In ISO 31/4, "thermal resistance" is called "thermal insulance" or "coefficient of thermal insulation", with the symbol M.

	Quantity	Unit
2.9 surface coefficient of heat transfer: Density of heat flow rate at a surface in the steady state divided by the temperature difference between that surface and the surroundings: $$h = \frac{q}{T_s - T_a}$$ NOTE — This assumes the definition of the surface through which the heat is transferred, the temperature of the surface, T_s, and the ambient temperature, T_a (with reference to free or forced convection and radiation from surrounding surfaces, etc.).	h	W/(m²·K)
2.10 thermal conductance: Reciprocal of thermal resistance from surface to surface under conditions of uniform density of heat flow rate: $$\Lambda = \frac{1}{R}$$ NOTE — "Thermal conductance" should be replaced by "surface thermal conductance" when it may be confused with "linear thermal conductance" (2.11).	Λ	W/(m²·K)
2.11 linear thermal conductance: Reciprocal of linear thermal resistance from surface to surface under conditions of uniform linear density of heat flow rate: $$\Lambda_l = \frac{1}{R_l}$$	Λ_l	W/(m·K)
2.12 thermal transmittance: Heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on each side of a system: $$U = \frac{\Phi}{(T_1 - T_2)A}$$ NOTES 1 This assumes the definition of the system, the two reference temperatures, T_1 and T_2, and other boundary conditions. 2 "Thermal transmittance" should be replaced by "surface thermal transmittance" when it may be confused with "linear thermal transmittance" (2.13). 3 The reciprocal of the thermal transmittance is the total thermal resistance between the surroundings on each side of the system.	U	W/(m²·K)
2.13 linear thermal transmittance: Heat flow rate in the steady state divided by length and by the temperature difference between the surroundings on each side of a system: $$U_l = \frac{\Phi}{(T_1 - T_2)\,l}$$ NOTES 1 This assumes the definition of the system, the two reference temperatures, T_1 and T_2, and other boundary conditions. 2 The reciprocal of the linear thermal transmittance is the total linear thermal resistance between the surroundings on each side of the system.	U_l	W/(m·K)
2.14 heat capacity: Quantity defined by the equation: $$C = \frac{dQ}{dT}$$ NOTE — When the temperature of a system is increased by dT as a result of the addition of a small quantity of heat dQ, the quantity dQ/dT is the heat capacity.	C	J/K

	Quantity	Unit
2.15 specific heat capacity: Heat capacity divided by mass.	c	J/(kg·K)
2.15.1 specific heat capacity at constant pressure	c_p	J/(kg·K)
2.15.2 specific heat capacity at constant volume	c_V	J/(kg·K)
2.16 *thermal diffusivity: Thermal conductivity divided by the density and the specific heat capacity:	a	m^2/s

$$a = \frac{\lambda}{\varrho c}$$

NOTES

1 For fluids the appropriate specific heat capacity is c_p.

2 The definition assumes that the medium is homogeneous and opaque.

3 The thermal diffusivity is relevant to the non-steady state and may be measured directly or calculated from separately measured quantities by the above formula.

4 Among others, thermal diffusivity accounts for the response of the temperature at a location inside a material to a change of temperature at the surface. The higher the thermal diffusivity of the material, the more sensitive the interior temperature is to changes of the surface temperature.

	Quantity	Unit
2.17 thermal effusivity: Square root of the product of thermal conductivity, density and specific heat capacity:	b	$J/(m^2 \cdot K \cdot s^{1/2})$

$$b = \sqrt{\lambda \varrho c}$$

NOTES

1 For fluids the appropriate specific heat capacity is c_p.

2 This property is relevant to the non-steady state. It may be measured or calculated from separately measured quantities by the above formula. Among others, thermal effusivity accounts for the response of a surface temperature to a change of the density of heat flow rate at the surface. The lower the thermal effusivity of the material the more sensitive the surface temperature is to changes of heat flow at the surface.

3 Energy performance of buildings

	Quantity	Unit
3.1 volume coefficient of heat loss: Heat flow rate from the building divided by the volume and by the difference of temperature between the internal and external environment:	F_v	$W/(m^3 \cdot K)$

$$F_v = \frac{\Phi}{V \cdot \Delta T}$$

NOTE — The heat flow rate may optionally include the contributions of heat transmissions through the building envelope, ventilation, solar radiation, etc. The volume, V, shall be defined.

The use of volume coefficient of heat loss assumes a conventional definition of internal temperature, external temperature, volume and the different contributions resulting in the heat flow rate.

	Quantity	Unit
3.2 areal coefficient of heat loss: Heat flow rate from the building divided by the area and the difference of temperature between the internal and external environment:	F_s	$W/(m^2 \cdot K)$

$$F_s = \frac{\Phi}{A \cdot \Delta T}$$

	Quantity	Unit
NOTE — The heat flow rate may optionally include the contributions of heat transmissions through the building envelope, ventilation, solar radiation, etc. The area may optionally be the envelope area, the floor area, etc. The use of areal coefficients of heat loss assumes a conventional definition of internal temperature, external temperature, area and the different contributions resulting in the heat flow rate.		
3.3 ventilation rate: Number of air changes in a defined volume divided by time.	n	h^{-1}
NOTE — The unit for ventilation rate, h^{-1}, is not an SI unit. However, the number of air changes per hour is the generally accepted way to express ventilation rate.		
4 Symbols and units for other quantities		
4.1 thermodynamic temperature	T	K
4.2 Celsius temperature	θ	°C
4.3 thickness	d	m
4.4 length	l	m
4.5 width; breadth	b	m
4.6 area	A	m^2
4.7 volume	V	m^3
4.8 diameter	D	m
4.9 time	t	s
4.10 mass	m	kg
4.11 density	ϱ	kg/m^3

5 Subscripts

In order to avoid confusion, it will often be necessary to use subscripts or other identification marks. In these cases, their meaning shall be explicit.

However, the following subscripts are recommended.

interior	i
exterior	e
surface	s
interior surface	si
exterior surface	se
conduction	cd
convection	cv
radiation	r
contact	c
gas (air) space	g
ambient	a

Annex

Concept of thermal conductivity

A.0 Introduction

To facilitate the understanding of the applicability of the concept of thermal conductivity, this annex sets out a more rigorous mathematical treatment.

A.1 Thermal gradient grad T at a point P

This is a vector in the direction of the normal n to the isothermal surface containing P. Its magnitude is equal to the derivative of the temperature T versus the distance from P along this normal, n, the unit vector of which is $\vec{e}_n$.

From this definition

$$\text{grad } T \cdot \vec{e}_n = \frac{\partial T}{\partial n} \qquad \ldots (1)$$

A.2 (Surface) density of heat flow rate, q, at a point P (of a surface through which heat is transferred)

This is defined as

$$q = \left(\frac{\mathrm{d}\Phi}{\mathrm{d}A}\right)_\mathrm{P} \qquad \ldots (2)$$

When dealing with heat exchanged by conduction at each point of the body where conduction exists, the quantity q depends on the orientation of the surface (i.e. on the orientation of the normal at P to the surface of area A) and it is possible to find a direction, n, normal to a surface of area A_n containing P where the value of q is maximum and designated by vector $\vec{q}$:

$$\vec{q} = \left(\frac{\partial \Phi}{\partial A_n}\right)_\mathrm{P} \vec{e}_n \qquad \ldots (3)$$

For any other surface of area A_s containing P, the (surface) density of heat flow rate, q is the component of $\vec{q}$ in the direction s normal to that surface at P.

Vector $\vec{q}$ is given the name "thermal flux density" (not "heat flux density"). "Thermal flux" and "heat flow rate" are equivalent expressions when dealing with conduction. Whenever vector $\vec{q}$ cannot be defined (in convection and in most cases of radiation), only the expressions "heat flow rate" and "(surface) density of heat flow rate" shall be used.

A.3 Thermal resistivity, r, at a point P

This is the quantity that permits the computation by Fourier's law of the vector grad T at point P from the vector $\vec{q}$ at point P. The simplest situation (thermally isotropic materials) is when grad T and $\vec{q}$ are parallel and opposite, so that r is defined at each point as the proportionality constant relating the vectors grad T and $\vec{q}$:

$$\text{grad } T = -r\vec{q} \qquad \ldots (4)$$

In this case, r is also the opposite of the ratio at the same point between the components of grad T and $\vec{q}$ along any direction s and does not depend on the direction s chosen.

In the general case (thermally isotropic or anisotropic materials), each of the three components that define grad T is a linear combination of the components of the vector $\vec{q}$. The thermal resistivity is, therefore, defined through the tensor $[\vec{\vec{r}}]$ of the nine coefficients of these linear combinations and through the following formal relationship:

$$\text{grad } T = -[\vec{\vec{r}}] \cdot \vec{q} \qquad \ldots (5)$$

If the thermal resistivity r or $[\vec{\vec{r}}]$ is constant with respect to coordinates and time, it may be assumed as a thermal property at a given temperature.

A.4 Thermal conductivity, λ, at a point P

This is the quantity that permits the computation of the vector $\vec{q}$ at P from the vector grad T at P, i.e. its product with thermal resistivity is one or a unit tensor. If $\vec{q}$ and grad T are parallel and opposite, it is

$$\vec{q} = -\lambda \text{ grad } T$$
$$\lambda r = 1 \qquad \ldots (6)$$

Like thermal resistivity, thermal conductivity is, in the most general case, a tensor $[\vec{\vec{\lambda}}]$ of the nine coefficients of the linear combinations of the components of grad T that define each component of $\vec{q}$, through the following formal relationship:

$$\vec{q} = -\vec{\vec{\lambda}} \text{ grad } T \qquad \ldots (7)$$

It is obvious that $[\vec{\vec{\lambda}}]$ may be obtained by inverting $[\vec{\vec{r}}]$ and vice versa. If the thermal conductivity λ or $[\vec{\vec{\lambda}}]$ is constant with respect to coordinates and time, it may be assumed as a thermal property at a given temperature.

The thermal conductivity may be a function of the temperature and of the direction (anisotropic material); it is, therefore, necessary to know the relationship with these parameters.

Consider a body of thickness d, bounded by two plane parallel and isothermal faces of temperatures T_1 and T_2, each of these faces having an area A. The lateral edges bounding the main faces of this body are assumed to be adiabatic and perpendicular to them. Suppose that the material form of which the body is made is stable, homogeneous and isotropic (or anisotropic with a symmetry axis normal to the main faces). In such conditions, the following relationships, derived from Fourier's law under steady state conditions, apply if the thermal conductivity λ or $[\vec{\lambda}]$ or thermal resistivity r or $[\vec{r}]$ is independent of temperature.

$$\lambda = \frac{1}{r} = \frac{\Phi d}{A(T_1 - T_2)} = \frac{d}{R} \quad \ldots (8)$$

$$R = \frac{A(T_1 - T_2)}{\Phi} = \frac{d}{\lambda} = rd \quad \ldots (9)$$

If all the above conditions are met except that the thermal conductivity λ or $[\vec{\lambda}]$ is a linear function of temperature, the above relationships still apply if the thermal conductivity is computed at the mean temperature $T_m = (T_1 + T_2)/2$.

Similarly, if a body of length l is bounded by two coaxial cylindrical isothermal surfaces of temperatures T_1 and T_2 and of diameters D_i and D_e, respectively, and if the ends of the body are flat adiabatic surfaces perpendicular to the cylinders, then, for materials that are stable, homogeneous and isotropic, the following relationships, derived from Fourier's law under steady state conditions, apply if the thermal conductivity λ or thermal resistivity r are independent of temperature:

$$\lambda = \frac{1}{r} = \frac{\Phi \ln \frac{D_e}{D_i}}{2\pi l (T_1 - T_2)} = \frac{\frac{D}{2} \ln \frac{D_e}{D_i}}{R} \quad \ldots (10)$$

$$R = \frac{(T_1 - T_2)\pi l D}{\Phi} = \frac{1}{\lambda}\frac{D}{2}\ln\frac{D_e}{D_i} = r\frac{D}{2}\ln\frac{D_e}{D_i} \quad \ldots (11)$$

where D may be either the external or the internal diameter or any other specified diameter.

If all above conditions are met except that the thermal conductivity λ is a linear function of temperature, the above relationships still apply if the thermal conductivity is computed at the mean temperature $T_m = (T_1 + T_2)/2$.

With the above limitations, formulae (8) and (10) are normally used to derive from measured quantities the thermal conductivity of homogeneous opaque medium at a mean temperature T_m.

The same formulae (8) and (10) are often used to derive from measured quantities a thermal property of porous media for which heat transfers are more complex and can follow three modes: radiation, conduction and, sometimes, convection. The measured thermal property that takes all these transfers into account can still be called thermal conductivity (sometimes called apparent, equivalent or effective thermal conductivity) when, for a medium of homogeneous porosity, it is essentially independent of the geometrical dimensions of the specimen, of the emitting properties of the surfaces which limit this specimen and of the temperature difference $(T_1 - T_2)$.

When these conditions are not fulfilled, the surface thermal resistance must be used to characterize a specimen of a given geometry under a given temperature difference $(T_1 - T_2)$ and under given emittances of the boundary surfaces.

UDC 669.86 : 001.4

Descriptors: thermal insulation, physical indices, definitions, symbols, units of measurement.

Price based on 7 pages