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Thermal insulation — Physical quantities and definitions

Isolation thermique — Grandeurs physiques et définitions

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Foreword

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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*.

Contents

Thermal insulation — Physical quantities and definitions

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

	Symbol for quantity	Symbol for unit
2.1 heat; quantity of heat	Q	J
2.2 heat flow rate: The 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/m²
2.4 linear density of heat flow rate: Heat flow rate divided by length: $$q_l = \frac{d\Phi}{dl}$$	q_l	W/m
2.5 thermal conductivity: Quantity defined by the following relation: $$\vec{q} = -\lambda \operatorname{grad} T$$ 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 testing conditions.	λ	W/(m·K)
2.6 thermal resistivity: Quantity defined by the following relation: $$\operatorname{grad} T = -r\vec{q}$$ NOTE — A rigorous treatment of the concept of thermal resistivity is given in the annex.	r	(m·K)/W

2.7 * thermal resistance:[1] Temperature difference divided by the density of heat flow rate in the steady state condition:

Symbol for quantity	Symbol for unit
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).

2.8 * linear thermal resistance:[2] Temperature difference divided by the linear density of heat flow rate in the steady state condition:

Symbol for quantity	Symbol for unit
R_l	$(m \cdot K)/W$

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

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.

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:

Symbol for quantity	Symbol for unit
h	$W/(m^2 \cdot K)$

$$h = \frac{q}{T_s - T_a}$$

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.).

2.10 thermal conductance: The reciprocal of thermal resistance from surface to surface under conditions of uniform density of heat flow rate:

Symbol for quantity	Symbol for unit
Λ	$W/(m^2 \cdot K)$

$$\Lambda = \frac{1}{R}$$

NOTE — "Thermal conductance" should be replaced by "surface thermal conductance" when it may be confused with "linear thermal conductance" (2.11).

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

2) See the footnote to 2.7.

	Symbol for quantity	Symbol for unit
2.11 linear thermal conductance: The reciprocal of linear thermal resistance from surface to surface under conditions of uniform linear density of heat flow rate:	Λ_l	W/(m.K)

$$\Lambda_l = \frac{1}{R_l}$$

2.12 thermal transmittance: The 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	W/(m²·K)

$$U = \frac{\Phi}{(T_1 - T_2)A}$$

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.

2.13 linear thermal transmittance: The 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	W/(m·K)

$$U_l = \frac{\Phi}{(T_1 - T_2)\,l}$$

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.

2.14 heat capacity: The quantity defined by the equation	C	J/K

$$C = \frac{dQ}{dT}$$

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.

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: The thermal conductivity divided by the density and the specific heat capacity:	a	m²/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.

	Symbol for quantity	Symbol for unit
2.17 thermal effusivity: The square root of the product of thermal conductivity, density and specific heat capacity: $b = \sqrt{\lambda \varrho c}$	b	$J/(m^2 \cdot K \cdot s^{1/2})$

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 Symbols and units for other quantities

	Symbol for quantity	Symbol for unit
3.1 thermodynamic temperature	T	K
3.2 Celsius temperature	θ	°C
3.3 thickness	d	m
3.4 length	l	m
3.5 width; breadth	b	m
3.6 area	A	m^2
3.7 volume	V	m^3
3.8 diameter	D	m
3.9 time	t	s
3.10 mass	m	kg
3.11 density	ϱ	kg/m^3

4 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

The 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 $\vec{q}$:

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

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.

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

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

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:

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

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

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.