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Thermal performance of buildings and building components — Physical quantities and definitions

Performance thermique des bâtiments et des matériaux pour le bâtiment — Grandeurs physiques et définitions

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see /www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*.

This third edition of ISO 7345 cancels and replaces the second edition (ISO 7345:1987), which has been technically revised.

This edition includes the following significant changes with respect to the previous edition:

— title of the standard updated from '*Thermal insulation — Physical quantities and definitions*' to '*Thermal performance of buildings and building elements — Physical quantities and definitions*';

— title of ISO/TC 163 corrected (Foreword);

— ISO 31-4 replaced by ISO 80000-5 in the note in the Scope and added to the Bibliography;

— symbols, names and definitions (in 3.3 and 3.4) adapted to current state ($\Lambda \rightarrow L$, $\Lambda_l \rightarrow L_{2D}$, $U_l \rightarrow \Psi$, coefficient of heat loss → heat transfer coefficient);

— "areal" used instead of "surface" in quantity names (Clause 3) where "surface" was meant to distinguish between a length-related quantity ("linear") and an area-related quantity (now "areal") with similar name;

— Formula in 3.1.4 corrected;

— subscript l added in 3.4;

— added a Note 1 to entry in 3.1.11 and a Note 3 to entry in 3.1.13;

— H' added in 3.2.2 as an alternative name for F_s;

— added "for homogeneous solids" to A.1 in Annex A.

Introduction

This document is intended to be used in conjunction with other vocabularies related to thermal insulation. These include:

— ISO 7945, *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*

— ISO 9288, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions*

NOTE Annex A provides an explanation of the concept of thermal conductivity.

Thermal performance of buildings and building components — Physical quantities and definitions

1 Scope

This document defines physical quantities used in the thermal performance of buildings and building elements, and gives the corresponding symbols and units.

NOTE Because the scope of this document is restricted to thermal performance and energy use in the built environment, some of the definitions it contains differ from those given ISO 80000-5.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1 Physical quantities and definitions

3.1.1
heat
quantity of heat
Q
Note 1 to entry: Unit: J.

3.1.2
heat flow rate
Φ
quantity of heat transferred to or from a system divided by time

$$\Phi = \frac{dQ}{dt}$$

Note 1 to entry: Unit: W.

3.1.3
density of heat flow rate
q
heat flow rate divided by area

$$q = \frac{d\Phi}{dA}$$

Note 1 to entry: The word “density” should be replaced by “areal density” when it may be confused with *linear density* (3.1.4).

Note 2 to entry: Unit: W/m^2.

3.1.4
linear density of heat flow rate
q_1
heat flow rate divided by length:

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

Note 1 to entry: Unit: W/m.

3.1.5
thermal conductivity
λ
quantity defined by the following relation:

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

Note 1 to entry: 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.

Note 2 to entry: Unit: W/(m·K).

3.1.6
thermal resistivity
r
quantity defined by the following relation:

$$\operatorname{grad} T = -r\,\vec{q}$$

Note 1 to entry: A rigorous treatment of the concept of thermal resistivity is given in Annex A.

Note 2 to entry: Unit: (m·K)/W.

3.1.7
thermal resistance
R
temperature difference divided by the density of heat flow rate in the steady state condition:

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

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

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

Note 2 to entry: where *d* is the thickness of the layer.

Note 3 to entry: 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.

Note 4 to entry: 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.).

Note 5 to entry: When quoting values of thermal resistance, T_1 and T_2 must be stated.

Note 6 to entry: "Thermal resistance" should be replaced by "areal thermal resistance" when it may be confused with *linear thermal resistance* (3.1.8).

Note 7 to entry: Unit: $(m^2 \cdot K)/W$.

3.1.8
linear thermal resistance

R_l

temperature difference divided by the linear density of heat flow rate in the steady state condition:

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

Note 1 to entry: 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.

Note 2 to entry: 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.).

Note 3 to entry: When quoting values of linear thermal resistance, T_1 and T_2 must be stated.

Note 4 to entry: Unit: $(m \cdot K)/W$.

3.1.9
surface coefficient of heat transfer

h

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 1 to entry: 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.). The surface us usually denoted by an index *e* for external and *i* for internal surface.

Note 2 to entry: Unit: $W/(m^2 \cdot K)$.

3.1.10
thermal conductance

L

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

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

Note 1 to entry: "Thermal conductance" should be replaced by "areal thermal conductance" when it may be confused with *linear thermal conductance* (3.1.11)

Note 2 to entry: Unit: $W/(m^2 \cdot K)$.

3.1.11
linear thermal conductance
L_l
W/(m·K)
reciprocal of linear thermal resistance from surface to surface under conditions of uniform linear density of heat flow rate:

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

Note 1 to entry: Unit: W/(m·K).

3.1.12
thermal transmittance
U
heat flow rate in the steady state divided by area and by the temperature difference between the surroundings on both sides of a flat uniform system:

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

Note 1 to entry: This assumes the definition of the system, the two reference temperatures, T_1 and T_2, and other boundary conditions.

Note 2 to entry: "Thermal transmittance" should be replaced by "areal thermal transmittance" when it may be confused with *linear thermal transmittance* (3.1.13).

Note 3 to entry: The reciprocal of the thermal transmittance is the total thermal resistance between the surroundings on both sides of the flat uniform system.

Note 4 to entry: Unit: W/(m^2·K).

3.1.13
linear thermal transmittance
Ψ
heat flow rate in the steady state divided by length and by the temperature difference between the surroundings on each side of a system:

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

Note 1 to entry: This assumes the definition of the system, the two reference temperatures, T_1 and T_2, and other boundary conditions.

Note 2 to entry: The reciprocal of the linear thermal transmittance is the total linear thermal resistance between the surroundings on each side of the system.

Note 3 to entry: When Ψ is used to characterize linear thermal bridges in the building envelope Ψ is not the *total* but the *additional* heat transfer due to the thermal bridge [i.e. additional to the heat transfer taken into account by the (areal) thermal transmittance U].

Note 4 to entry: Unit: W/(m·K).

3.1.14
heat capacity
C
quantity defined by the formula:

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

Note 1 to entry: 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.

Note 2 to entry: Unit: J/K.

3.1.15
specific heat capacity
c
heat capacity divided by mass:

$$c = \frac{C}{m}$$

Note 1 to entry: Unit: J/(kg·K).

3.1.15.1
specific heat capacity at constant pressure
c_p

$$c_p = \frac{C}{m}$$

Note 1 to entry: Unit: J/(kg·K).

3.1.15.2
specific heat capacity at constant volume
c_v

$$c_v = \frac{C}{m}$$

Note 1 to entry: Unit: J/(kg·K).

3.1.16
thermal diffusivity
a
thermal conductivity divided by the density and the specific heat capacity:

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

Note 1 to entry: For fluids the appropriate specific heat capacity is c_p.

Note 2 to entry: The definition assumes that the medium is homogeneous and opaque.

Note 3 to entry: 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.

Note 4 to entry: 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.

Note 5 to entry: Unit: m^2/s.

3.1.17
thermal effusivity
b
square root of the product of thermal conductivity, density and specific heat capacity:

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

Note 1 to entry: For fluids the appropriate specific heat capacity is c_p.

Note 2 to entry: 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.

Note 3 to entry: Unit: $J/(m^2 \cdot K \cdot s^{1/2})$.

3.2 Energy performance of buildings

3.2.1
volumetric heat transfer coefficient

F_V

heat flow rate between the building (i.e. the internal environment) and the external environment divided by the volume and by the difference of temperature between the internal and external environment:

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

Note 1 to entry: The heat flow rate may optionally include the contributions of heat transmissions through the building envelope, ventliation, solar radiation, etc. The volume, V, shall be defined.

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

Note 2 to entry: Unit: $W/(m^3 \cdot K)$.

3.2.2
areal heat transfer coefficient

F_S, H'

heat flow rate between the building (i.e. the internal environment) and the external environment divided by the area and the difference of temperature between the internal and external environment:

$$F_S = H' = \frac{\Phi}{A \cdot \Delta T}$$

Note 1 to entry: The heat flow rate may optionally include the contributions of heat transmissions through the building envelope, thermal bridges, ventilation, solar radiation, etc. The area may optionally be the envelope area, the floor area, etc. The temperature difference may optionally be a weighted temperature difference.

The use of areal heat transfer coefficients assumes a conventional definition of internal temperature, external temperature, area and the different contributions resulting in the heat flow rate.

Note 2 to entry: Unit: $W/(m^2 \cdot K)$.

3.2.3
ventilation rate

n

number of air changes in a defined volume divided by time

Note 1 to entry: Unit: h^{-1}.

Note 2 to entry: 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.

3.3 Symbols and units for other quantities

Quantity	Symbol	Unit
thermodynamic temperature	T	K
Celsius temperature	θ	°C
thickness	d	m
length	l	m
width; breadth	b	m
area	A	m^2
volume	V	m^3
diameter	D	m
time	t	s
mass	m	kg
density	ϱ	kg/m^3

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
linear	l

Annex A
(informative)

Concept of thermal conductivity

A.1 General

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

A.2 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 Formula (A.1):

$$\mathrm{grad}\, T \cdot \vec{e}_n = \frac{\delta T}{\delta n} \tag{A.1}$$

A.3 (Surface) density of heat flow rate, *q*, at a point *P*(of a surface through which heat is transferred)

This is defined as Formula (A.2):

$$q = \left(\frac{d\Phi}{dA} \right)_P \tag{A.2}$$

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 $\vec{q}$ in Formula (A.3):

$$\vec{q} = \left(\frac{\partial \Phi}{\partial A_n} \right)_P \vec{e}_n \tag{A.3}$$

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.4 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 $\vec{q}$ in Formula (A.4):

$$\text{grad}\, T = -r\,\vec{q} \tag{A.4}$$

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 $\left[\vec{\vec{r}}\right]$ of the nine coefficients of these linear combinations and through Formula (A.5):

$$\text{grad}\, T = -\left[\vec{\vec{r}}\right] \cdot \vec{q} \tag{A.5}$$

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

A.5 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 *q* and grad *T* are parallel and opposite, it is as per Formula (A.6):

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

$$\lambda r = 1 \tag{A.6}$$

Like thermal resistivity, thermal conductivity is, in the most general case, a tensor $\left[\vec{\vec{\lambda}}\right]$ of the nine coefficients of the linear combinations of the components of grad *T* that define each component of $\vec{q}$, through Formula (A.7):

$$\vec{q} = -\left[\vec{\vec{\lambda}}\right] \operatorname{grad} T \tag{A.7}$$

It is obvious that $\left[\vec{\vec{\lambda}}\right]$ may be obtained by jnverting $\left[\vec{\vec{r}}\right]$ and vice versa. If the thermal conductivity λ. or $\left[\vec{\vec{\lambda}}\right]$ 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 $\left[\vec{\vec{\lambda}}\right]$ or thermal resistivity r or $\left[\vec{\vec{r}}\right]$ is independent of temperature [see Formulae (A.8) and (A.9)].

$$\lambda = \frac{1}{r} = \frac{\Phi d}{A\left(T_1 - T_2\right)} = \frac{d}{R} \tag{A.8}$$

$$R = \frac{A\left(T_1 - T_2\right)}{\Phi} = \frac{d}{\lambda} = rd \tag{A.9}$$

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

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 [see Formulae (A.10) and (A.11)]:

$$\lambda = \frac{1}{r} = \frac{\Phi \ln \dfrac{D_e}{D_i}}{2\pi l\left(T_1 - T_2\right)} = \frac{\dfrac{D}{2} \ln \dfrac{D_e}{D_i}}{R} \tag{A.10}$$

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

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

