SLOVENSKI STANDARD

SIST EN ISO 13786:2000

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Toplotne znaĿilnosti delov stavb - DinamiĿne toplotne znaĿilnosti - RaĿunske metode (ISO 13786:1999)

Thermal performance of building components - Dynamic thermal characteristics - Calculation methods (ISO 13786:1999)

Wärmetechnisches Verhalten von Bauteilen - Dynamisch-thermische Kenngrößen - Berechnungsverfahren (ISO 13786:1999)

Performance thermique des composants de bâtiments - Caractéristiques thermiques dynamiques - Méthodes de calcul (ISO 13786:1999)

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Thermal performance of building components - Dynamic thermal characteristics - Calculation methods (ISO 13786:1999)

Performance thermique des composants de bâtiment - Caractéristiques thermiques dynamiques - Méthodes de calcul (ISO 13786:1999)

Wärmetechnisches Verhalten von Bauteilen - Dynamisch-thermische Kenngrößen - Berechnungsverfahren (ISO 13786:1999)

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
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Foreword

The text of EN ISO 13786:1999 has been prepared by Technical Committee CEN/TC 89 "Thermal performance of buildings and building components", the secretariat of which is held by SIS, in collaboration with Technical Committee ISO/TC 163 "Thermal insulation".

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2000, and conflicting national standards shall be withdrawn at the latest by March 2000.

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

This standard is one of a series of standards on calculation methods for the design and evaluation of the thermal performance of buildings and building components.

Introduction

The dynamic thermal characteristics of a building component describe the thermal behaviour of the component when it is subject to variable boundary conditions, i.e. variable heat flow rate or variable temperature on one or both of its boundaries. In this standard, only sinusoidal boundary conditions are considered: boundaries are submitted to sinusoidal variations of temperature or heat flow rate.

The properties considered are thermal admittances and thermal dynamic transfer properties, relating cyclic heat flow rate to cyclic temperature variations. Thermal admittance quantifies the heat storage property of a component. It relates heat flow rate to temperature variations on the same side of the component. Thermal dynamic transfer properties relate physical quantities on one side of the component to those on the other side.

1 Scope

This standard specifies the characteristics related to dynamic thermal behaviour of complete building components and gives methods for their calculation. It also specifies the information on building materials required for its use. Since the characteristics depend on the way materials are combined to form building components, the standard is not applicable to building materials or to unfinished building components.

The definitions given in this standard are applicable to any building component. A simplified calculation method is provided for plane components consisting of plane layers of homogeneous or substantially homogeneous building materials.

The dynamic thermal characteristics defined in this standard can be used in product specifications of complete building components.

The dynamic thermal characteristics can also be used in calculation of :

- the internal temperature in a room;
- the daily peak power and energy needs for heating or cooling;
- the effects of intermittent heating or cooling; etc.

Annex A provides simpler methods for the estimation of the heat capacities in some limited cases. In particular, the methods in annex A are suitable for the determination of dynamic thermal properties required for the estimation of energy use. These approximations are not appropriate, however, for product characterisation.

Annex B gives the basic principle and examples of applications of the dynamic thermal characteristics defined in this standard

Annex C provides information for programming the calculation method.

Annex D gives an example of calculation for a building component.

2 Normative references

This standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of the publications apply to this standard only when incorporated in it or by amendment or revision. For undated references, the latest edition of the publication referred to applies.

EN ISO 6946, Building components and building elements - Thermal resistance and thermal transmittance - Calculation method (ISO 6946)

EN ISO 7345, Thermal insulation - Physical quantities and definitions (ISO 7345)

EN ISO 10211-1, Thermal bridges in building construction - Heat flows and surface temperatures - Part 1: General calculation methods (ISO 10211-1)

3 Definitions, symbols and units

For the purposes of this standard, the definitions of EN ISO 7345 and those given below apply.

3.1 Definitions valid for any component

3.1.1 component: Part of a building, such as a wall, floor or roof, or a part of these elements.

3.1.2 thermal zone of a building: Part of a building throughout which the internal temperature has or is assumed to have negligible spatial variations.

NOTE The external environment can also be considered as a zone.

3.1.3 sinusoidal conditions: Conditions in which the variations of the temperature and heat flows around their long term average values are described by a sine function of time. Using complex numbers, the temperature in zone n can be described by:

$$\theta_n(t) = \bar{\theta}_n + \left|\hat{\theta}_n\right| \cos(\omega t + \psi) = \bar{\theta}_n + \frac{1}{2}\left[\hat{\theta}_{+n} e^{\mathrm{j}\omega t} + \hat{\theta}_{-n} e^{-\mathrm{j}\omega t}\right] \quad (1)$$

and the heat flow by:

$$\Phi_n(t) = \bar{\Phi}_n + \left|\hat{\Phi}_n\right| \cos(\omega t + \varphi) = \bar{\Phi}_n + \frac{1}{2}\left[\hat{\Phi}_{+n} e^{\mathrm{j}\omega t} + \hat{\Phi}_{-n} e^{-\mathrm{j}\omega t}\right] \quad (2)$$

where

$\bar{\theta}_n$ and $\bar{\Phi}_n$ are average values of temperature and heat flow;

$|\hat{\theta}_n|$ and $|\hat{\Phi}_n|$ are amplitudes of temperature and heat flow variations;

$\hat{\theta}_{\pm n}$ and $\hat{\Phi}_{\pm n}$ are complex amplitudes defined by:

$$\hat{\theta}_{\pm n} = |\hat{\theta}_n| e^{\pm j\psi} \quad \text{and} \quad \hat{\Phi}_{\pm n} = |\hat{\Phi}_n| e^{\pm j\varphi} \tag{3}$$

ω is the angular frequency of the variations.

3.1.4 periodic thermal conductance (L_{mn}): Complex number defined under sinusoidal conditions by:

$$\hat{\Phi}_m = -\sum_n L_{mn} \hat{\theta}_n \tag{4}$$

Zones m and n could be either different or the same.

3.1.5 heat capacity: Inverse of the imaginary part of the inverse of periodic thermal conductance related to one side of the element, divided by the angular frequency:

$$C_m = \frac{1}{\omega \, \Im\left(\frac{1}{L_{mm}}\right)} = \frac{T}{2\pi \Im\left(\frac{\hat{\theta}_m}{\hat{\Phi}_m}\right)} \tag{5}$$

3.1.6 time shift (Δt): Period of time between the maximum amplitude of a cause and the maximum amplitude of its effect.

3.2 Definitions valid only for one dimensional heat flow

3.2.1 plane component: Component for which the smallest curvature radius is at least five times its thickness.

3.2.2 homogeneous material layer: Layer of material in which the largest size of inhomogeneities do not exceed one fifth of the thickness of the layer.

3.2.3 thermal admittance, periodic thermal transmittance: Complex quantities defined as the complex amplitude of the density of heat flow rate through the surface of the component adjacent to zone m, divided by the complex amplitude of the temperature in zone n. The heat flow rate is defined as positive when it enters the surface of the component.

$$Y_{mn} = \frac{L_{mn}}{A} = -\frac{\hat{q}_m}{\hat{\theta}_n} \tag{6}$$

Y_{mm} are thermal admittances, Y_{mn} $(m \neq n)$ are periodic thermal transmittances.

3.2.4 areic heat capacity: Heat capacity divided by area of the element:

$$\chi_m = \frac{C_m}{A} = \frac{1}{\omega \, \Im\left(\frac{1}{Y_{mm}}\right)} = \frac{T}{2\pi \Im\left(\frac{\hat{\theta}_m}{\hat{q}_m}\right)} \tag{7}$$

The heat capacities are then:

$$C_m = A\chi_m \tag{8}$$

NOTE There are two thermal admittances and heat capacities for a component separating two zones, all depend on the period of the thermal variations.

3.2.5 decrement factor (*f*): Ratio of the dynamic thermal transmittance to the thermal transmittance under steady state conditions, *U*.

$$f = \frac{|\hat{q}_m|}{|\hat{\theta}_n| U} = \frac{|L_{mn}|}{AU} \quad \text{with} \quad m \neq n \tag{9}$$

3.2.6 periodic penetration depth: Depth at which the amplitude of the temperature variations are reduced by a factor e (base of natural logarithms, e = 2,718...) in a homogeneous material of infinite thickness subjected to sinusoidal temperature variations on its surface:

$$\delta = \sqrt{\frac{\lambda \ T}{\pi \rho c}} \tag{10}$$

3.2.7 heat transfer matrix: Matrix relating the complex amplitudes of temperature and heat flow rate on one side of a component to the complex amplitudes of temperature and heat flow rate on the other side:

$$\begin{pmatrix} \hat{\theta}_2 \\ \hat{q}_2 \end{pmatrix} = \begin{pmatrix} Z_{11} Z_{12} \\ Z_{21} Z_{22} \end{pmatrix} \cdot \begin{pmatrix} \hat{\theta}_1 \\ \hat{q}_1 \end{pmatrix} \tag{11}$$

3.3 Symbols and units

For the purpose of this standard, the terms, symbols and units given in table 1 apply:

Table 1 - Terms, symbols and units

Symbol	Quantity	Unit
A	area	m²
C	heat capacity	J/K
L_{mn}	periodic thermal conductance	W/K
R	thermal resistance	m² K/W
T	period of the variations	s
U	thermal transmittance under steady state boundary conditions	W/(m²·K)
Y_{mm}	thermal admittance	W/(m²·K)
Y_{mn}	dynamic thermal transmittance	W/(m²·K)
$\mathbf{Z}$	heat transfer matrix environment to environment	
Z_{mn}	element of the heat transfer matrix	
a	thermal diffusivity	m²/s
c	specific heat capacity	J/(kg·K)
d	thickness of a layer	m
f	decrement factor	-
j	unit on the imaginary axis for a complex number; $j = \sqrt{-1}$	
q	density of heat flow rate	W/m²
t	time	s
x	distance through the component	m
Δt	time shift: time lead (if positive), or time lag (if negative).	s
δ	periodic penetration depth of a heat wave in a material	m
Φ	heat flow rate	W

ξ	ratio of the thickness of the layer to the penetration depth	
λ	design thermal conductivity	W/(m·K)
ρ	density	kg/m³
θ	temperature	°C
ω	angular frequency = $\frac{2\pi}{T}$	s^{-1}
φ, ψ	phase differences	rad
χ	areic heat capacity	J/(m²·K)

Indices		Other symbols	
a	for an air layer	^	complex amplitude
e	external	¯	mean value
i	internal	| |	modulus of a complex number
m, n	for the thermal zones	arg	argument of a complex number
s	related to surface		
ss	from surface to surface		

4 Period of the thermal variations

The definition of dynamic thermal characteristics and the formulae for their calculation are valid for any period of thermal variations.

The values of dynamic thermal characteristics depend on the periods. If more than one period is considered, an additional suffix shall be added to all quantities affected so as to distinguish between the values for different period.

Practical time periods are:

- one hour (3600 s), which corresponds to very short time variations, such as those resulting from temperature control systems;
- one day (86 400 s), corresponding to daily meteorological variations and temperature setback;
- one week (604 800 s), corresponding to longer term averaging of the building;
- one year (31 556 926 s), useful for treatment of heat transfer through the ground.

5 Data required

The data required to compute the dynamic thermal characteristics are:

a) the detailed drawings of the product, with dimensions;

b) for each material used in the product:
   - the thermal conductivity, λ;
   - the specific heat capacity, c;
   - the density, ρ.

These values shall be the design values of the materials used.

6 Transfer matrix of a multi-layer component

6.1 General

The calculation of dynamic thermal characteristics of non-plane components and of components containing very important thermal bridges shall be made by solving the equation of heat transfer under periodic boundary conditions. For this purpose, the rules for modelling the component as given in EN ISO 10211-1 shall be used together with numerical methods such as finite difference and finite element techniques.

Clause 6 applies to components consisting of plane homogeneous layers. Thermal bridges usually allowed in building components do not affect significantly the dynamic thermal characteristics, and can hence be neglected.

6.2 Procedure

The procedure is as follows:

1) identify the materials comprising the layers of the building component and the thickness of these layers, and determine the thermal characteristics of the materials;
2) specify the period of the variations at the surfaces;
3) calculate the penetration depth for the material of each layer;
4) determine the elements of the transfer matrix for each layer;
5) multiply the layer transfer matrices, excluding those of the boundary layers, in the correct order to obtain the transfer matrix of the component.

6.3 Transfer matrix of a homogenous layer

The periodic penetration depth for the material of the layer is calculated from its thermal properties and the period T using equation (10).

The ratio of the thickness of the layer to the penetration depth is then:

$$\xi = \frac{d}{\delta} \tag{12}$$

The matrix elements Z_{mn} are calculated as follows:

$$Z_{11} = Z_{22} = \cosh(\xi)\cos(\xi) + \mathrm{j}\sinh(\xi)\sin(\xi)$$

$$Z_{12} = -\frac{\delta}{2\lambda}\{\sinh(\xi)\cos(\xi) + \cosh(\xi)\sin(\xi) + \mathrm{j}\,[\cosh(\xi)\sin(\xi) - \sinh(\xi)\cos(\xi)]\} \tag{13}$$

$$Z_{21} = -\frac{\lambda}{\delta}\{\sinh(\xi)\cos(\xi) - \cosh(\xi)\sin(\xi) + \mathrm{j}\,[\sinh(\xi)\cos(\xi) + \cosh(\xi)\sin(\xi)]\}$$

6.4 Transfer matrix of plane air cavities

The specific heat capacity of such layers is neglected. Hence, if R_a is the thermal resistance of the air layer, including convection, conduction and radiation, its transfer matrix is:

$$\mathbf{Z}_a = \begin{pmatrix} 1 & -R_a \\ 0 & 1 \end{pmatrix} \tag{14}$$

The thermal resistance of the air layer shall be calculated in accordance with EN ISO 6946.

6.5 Transfer matrix of a building component

The transfer matrix of the building component from surface to surface is:

$$\mathbf{Z} = \begin{pmatrix} Z_{11} Z_{12} \\ Z_{21} Z_{22} \end{pmatrix} = \mathbf{Z}_N \mathbf{Z}_{N\text{-}1} \ldots \mathbf{Z}_3 \mathbf{Z}_2 \mathbf{Z}_1 \qquad (15)$$

where $\mathbf{Z_1}, \mathbf{Z_2}, \mathbf{Z}_i, \ldots, \mathbf{Z}_N$, are the transfer matrices of the various layers of the building component, beginning from layer 1. As a convention for building envelope components, layer 1 shall be the innermost layer.

The transfer matrix from environment to environment through the building component is:

$$\mathbf{Z_{ee}} = \mathbf{Z}_{s2}\, \mathbf{Z}\, \mathbf{Z}_{s1} \qquad (16)$$

where $\mathbf{Z}_{s1}$ and $\mathbf{Z}_{s2}$ are the transfer matrices of the boundary layers, given by:

$$\mathbf{Z}_s = \begin{pmatrix} 1 & -R_s \\ 0 & 1 \end{pmatrix} \qquad (17)$$

R_s being the surface resistance of the boundary layer including convection and radiation. These shall be in accordance with EN ISO 6946.

7 Dynamic thermal characteristics

7.1 Characteristics for any component

The dynamic thermal characteristics of any component are periodic thermal conductances, L_{mn}, and heat capacities, C_m, as given in 3.1.4 and 3.1.5. Boundary layers are not taken into account for the calculation of heat capacities.

7.2 Characteristics for components made of plane and homogeneous layers

7.2.1 Thermal admittances and periodic thermal conductances

The thermal admittances are:

$$Y_{11} = \frac{Z_{11} - 1}{Z_{12}} \quad \text{and} \quad Y_{22} = \frac{Z_{22} - 1}{Z_{12}} \qquad (18)$$

Y_{11} is for the internal side of the component, while Y_{22} is for the external side.

The periodic thermal conductances are then:

$$L_{11} = AY_1 = \frac{AZ_{11} - 1}{Z_{12}} \quad \text{and} \quad L_{22} = AY_2 = \frac{AZ_{22} - 1}{Z_{12}} \qquad (19)$$

The time lead of admittance Y_{mn} or of periodic thermal conductance L_{mn} is:

$$\Delta t_Y = \frac{T}{2\pi} \arg(Y_{mn}) \qquad (20)$$

with the argument evaluated in the range 0 to π.