

BS EN ISO 13791:2012



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Thermal performance of buildings — Calculation of internal temperatures of a room in summer without mechanical cooling — General criteria and validation procedures

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National foreword

This British Standard is the UK implementation of EN ISO 13791:2012. It supersedes BS EN ISO 13791:2004, which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/540/8, Mirror committee for ISO/TC 163 - Thermal Performance and Energy use in the built Environment.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

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temperatures of a room in summer without mechanical cooling -
General criteria and validation procedures (ISO 13791:2012)

Performance thermique des bâtiments - Calcul des
températures intérieures en été d'un local sans dispositif de
refroidissement - Critères généraux et procédures de
validation (ISO 13791:2012)

Wärmetechnisches Verhalten von Gebäuden -
Sommerliche Raumtemperaturen bei Gebäuden ohne
Anlagentechnik - Allgemeine Kriterien und
Validierungsverfahren (ISO 13791:2012)

This European Standard was approved by CEN on 14 March 2012.

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COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (EN ISO 13791:2012) has been prepared by Technical Committee ISO/TC 163 "Thermal performance and energy use in the built environment" in collaboration with Technical Committee CEN/TC 89 "Thermal performance of buildings and building components" the secretariat of which is held by SIS.

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of an identical text or by endorsement, at the latest by September 2012, and conflicting national standards shall be withdrawn at the latest by September 2012.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

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Endorsement notice

The text of ISO 13791:2012 has been approved by CEN as a EN ISO 13791:2012 without any modification.

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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. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

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Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 13791 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This second edition cancels and replaces the first edition (ISO 13791:2004), which has been technically revised. The main changes compared to the previous edition are given in the following table:

Clause/subclause	Changes
2	Added ISO 9050, ISO 10292, ISO 15099, ISO 15927-2 and EN 673
3.2	Deleted q_a and v_m and added m_a
4.2.1	Amended Equation (1) Deleted $m_{a,i}$ and added the descriptions of ρ_a and v_{ai}
4.5.6.1	Replaced q_a by m_a
8.3.9.1	Amended the values in Tables 22 and 23
8.3.9.2	Amended the values in Tables 24 and 25
I.2.2	Replaced m by m_a Amended Equation (I.1) and added the descriptions of n and Δp_0 Amended Equation (I.4) and added the description of ΔC_w Amended the unit used in Table I.1
I.2.3	Replaced m , m_w and m_T by m_a , $m_{a,w}$ and $m_{a,T}$, respectively Amended Equations (I.5), (I.6), (I.9), (I.10), (I.11), (I.12), (I.13) and (I.14) Replaced A by A_T in Equation (I.13) Replaced Δc_p by ΔC_w Added the descriptions of Equations (I.8) and (I.10)
I.2.3.3.3	Amended the description I.2.3.3.3
I.3.2	Replaced Δc_p by ΔC_w Replaced m_w by $m_{a,w}$
I.3.3	Replaced m_T by $m_{a,T}$
Annex J	Amended the values in Tables J.1 and J.2
Annex K	Added as a new annex

Introduction

This International Standard is intended for use by specialists to develop and/or validate methods for the hourly calculation of the internal temperatures of a single room.

Examples of application of such methods include:

- a) assessing the risk of internal overheating;
- b) optimizing aspects of building design (building thermal mass, solar protection, ventilation rate, etc.) to provide thermal comfort conditions;
- c) assessing whether a building requires mechanical cooling.

Criteria for building performance are not included. They can be considered at national level. This International Standard can also be used as a reference to develop more simplified methods for the above and similar applications.

Thermal performance of buildings — Calculation of internal temperatures of a room in summer without mechanical cooling — General criteria and validation procedures

1 Scope

This International Standard specifies the assumptions, boundary conditions, equations and validation tests for a calculation procedure, under transient hourly conditions, of the internal temperatures (air and operative) during warm periods, of a single room without any cooling/heating equipment in operation. No specific numerical techniques are imposed by this International Standard. Validation tests are included in Clause 8. An example of a solution technique is given in Annex A.

This International Standard does not contain sufficient information for defining a procedure able to determine the internal conditions of special zones such as attached sun spaces, atria, indirect passive solar components (trombe walls, solar panels) and zones in which the solar radiation may pass through the room. For such situations different assumptions and more detailed solution models are needed (see Bibliography).

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 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

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

ISO 9050, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

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

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

ISO 9346, *Hygrothermal performance of buildings and building materials — Physical quantities for mass transfer — Vocabulary*

ISO 10077-1, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 1: General*

ISO 10077-2, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 2: Numerical method for frames*

ISO 10292, *Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing*

ISO 13370, *Thermal performance of buildings — Heat transfer via the ground — Calculation methods*

ISO 15099, *Thermal performance of windows, doors and shading devices — Detailed calculations*

ISO 15927-2, *Hygrothermal performance of buildings — Calculation and presentation of climatic data — Part 2: Hourly data for design cooling load*

EN 410, *Glass in building — Determination of luminous and solar characteristics of glazing*

EN 673, *Glass in building — Determination of thermal transmittance (U value) — Calculation method*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 9251, ISO 9288, ISO 9346 and the following apply.

3.1.1

internal environment

closed space delimited from the external environment or adjacent spaces by the building fabric

3.1.2

room element

wall, roof, ceiling, floor, door or window that separates the internal environment from the external environment or an adjacent space

3.1.3

room air

air of the internal environment

3.1.4

internal air temperature

temperature of the room air

3.1.5

internal surface temperature

temperature of the internal surface of a building element

3.1.6

mean radiant temperature

uniform surface temperature of an enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform enclosure

3.1.7

operative temperature

uniform temperature of an enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual non-uniform environment

3.2 Symbols and units

For the purposes of this document, the following symbols and units apply.

Symbol	Definition	Unit
A	area	m^2
A_c	area of the surface in contact with the air layer	m^2
A_f	floor area	m^2
A_j	area of room element j	m^2
A_p	projected area of the considered system	m^2
A_s	sunlit area	m^2
A_{sh}	shaded area	m^2
a	thermal diffusivity	m^2/s
C	heat capacity	J/K
c	specific heat capacity	$\text{J}/(\text{kg}\cdot\text{K})$
c_a	specific heat capacity of air	$\text{J}/(\text{kg}\cdot\text{K})$
c_d	coefficient of discharge	—
c_{me}	specific heat capacity of the medium	$\text{J}/(\text{kg}\cdot\text{K})$
c_v	velocity coefficient	—
d	thickness	m
E_r	ventilation parameter	—
F	view factor	—
F_{sk}	view factor from the element with the sky	—
f_d	solar distribution factor	—
f_{ic}	internal convective factor	—
f_s	sunlit factor	—
f_{sa}	solar to air factor	—
f_{sl}	solar loss factor	—
G_i	moisture production	kg/s
G_v	moisture influx by ventilation	kg/s
g_s	heat flow rate per volume	W/m^3
g	acceleration due to gravity	m/s^2
H	height of the element	m
h	surface coefficient of heat transfer	$\text{W}/(\text{m}^2\cdot\text{K})$
h_a	convective heat transfer coefficient for ventilated layers	$\text{W}/(\text{m}^2\cdot\text{K})$
h_c	convective heat transfer coefficient of the surface	$\text{W}/(\text{m}^2\cdot\text{K})$
h_g	convective heat transfer coefficient for closed spaces	$\text{W}/(\text{m}^2\cdot\text{K})$
h_{lr}	long-wave radiative heat transfer coefficient	$\text{W}/(\text{m}^2\cdot\text{K})$

I	intensity of solar radiation	W/m ²
I_d	diffuse component of the solar radiation reaching the surface	W/m ²
I_D	direct component of the solar radiation reaching the surface	W/m ²
$J_{lr,j}$	long-wave radiosity	W/m ²
k	crack coefficient	—
l	length	m
m_a	mass air flow rate	kg/s
$m_{a,m}$	mass forced air flow rate by mechanical ventilation	kg/s
$m_{a,n}$	mass air flow rate by natural ventilation	kg/s
$m_{a,T}$	mass flow rate due to temperature	kg/s
$m_{a,w}$	mass flow rate due to wind	kg/s
n	flow exponent	—
p	pressure	Pa
q	density of heat flow rate	W/m ²
q_c	density of heat flow rate by convection	W/m ²
q_{cd}	density of heat flow rate by conduction	W/m ²
$q_{c,i}$	density of heat flow rate by conduction at the internal surface	W/m ²
q_{lr}	density of heat flow rate due to long-wave radiation exchanged with other internal surfaces	W/m ²
q_{sk}	correction for the long-wave radiation exchanges from the wall to the sky	W/m ²
q_{sr}	density of heat flow rate due to the absorbed short-wave radiation	W/m ²
R	thermal resistance	m ² ·K/W
T	thermodynamic temperature	K
T_e	temperature of the environment	K
T_{in}	temperature of the air entering the air layer	K
T_{out}	temperature of the air leaving the layer	K
t	time	s
U	thermal transmittance	W/(m ² ·K)
V	volume	m ³
v	velocity	m/s
x,y,z	co-ordinates	m
Λ	thermal conductance	W/(m ² ·K)
Φ	heat flow rate	W
Φ_i	heat flow rate due to internal sources	W
Φ_{sa}	solar to air heat flow rate	W
Φ_{sr}	heat flow rate of solar radiation entering the room	W

Φ_v	heat flow rate by ventilation	W
Φ_{va}	heat flow rate due to the air entering the room through air layers within the elements bounding the room	W
α	solar absorptance	—
ε	long-wave emissivity of the surface	
θ	celsius temperature	°C
$\theta_{a,d}$	defined air temperature of the adjacent room	°C
$\theta_{a,e}$	air temperature of the adjacent room	°C
$\theta_{a,i}$	temperature of the internal air	°C
θ_v	temperature of the mechanically supplied air	°C
λ	thermal conductivity	W/(m·K)
μ	viscosity	kg/(m·s)
ν_i	humidity by volume of internal air	kg/m ³
ν_{in}	humidity by volume of inflowing air	kg/m ³
ρ	solar reflectance	—
ρ_a	density of air	kg/m ³
ρ_m	average solar reflection coefficient of room surfaces	—
ρ_{me}	density of the medium	kg/m ³
$\rho_{a,0}$	density of the air at the temperature T_0	kg/m ³
σ	Stefan-Boltzmann constant	W/(m ² ·K ⁴)

3.3 Subscripts

a	air	cd	conduction
b	building	ec	external ceiling
c	convection	ef	external floor
D	direct solar radiation	eq	equivalent
d	diffuse solar radiation	ic	internal ceiling
e	external	if	internal floor
g	ground	il	inlet section
i	internal	lr	long-wave radiation
l	leaving the section	mr	mean radiant
n	normal to surface	op	operative
r	radiation	sa	solar to air
s	surface	sk	sky
sl	solar loss	t	time
sr	short-wave radiation	v	ventilation
va	ventilation through air cavity		

4 Determination of internal temperatures

4.1 Assumptions

The evaluation of the internal temperature of a room involves the solution of a system of equations of the transient heat and mass transfers between the external and internal environment through the opaque and transparent elements bounding the room envelope. The procedures given in this International Standard allow the user to determine the time-dependent temperature of each component, including the internal air. Accepted assumptions for the calculation of the internal temperatures of a single room under transient conditions in absence of any cooling plant are:

- the air temperature is uniform throughout the room;
- the various surfaces of the room elements are isothermal;
- the thermophysical properties of the materials composing the room elements are time-independent;
- the heat conduction through the room elements (excluding to the ground) is assumed to be one-dimensional;
- the heat conduction to the ground through room elements is treated by an equivalent one-dimensional heat flow rate according to ISO 13370;
- the effect of thermal bridges is generally neglected, but if it is considered the heat storage contribution of the thermal bridges is neglected;
- air spaces are treated as air layers bounded by two isothermal and parallel surfaces;
- convective heat transfer coefficients: at the external surface they depend on the wind velocity and direction, at the internal surface they depend on the direction of the heat flow;
- the long-wave radiative heat flow rate at the external surfaces of the room elements is related to a time-independent heat transfer coefficient;
- the external radiant environment (sky excluded) is at the external air temperature (see 4.5.4.1);
- the distribution of solar radiation within the room is time-independent;
- the dimensions of each element are measured inside the room;
- the mean radiant temperature is calculated by weighting the various internal surface temperatures according to the relevant areas;
- the operative temperature is the average between the internal air temperature and the mean surface temperature.

4.2 Evaluation of the relevant temperatures

4.2.1 Internal air temperature

The air temperature of a room, at any given time, is obtained by solving Equation (1), where heat flow rates to room air are taken as positive:

$$\sum_{j=1}^N (A q_{c,i})_j + \Phi_v + \Phi_{i,c} + \Phi_{sa} + \Phi_{va} = c_a \rho_a V_{a,i} \frac{\partial \theta_{a,i}}{\partial t} \quad (1)$$

where

- N is the number of internal surfaces delimiting the internal air;
- A is the area of each building element;
- $q_{c,i}$ is the density of the heat flow rate by convection at the internal surface (see 4.5.2.2);
- Φ_v is the heat flow rate by ventilation (see 4.5.6);
- $\Phi_{l,c}$ is the convective part of heat flow rate due to internal sources (see 4.5.5);
- Φ_{sa} is the solar to air heat flow rate (see 4.5.3.4);
- Φ_{va} is the heat flow rate due to the air entering the room through air layers within the elements bounding the room;
- c_a is the specific heat capacity of air;
- ρ_a is the density of the internal air;
- $V_{a,i}$ is the volume of the internal air;
- $\theta_{a,i}$ is the temperature of the internal air;
- t is the time.

NOTE Because of the very small value of the term $(\rho_a V_{a,i})$ the right-hand side of Equation (1) can be assumed to be zero.

4.2.2 Internal surface temperature

The internal surface temperature at element j is obtained by solving Equation (2), where heat flow rates to the internal surface, except $q_{c,j}$, are taken as positive:

$$q_{lr,j} + q_{sr,j} + q_{c,j} + q_{cd,j} + \frac{\Phi_{l,r}}{\sum_{j=1}^N A_j} = 0 \quad (2)$$

where

- q_{lr} is the density of heat flow rate due to long-wave radiation exchanged with other internal surfaces (see 4.5.4.2);
- q_{sr} is the density of heat flow rate due to the absorbed short-wave radiation (see 4.5.3.2);
- q_c is the density of heat flow rate released to room air by convection (see 4.5.2.2);
- q_{cd} is the density of heat flow rate by conduction (see 4.5.1);
- $\Phi_{l,r}$ is the heat flow rate due to the radiative component of internal gains (see 4.5.5);
- N is the number of surfaces delimiting the internal air;
- A_j is the area of room element j .

4.2.3 Surface delimiting two solid layers

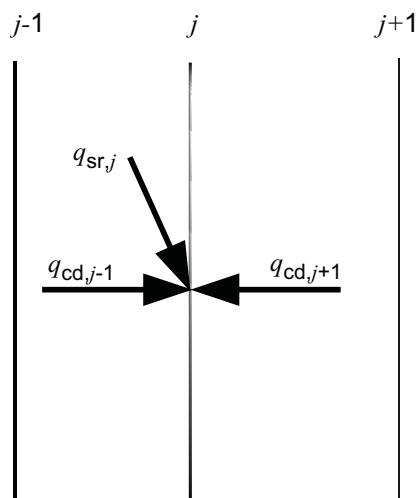


Figure 1 — Surface delimiting two layers

The temperature at surface j delimiting two layers in an element (Figure 1) is obtained by solving Equation (3):

$$q_{cd,j-1} + q_{cd,j+1} + q_{sr,j} = 0 \quad (3)$$

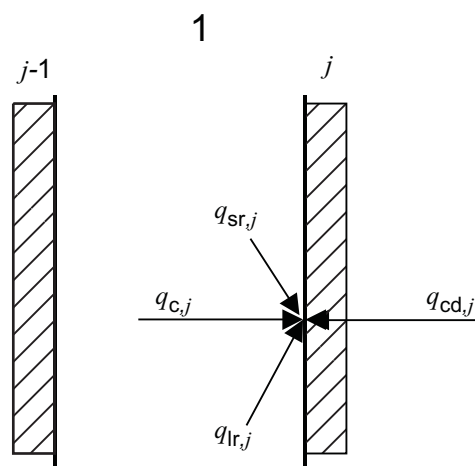
where

$q_{cd,j-1}$ is the density of heat flow rate by conduction from the $j-1$ surface (see 4.5.1);

$q_{cd,j+1}$ is the density of heat flow rate by conduction from the $j+1$ surface (see 4.5.1);

$q_{sr,j}$ is the density of heat flow rate due to the solar radiation absorbed by the surface j .

4.2.4 Surface of an air layer



Key

1 air layer

Figure 2 — Surface delimiting an air layer

The temperature at surface j of an air layer (Figure 2) is obtained by solving Equation (4):

$$q_{c,j} + q_{lr,j} + q_{cd,j} + q_{sr,j} = 0 \quad (4)$$

where

q_c is the density of the total heat flow rate released to the air layer (see 4.5.2);

q_{lr} is the density of the heat flow rate received by long-wave radiation across the air layer (see 4.5.4);

q_{cd} is the density of the heat flow by conduction (see 4.5.1);

q_{sr} is the density of heat flow rate absorbed due to an external source (e.g. solar radiation).

4.2.5 External surface of a room element

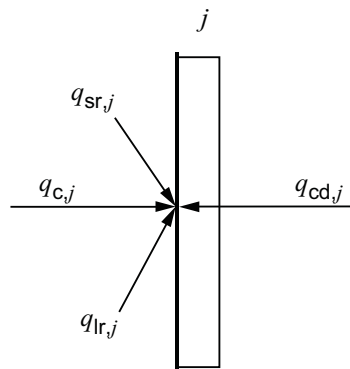


Figure 3 — External surface of an element

The temperature at surface j of a room element (Figure 3) is obtained by solving Equation (5):

$$q_{lr,j} + q_{sr,j} + q_{c,j} + q_{cd,j} = 0 \quad (5)$$

where

q_{lr} is the density of heat flow rate by long-wave radiation at the surface (see 4.5.4.1);

q_{sr} is the density of heat flow rate due to the short-wave radiation absorbed by the surface (see 4.5.3.1);

q_c is the density of heat flow rate by convection with the air (see 4.5.2.2);

q_{cd} is the density of the conduction heat flow rate (see 4.5.1).

4.2.6 Relevant temperatures for special construction elements

4.2.6.1 Ceiling below an attic

The ceiling, the air space and the roof are considered as a single horizontal element with one-dimensional heat flow. The air space is considered as an air layer, treated in 4.5.2.3 and 4.5.2.4.

4.2.6.2 Floor on ground

The floor and the soil are considered as a single horizontal element with the heat flow treated according to ISO 13370. Boundary conditions are specified in 4.4.4.

4.2.6.3 Floor over cellar

The cellar is treated as an unheated basement according to ISO 13370. The calculation procedure is according to ISO 13370. Boundary conditions are specified in 4.4.5.

4.2.6.4 Floor over crawl space

The floor, the crawl space and the soil are treated as a suspended floor according to ISO 13370. Boundary conditions are specified in 4.4.5.

4.2.6.5 Glazed element

A glazed element is composed of a number of planes (glazing panes and possibly blinds) which are in thermal equilibrium with one another. The evaluation of temperatures of each plane is made using the following assumptions:

- the heat storage effects in the various planes are neglected;
- the heat flow by convection through the air layers between each pane is calculated according to 4.5.2.3 and 4.5.2.4;
- the density of heat flow rate due to the long-wave radiation between the various planes is calculated according to 4.5.4.3;
- the density of heat flow rate due to the short-wave radiation absorbed by each plane is treated as a source term.

4.3 Room thermal balance

In each equation of 4.2, the time-dependent heat flow rates shall be expressed in terms of operators which relate the heat flow rate at the internal surface of each element to the temperature at the internal and external surface, and that of the internal air, by using suitable mathematical models of the heat transfer processes. The temperature of the internal air, together with the temperature of the different surfaces, shall be determined by solving the global equation system at each time step considered. A general expression of the equation system is expressed in Equation (6):

$$\begin{pmatrix} \Pi_{1,1} & \Pi_{1,2} & \Pi_{1,N} & \Pi_{1,N+1} \\ \Pi_{2,1} & \Pi_{2,2} & \Pi_{2,N} & \Pi_{2,N+1} \\ \Pi_{N,1} & \Pi_{N,2} & \Pi_{N,N} & \Pi_{N,N+1} \\ \Pi_{N+1,1} & \Pi_{N+1,2} & \Pi_{N+1,N} & \Pi_{N+1,N+1} \end{pmatrix} \cdot \begin{pmatrix} \theta_{is,1} \\ \theta_{is,2} \\ \theta_{is,N} \\ \theta_a \end{pmatrix} = \begin{pmatrix} \Gamma_1 \\ \Gamma_2 \\ \Gamma_N \\ \Gamma_{N+1} \end{pmatrix} \quad (6)$$

where

- N is the number of elements bounding the room corresponding to the internal surfaces delimiting the internal air;
- Π are the coefficients of the unknown temperatures (θ) (from 1 to N relating to the internal surfaces, $N + 1$ relating to the internal air);
- Γ are the coefficients of the known terms (from 1 to N relating to the internal surfaces, $N + 1$ relating to the internal air);

θ are the unknown temperatures (from 1 to N relating to the internal surfaces, $N + 1$ relating to the internal air).

The “ II ” and “ I ” terms are obtained by rewriting Equation (1) and Equation (2) in order to separate the unknown parameters [air temperature at the given time t for Equation (1) and the internal surface temperature for each component at the given time t for Equation (2)] from the known parameters. The form of these equations depends on the solution technique adopted.

4.4 Boundary conditions

4.4.1 Single room

A single room model requires the knowledge of the conditions of adjacent rooms. The two following situations are considered:

- adjacent room with the same conditions (similar rooms);
- adjacent room with defined internal conditions.

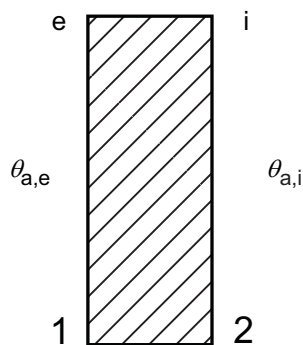
If boundary conditions are very different from the above, the simple room model specified in this International Standard shall not be used and it is necessary to calculate the real boundary conditions by a multi-room model able to take account of the heat transfer between the different rooms. This may be achieved by:

- a) simultaneous solution of the global system equations for all rooms, or
- b) iterative procedure by considering, as boundary conditions for each room, the temperatures determined at the previous time step.

4.4.2 Similar rooms

4.4.2.1 Partition (vertical) wall

Referring to Figure 4, the following boundary conditions are considered as shown in Equation (7):



Key

- 1 similar
- 2 internal

Figure 4 — Partition vertical wall

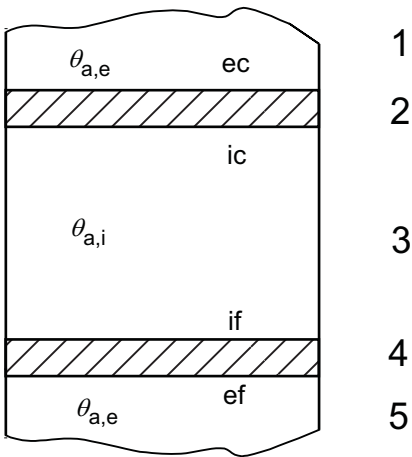
$$\begin{aligned}\theta_{a,e} &= \theta_{a,i} \\ q_{sr,e} &= q_{sr,i} \\ q_{lr,e} &= q_{lr,i} \\ h_{c,e} &= h_{c,i}\end{aligned}\tag{7}$$

where

- $\theta_{a,e}$ is the air temperature of the adjacent room;
- $\theta_{a,i}$ is the air temperature of the room;
- $q_{sr,e}$ is the density of heat flow rate due to absorbed short-wave radiation at the external surface of the wall;
- $q_{lr,e}$ is the density of the heat flow rate by long-wave radiation exchanged with the other surfaces of the adjacent room;
- $q_{sr,i}$ is the density of heat flow rate due to absorbed short-wave radiation at the internal surface of the wall (see 4.5.3.2);
- $q_{lr,i}$ is the density of the heat flow rate received by long-wave radiation at the internal surface of the wall from the other internal surfaces (see 4.5.4.2);
- $h_{c,e}$ is the convective heat transfer coefficient at the external surface;
- $h_{c,i}$ is the convective heat transfer coefficient at the internal surface (see Table 1).

4.4.2.2 Ceiling/floor

Referring to Figure 5, the following boundary conditions are considered as shown in Equation (8):



- Key**
- 1 similar room
 - 2 ceiling
 - 3 room
 - 4 floor
 - 5 similar room

Figure 5 — Ceiling/floor adjacent to similar rooms

$$\begin{aligned}
 \theta_{a,e} &= \theta_{a,i} \\
 q_{sr,ec} &= q_{sr,if} \\
 q_{lr,ec} &= q_{lr,if} \\
 q_{sr,ef} &= q_{sr,ic} \\
 q_{lr,ef} &= q_{lr,ic} \\
 h_{c,ec} &= h_{c,if} \\
 h_{c,ef} &= h_{c,ic}
 \end{aligned}
 \tag{8}$$

where

- $\theta_{a,e}$ is the air temperature of the adjacent room;
- $\theta_{a,i}$ is the air temperature of the room;
- $q_{sr,ec}$ is the density of heat flow rate due to absorbed short-wave radiation at the external surface of the ceiling;
- $q_{sr,ic}$ is the density of heat flow rate due to absorbed short-wave radiation at the internal surface of the ceiling (see 4.5.3.2);
- $q_{sr,ef}$ is the density of heat flow rate due to absorbed short-wave radiation at the external surface of the floor;
- $q_{sr,if}$ is the density of heat flow rate due to absorbed short-wave radiation at the internal surface of the floor (see 4.5.3.2);
- $q_{lr,ef}$ is the density of the heat flow rate by long-wave radiation by the external surface of the floor with the other external surfaces;
- $q_{lr,if}$ is the density of the heat flow rate by long-wave radiation by the internal surface of the floor with the other internal surfaces (see 4.5.4.2);
- $q_{lr,ec}$ is the density of the heat flow rate by long-wave radiation from the external surface of the ceiling to the other external surfaces;
- $q_{lr,ic}$ is the density of the heat flow rate by long-wave radiation from the internal surface of the ceiling to the other internal surfaces (see 4.5.4.2);
- $h_{c,ec}$ is the convective heat transfer coefficient at the external surface of the ceiling;
- $h_{c,if}$ is the convective heat transfer coefficient at the internal surface of the floor (see Table 1);
- $h_{c,ef}$ is the convective heat transfer coefficient at the external surface of the floor;
- $h_{c,ic}$ is the convective heat transfer coefficient at the internal surface of the ceiling (see Table 1).

4.4.3 Adjacent room with defined value of the air temperature

For each component of the envelope (see Figure 6) the following boundary conditions are considered as shown in Equation (9):

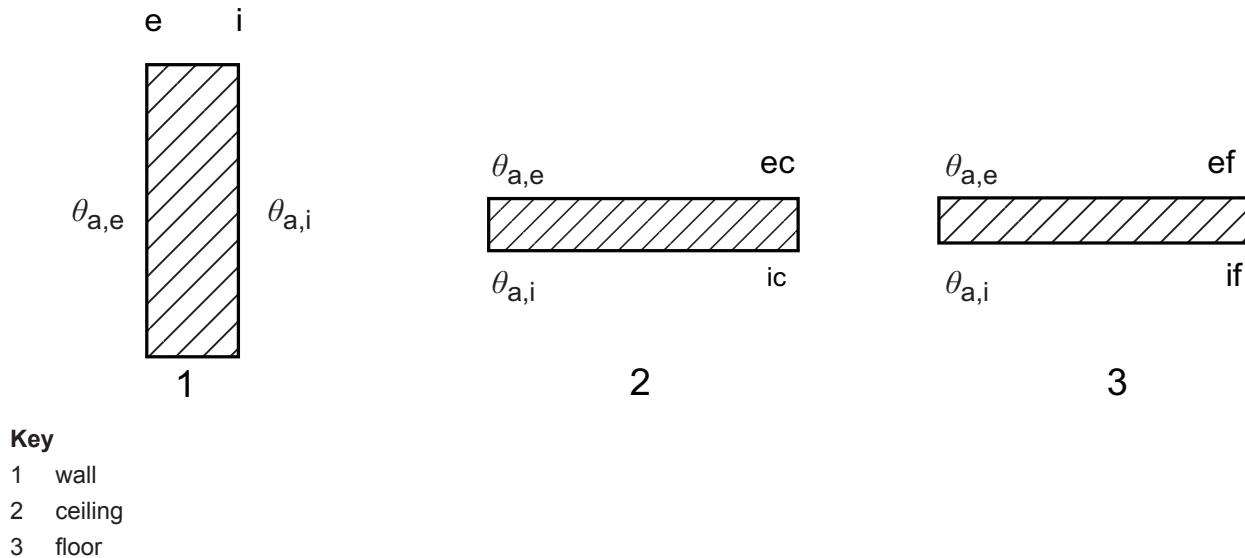


Figure 6 — Wall, ceiling and floor adjacent to room with defined internal conditions

$$\begin{aligned}
 \theta_{a,e} &= \theta_{a,d} \\
 q_{sr,e} &= 0 \\
 h_{c,e} &= h_{c,i} \\
 h_{c,ec} &= h_{c,if} \\
 h_{c,ef} &= h_{c,ic}
 \end{aligned} \tag{9}$$

where

- $\theta_{a,d}$ is the defined air temperature of the adjacent room;
- $q_{sr,e}$ is the density of heat flow rate due to absorbed short-wave radiation at the external surface;
- $h_{c,e}$ is the convective heat transfer coefficient at the external surface of the vertical wall;
- $h_{c,i}$ is the convective heat transfer coefficient at the internal surface of the vertical wall (see Table 1);
- $h_{c,ec}$ is the convective heat transfer coefficient at the external surface of the ceiling;
- $h_{c,if}$ is the convective heat transfer coefficient at the internal surface of the floor (see Table 1);
- $h_{c,ef}$ is the convective heat transfer coefficient at the external surface of the floor;
- $h_{c,ic}$ is the convective heat transfer coefficient at the internal surface of the ceiling (see Table 1).

4.4.4 Floor on ground

The heat transfer between the room and the external environment through the ground is calculated as the sum of a steady state component and a monthly variable component as specified in ISO 13370. The monthly variable component is treated as one-dimensional and perpendicular to the floor surface. The calculation procedure shall combine this heat flow rate with the thermal storage of the floor construction together with a 0,5 m thick layer of soil beneath it as described in ISO 13370.

4.4.5 Cellar or crawl space

A cellar is treated as an unheated basement according to ISO 13370. Heat transfers are calculated as in 4.4.4, including 0,5 m of soil at each side of the cellar and below the cellar. A crawl space is treated as a suspended floor according to ISO 13370. Heat transfers are calculated as in 4.4.4.

4.4.6 Ceiling below attic

According to the assumptions of 4.2.6.1, the boundary conditions are represented by:

$\theta_{a,e}$ is the external air temperature;

$q_{sr,e}$ is defined by Equation (17);

$q_{lr,e}$ is defined by Equation (24).

4.5 Terms in the thermal balance equations

4.5.1 Heat conduction through components

For elements with constant thermal conductivity and specific heat capacity, the density of heat flow by conduction is governed by Equations (10) and (11):

$$q_{cd,n} = -\lambda \left(\frac{\partial \theta}{\partial n} \right) \quad (10)$$

$$\lambda \left(\frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2} \right) + g = c_{me} \rho_{me} \frac{\partial \theta}{\partial t} \quad (11)$$

where

θ is the temperature of the component (in direction of the heat flow) at the time t ;

$q_{cd,n}$ is the density of heat flow rate in direction n ;

λ is the thermal conductivity of the medium;

c_{me} is the specific heat capacity of the medium;

ρ_{me} is the density of the medium;

g is the heat source term (heat flow rate per volume);

x, y, z are co-ordinates.

These equations may be solved by any appropriate procedure which provides results in accordance with the validation procedure given in Clause 7.

NOTE A suitable procedure is described in Annex A.

4.5.2 Convective heat transfer

4.5.2.1 General

Convective heat transfer occurs at the boundary surfaces of each building element and through air layers.

4.5.2.2 Convective heat flow rate at the surfaces of an element

The density of convective heat flow rate at the internal and external surface of element is given by Equation (12):

$$q_c = h_c(\theta_s - \theta_a) \quad (12)$$

where

h_c is the convective heat transfer coefficient of the surface;

θ_s is the surface temperature;

θ_a is the air temperature.

At the external surface the values of the convective heat transfer coefficient $h_{c,e}$, are given by Equation (13):

$$h_{c,e} = 4 + 4 \times v \quad (13)$$

where v is the wind velocity near the surface.

The wind velocity near the surface, v , depends on the climatic data of the locality and on the envelope characteristics. Unless otherwise specified, the value of 1 m/s shall be used. The values of the convective heat transfer coefficient at the internal surface, $h_{c,i}$, are given in Table 1.

Table 1 — Convective heat transfer coefficient at the internal surface

Vertical wall W/(m ² ·K)	Heat flow upwards W/(m ² ·K)	Heat flow downwards W/(m ² ·K)
2,5	5,0	0,7
NOTE The values in this table were determined using the equations given in ISO 6946 for the following conditions: — temperature difference ($\theta_{s,i} - \theta_{a,i}$) < 10 K; — surface hydraulic diameter = 4,5 m ($4 \times \text{area/perimeter}$).		

The air temperature required in Equation (12) is:

- for internal surfaces: the room air temperature;
- for external surfaces: the conditions given in Table 2.

Table 2 — Air temperature

Building elements	Air temperature conditions
External wall, roof	External air temperature
Partition wall, ceiling and roof to similar room	Internal air temperature
Partition wall, ceiling and roof to adjacent room with different conditions	Air temperature of the adjacent room
Floor on ground	Mean monthly external air temperature
Floor on cellar	Temperature of the cellar

4.5.2.3 Convective heat transfer through unventilated air layers

The density of convective heat flow rate through an unventilated air layer, q_c , is given by Equation (14):

$$q_c = A_a \Delta\theta \quad (14)$$

where

$\Delta\theta$ is the temperature difference between the surfaces delimiting the layer;

A_a is the thermal conductance of the air layer.

The thermal conductance of an unventilated air layer is calculated according to:

- ISO 6946 between opaque surfaces;
- ISO 10077-1, ISO 10077-2, ISO 15099, ISO 10292 or EN 673 between transparent surfaces.

NOTE For transparent surfaces, the thermal conductance of an unventilated air layer can be calculated assuming the following reference conditions:

- air density: 1,139 kg/m³
- dynamic viscosity: $1,861 \times 10^{-5}$ kg/(m·s)
- thermal conductivity: 0,026 4 W/(m·K)
- specific heat capacity: 1 008 J/(kg·K)
- thermodynamic temperature: 300 K
- temperature difference: 5 K

Table 3 gives some values of thermal conductance, A_a , for vertical and horizontal unventilated air layers between transparent components. For other thicknesses, thermal conductance may be derived by interpolation.

**Table 3 — Thermal convective conductance of unventilated air layers between opaque surfaces
(calculated in accordance with ISO 6946)**

Air layer thickness m	Vertical air layer	Horizontal air layer	
	Thermal conductance Λ_a W/(m ² ·K)	Heat flow upwards	Heat flow downwards
		Thermal conductance Λ_a W/(m ² ·K)	Thermal conductance Λ_a W/(m ² ·K)
0,01	2,50	2,50	2,50
0,05	1,25	1,95	0,50
0,10	1,25	1,95	0,33
0,20	1,25	1,95	0,24

**Table 4 — Thermal convective conductance of unventilated air layers between transparent surfaces
(calculated in accordance with EN 673)**

Air layer thickness m	Vertical air layer	Horizontal air layer	
	Thermal conductance Λ_a W/(m ² ·K)	Heat flow upwards	Heat flow downwards
		Thermal conductance Λ_a W/(m ² ·K)	Thermal conductance Λ_a W/(m ² ·K)
0,01	2,64	2,64	2,64
0,025	1,06	2,00	1,06
0,05	1,16	1,79	0,53
0,10	1,28	1,60	0,26
0,20	1,41	1,43	0,13
NOTE The value corresponding to 25 mm thickness is necessary for interpolation.			

4.5.2.4 Convective heat transfer through ventilated air layer

The convective heat flow rate through a ventilated air layer, Φ_{va} , depends on the air flow rate in the air layer. The heat flow rates to be considered are:

- a) the convective heat flow rate, Φ_{va} , due to air passing through the air layer and into the room, given by Equation (15):

$$\Phi_{va} = m_{a,v} c_a (\theta_l - \theta_{a,i}) \quad (15)$$

where

$m_{a,v}$ is the mass air flow through the air layer;

θ_l is the temperature of the air leaving the layer;

b) the convective heat flow rate, $\Phi_{c,j}$, between surfaces and air, given by Equation (16):

$$\begin{aligned}\Phi_{c,j} &= h_a A_c (\theta_j - \theta_{eq}) \\ \Phi_{c,j+1} &= h_a A_c (\theta_{j+1} - \theta_{eq})\end{aligned}\quad (16)$$

where

- A_c is the area of the surface in contact with the air layer;
- h_a is the convective heat transfer coefficient for ventilated layers;
- θ_{eq} is the equivalent temperature of the air in the layer;
- j and $j + 1$ is the surfaces delimiting the air layer.

NOTE A procedure for determining the parameters in Equations (15) and (16) is given in Annex B.

4.5.3 Short-wave radiation heat transfers

4.5.3.1 Short-wave radiation heat transfer at the external surface of opaque element

The density of short-wave radiation heat flow rate at the external surface of an opaque element is given by Equation (17):

$$q_{sr,e} = \alpha_{sr} (f_s I_D + I_d) \quad (17)$$

where

- α_{sr} is the solar absorptance;
- f_s is the sunlit factor;
- I_D is the direct component of the solar radiation reaching the surface;
- I_d is the diffuse component of the solar radiation reaching the surface.

The values of solar absorptance of external opaque surfaces, α_{sr} , depend on the characteristics of the external surface of the element. Table 5 gives values of the solar absorptance as a function of the colour of the external surface that may be used when no specific values are available.

Table 5 — Solar absorptance of external opaque surfaces

	Light colour	Intermediate colour	Dark colour
α_{sr}	0,3	0,6	0,9

The values of the direct, I_D , and diffuse, I_d , components of the solar radiation reaching the differently oriented surfaces may be derived from national data.

The sunlit factor, f_s , is given by Equation (18):

$$f_s = \frac{A_s}{A} \quad (18)$$

where

A_s is the sunlit area of the wall (defined in 4.5.3.5);

A is the total area of the wall.

4.5.3.2 Short-wave radiation heat transfer at the internal surface of opaque elements

The density of heat flow rate by short-wave radiation absorbed at the internal surface of an opaque element is given by Equation (19):

$$q_{sri} = (1 - f_{sa})(1 - f_{sl})(\Phi_{sr,D} + \Phi_{sr,d})f_d \quad (19)$$

where

f_{sa} is the solar to air factor of the room;

f_{sl} is the solar loss factor of the room;

f_d is the distribution factor of the solar radiation at the internal surface of the element;

$\Phi_{sr,D}$ is the heat flow rate due to the direct component of solar radiation entering the room;

$\Phi_{sr,d}$ is the heat flow rate due to the diffuse component of solar radiation entering the room.

The heat flow rates due to the direct and diffuse components of the solar radiation entering the room are given by Equations (20) and (21), respectively:

$$\Phi_{sr,D} = \sum_{j=1}^J (I_D \tau_D A_s)_j \quad (20)$$

$$\Phi_{sr,d} = \sum_{j=1}^J (I_d \tau_d A)_j \quad (21)$$

where

J is the number of glazing systems;

I_D is the direct component of solar radiation reaching the external surface of the system j ;

I_d is the diffuse component of solar radiation reaching the external surface of the glazing system j ;

τ_D is the direct solar transmittance of the glazing system;

τ_d is the diffuse solar transmittance of the glazing system;

A_s is the sunlit area of the glazing (see 4.5.3.5);

A is the glazing area.

The direct and diffuse solar transmittance of each glazing system τ_D and τ_d shall be determined according to ISO 9050 or EN 410. If no values are available, τ_D and τ_d shall be calculated at the normal incident angle.

Solar to air factor

The solar to air factor, f_{sa} , is the fraction of solar heat entering the room through the glazing which is immediately transferred to the internal air. This fraction depends on the quantity of internal items with very low thermal capacity such as carpets and furniture. It is assumed to be time-independent.

Solar loss factor

The solar loss factor, f_{sl} , is the fraction of the solar radiation entering the room which is reflected back to the external environment. It depends on the geometrical characteristics and solar properties of the glazing system, the exposure of the glazing, the solar angles and the room geometry and colour of the surfaces. It is assumed to be time-independent.

Distribution factors

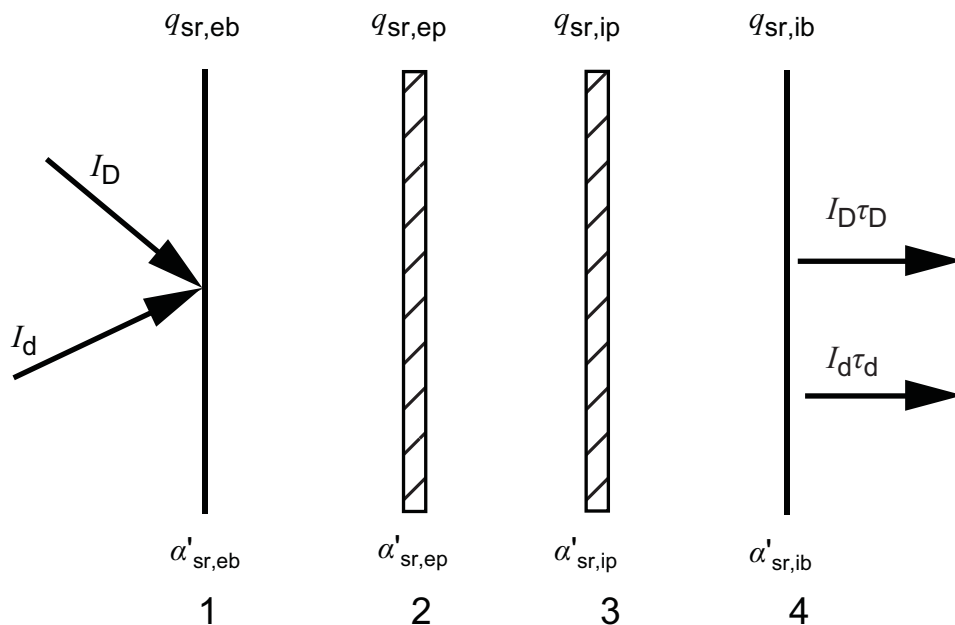
The distribution factors, f_d , define the amount of the direct solar radiation absorbed per area at the different internal surfaces of the walls, ceiling, floor, etc. They depend on the solar angles, the geometrical dimensions of glazing and room, the short-wave reflectance of components, and the furniture and furnishings. It is assumed to be time-independent.

NOTE Unless otherwise specified, values of f_{sa} , f_{sl} and f_d given in informative Annex G can be used.

4.5.3.3 Short-wave radiation heat flow rate for transparent elements (including blinds and curtains)

Transparent elements partially transmit, reflect and absorb the solar radiation impinging on their external surface. For multi-layered glazed elements (e.g. double pane window with internal and/or external blind) the following solar parameters are required:

- direct and diffuse solar energy transmittance of the system, τ_D and τ_d ;
- equivalent direct and diffuse solar energy absorptance of each component of the glazed system, α'_{sr} .



Key

- 1 external blind (eb)
- 2 external pane (ep)
- 3 internal pane (ip)
- 4 internal blind (ib)

Figure 7 — Double pane with internal and external blinds

These solar parameters shall be calculated according to ISO 9050 or EN 410, taking into account the solar energy transmittance and reflectance of each component. If no data are available for various incident angles, values of these parameters at the normal incident angle can be taken as safe values. The density of heat flow rate for element j of the glazing system due to the absorbed solar radiation is then determined in Equation (22) as:

$$q_{sr,j} = \alpha'_{sr,j}(I_D f_s + I_d) \quad (22)$$

where

j is the element of the glazing system;

α'_{sr} is the equivalent solar absorptance.

If curtains or venetian blinds are present, the following situations can occur:

- a) curtain/blind completely closed;
- b) curtain/blind not completely closed.

In case a) the glazing component and the curtain/blind are treated as a single envelope component having appropriate solar coefficients.

In case b) two different components shall be considered:

- the portion of glazing area not covered by the curtain/blind, comprising the glazing component only;
- the portion of glazing area covered by the curtain/blind, treated as in case a).

4.5.3.4 Solar to air heat flow rate

The solar to air heat flow rate, Φ_{sa} , is the heat flow rate due to solar radiation, entering through the glazing system, directly transferred to the internal air. It is given by Equation (23):

$$\Phi_{sa} = f_{sa}(1 - f_{sl})(\Phi_{sr,D} + \Phi_{sr,d}) \quad (23)$$

The parameters in Equation (23) are the same as in Equation (19).

4.5.3.5 Sunlit area of room element

When external obstructions are present, the area of an element can be partially shaded. Obstructions considered in this International Standard are: horizontal overhangs, side fins, window set back and surrounding constructions. A sunlit factor is defined in Equation (18) and may be added for the diffuse radiation in Equations (17) and (22). For the sake of safety, it may be assumed that:

- the effect of shading is only to reduce the direct solar component;
- the effect of mutual reflections is negligible.

The evaluation of the sunlit area may be obtained by any appropriate procedure that provides results in accordance with the validation tests given in Clause 7.

NOTE A suitable procedure is described in Annex C.

4.5.4 Long-wave radiation heat transfer

4.5.4.1 Heat flow rate at the external surface

According to the assumptions of 4.1, the density of net long-wave radiant heat flow rate received by an external surface, q_{lr} , is given by Equation (24):

$$q_{lr} = h_{lr}(\theta_{a,e} - \theta_{s,e}) - q_{sk} \quad (24)$$

where

h_{lr} is the long-wave radiative heat transfer coefficient;

$\theta_{a,e}$ is the external air temperature;

$\theta_{s,e}$ is the external surface temperature;

q_{sk} is the correction for the long-wave radiation exchanges from the wall to the sky.

Using thermodynamic temperatures ($T = \theta + 273,15$), the value of h_{lr} is approximated by Equation (25):

$$h_{lr} = 4 \times \varepsilon \sigma \left(\frac{T_{a,e} + T_{s,e}}{2} \right)^3 \quad (25)$$

where

ε is the long-wave emissivity of the surface;

σ is the Stefan-Boltzmann constant;

$T_{a,e}$ is the external air temperature;

$T_{s,e}$ is the surface temperature.