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Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - Simplified methods (ISO 13792:2005)

Performances thermiques des bâtiments - Calcul de la température interne d'une pièce sans climatisation mécanique en été - Méthodes simplifiées (ISO 13792:2005)

Wärmetechnisches Verhalten von Gebäuden - Sommerliche Raumtemperaturen bei Gebäuden ohne Anlagentechnik - Vereinfachtes Berechnungsverfahren (ISO 13792:2005)

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Foreword

This document (EN ISO 13792:2005) 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 performance and energy use in the built environment”, Subcommittee SC 2, "Calculation methods".

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of an identical text or by endorsement, at the latest by August 2005, and conflicting national standards shall be withdrawn at the latest by August 2005.

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 elements.

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

Introduction

Knowledge of the internal temperature of a room in the warm period is needed for several purposes such as:

a) defining the characteristics of a room at the design stage, in order to prevent or limit overheating in summer;

b) assessing the need for a cooling installation.

The internal temperature is influenced by many parameters such as climatic data, envelope characteristics, ventilation and internal gains. The internal temperature of a room in the warm period can be determined using detailed calculation methods. EN ISO 13791 lays down the assumptions and the criteria which have to be satisfied for assessment of internal conditions in the summer with no mechanical cooling. However, for a number of applications the calculation methods based on EN ISO 13791 are too detailed. Simplified methods are derived from more or less the same description of the heat transfer processes in a building. Each calculation method has its own simplification, assumptions, fixed values, special boundary conditions and validity area. A simplified method can be implemented in many ways. In general the maximum allowed simplification of the calculation method and the input data is determined by the required amount and accuracy of the output data.

This document defines the level, the amount and the accuracy of the output data and the allowed simplification of the input data.

No particular calculation methods are included in the normative part of this standard. As examples, two calculation methods are given in Annex A. They are based on the simplification of the heat transfer processes that guarantees the amount and the accuracy of the output data and the simplification of the input data required by this standard.

The use of these simplified calculation methods does not imply that other calculation methods are excluded from standardisation, nor does it hamper future developments. Clause 6 gives the criteria which have to be satisfied in order that a method complies with this document.

1 Scope

This document specifies the required input data for simplified calculation methods for determining the maximum, average and minimum daily values of the operative temperature of a room in the warm period:

a) to define the characteristics of a room in order to avoid overheating in summer at the design stage;

b) to define whether the installation of a cooling system is necessary or not.

Clause 6 gives the criteria to be met by a calculation method in order to satisfy this document.

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.

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.*

EN 13363-1, *Solar protection devices combined with glazing – Calculation of solar and light transmittance – Part 1: Simplified method.*

EN ISO 6946, *Building components and building elements – Thermal resistance and thermal transmittance – Calculation method (ISO 6946:1996).*

EN ISO 7345:1995, *Thermal insulation – Physical quantities and definitions (ISO 7345:1987).*

EN ISO 10077-1, *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: Simplified method (ISO 10077-1:2000).*

EN ISO 13370, *Thermal performance of buildings – Heat transfer via the ground – Calculation methods (ISO 13370:1998).*

EN ISO 13786,*Thermal performance of building components – Dynamic thermal characteristics – Calculation methods (ISO 13786:1999).*

EN ISO 13791:2004, *Thermal performance of buildings – Calculation of internal temperatures of a room in summer without mechanical cooling – General criteria and calculation procedures (ISO 13791:2004).*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 7345:1995 and the following apply.

3.1.1
internal environment
closed space delimited from the external environment or adjacent spaces by an envelope element

3.1.2
room element
wall, ceiling, roof, floor, door or window which separates the room from the adjacent spaces or external environment

3.1.3
room air
air in the room

3.1.4
internal air temperature
temperature of the room air

3.1.5
internal surface temperature
temperature of the internal surface of each element of the envelope

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 enclosure

NOTE For simplification the mean value of the air temperature and the mean radiant temperature of the room can be used.

3.2 Symbols and units

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

Symbol	Quantity	Unit
A	area	m^2
C	heat capacity	J/K
I	intensity of solar radiation	$W/\ m^2$
m	mass	Kg
R	thermal resistance	$m^2\cdot K/W$
T	thermodynamic temperature	K
U	thermal transmittance under steady state conditions	$W/(m^2\cdot K)$
V	volume	m^3
c_p	specific heat capacity of air at constant pressure	$J/(kg\cdot K)$
d	thickness	m
f_{sl}	solar loss factor	-
f_s	sunlit factor	-
f_v	ventilation factor	-
g	total solar energy transmittance	-
h	surface coefficient of heat transfer	$W/(m^2\cdot K)$
l	length	m
q_a	mass air flow rate	kg/s
q	density of heat flow rate	W/m^2
q^*	heat flow rate per volume	W/m^3
t	time	s
v	velocity	m/s
Λ	thermal conductance	$W/(m^2\cdot K)$
Φ	heat flow rate	W
α	solar absorptance	-
ε	total hemispherical emissivity	-
θ	Celsius temperature	°C
λ	thermal conductivity	$W/(m\cdot K)$
ρ	density	kg/m^3
ρ	solar reflectance	-
τ	solar direct transmittance	-

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
t	time	sr	short wave radiation
v	ventilation	va	ventilation through air cavity

4 Input data and results

4.1 Assumptions

For the scope of this document the following basic assumptions are made:

— the room is considered a closed space delimited by enclosure elements;

— the air temperature is uniform throughout the room;

— the various surfaces of the enclosure elements are isothermal;

— the thermophysical properties of the material composing the enclosure elements are constant;

— the heat conduction through each enclosure element is one dimensional;

— air spaces within the envelope elements are considered as air layers bounded by two isothermal surfaces;

— the mean radiant temperature is calculated as an area-weighted average of the radiant temperature at each internal surface;

— the operative temperature is calculated as the arithmetic mean value of the internal air temperature and the mean radiant temperature;

— the distribution of the solar radiation on the internal surfaces of the room is time independent;

— the spatial distribution of the radiative part of the heat flow due to internal sources is uniform;

— the long-wave radiative and the convective heat transfers at each internal surface are treated separately;

— the dimensions of each component are measured at the internal side of the enclosure element;

— the effects of the thermal bridges on heat transfers are neglected.

4.2 Boundary conditions and input data

4.2.1 Boundary conditions

4.2.1.1 General

The elements of the envelope are divided into:

— external elements: these include the elements separating the internal environment from the outside and from other zones (i.e. attic, ground, crawl space);

— internal elements: these include the elements (vertical and horizontal) separating the internal environment from other rooms which can be considered to have the same thermal conditions.

4.2.1.2 External elements

External elements are those separating the room from the external environment and from zones at different thermal conditions (e.g. attic, ground, crawl space).

Boundary conditions consist of defined hourly values of:

— external air temperature;

— intensity of the solar radiation on each orientation;

— sky radiant temperature;

— air temperature for the adjacent zones which cannot be considered at the same thermal conditions as the examined room.

For elements in contact with the ground the external temperature is assumed to be the mean monthly value of the external air temperature.

4.2.1.3 Internal elements

Internal elements are those separating the room from other rooms which can be considered to have the same thermal conditions.

Internal elements are assumed to be adiabatic, which means that the values of the following quantities are considered to be the same on either side of the element:

— the air temperature;

— the mean radiant temperature;

— the solar radiation absorbed by the surface.

4.2.2 Heat transfer coefficients

For the purposes of this document the following values shall be used:

— internal convective heat transfer coefficient h_{ci} = 2,5 W/(m^2·K);

— internal long-wave radiative heat transfer coefficient h_{ri} = 5,5 W/(m^2·K);

— external convective heat transfer coefficient h_{ce} = 8,0 W/(m^2·K);

— external long-wave radiative heat transfer coefficient h_{re}= 5,5 W/(m^2·K);

— internal surface coefficient of heat transfer h_i = 8,0 W/(m^2·K);

— external surface coefficient of heat transfer h_e = 13,5 W/(m^2·K).

4.2.3 Geometrical and thermophysical parameters of the room envelope

4.2.3.1 Opaque elements

For each element the following data are required:

— area calculated using the internal dimensions;

— summertime thermal transmittance (U*);

— thermal inertia characteristics [see EN ISO 13786];

— for external elements, sunlit factor and solar energy transmittance.

The summertime thermal transmittance, U*, is given by:

$$U^* = \frac{1}{\frac{1}{U} - 0{,}17 + \frac{1}{h_i} + \frac{1}{h_e}} \tag{1}$$

where

U is the conventional thermal transmittance with standard surface resistances defined below;

0,17 is the sum of the conventional internal and external surface resistances as defined in EN ISO 6946;

h_e is the external surface coefficient of heat transfer defined in 4.2.2;

h_i is the internal surface coefficient of heat transfer defined in 4.2.2.

The thermal transmittance, U, may be determined from:

— building elements in contact with the external air: EN ISO 6946;

— building elements in contact with the ground: EN ISO 13370.

The thermal inertia characteristics shall be determined according to EN ISO 13786.

NOTE The sunlit factor differs from the shading correction factor, defined in ISO 13790, which includes diffuse solar radiation.

The sunlit factor, f_s, is given by:

$$f_s = \frac{A_s}{A} \tag{2}$$

where

A_s is the area of the sunlit part of the wall (see 6.3);

A is the total area of the wall.

The solar energy transmittance, g, is the ratio of the heat flow through the element due to the absorbed solar radiation, to the incident solar radiation. It is given by:

— element with no air cavity (or closed air cavity):

$$g = \frac{\alpha\, U^*}{h_e} \tag{3}$$

where α is the direct solar absorptance of the external surface.

— element with open air cavity (external air):

$$g = f_v S_{fc} + (1 - f_v)\, S_{fv} \tag{4}$$

where

f_v is the ventilation coefficient derived from Table 1 as a function of ventilation in the cavity;

S_{fc} is the solar energy transmittance for the closed cavity;

S_{fv} is the solar energy transmittance for the ventilated cavity, given by:

$$S_{fv} = \frac{\alpha}{h_e}\left[\frac{U^*_e \cdot U^*_i}{U^*_e + U^*_i + h'}\right] \tag{5}$$

where

U^*_e is the thermal transmittance between the external environment and the air cavity defined as in Equation (1);

U^*_i is the thermal transmittance between the internal environment and the air cavity defined as in Equation (1);

h_e is the external surface coefficient of heat transfer (defined in 4.2.2);

α is the direct solar absorptance of the external surface of the element;

with

$$h' = h_c (h_c + 2 h_r) / h_r \quad (6)$$

where

h_c is the convective heat transfer coefficient between the surface of the ventilated air layer and the air in the cavity;

h_r is the radiative heat transfer coefficient between the two surfaces of the air layer.

Using the following values: $h_c = 5$ W/(m^2·K) $h_r = 5$ W/(m^2·K)

$h' = 15$ W/(m^2·K),

Table 1 gives the ventilation coefficient f_v depending on the ratio between the cavity area (A_c) and the wall area (A_w).

The cavity area is the air flow area; the wall area is the conduction heat flow area.

Table 1 – Ventilation coefficient f_v

	$A_c/A_w \leq 0{,}005$	$0{,}005 < A_c/A_w \leq 0{,}10$	$0{,}10 < A_c/A_w$
f_v	0,8	0,5	0,2

In the absence of an actual measured value, the direct solar absorptance of the external surface may be derived from Table 2 as function of its colour.

Table 2 – Direct solar absorptance of external surface

	Light colour	**Medium colour**	**Dark colour**
α	0,3	0,6	0,9

4.2.3.2 Glazed elements

For each glazing element the following data are required:

— area calculated including the frame;

— summertime thermal transmittance (U^* value);

— total solar transmittance (g) (τ in EN 410);

— secondary solar heat gain (q_i) of the glazing by convection and long-wave radiation due to the absorbed solar radiation;

— tertiary heat transfer factor (S_{f3}) of the glazing by ventilation due to the absorbed solar radiation;

— the sunlit factor due to external obstruction f_s.

The summertime thermal transmittance, U^*, is determined by using Equation (1).

The thermal transmittance, U, is determined according to EN 673 and EN ISO 10077-1.

The solar direct transmittance, (τ), and the secondary and tertiary heat transfer factors S_{f2} and S_{f3} are determined from EN 13363-1.

a) 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 presence of internal elements with very low heat capacity, such as carpets and furniture. It is assumed to be time independent and, unless otherwise specified, the values in informative Annex G of EN ISO ISO 13791:2004 may be used.

b) Solar loss factor

The solar loss factor, f_{sl}, is the fraction of the solar radiation entering the room which is reflected back outside. It depends on the solar position, solar properties, dimensions and exposure of the glazing system, the room geometry and the reflectivity of the internal room surfaces. It is assumed to be time independent. Unless otherwise specified, values of f_{sl} in informative Annex G of EN ISO 13791:2004 may be used.

NOTE The procedure for evaluating the sunlit factor due external obstruction f_s can be defined in national standards. Such a procedure is given in Annex C.

4.2.3.3 Special elements

a) Ceiling below attic

The element formed by the ceiling, the air space and the roof is considered as a single horizontal element with one-dimensional heat flow. The air space is considered as an air cavity and treated according to EN ISO 6946.

b) Floor on ground

The ground formed by the floor and the soil is considered as a single horizontal layer, which may include an air gap. The heat flow through the element is the sum of a monthly mean value and a variable term. The monthly mean value is calculated using the mean internal and external temperatures, and (taken as constant and equal to the mean monthly value) the thermal transmittance determined according to EN ISO 13370. The variable term is calculated assuming the mean temperature difference is zero. The depth of soil is taken to be 0,5 m.

c) Cellar

A cellar can be considered as an adjacent room with fixed air temperature.

d) Crawl space

A crawl space is treated as a floor on ground according to EN ISO 13370.

4.2.4 Air change rate

The air change rate depends on the tightness of the envelope and on the opening of any doors and windows.

At a design stage the air change rate is expressed as a function of the:

— location of the building;

— pattern of air ventilation;

— number of facades with windows.

The location may be categorised as:

— city centre area;

— suburban area;

— open area.

The pattern of air ventilation is related to the time schedule of the opening and closing of windows and whether windows are located on one or on more facades.

The following time schedules are considered:

— windows open day and night;

— windows closed day and night;

— window closed during the day and open during the night.

NOTE Data on the time of opening and closing of the windows and on hourly air change rates can be defined at a national level. Annex B gives examples of appropriate values of the air change rates.

4.2.5 Internal gain

Internal gains derive from lighting, equipment and occupant. The pattern of the heat flow due to internal gains is related to the occupants' behaviour and to the utilisation of the room.

NOTE Data on the time schedule of utilisation of the room, and the heat flow for each type of utilisation, can be defined at a national level. If information is not available the values included in Annex D can be used.

4.3 Output data

Results of the calculations are the maximum, average and minimum daily values of the operative temperature of the considered room under defined external and internal conditions.

5 Calculation procedure

The calculation procedure is based on the following steps:

a) definition of the climatic data of the location;

b) definition of the room for which the control is required;

c) definition of the elements of the envelope enclosing the room (area, exposure, boundary conditions);

d) calculation of the thermophysical parameters (steady state and transient conditions) and the solar energy transmittance of opaque and transparent elements;

e) definition of the ventilation pattern;

f) definition of the internal gains;

g) evaluation of the maximum, average and minimum daily values of the operative temperature.

The level of accuracy of a calculation procedure shall be checked using the validation procedure given in Clause 6, leading to a classification into one of three accuracy classes 1, 2 and 3 (see 6.2).

6 Validation procedures

6.1 Introduction

This document does not impose any specific calculation method for the evaluation of the operative temperature of a single room nor the calculation of the sunlit factor. The cases used in Clause 6 are based on EN ISO 13791.

6.2 Validation procedure for the calculation method

6.2.1 General

The model validation includes the calculation of the operative temperature under cyclic conditions for several cases indicated below, and the comparisons of these values with those reported in Table 11.

6.2.2 Geometry

The values of geometrical characteristics of the rooms (based on external dimensions) are given in Table 3.

Table 3 – Room data

Element		Geometry A	Geometry B
Area (m^2):			
External opaque wall		6,58	3,08
Glazing area		3,50	7,00
Partition wall	(left)	15,40	15,40
	(right)	15,40	15,40
	(back)	10,08	10,08
Floor		19,80	19,80
Ceiling		19,80	19,80
Volume (m^3)		55,44	55,44

The room geometry is shown in Figure 1.

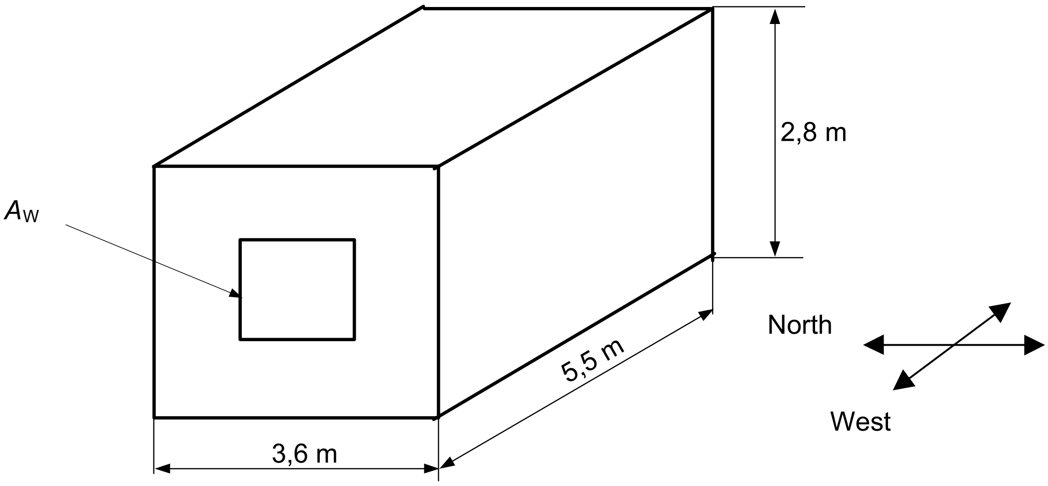


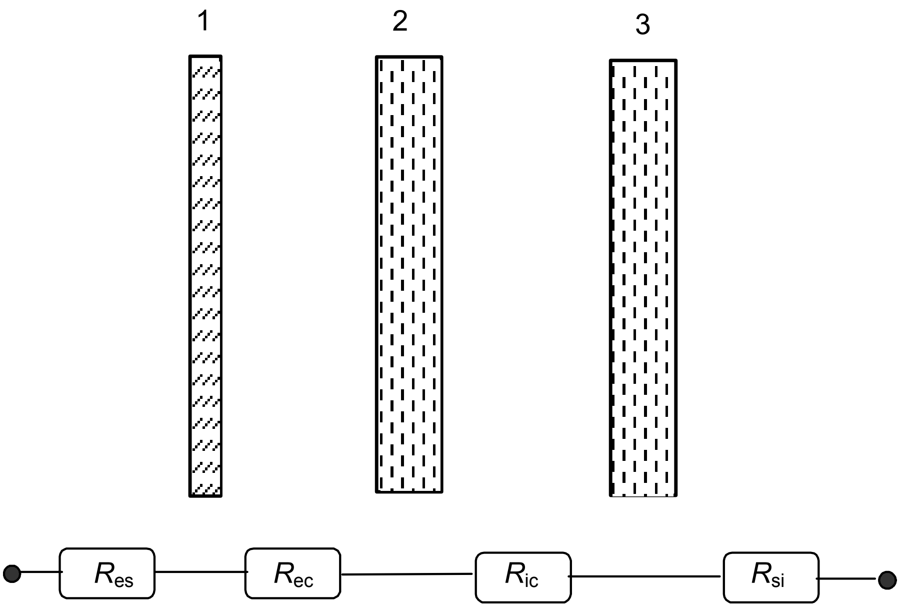
Figure 1 – Room geometries A and B

6.2.3 Description of elements

The thermophysical characteristics of the walls, ceiling and floor are reported in Table 4. The thermophysical properties of the glass panes composing the glazing system and the external shade are reported in Figure 2.

As far as these test cases are concerned, the solar properties of glass panes are independent of the angle of incidence. The optical properties of each panel are reported in Table 5.

External, cavity and internal thermal resistances
R_{se} = 0,074 m^2·K/W
R_{ec} = 0,080 m^2·K/W
R_{ic} = 0,173 m^2·K/W
R_{si} = 0,125 m^2·K/W



Key

1 External shade (or blind)
2 External pane, 6 mm
3 Internal pane, 6 mm

Figure 2 – Double pane (DP) glazing system with external shading device

Table 4 – Thermophysical properties of the opaque components

	d m	λ W/(m·K)	ρ kg/m^3	c_p kJ/(kg·K)
Type no. 1 (external wall)				
Outer layer	0,115	0,99	1800	0,85
Insulation layer	0,06	0,04	30	0,85
Masonry	0,175	0,79	1600	0,85
Internal plastering	0,015	0,70	1400	0,85
Type no. 2 (internal wall)				
Gypsum plaster	0,012	0,21	900	0,85
Mineral wool	0,10	0,04	30	0,85
Gypsum plaster	0,012	0,21	900	0,85
Type no. 3 (ceiling/floor)				
Floor covering	0,004	0,23	1500	1,5
Concrete floor	0,06	1,40	2000	0,85
Insulation	0,04	0,04	50	0,85
Concrete	0,18	2,10	2400	0,85
Type no. 4 (ceiling/floor)				
Plastic floor covering	0,004	0,23	1500	1,5
Concrete floor	0,06	1,40	2000	0,85
Insulation	0,04	0,04	50	0,85
Concrete	0,18	2,10	2400	0,85
Mineral wool	0,10	0,04	50	0,85
Acoustic board	0,02	0,06	400	0,84
Type no. 5 (roof)				
External layer	0,004	0,23	1500	1,3
Insulation	0,08	0,04	50	0,85
Concrete	0,20	2,1	2400	0,85

Table 5 - Solar characteristics of the glazed element and the shade for all incident angles

Component	τ_n	ρ_n
Pane	0,84	0,08
Shade	0,2	0,50

6.2.4 Combination of elements

Three combinations of elements are considered as given in Table 6. The numbers in Table 6 refer to the wall types in Table 4. For the definition of adiabatic see 4.2.1.3

Table 6 – Test cases

Test no.	External opaque wall	Internal adiabatic wall	Adiabatic ceiling	Adiabatic floor	Roof
1	1	2	4	4	
2	1	2	3	3	
3	1	2		3	5

6.2.5 Climatic data

The climatic data are given in Tables 7, 8 and 9.

Table 7 – Solar radiation 15 July

Hour	Climate A		Climate B	
	Horizontal W/m^2	Vertical West W/m^2	Horizontal W/m^2	Vertical West W/m^2
4	0	0	0	0
5	4	2	69	22
6	168	45	225	55
7	369	78	388	80
8	557	103	539	101
9	719	122	669	117
10	842	137	768	128
11	920	145	831	135
12	946	160	852	150
13	920	381	831	366
14	842	576	768	558
15	719	720	669	703
16	557	787	539	778
17	369	740	388	756
18	168	511	225	604
19	4	20	69	271
20	0	0	0	0

Any combination of solar parameters that leads to the values given in Table 7 is acceptable.

Table 8 – External air temperature for climate A (15 July)

Hour	θ_{ao} °C	Hour	θ_{ao} °C	Hour	θ_{ao} °C	Hour	θ_{ao} °C
1	23,6	**7**	22,8	**13**	32,7	**19**	29,9
2	23,0	**8**	23,9	**14**	33,6	**20**	28,4
3	22,5	**9**	25,8	**15**	34,0	**21**	27,0
4	22,1	**10**	27,3	**16**	33,6	**22**	25,8
5	22,0	**11**	29,3	**17**	32,8	**23**	24,9
6	22,2	**12**	31,2	**18**	31,5	**24**	24,2

Table 9 – External air temperature for climate B

Hour	θ_{ao} °C	Hour	θ_{ao} °C	Hour	θ_{ao} °C	Hour	θ_{ao} °C
1	14,1	**7**	13,1	**13**	26,2	**19**	22,6
2	13,3	**8**	14,6	**14**	27,5	**20**	20,5
3	12,6	**9**	16,6	**15**	28,0	**21**	18,7
4	12,2	**10**	19,0	**16**	27,5	**22**	17,1
5	12,0	**11**	21,8	**17**	26,4	**23**	15,8
6	12,3	**12**	24,3	**18**	24,6	**24**	14,9

The values of the solar radiation and temperatures reported in Tables 7, 8 and 9 correspond to instantaneous value at the given hour (for example the solar radiation is 225 W/m^2 for a horizontal surface at 6:00). The evolution during an hour is assumed to be linear between the value at the beginning and the end of the hour. The input data have to be adapted to each calculation method following these assumptions.

The sky radiant temperature is equal to external air temperature.

6.2.6 Internal energy sources

The total heat flow rate per floor area due to internal sources is given in Table 10. The heat flow is assumed to be transferred to the room by convection and radiation in equal proportions (50 % for each).

Table 10 – Total heat flow due to internal sources per floor area

Hour	Φ_{ic} W/m^2	Hour	Φ_{ic} W/m^2	Hour	Φ_{ic} W/m^2	Hour	Φ_{ic} W/m^2
0 to1	0	6 to 7	0	12 to 13	10	18 to19	15
1 to 2	0	7 to 8	1	13 to 14	10	19 to 20	15
2 to 3	0	8 to 9	1	14 to15	10	20 to 21	15
3 to 4	0	9 to10	1	15 to16	1	21 to 22	15
4 to 5	0	10 to11	1	16 to17	1	22 to 23	10
5 to 6	0	11 to 12	10	17 to 18	1	23 to 24	0

The daily total value of the internal gains is 117 Wh/m^2.

6.2.7 Ventilation pattern

Three different ventilation patterns are considered, with air changes rates as follows:

a) 1 h^{-1}, constant;

b) 0,5 h^{-1} from 06:00 to 18:00 and 10 h^{-1} from 18:00 to 06:00;

c) 10 h^{-1} constant.

The characteristics of air are as follows:

— specific heat capacity: 1008 J/(kg·K);

— density: 1,139 kg/m^3.

6.2.8 Test results

For each test the following data, determined in cyclic conditions, shall be calculated:

— daily average value of the operative temperature $\theta_{op,av}$

— daily minimum value of the operative temperature $\theta_{op,min}$

— daily maximum value of the operative temperature $\theta_{op,max}$

The maximum and minimum value are extracted from the 24 hourly values obtained as the average for each hour (e.g. from 07:00 to 08:00).

NOTE More information is given in the paper of P. Romagnoni and J.-R. Millet in the ASHRAE Transactions 2002, V. 108, Pt 2.

Table 11 – Reference values of the operative temperature

Room	Ventilation	$\theta_{op,max}$ °C	$\theta_{op,ave}$ °C	$\theta_{op,min}$ °C
A.1	a)	38,8	35,9	33,6
	b)	34,1	29,5	25,6
	c)	33,6	29,1	25,4
A.2	a)	37,7	35,9	34,5
	b)	32,3	29,5	26,6
	c)	32,4	29,1	26,4
A.3	a)	40,6	38,6	37,0
	b)	35,0	31,4	28,0
	c)	33,6	30,2	27,4
B.1	a)	35,9	30,8	27,1
	b)	30,0	22,3	16,5
	c)	28,3	21,6	16,3
B.2	a)	33,9	30,8	28,6
	b)	26,9	22,3	18,1
	c)	26,5	21,6	17,8
B.3	a)	35,8	32,5	30,2
	b)	29,3	24,0	19,2
	c)	27,5	22,6	18,7

Each test case is classified into one of three classes 1, 2, 3 on the basis of the difference Δ between the calculated value and the reference value. The considered procedure is classified according to the worst resulting test. For the three classes, the limiting Δ values are as follows. The following classes are defined:

Class 1 ±1 K

Class 2 +2, -1 K

Class 3 +3, -1 K

6.3 Validation procedure for the sunlit factor due to external obstructions

The calculation of the sunlit factor, defined in 4.5.3.5 of EN ISO 13791:2004, is to be validated for a vertical surface with the following dimensions:

Height: 2,8 m

Width: 3,6 m

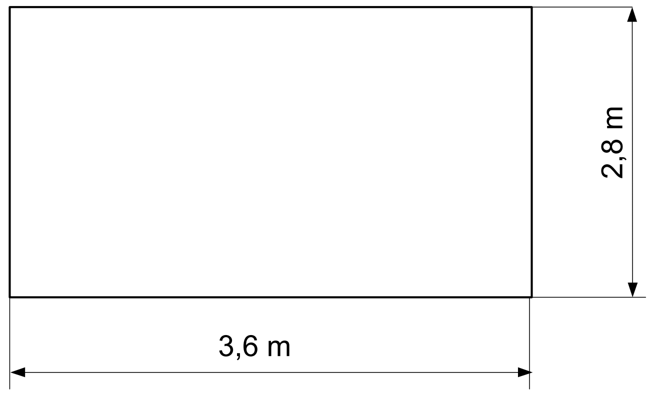


Figure 3 – Dimensions of the wall for test cases

The calculation shall refer to 15 July, latitude 52° N. The validation procedure consists of three test cases.

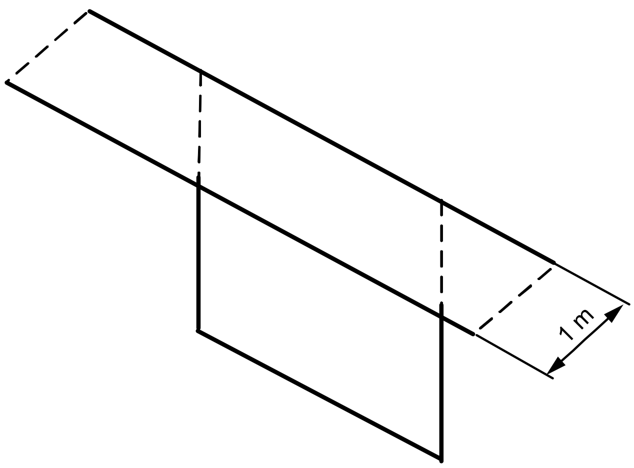


Figure 4a – Test No.1: Infinite horizontal overhang – South orientation (north hemisphere)

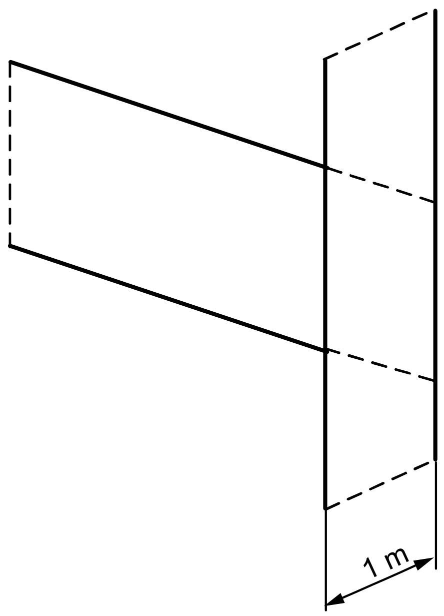


Figure 4b – Test No.2: Loggia – South orientation (north hemisphere)

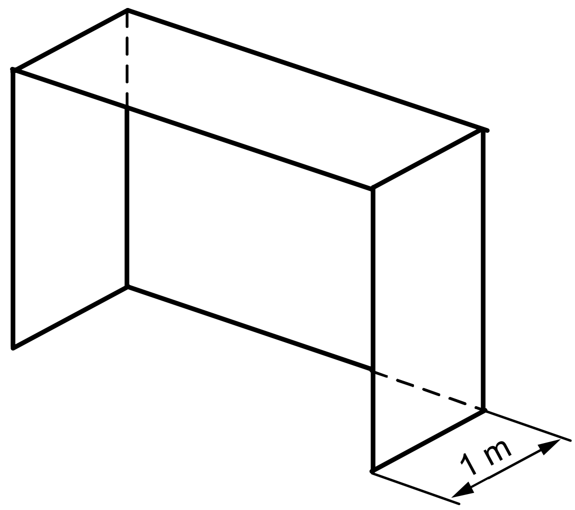


Figure 4c – Test No.3: Infinite right side fin – West orientation

Figure 4 – Test cases

Following Table gives results for the reference sunlit factor (f_s) obtained for the three test cases.

It gives also, for information, the value of projection of the azimuthal solar angle compared to the wall perpendicular vector (Θ).

Table 12 – Reference values of the sunlit factor

	Test case 1		Test case 2		Test case 3	
Hour	**Θ**	f_s	**Θ**	f_s	**Θ**	f_s
0.5	-	-	-	-	-	-
1.5	-	-	-	-	-	-
2.5	-	-	-	-	-	-
3.5	-	-	-	-	-	-
4.5	-	-	-	-	-	-
5.5	-	-	-	-	-	-
6.5	-	-	-	-	-	-
7.5	86,8	0,0	-	-	86,8	0,00
8.5	77,2	0,00	-	-	77,3	0,00
9.5	69,0	0,26	-	-	69,0	0,15
10.5	63,0	0,36	-	-	63,0	0,28
11.5	59,8	0,39	-	-	59,8	0,37
12.5	59,8	0,39	83,0	0,00	59,8	0,37
13.5	63,0	0,36	691	0,65	63,0	0,28
14.5	69,0	0,26	55,5	0,82	69,0	0,15
15.5	77,2	0,00	42,4	0,92	77,2	0,00
16.5	86,8	0,00	30,7	0,98	86,8	0,00
17.5	-	-	22,6	1,00	-	-
18.5	-	-	22,6	1,00	-	-
19.5	-	-	30,7	1,00	-	-
20.5	-	-	42,2	1,00	-	-
21.5	-	-	53,8	1,00	-	-
22.5	-	-	64,5	1,00	-	-
23.5	-	-	72,2	1,00	-	-

For each case, the absolute difference between the calculated f_s value and the reference must be less than 0,05.

Annex A
(informative)

Examples of solution model

A.1 Introduction

This Annex gives two examples of simple calculation methods for the evaluation of the operative temperature of a room according to the type of inputs defined in this document.

The calculation methods are based on the following representation of the heat transfer processes:

a) a network of resistances and capacities (RC three-nodes model) of the heat transfers between the internal and external environment;

b) separation of the steady state contribution from the variable contribution described by predetermined harmonic heat transfer parameters (admittance procedure).

A.2 RC three-nodes model

A.2.1 Presentation

The calculation model is based on the simplifications of the heat transfer between the internal and external environment reported in the following Figure**.**

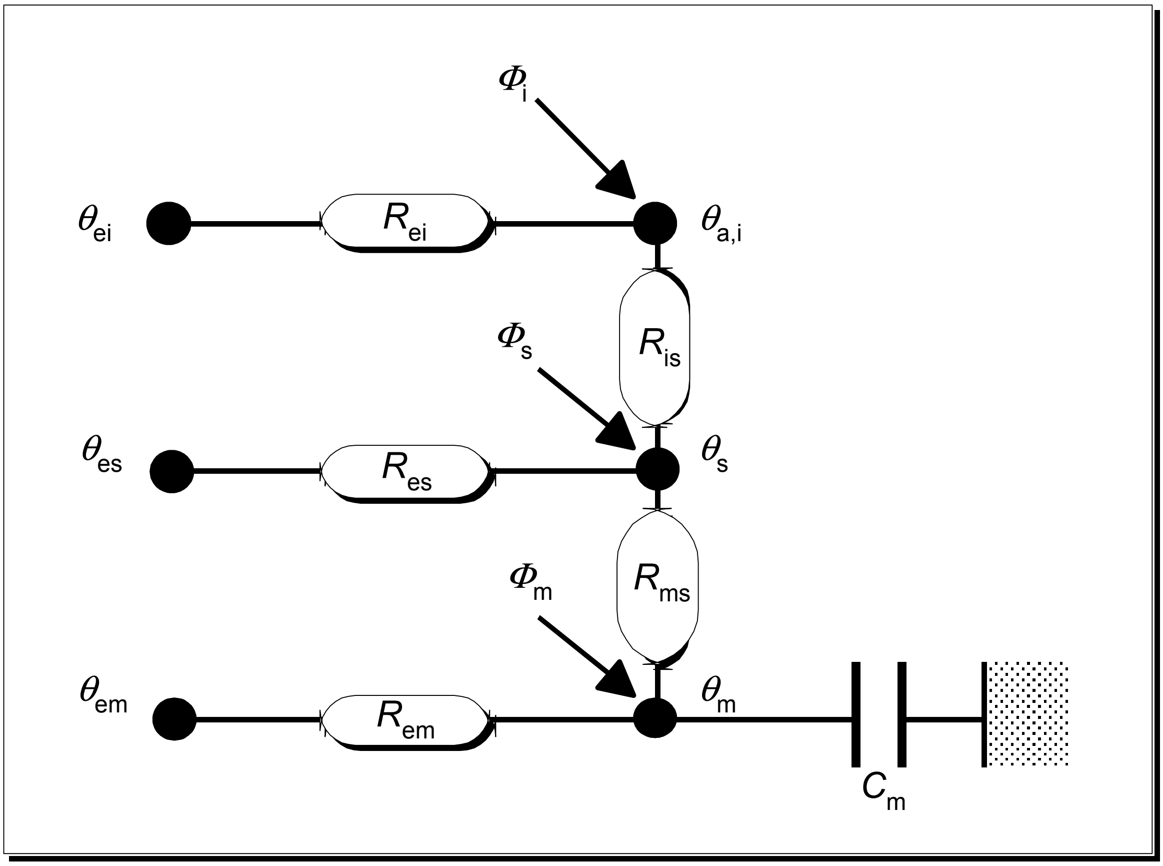


Figure A.1 – Network of resistances and capacities (RC three-nodes model)

According to this representation the envelope components are divided as:

— light opaque external components;

— heavy opaque external components;

— glazing components;

— internal components.

The relevant nodes are defined related to:

$\theta_{a,i}$	indoor air temperature;
θ_s	star temperature;
θ_m	mass temperature;
θ_{ei}	outdoor air temperature;
θ_{es}, θ_{em}	equivalent outdoor air temperature of external components.

The equivalent resistances (K/W) and heat capacity (J/K) between the internal and the external environment considered are:

R_{ei}	thermal resistance due to air ventilation;
R_{es}, R_{em}	thermal resistances of external components between outside and inside;
R_{is}, R_{ms}	thermal resistance correspondent to the heat exchanges, between the internal surfaces and the internal air;
C_m	heat capacity of the enclosure elements.

The heat flows (W) considered are:

Φ_i	heat flow to θ_i node;
Φ_s	heat flow to θ_s node;
Φ_m	heat flow to θ_m node.

For each components the following parameters are required:

- light opaque external components (depth ≤ 12 cm)	thermal transmittance	U
	solar factor	S_f
	solar radiation	I_{sr}
	area	A
- heavy opaque external components (depth > 12 cm)	thermal transmittance	U
	solar factor	S_f
	solar radiation	I_{sr}
	area	A
- glazing components	thermal transmittance	U
	solar direct transmittance (τ in EN 410)	S_{f1}
	secondary heat transfer factor towards inside (q_i in EN 410)	S_{f2}
	tertiary heat transfer coefficient	S_{f3}
	solar radiation	I_{sr}
	area	A
- all components	heat capacity per area	C
	area	A
- room	air flow rate	n
	room volume	V

A.2.2 Determination of the air and operative temperatures

The solution model is based on the scheme of Crank-Nicolson considering a time step of one hour. The temperatures are the average between time t and t - 1 except for $\theta_{m,t}$ and $\theta_{m,t-1}$ that are instantaneous values at time t and t - 1.

For a given time step, $\theta_{m,t}$ is calculated from the previous value $\theta_{m,t-1}$ by:

$$\theta_{m,t} = [\theta_{m,t-1} \, (C_m / 3600 - 0,5 \, (H_3+H_{em}) + \Phi_{mtot}] / [C_m / 3600 + 0,5 \, (H_3+H_{em})] \qquad \text{(A.1)}$$

For the time step considered, the average values of nodes temperatures are given by:

$$\theta_m = (\theta_{m,t} + \theta_{m,t-1}) / 2 \qquad \text{(A.2)}$$

$$\theta_s = [H_{ms} \, \theta_m + \Phi_s + H_{es} \, \theta_{es} + H_1 \, (\theta_{ei} + \Phi_1 / H_{ei})] / (H_{ms} + H_{es} + H_1) \qquad \text{(A.3)}$$

$$\theta_i = [H_{is} \, \theta_s + H_{ei} \, \theta_{ei} + \Phi_i] / (H_{is} + H_{ei}) \qquad \text{(A.4)}$$

and the operative temperature (average between air and mean radiant temperature) by

$$\theta_{op} = [\theta_i + (1+ h_{ci} / h_{rs})\ \theta_s - h_{ci}\ \theta_i / h_{rs}] / 2 \qquad \text{(A.5)}$$

with

$h_{rs} = 1{,}2\ h_{ri}$

$H_1 = 1 / (1 / H_{ei} + 1 / H_{is})$

$H_2 = H_1 + H_{es}$

$H_3 = 1 / (1 / H_2 + 1 / H_{ms})$

$\Phi_{mtot} = \Phi_m + H_{em}\ \theta_{em} + H_3\ [\Phi_s + H_{es}\ \theta_{es} + H_1\ (\Phi_i / H_{ei} + \theta_{ei})] / H_2$

where

H_{ei} is the heat transfer coefficient due to the air ventilation given by Equation (A.6);

H_{is} is the heat transfer coefficient due to internal exchanges by convection and radiation given in Equation (A.7);

H_{es} is the global heat transfer coefficient between the internal and external environment given by Equation (A.8);

H_{ms} is the conventional internal heat transfer coefficient given by Equation (A.9);

H_{em} is the conventional heat transfer coefficient between the external environment and the internal surface of the heavy components given by Equation (A.10);

C_m is the heat capacity of the envelope components given by Equation (A.11);

θ_{es} is the equivalent outdoor air temperature of the light external components given by Equation (A.13);

θ_{em} is the equivalent outdoor air temperature of the heavy external components given by Equation (A.14);

Φ_i is the heat flow to air node due to internal sources or direct solar radiation or convective heat gains due to window ventilated inner air layer given by Equation (A.21);

Φ_s is the heat flow to star node due to internal sources or direct solar radiation given by Equation (A.22);

Φ_m is the heat flow to mass node due to internal sources or direct solar radiation given by Equation (A.23).

The calculation is repeated for several cycles until the convergence on the internal temperature values is obtained. The convergence is obtained if the difference between the θ_m, 24 h temperature of two subsequent cycles is less than 0,01 °C.

A.2.3 Terms in Equations (A.1), (A.2), (A.3), (A.4) and (A.5)

The different terms are the following:

Heat transfer coefficients

Heat transfer coefficient due to the air ventilation:

$$H_{ei} = \text{air specific heat capacity} \cdot \text{air density} \cdot n \cdot V / 3600 \qquad \text{(A.6)}$$

with n: air changes per hour; V: room volume

$$H_{is} = A_t / (1/h_{ci} - 1/h_{is}) \qquad \text{(A.7)}$$

with

$h_{is} = h_{ci} + h_{rs}$; $\quad A_t = \sum_{i=1}^{C} A_i$

A_t is the total exposed area of components facing the internal environment

$$H_{es} = H_{T1} + H_{Tw} \tag{A.8}$$

with

$$H_{T1} = \sum_{k=1}^{l} A_k \; U_k$$

$$H_{Tw} = \sum_{j=1}^{w} A_j \; U_j$$

H_{es} corresponds to light external opaque components (H_{Tl}) and windows (H_{Tw}).

$$H_{ms} = h_{is} \; A_m \tag{A.9}$$

A_m is given in Equation (A.12).

$$H_{em} = 1/\,(1/H_{Th} - 1/H_{ms}) \tag{A.10}$$

$$H_{Th} = \sum_{y=1}^{h} A_y \; U_y$$

H_{Th} corresponds to heavy external opaque components.

The thermal mass of the structure C_m is calculated in accordance with EN ISO 13786 for a 24 h period variation:

$$C_m = \sum_{i=1}^{c} A_i \; C_i \tag{A.11}$$

with

- C_i equivalent internal heat capacity of the component;
- A_i is the area of the component;
- c is the number of components facing the indoor environment; (e.g. both internal and external components).

The equivalent thermal mass area A_m is given by:

$$A_m = \frac{C_{m2}}{\sum_{i=1}^{c} A_i \; C_{i2}} \tag{A.12}$$

Equivalent outdoor temperatures

$$\theta_{es} = \theta_{ei} + \Phi_{sl} \,/\, H_{es} \tag{A.13}$$

$$\theta_{em} = \theta_{ei} + \Phi_{sh} \,/ H_{Th} \tag{A.14}$$

The solar radiation reaching the surface of the building envelope components is given by:

$$I_{sr} = f_s \; I_D + I_d + I_r$$

where

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;

I_r is the reflected component of the solar radiation reaching the surface.

The heat flow due to the solar radiation absorbed and the sky vault losses by the light components (opaque and transparent) is given by:

$$\Phi_{sl} = \sum_{k=1}^{l} [A(S_f I_{sr} - q_{er} \frac{U}{h_e})]_k + \sum_{j=1}^{w} [A(S_{f2} I_{sr} - q_{er} \frac{U}{h_e})]_j \tag{A.15}$$

The heat flow due to the solar radiation absorbed and the sky vault losses by the opaque heavy components is given by:

$$\Phi_{sh} = \sum_{y=1}^{h} [A(S_f I_{sr} - q_{er} \frac{U}{h_e})]_y \tag{A.16}$$

Heat flows to node temperatures

The heat flow due to solar radiation directly transmitted through the windows is given by:

$$\Phi_{sd} = \sum_{j=1}^{w} [A(1 - f_{sl}) S_{f1} I_{sr})]_j \tag{A.17}$$

The total heat flow due to solar radiation transmitted by the temperature increase of air passing through window inner ventilated air layers is given by:

$$\Phi_{svl} = \sum_{j=1}^{w} [(A\, S_{f3} I_{sr})]_j \tag{A.18}$$

The heat flows due to the internal sources, are given by:

$$\Phi_{intc} = \sum_{i=1}^{s} \Phi_{intc,i} \tag{A.19}$$

$$\Phi_{intr} = \sum_{i=1}^{s} \Phi_{intr,i} \tag{A20}$$

where

s is the number of internal sources;

Φ_{intc} is the convective heat flow of each internal source;

Φ_{intr} is the radiative heat flow of each internal source.

The heat flows to temperature nodes are given by:

$\Phi_i = \Phi_{svl} + f_{sa}\, \Phi_{sd} + \Phi_{intc}$ to air node (A.21)

$\Phi_s = P_{rs}\,(1 - f_{sa})\, \Phi_{intr} + P_{rsd}\, \Phi_{sd}$ to star node (A.22)

$\Phi_m = P_{rm}\,(1 - f_{sa})\, \Phi_{intr} + P_{rmd}\, \Phi_{sd}$ to mass node (A.23)

where

P_{rs} and P_{rm} are the parts of the internal radiative gains respectively to θ_s and θ_m nodes

$$P_{rs} = (A_t - A_m - H_{es}/ h_{is}) / A_t \quad (A.24)$$

$$P_{rm} = A_m / A_t \quad (A.25)$$

P_{rsd} and P_{rmd} are the parts of the direct solar radiative gains respectively to θ_s and θ_m nodes, assuming that the solar short wave radiation back to the window is already taken into account in the solar loss coefficient f_{sl}.

$$P_{rsd} = [A_t - A_m - A_w - (H_{es}/ h_{is})] / (A_t - A_w) \quad (A.26)$$

$$P_{rmd} = A_m /(A_t - A_w) \quad (A.27)$$

A_w is the total window area, given by:

$$A_w = \sum_{j=1}^{w} A_j$$

where

l	is the number of light opaque components;
w	is the number of glazing components;
h	is the number of heavy opaque components;
S_f	is the solar factor of each opaque component;
S_{f1}	is the window solar direct transmittance;
S_{f2}	is the window secondary solar factor;
S_{f3}	is the window tertiary heat transfer factor;
I_{sr}	is the intensity of the solar radiation reaching the surface;
f_{sl}	is the solar loss factor for windows;
f_s	is the sunlit factor due to external obstructions, derived from EN 410;
f_{sa}	is the solar to air factor defined in EN 410;
q_{er}	is the density of heat flow from the external environment to the sky vault.

A.3 Admittance procedure

A.3.1 Thermophysical parameters of the envelope components

Heat transmission parameters

- external wall :
  - thermal transmittance U^*,
  - decrement factor Fa and time lag φ of the density of heat flow rate at the internal surface resulting from a harmonic variation of the temperature on the external surface
  - surface factor F_s
  - admittance Y_e
- internal wall:
  - surface factor F_s
  - admittance Y_i

Solar parameters

- opaque components:

solar factor	S_f
sunlit factor due to external obstructions	f_s

- transparent components:

solar direct transmittance	S_{f1} (τ in EN 410)
secondary heat transfer factor	
to inside	S_{f2}
tertiary heat transfer factor	S_{f3}
sunlit factor	f_s

The transient parameters of the opaque components are determined from the four elements of the matrix transfer ***Z*** evaluated according to EN ISO 13786 for a time period of 24 h, using the following surface resistances:

external component :	internal surface	R_{si} = 0,22 m^2·K /W
	external surface	R_{se} = 0,075 m^2·K /W
internal component :	internal surface	R_{si} = 0,22 m^2·K /W
	external surface	R_{si} = 0,22 m^2·K /W

NOTE These values refer to a room with two external walls and a roof. This geometry is assumed as reference for the calculation of the transient parameters.

The procedure for determining the transient parameters, required by the calculation method, is the following:

Decrement factor and time lag

The decrement factor is given by the modulus of the complex number defined as:

$$f_c = \frac{1}{U^* Z_{12}} \tag{A.28}$$

$$F_a = |f_c| \tag{A.29}$$

Z_{12},Z_{22}, etc. are terms of the matrix ***Z*** (see above). Time lag is given by:

$$\varphi = \frac{12}{\pi} \arg\left(\frac{Im(f_c)}{Re(f_c)}\right) \tag{A.30}$$

where

Im is the imaginary part of the complex number f_c;

Re is the real part of the complex number f_c.

The argument is evaluated in the field π to 0 radians. In this case φ represents the time lag.

For transparent components the decrement factor is assumed to be equal to 1, the time lag is assumed to be 0.

Surface factor F_s

— external component:

$$F_s = 1 - R_{si} \left| \frac{Z_{22}}{Z_{12}} \right| \qquad \text{(A.31)}$$

— internal component:

$$F_s = 1 - R_{si} \left| \frac{Z_{22}}{Z_{12}} \right| \qquad \text{(A.32)}$$

where

$| \; |$ denotes the modulus of a complex number.

Admittance Y

— external component

$$Y_e = \left| \frac{Z_{22}}{Z_{12}} \right| \qquad \text{(A.33)}$$

— internal component:

$$Y_i = \left| \frac{Z_{22} - 1}{Z_{12}} \right| \qquad \text{(A.34)}$$

A.3.2 Calculation of the internal air temperature

A.3.2.1 General

The internal air temperature at a given time t is given by:

$$\theta_{ai,t} = \frac{\Phi_{T,t} + (Y_T - H_T) \cdot \theta_{ai,m}}{Y_T + c \cdot m_t} \qquad \text{(A.35)}$$

where

Φ_T is the thermal load (determined in A.3.2.2.1), in W;

Y_T is the total admittance of the envelope, in W/K;

H_T is the total transmission factor of the envelope, in W/K;

$\theta_{ai,m}$ is the average daily value of the indoor air temperature, in °C;

c is the specific heat of the ventilation air (1000 J/kg);

m is the mass flow rate, in kg/s.

A.3.2.2 Terms included in Equation (A.35)

A.3.2.2.1 Thermal load Φ_T

The thermal load at any given time t is given by:

$$\Phi_{T,t} = f_c \Phi_{co,t} + f_r \Phi_{sr,t} + \Phi_{v,t} + \Phi_{is} + \Phi_{sv} \tag{A.36}$$

where

Φ_{co} is the transmission thermal load contribution;

Φ_{sr} is the solar thermal load;

f_c is a correction factor;

f_r is a correction factor;

Φ_v is the ventilation thermal load;

Φ_{is} is the internal source thermal load;

Φ_{sv} is the thermal load due to the ventilation solar factor.

Transmission thermal load Φ_{co}

The transmission thermal load Φ_{co}, at any given time t is given by:

$$\Phi_{co,t} = \sum_{j=1}^{p} \Phi_{op,j} + \sum_{j=1}^{w} \Phi_{w,j} \tag{A.37}$$

where

p is the number of opaque components;

w is the number of glazing components;

$\Phi_{op,j}$ is the transmission thermal load for opaque component j;

$\Phi_{w,j}$ is the transmission thermal load for transparent component j.

The transmission thermal load due to opaque components is given by:

$$\Phi_{op,t} = U^* A((\theta_{e,(t-\varphi)} - \theta_{e,m})F_a + \theta_{e,m}) \tag{A.38}$$

where

U^* is the thermal transmittance of each component;

A is the area;

$\theta_{e,(t-\varphi)}$ is the external temperature at the time (t - φ);

φ is the time lag;

$\theta_{e,m}$ is the mean daily value of the external temperature;

F_a is the decrement factor.

The transmission thermal load due to glazing component, is given by:

$$\Phi_{w,t} = A(U^* \cdot \theta_{e,t} + S_f \cdot I_{sr} \cdot f_s - U^* \cdot q_{er} / h_e) \quad \text{(A.39)}$$

where

S_{f2} is the secondary internal heat transfer factor;

U^* is the thermal transmittance;

I_{sr} is the total solar radiation impinging on the external surface;

f_s is the sunlit factor due to external obstructions;

q_{er} is the heat flow rate from the external surface to the sky vault;

h_e is the external heat transfer coefficient.

The external temperature is given by:

— external opaque component

$$\theta_{e,t} = \theta_{ae,t} + I_{sr}\, S_{f1}\, f_s - \frac{q_{er}}{h_e} \quad \text{(A.40)}$$

where

θ_{ae} is the external air temperature;

S_{f1} is the solar factor;

I_{sr} is the total solar radiation;

f_s is the sunlit factor;

q_{er} is the density of heat flow rate by radiation from the external surface to the sky vault;

h_e is the external heat transfer coefficient.

The corrections factors f_c and f_r are given by:

$$f_c = 1 - 0{,}194\, (\frac{H_T}{A_T}) + 0{,}021\, (\frac{H_T}{A_T})^2$$
$$f_r = 1 - 0{,}320\, (\frac{H_T}{A_T}) + 0{,}03\, (\frac{H_T}{A_T})^2 \quad \text{(A.41)}$$

where

H_T is the total transmission factor of the envelope defined in Equation (A.45);

A_T is the total area of the envelope.

Solar thermal load contribution

The thermal load due to the solar contribution through the glazing elements is given by:

$$\Phi_{sr,t} = (F_{sm}(\Phi_{er,t} - \Phi_{erm}) + \Phi_{erm}) \quad \text{(A.42)}$$

where

F_{sm} is the surface factor of the envelope;

Φ_{er} is the heat flow rate due to the solar radiation through the glazing components;

Φ_{erm} is the mean daily value of the heat flux due to the solar radiation through the glazing components.

The heat flow due to the solar radiation through the glazing components is given by:

$$\Phi_{er,t} = f_t \sum_{1}^{w} (A_w \, I_{sr} \, f_s \, f_{ex} \, S_{f1})_j \qquad \text{(A.43)}$$

where

f_t is the frame factor;

w is the number of glazing components;

A_w is the area of each component including the frame;

I_{sr} is the total solar radiation on the external surface;

f_{ex} is the exposure factor;

f_s is the sunlit factor due to external obstruction.

The frame factor f_t may be taken as 0,9.

The exposure coefficient is given in Table A.1 as a function of the exposure of the glazing.

Table A.1 – Exposure coefficients

	S	**SW/SE**	**NW/NE**	**E/W**	**N**
f_{ex}	0,81	0,92	0,92	0,97	0,87

The daily heat flow rate due to the solar radiation through the glazing components is given by;

$$\Phi_{srm} = (\sum_{1}^{24} \Phi_{sr,t}) / 24 \qquad \text{(A.44)}$$

Coefficients H_T, Y_T, f_{sm}

The total transmission factor H_T is given by:

$$H_T = \sum_{j=1}^{d} (U^*{}_j A_j) \qquad \text{(A.45)}$$

where

d is the number of the external components.

The total admittance of the envelope is given by:

$$Y_T = \sum_{j=1}^{n} Y_j A_j \qquad (A.46)$$

where

n is the number of the elements of the envelope;

Y_j is the admittance of each component;

A_j is the area of each component.

The admittance of the glazing components is given by:

$$Y_w = \frac{1}{1/U^*_w + 0{,}1} \qquad (A.47)$$

where

U^*_w is the thermal transmittance of the glazing component;

0,1 is a correction factor due to the internal long-wave radiative heat exchanges.

The envelope surface factor F_{sm} is given by:

$$F_{sm} = \frac{\sum_{j=1}^{n} F_{s,j} A_j}{\sum_{j=1}^{n} A_j} \qquad (A.48)$$

A.3.2.2.2 Calculation of the ventilation thermal load

The ventilation thermal load at any given time is given by:

$$\Phi_v = c \cdot m \cdot \theta_{ae,t} \qquad (A.49)$$

where

c is the specific heat of the air of ventilation [1000 J/(kg·K)];

m is the mass flow rate, in kg/s;

θ_{ae} is the external air temperature, in °C.

A.3.2.2.3 Calculation of the thermal load due to internal heat sources

The thermal load due to internal heat sources at any given time is given by:

$$\Phi_{is} = \sum_{j=1}^{s} \Phi_{is,j} \qquad (A.50)$$

where

s is the number of internal heat sources;

Φ_{is} is the heat flow rate due to each internal heat source.

A.3.2.2.4 Calculation of the thermal load due to the ventilation solar factor

The thermal load to the tertiary heat transfer factor S_{f3} is given by:

$$\Phi_{sv} = \sum_{j=1}^{w} (A\,S_{f3}\,f_s\,I_{sr})_j \qquad \text{(A.51)}$$

where

- w is the number of glazing component;
- A is the area of each component;
- S_{f3} is the solar ventilation factor;
- f_s is the sunlit factor;
- I_{sr} is the total solar radiation intensity.

A.3.2.3 Mean daily value of the indoor air temperature

The mean daily value of the indoor air temperature is given by:

$$\theta_{am} = \frac{\sum_{1}^{24} \left(\frac{\Phi_{T,t}}{Y_T + c\,m_t}\right)}{24 - (Y_T - H_T)\sum_{1}^{24}\left(\frac{1}{Y_T + c\,m_t}\right)} \qquad \text{(A.52)}$$

A.3.3 Mean radiant temperature

The values of the mean radiant temperature, averaged over all surfaces components, at any given time is given by:

$$\theta_{mr,t} = \frac{(\sum_{1}^{n} A_i)h_{ci}\,\theta_{a,t} + c\,m_t(\theta_{a,t} - \theta_{ae,t}) - \Phi_{is,t} - \Phi_{sv,t}}{(\sum_{1}^{n} A_i)\,h_{ci}} \qquad \text{(A.53)}$$

where

- n is the number of the components;
- A is the area of each component;
- h_{ci} is the convective internal heat transfer coefficient.

A.3.4 Operative temperature

The operative temperature at any time is given by:

$$\theta_{dr,t} = \frac{\theta_{a,t} + \theta_{mr,t}}{2} \qquad \text{(A.54)}$$

Annex B
(informative)

Air changes for natural ventilation

B.1 Introduction

This Annex gives the values of the air change rate for natural ventilation. They have been determined by applying the procedure included in EN ISO 13791.

B.2 Evaluation of the air change rate for natural ventilation

B.2.1 General

In the following tables the number of air changes per hours are determined as a function of the open area of the window S_a and for the two situations:

— windows in one facade only;

— windows in two facades.

The open area factor of the window S_a is defined as the ratio between the effective open area of the window and the total window area.

B.2.2 Windows on one facade only

Table B.1 – Window opened day and night

S_a	0,1	0,5	0,9
Air change rate [h^{-1}]	0,5	1,5	3

Table B.2 – Window opened during the night and closed during the day

	Day		Night	
S_a	0,1	0,5	0,1	0,5
Air change rate [h^{-1}]	0,5	1,0	2,5	2,5

B.2.3 Windows on two facades

Table B.3 – Window opened day and night

S_a	0,1	0,5	0,9
Air change rate [h^{-1}]	2,0	4,0	7,0

Table B.4 – Window opened during the night and closed during the day

	Day		Night	
S_a	0,1	0,5	0,1	0,5
Air change rate [h^{-1}]	2,0	4,0	7,5	7,5

When internal curtains are present, the shaded area factor S_a is multiplied by 0,9 (light curtain) or 0,5 (heavy curtain).

Annex C
(informative)

Evaluation of the shaded area of a plane surface due to external obstructions

C.1 Introduction

This Annex gives a procedure for determining the sunlit factor f_s of a plane surface when obstructions such as overhangs, side fins, window reveals and other buildings are present.

C.2 Calculation procedure

When external obstructions are present, the external surface of a wall can be partially shaded. The sunlit factor f_s is defined as the ratio between the sunlit area and the total area of the component. The most important obstructions are horizontal overhangs, vertical side fins, window reveals and other building. The simplest forms of shading element (an object causing shading) are rectilinear with the major axis either vertical or horizontal and the minor axis parallel or perpendicular to the facade. Such elements include fins, mullions, sills and reveals. Referring to Figure C.1, the vertical shaded distance x_v caused by a horizontal element of infinite length is given by:

$$x_v = d \tan\beta / \cos\omega \qquad \text{(C.1)}$$

where

- ω is the solar wall azimuth angle;
- β is the solar altitude angle;
- d is the depth of the shading element.

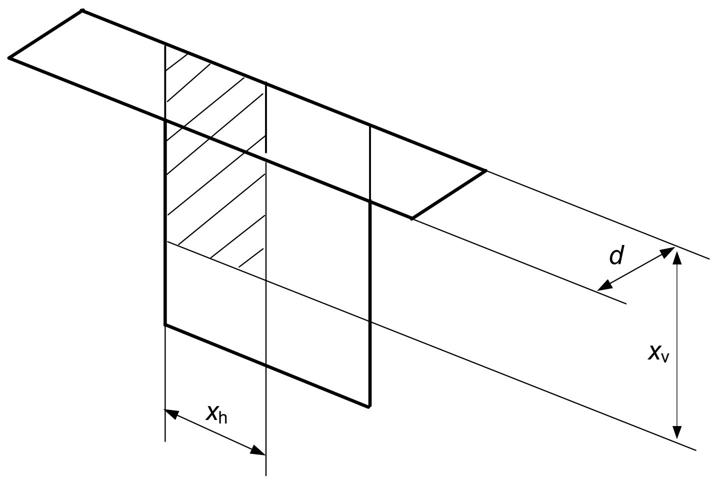


Figure C.1 – Horizontal shading

The horizontally shaded distance x_h is calculated as:

$$x_h = d \tan\omega \qquad \text{(C.2)}$$

The solar angles β and ω depend on the solar position and they are influenced by:

- latitude of the site;
- time (hour and day);
- facade orientation and tilt.

If γ is the solar azimuth angle, the wall azimuth angle ω is determined as:

$$\omega = \gamma - \alpha \qquad \text{(C.3)}$$

where α is the angle between the perpendicular to the considered wall and the south direction.

Conventionally the following assumptions are considered:

	East	**South**	**West**	**North**
α	90°	0°	-90°	180°

After having determined the x_h and x_v coordinates, the shaded area of the components are determined adopting the following assumptions:

— if both x_h and x_v are greater than the dimensions of the component it is taken as being completely shaded;

— if they are less, the shaded area is determined as follows:

$$A_s = w\, d\, [\tan\beta / \cos\omega] + h\, d \tan\omega - d_2 \tan\beta \tan\omega / \cos\omega \qquad \text{(C.4)}$$

where

- w is the depth of the facade;
- h is the height of the facade;
- d is the depth of the shading element.

Generally Equation (C.4) can be considered valid when the ratio between horizontal overhang and facade length is greater than 3.

For infinite vertical side fins (Figure C.2), the shaded area is determined as:

$$A_s = x_h\, d \qquad \text{(C.5)}$$

where x_h is determined by using Equation (C.2).

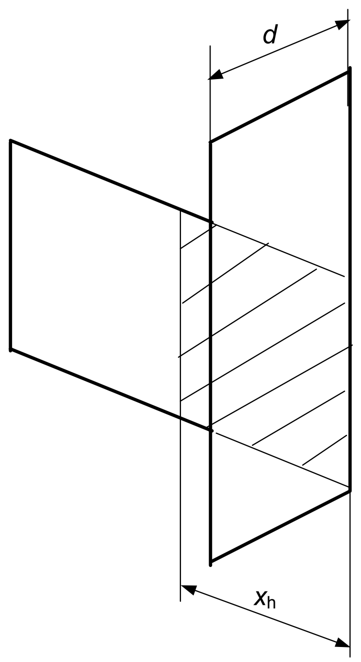


Figure C.2 – Infinite vertical side fin

Annex D
(informative)

Internal gains

D.1 Introduction

This Annex gives typical values of heat flow due to internal energy sources for residential and non-residential buildings.

D.2 Residential building

Table D.1 gives the values of the total heat flow rate due to internal sources for different rooms of residential buildings expressed in watts per floor area.

Table D.1 – Heat flow rate per floor area (W/m^2)

Hour	Kitchen	Dining room	Bedroom
1	5	0	5
2	5	0	5
3	5	0	5
4	5	0	5
5	5	0	5
6	5	0	5
7	10	1	2
8	10	1	2
9	7	1	2
10	7	1	0
11	7	10	0
12	10	10	0
13	15	10	0
14	15	10	0
15	10	1	0
16	5	1	0
17	5	1	0
18	15	15	0
19	15	15	0
20	15	15	0
21	10	15	0
22	5	10	2
23	5	0	5
24	5	0	5

D.3 Non-residential building

For a non-residential building the effect of the internal sources can be very important. In the following Table D.2 suggested values of the heat gain attributable to people, lighting and office equipment, are given.

Table D.2 – Heat gains of people, lighting and equipment in offices and restaurants

Activity	Total heat		Sensible heat
	Met [a]	W/person [a b]	W/person [a]
Reclining	0,8	80	55
Seated, relaxed	1,0	100	70
Sedentary activity (office, school, laboratory)	1,2	125	75
Standing, light activity (shopping, laboratory, light industry)	1,6	170	85
Standing, medium activity (shop assistant, machine work)	2,0	210	105
Walking on the level:			
2 km/h	1,9	200	100
3 km/h	2,4	250	105
4 km/h	2,8	300	110
5 km/h	3,4	360	120

[a] 1 met = 58 W/m^2

[b] Rounded value for a human body with a surface of 1,8 m^2 per person.

Annex E
(informative)

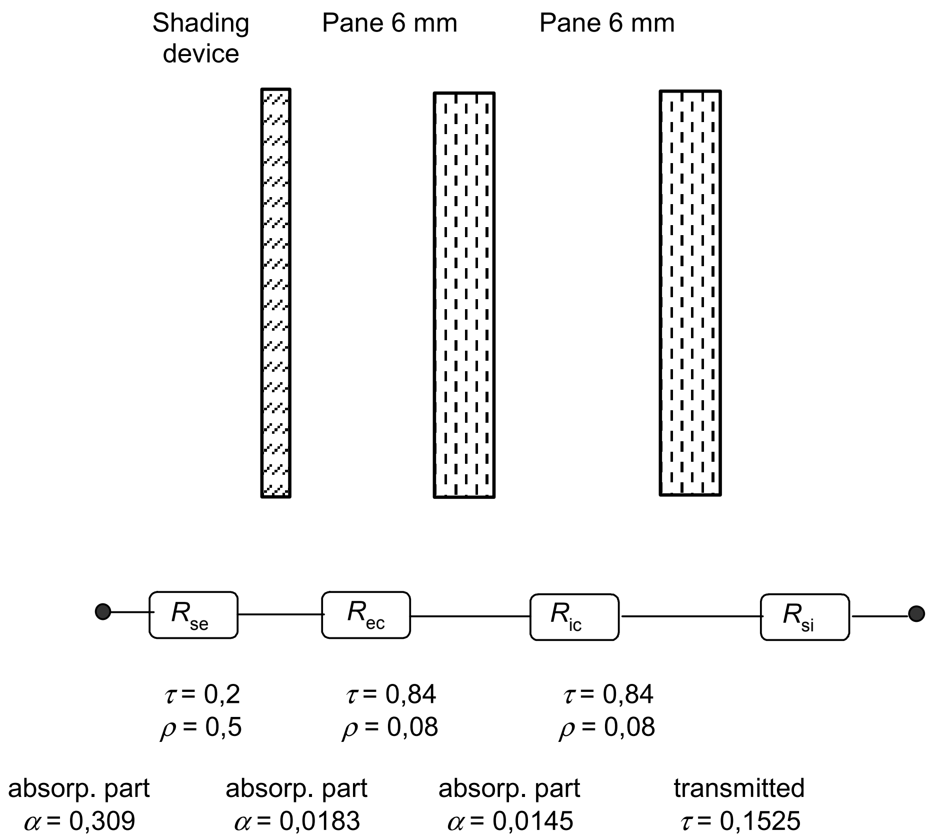
Examples of calculation

E.1 Room characteristics

Details of the window system are given in Figure E.1, while the room geometry is illustrated in Figure E.1. Thermophysical properties of the room envelope are reported in Tables E.1, E.2 and E.6. Geometric data are summarised in Figure E.2 and Table E.5. Climatic data are summarised in Table E.3. Internal heat gains are given in Table E.4. This case corresponds to the B1a test case of the validation procedure.

Table E.1 – Double pane glazing system plus external shading – Characteristics of the glazing pane and the shade

Component	d mm	λ W/(m·K)	ρ kg/m³	c J/(kg·K)	ε	τ_n	ρ_n
Pane	6	1,16	2500	1000	0,837	0,84	0,08
Shade	2	2,5	1800	1000	0,95	0,2	0,50



R_{se} = 0,074 m²·K/W; R_{ec} = 0,080 m²·K/W; R_{ic} = 0,173 m²·K/W; R_{si} = 0,125 m²·K/W

τ and ρ are the solar direct transmittance and the solar direct reflectance of each component respectively.

Figure E.1 – Double pane glazing system

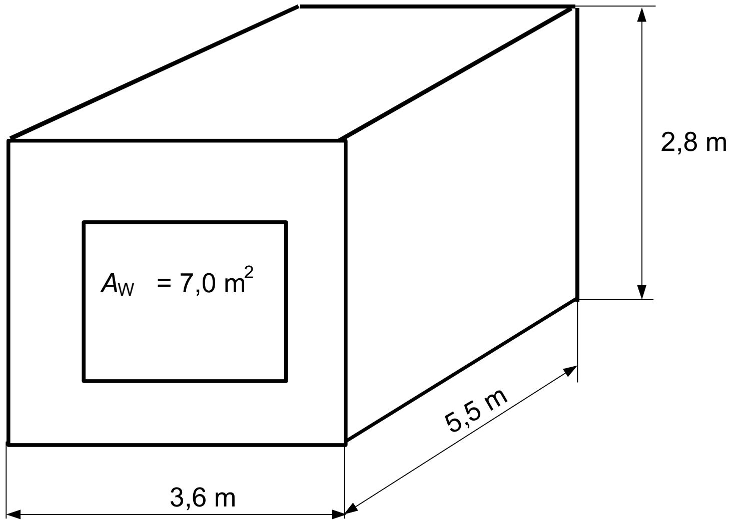


Figure E.2 – Room geometry

Table E.2 – Thermophysical properties of opaque components

	d m	***λ*** W/(m·K)	***ρ*** kg/m³	***c_p*** kJ/(kg·K)
Type no.1 (external wall)				
Outer layer	0,115	0,99	1800	0,85
Insulating layer	0,06	0,04	30	0,85
Masonry	0,175	0,79	1600	0,85
Internal plastering	0,015	0,70	1400	0,85
Type no.2 (internal wall)				
Gypsum plaster	0,012	0,21	900	0,85
Mineral wool	0,10	0,04	30	0,85
Gypsum plaster	0,012	0,21	900	0,85
Type no.3 (ceiling/ floor)				
Plastic covering	0,004	0,23	500	1,5
Cement floor	0,04	1,40	2000	0,85
Mineral wool	0,10	0,04	50	0,85
Concrete	0,18	2,10	2400	0,85
Type no.4 (ceiling/floor)				
Carpet	0,006	0,08	300	1,3
Concrete	0,20	2,1	2400	0,85
Mineral wool	0,10	0,04	50	0,85
Acoustic board	0,02	0,06	400	0,84

Table E.3 – Climate B data (Latitude 52°N)

Hour	θ_o	I_{Tw}	**Hour**	θ_o	I_{Tw}
1	14,08	0	**13**	26,24	366
2	13,28	0	**14**	27,52	558
3	12,64	0	**15**	28,00	703
4	12,16	0	**16**	27,52	778
5	12,00	22	**17**	26,40	756
6	12,32	55	**18**	24,64	604
7	13,12	80	**19**	22,56	271
8	14,56	101	**20**	21,44	0
9	16,64	117	**21**	18,72	0
10	10,94	128	**22**	17,12	0
11	21,76	135	**23**	15,84	0
12	24,32	150	**24**	14,88	0

Table E.4 – Heat flow due to internal heat sources per floor area

Hour	Φ_{ic} W/m^2	**Hour**	Φ_{ic} W/m^2	**Hour**	Φ_{ic} W/m^2	**Hour**	Φ_{ic} W/m^2
1	0	**7**	1	**13**	10	**19**	15
2	0	**8**	1	**14**	10	**20**	15
3	0	**9**	1	**15**	1	**21**	15
4	0	**10**	1	**16**	1	**22**	10
5	0	**11**	10	**17**	1	**23**	0
6	0	**12**	10	**18**	15	**24**	0

Ventilation:

a) 1 air change per hour

Boundary conditions

External convective heat transfer coefficient: $h_{c,e}$ = 8,0 W/(m^2·K)

Internal convective heat transfer coefficient: $h_{c,i}$ = 2,5 W/(m^2·K)

Radiative heat transfer coefficient $h_{r,e}$ = 5,5 W/(m^2·K) (all surfaces)

(valid for ε = 0,9 and T_{mrt} = 303 K)

Solar absorptance of all wall surfaces α_{sr} = 0,6

Table E.5 – Characteristics of the room elements

A	area of each component (related to the internal dimensions)	m^2
U^*	thermal transmittance	$W/(m^2{\cdot}K)$
M	equivalent thermal mass per area	kg/m^2
S_f	solar factor	-
τ	solar direct transmittance	-
S_{f2}	secondary heat transfer factor	-
S_{f3}	tertiary heat transfer factor	-
f_a	decrement factor	-
φ	time lag	hour
Y	admittance	$W/(m^2{\cdot}K)$

Table E.6 – Geometric and thermophysical parameters

	A	U^*	M	S_f	τ	S_{f2}	S_{f3}	f_a	f_s	Y
Opaque wall	3,08	0,486	141	0,0216	0	0	0	0,11	0,28	3,25
Window	7,00	2,21	15	0,221	0,153	0,068	0	0,00	0,00	1,95
Internal walls	40,88	-	10,8	0	0	0	0	0,00	0,83	0,75
Ceiling	19,8	-	8	0	0	0	0	0,00	0,86	0,63
Floor	19,80	-	107	0	0	0	0	0,00	0,28	3,24

Volume of the room 55,44 m^3

Total area of components 90,58 m^2

E.2 Example of calculation for the RC3 nodes model

$A_t = 90{,}58\ m^2$

$A_w = 7\ m^2$

The heat capacity of the structure per volume is calculated as:

$C_m = 850\ (3{,}08 \times 141 + 7 \times 15 + 40{,}88 \times 10{,}8 + 19{,}8 \times 8 + 19{,}8 \times 107) = 2769$ kJ/K

$A_m = 36\ m^2$ calculated according to Equation (A.12)

$H_{ei} = 0{,}32 \times 1 \times 55{,}44 = 17{,}75$

$h_{rs} = 1{,}2 \times 5{,}5 = 6{,}6\ W/(m^2{\cdot}K)$

h_{ir} = 2,5 + 6,6 = 9,1 W/(m^2·K)

H_{ir} = 90,58 / [(1/ 2,5 – 1/ 9,1)] = 312,22 W/K

H_{er} = 7 × 2,21 = 15,47 W/K

H_{th} = 3,08 × 0,486 = 1,497 W/K

H_{mr} = 9,1 × 36 = 327,6 W/K

H_{em} = 1 / (1/ 1,497 – 1/ 327,6) = 1,504 W/K

P_{rs} = 0,5838

P_{rm} = 0,3974

P_{rsd} = 0,5489

P_{rmd} = 0,4307

Table E.7 gives the values of the following parameters:

θ_{es} sol-air temperature of the light external components, in °C

θ_{em} sol-air temperature of the opaque heavy components, in °C

Φ_{l} heat flow to θ_{l} node

Φ_{s} heat flow to θ_{s} node

Φ_{m} heat flow to θ_{m} node

θ_{op} calculated value of the operative temperature

Table E.7 – Values of sol-air temperatures, heat flow rate and operative temperature

From	To	θ_{es}	θ_{em}	Φ_i	Φ_s	Φ_m	θ_{op}
0	**1**	14,5	14,5	0,0	0,0	0,0	31,4
1	**2**	13,7	13,7	0,0	0,0	0,0	30,7
2	**3**	13,0	13,0	0,0	0,0	0,0	29,9
3	**4**	12,4	12,4	0,0	0,0	0,0	29,2
4	**5**	12,4	12,6	0,0	6,7	5,1	28,5
5	**6**	13,3	13,9	0,0	23,7	18,0	28,0
6	**7**	14,8	15,8	0,0	41,4	31,3	27,6
7	**8**	16,6	18,0	9,9	61,2	45,8	27,5
8	**9**	18,9	20,5	9,9	72,1	54,1	27,4
9	**10**	21,6	23,4	9,9	80,6	60,6	27,5
10	**11**	24,4	26,4	9,9	86,1	64,7	27,7
11	**12**	27,4	29,5	99,0	144,8	105,2	28,6
12	**13**	33,1	37,0	99,0	214,8	158,1	29,6
13	**14**	40,9	47,8	99,0	339,0	252,0	31,1
14	**15**	47,0	56,3	99,0	441,9	329,8	32,7
15	**16**	50,3	61,3	9,9	456,8	345,1	33,8
16	**17**	50,3	61,7	9,9	472,6	357,0	34,9
17	**18**	46,2	56,3	9,9	419,7	317,0	35,6
18	**19**	36,9	43,4	148,5	353,3	260,6	36,1
19	**20**	25,6	27,7	148,5	169,5	121,6	35,4
20	**21**	19,6	19,6	148,5	86,7	59,0	34,6
21	**22**	17,9	17,9	148,5	86,7	59,0	34,2
22	**23**	16,5	16,5	99,0	57,8	39,3	33,4
23	**24**	15,4	15,4	0,0	0,0	0,0	32,2

Results

The values of the operative temperatures are:

— maximum hourly value 36,1 °C

— mean value 31,2 °C

— minimum hourly value 27,4 °C

E.3 Admittance method

Parameters required:

volume	V = 55,44 m^3
total area	A_T = 90,56 m^2
external area	A_d = 10,08 m^2
mean transmittance	U^*_m = 0,189 W/(m^2·K)
correction factor	f_c = 0,964
correction factor	f_r = 0,941
global surface factor	f_{sm} = 0,689
transmittance coefficient	H_T = 16,5 W/K
total admittance	Y_T = 130,74 W/K

Table E.8 gives the values of the following parameters:

Φ_{op} transmission thermal load due to opaque components, in W

Φ_w transmission thermal load due to glazing components, in W

Φ_v thermal load due to ventilation, in W

Φ_{sr} thermal load due to solar contribute through the glazing component, in W

Φ_i thermal load due to internal gains, in W

Table E.8 – Thermal load contribution

Hour	Φ_{op} W	Φ_{w} W	Φ_{v} W	Φ_{sr} W	Φ_{i} W
1	41,7	221,9	261,5	56,7	0
2	43,2	199,9	246,6	56,7	0
3	44,3	190,2	234,7	56,7	0
4	44,7	183,0	225,8	56,7	0
5	44,4	180,6	222,8	80,7	0
6	43,0	185,4	228,8	116,5	0
7	40,4	197,4	243,7	143,8	19,8
8	38,4	219,2	270,4	165,6	19,8
9	37,9	250,4	309,0	182,9	19,8
10	37,7	286,5	353,6	195,6	19,8
11	37,5	327,5	404,1	203,4	198
12	37,3	366,0	451,6	218,7	198
13	37,2	394,9	487,3	452,7	198
14	37,1	414,2	511,1	661,2	198
15	37,0	421,4	520,0	818,8	19,8
16	36,9	414,7	511,1	899,5	19,8
17	37,0	397,3	490,3	875,5	19,8
18	37,3	370,8	457,6	710,7	297
19	37,6	339,5	418,9	349,9	297
20	37,9	322,6	398,1	56,7	297
21	38,4	281,7	347,6	56,7	297
22	38,9	257,6	317,9	56,7	198
23	39,4	238,4	294,2	56,7	0
24	39,9	223,9	276,0	56,7	0

$$\sum_{t=1}^{24}\left(\frac{1}{Y_{\mathrm{T}} + c \cdot m_t}\right) = 0{,}1607 \ \ \mathrm{m^2 \cdot K/W}$$

$$\sum_{t=1}^{24}\left(\frac{\Phi_{\mathrm{T},t}}{Y_{\mathrm{T}} + c \cdot m_t}\right) = 172{,}7 \ \ \mathrm{m^2 \cdot K}$$

$$\left(\sum_{k=1}^{n} A_k\right) h_{\mathrm{ci}} = 90{,}56 \times 2{,}5 = 226{,}4 \ \ \mathrm{W/K}$$

Table E.9 gives the values of the following parameters:

θ_{a} air temperature

θ_{mr} mean radiant temperature

θ_{op} operative temperature

Table E.9 – Values of the internal temperature

Hour	θ_a °C	θ_{mr} °C	θ_{op} °C
1	27,2	28,2	27,7
2	27,0	28,1	27,6
3	26,9	28,0	27,5
4	26,8	27,9	27,4
5	26,9	28,1	27,5
6	27,3	28,4	27,8
7	27,7	28,8	28,3
8	28,2	29,2	28,7
9	28,8	29,7	29,3
10	29,5	30,2	29,8
11	31,3	31,2	31,3
12	32,0	31,8	31,9
13	34,2	33,9	34,1
14	36,0	35,8	35,9
15	36,1	36,6	36,3
16	36,5	37,1	36,8
17	36,1	36,8	36,5
18	36,4	36,0	36,2
19	33,2	32,8	33,0
20	30,8	30,3	30,6
21	30,2	29,9	30,1
22	29,2	29,3	29,3
23	27,6	28,5	28,0
24	27,4	28,3	27,8

Results

The maximum, mean daily and minimum operative temperatures are:

— maximum hourly value 36,8 °C
— mean value 31,0 °C
— minimum hourly value 27,4 °C

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

Year	Publication	Title	EN	Year	Title
–	ISO 6946	Building components and building elements – Thermal resistance and thermal transmittance - Calculation method	EN ISO 6946	-	Building components and building elements – Thermal resistance and thermal transmittance - Calculation method (ISO 6946:1996)
1987	ISO 7345	Thermal insulation – Physical quantities and definitions	EN ISO 7345	1995	Thermal insulation – Physical quantities and definitions (ISO 7345:1987)
-	ISO 10077-1	Thermal performance of windows, doors and shutters – Calculation of thermal transmittance - Part 1: Simplified method	EN ISO 10077-1	-	Thermal performance of windows, doors and shutters – Calculation of thermal transmittance - Part 1: Simplified method (ISO 10077-1:2000)
-	ISO 13370	Thermal performance of buildings - Heat transfer via the ground – Calculation methods	EN ISO 13370	-	Thermal performance of buildings - Heat transfer via the ground – Calculation methods (ISO 13370:1998)
	ISO 13786	Thermal performance of building components – Dynamic thermal characteristics – Calculation methods	EN ISO 13786		Thermal performance of building components – Dynamic thermal characteristics – Calculation methods (ISO 13786:1999)
2004	ISO 13791	Thermal performance of buildings -- Calculation of internal temperatures of a room in summer without mechanical cooling - General criteria and validation procedures	EN ISO 13791	2004	Thermal performance of buildings – Thermal performance of buildings - Calculation of internal temperatures of a room in summer without mechanical cooling - General criteria and validation procedures (ISO 13791:2004))