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## Revised prEN 15255, Thermal performance of buildings – Sensible room cooling load calculation – General criteria and validation procedures

GTR Work item 00089045

This document contains prEN 15255 revised on the basis of the comments received in the CEN Enquiry.

Document CEN/TC 89 N 1079 contains the comments received in the Enquiry with the replies of CEN/TC 89/WG 6, Non steady state thermal behaviour of buildings.

**Documents CEN/TC 89 N 1079 and N 1080 are submitted to CEN/TC 89 requesting approval to submit prEN 15255 to CMC for Formal Vote. The CEN Members are kindly requested to approve draft resolution 385 (below) by returning the ballot paper (document CEN/TC 89 N 1081) by 7 September 2006. In parallel to this ballot the CEN/TC 89 Editing committee will review the draft standard.**

### ***Draft RESOLUTION number 385 taken by CEN/TC 89 by correspondence on 2006-09-07***

**Subject** : Decision on the future of prEN 15255 after CEN enquiry

CEN/TC 89, *Thermal performance of buildings and building components*,

- considering the table of decisions and the formal written proposals as distributed after the comments resolution meeting;
- considering the CEN/CENELEC Internal Regulations - Part 2, clause 11.2.3;
- considering Resolutions BT 34/2002, BT 42/2003 and related document BT N 6962 concerning timeframes for the development of ENs;

decides

to launch the formal vote on prEN 15255, Thermal performance of buildings – Sensible room cooling load calculation – General criteria and validation procedures (target date stage 45.00: 2006-10)

The decision was taken by *unanimity or simple majority with N positive votes, N negative vote(s) and N abstention(s)*.

**CEN/TC 89**

Date: 2006-08

**prEN 15255**

CEN/TC 89

Secretariat: SIS

## **Thermal performance of buildings — Sensible room cooling load calculation — General criteria and validation procedures**

*Wärmetechnisches Verhalten von Gebäuden — Berechnung der wahrnehmbaren Raumkühllast — Allgemeine Kriterien und Validierungsverfahren*

*Performance thermique des bâtiments — Calcul de la charge de refroidissement en chaleur sensible d'un local — Critères généraux et procédures de validation*

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## Foreword

This document prEN 15255 has been prepared by Technical Committee CEN/TC 89 “Thermal performance of buildings and building components”, the secretariat of which is held by SIS.

This document is currently submitted to the Formal Vote.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association (Mandate M/343), and supports essential requirements of EU Directive 2002/91/EC on the energy performance of buildings (EPBD).

This standard is one of a series of standards on general criteria and validation procedures for transient calculation methods for the design and the evaluation of the thermal and energy performance of buildings and building components. No existing European Standard is superseded.

The target audience of this standard are software developers of building simulation tools and policy makers in the building regulation sector. The standard specifies the boundary conditions and the simplifications needed to reach calculation results for the building part which are comparable.

It must be emphasized that there exist more sophisticated energy simulation methods and procedures including interactions with the HVAC and lighting systems which may be used for the design and optimization process of a building but are not in line with existing European Standards.

## Introduction

The proper design and sizing of air conditioning systems requires the calculation of the cooling load in the space to be conditioned (room cooling load). The variables affecting the room cooling load calculation are numerous, often difficult to define precisely and always intricately inter-related. Many cooling load components vary widely in magnitude during a 24-hour period.

Since these cyclic changes are often out of the phase with each other, they must be analyzed to establish the maximum room cooling load for a building or zone. A zoned system need handle no greater total cooling capacity than the largest hourly total of the simultaneous zone loads throughout a design day; but it needs to handle the peak cooling load for each zone at its peak hour. This means that a calculation method needs to be able to determine the cooling load of each zone throughout the calculation period.

A large number of calculation methods are available in Europe. These methods generally are based on different solution techniques that include simplifications of the real phenomena. According to those simplifications they are able to consider specific or general situations. One specific situation is represented by the calculation of the maximum peak load of a single zone for convective source with the control of the air temperature.

This standard includes the criteria and the level of input and output data required for a simplified calculation method of the cooling load of a single room.

A simplified load calculation method is given in the informative Annex A.

Any calculation method satisfies the standard if it complies with the assumptions, data requirement and the validation procedures described in Clause 7.

The series of European Standards, giving general criteria and validation procedures for the building part of energy simulation models for the different calculation subjects, are listed in the following table.

European Standard	Subject
EN ISO 13791 EN ISO 13792	Temperature calculations (air and operative)
EN 15255	Load calculations (sensible cooling)
EN 15265	Energy need calculations (heating and cooling)

## 1 Scope

This standard sets out the level of input and output data, and prescribes the boundary conditions required for a calculation method of the sensible cooling load of a single room under constant or/and floating temperature taking into account the limit of the peak cooling load of the system. It includes a classification scheme of the calculation method and the criteria to be met by a calculation method in order to comply with this standard.

The purpose of this standard is to validate calculation methods used to:

- evaluate the maximum cooling load for equipment selection and HVAC system design;
- evaluate the temperature profile when the cooling capacity of the system is reduced;
- provide data for evaluation of the optimum possibilities for load reduction;
- allow analysis of partial loads as required for system design, operation and control.

The validation procedure is used to check the room sensible heat balance model, taking into account:

- the external surface heat balance;
- the conduction through the building envelope;
- the effect of the thermal mass of the structures;
- the internal surface heat balance;
- the air heat balance;
- the heat balance solution method.

All other aspects are given either by fixed boundary conditions or by input data and are not in the focus of the model validation. It is assumed, that for all these other matters e.g. embedded heating and cooling systems, prescriptive models have to be used according to existing European standards.

## 2 Normative references

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

EN 410, *Glass in building – Determination of the light transmittance, solar direct transmittance, total solar energy transmittance and ultraviolet transmittance, and related glazing characteristics*

EN 13363-2, *Solar protection devices combined with glazing – Calculation of total solar energy transmittance and light transmittance - Part 2: Detailed calculation method*

## prEN 15255:2006 (E)

EN ISO 6946<sup>1</sup>, *Building components and building elements – Thermal resistance and thermal transmittance – Calculation method (ISO/DIS 6946:2005)*

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

EN ISO 9251, *Thermal insulation – Heat transfer conditions and properties of materials – Vocabulary (ISO 9251:1987)*

EN ISO 9288, *Thermal insulation – Heat transfer by radiation – Physical quantities and definitions (ISO 9288:1989)*

EN ISO 9346<sup>2</sup>, *Thermal insulation – Mass Transfer – Physical quantities and definitions (ISO/DIS 9346:2005)*

EN ISO 10077-1<sup>2</sup>, *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: General (ISO/FDIS 10077:2006)*

EN ISO 13370<sup>2</sup>, *Thermal performance of buildings – Heat transfer via the ground – Calculation methods (ISO/DIS 13370:2005)*

EN ISO 13786<sup>2</sup>, *Thermal performance of building components – Dynamic thermal characteristics – Calculation methods (ISO/DIS 13786:2005)*

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

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

## 3 Terms, definitions, symbols and units

### 3.1 Terms and definitions

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

#### 3.1.1

##### **internal environment**

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

#### 3.1.2

##### **envelope element**

element of a building fabric delimited by two parallel surfaces, one of them is exposed to the room under consideration

#### 3.1.3

##### **room air**

air of the internal environment

#### 3.1.4

##### **internal air temperature**

temperature of the room air

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<sup>1</sup> The revised version of this standard is expected to be published before EN 15255. The reference will be updated in the final version of EN 15255.

**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 environment

NOTE As approximation, the operative temperature is calculated as mean value of the air temperature and the mean radiant temperature.

**3.1.8****thermal source**

component of the thermal system from which the thermal power is transferred to the internal environment

**3.1.8.1****convective thermal source**

thermal source that interacts only with the air

**3.1.8.2****cool surface source**

thermal source that interacts with the surroundings by long- wave radiation and with the air by convection

**3.1.9****internal design temperature**

internal temperature assumed as reference for the system control. It may be the internal air or the operative temperature

**3.2 Symbols and units**

The principal symbols used are listed in the following table. Other symbols are defined where they are used within the standard.

Symbol	Quantity	Unit
$A$	area	$m^2$
$A_s$	sunlit area	$m^2$
$c$	specific heat capacity at constant pressure	$J/(kg \cdot K)$
$c_d$	coefficient of discharge	-
$d$	layer thickness	m
$f$	correction factor	-
$f_{df}$	solar distribution factor	-
$f_{ic}$	internal convective factor	-



$f_{fr}$	solar loss factor	-
$f_s$	sunlit factor	-
$f_{sa}$	solar to air factor	-
$h$	surface heat transfer coefficient	W/(m <sup>2</sup> ·K)
$I$	intensity of solar radiation	W/m <sup>2</sup>
$l$	length	m
$\dot{m}$	mass flow rate	kg/s
$P$	power	W
$q$	density of heat flow rate	W/m <sup>2</sup>
$R$	thermal resistance	m <sup>2</sup> ·K/W
$T$	thermodynamic temperature	K
$t$	time	s
$U$	thermal transmittance under steady state conditions	W/(m <sup>2</sup> ·K)
$V$	volume	m <sup>3</sup>
$v$	velocity	m/s
$\alpha$	solar absorptance	-
$\varepsilon$	total hemispherical emissivity	-
$\Phi$	heat flow rate	W
$\Lambda$	thermal conductance	W/(m <sup>2</sup> ·K)
$\lambda$	thermal conductivity	W/(m·K)
$\rho$	solar reflectance	-
$\rho$	density	kg/m <sup>3</sup>
$\theta$	Celsius temperature	°C
$\tau_e$	solar direct transmittance	-

### 3.3 Subscripts

a	air	sa	solar to air
av	average	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
n	normal to surface	mr	mean radiant
r	radiation	op	operative
t	time	sk	sky
ref	reference	set	set point value
v	ventilation	sr	short wave radiation
out	out of section	va	ventilation through air cavity

## 4 Basic assumptions

For the purposes of this standard the following basic assumptions are considered as minimum requirements:

- the room is considered to be a closed space delimited by enclosure elements;
- the air temperature is uniform throughout the room;
- the thermophysical properties of all materials composing the enclosure elements are constant;
- the convective heat transfer coefficients are fixed;
- the heat conduction through each enclosure element is one-dimensional and the surface of each enclosure element is isothermal;
- air spaces within envelope components are treated as air layers bounded by two isothermal surfaces;
- the mean radiant temperature is calculated as the area-weighted average of the internal surface temperatures of each component;
- the operative temperature is calculated as the arithmetic mean of the internal air temperature and the mean radiant temperature;

- the distribution of the solar radiation on the internal surfaces of the components of the room is time independent;
- the distribution of the radiative part of heat flux due to internal gains is uniform;
- the long-wave radiative and the convective heat transfers at the internal surface of each component are treated separately;
- thermal bridges are treated by steady state calculations.

## **5 Data requirement**

### **5.1 General**

For evaluating the hourly values of the room cooling load and the internal temperatures the following information is required:

- the design climatic data for the location;
- the descriptions of the envelope elements (area, exposure, boundary conditions);
- for each envelope element the calculation of the thermophysical parameters (steady state and transient conditions) and the solar factors of the opaque and the transparent components;
- the design internal temperature;
- the schedule of the ventilation and infiltration rate;
- the scheduled values of the convective and radiative heat flux due to lighting and occupants;
- the scheduled values of the convective and radiative heat flux due to internal equipment and appliances;
- the characteristics of the cooling system and maximum room cooling power.

### **5.2 Climatic data**

For a location with a given latitude and longitude the following hourly climatic data are required:

- external air temperature;
- the intensity of solar radiation (direct normal and diffuse horizontal);
- the external radiant temperature (sky and surrounding);
- the ground albedo.

NOTE Design climatic data, derived from EN ISO 15927-4, *Hygrothermal performance of buildings — Calculation and presentation of climatic data – Part 4: Hourly data for assessing the annual energy use for heating and cooling (ISO 15927-4:2005)*, can be included in a national annex.

### **5.3 Descriptions of the envelope elements**

#### **5.3.1 General**

The following types of room enclosure elements are considered:

- external components: opaque walls, windows including external and/ or internal shade, roof and floor;
- internal components: adjacent to similar rooms (adiabatic elements);  
adjacent to rooms with pre-defined conditions;
- components with a fixed known surface temperature (cooling surface).

The thermophysical properties shall be calculated according to the standards for specific elements, such as windows and glazing (EN ISO 10077-1, EN 410, EN 13363-2), walls and roofs (EN ISO 6946, EN ISO 13786) and ground floors (EN ISO 13370).

For each of these situations the boundary conditions are defined in 5.3.2.

### 5.3.2 Boundary conditions

#### 5.3.2.1 External components

Boundary conditions are the hourly values of the climatic data defined in 5.2 and solar shading by horizon, overhangs and fins. For an element in contact with the ground the design external temperature is defined in accordance with EN ISO 13370.

#### 5.3.2.2 Internal components

##### 5.3.2.2.1 Adjacent to similar rooms (adiabatic components)

The air temperature, the mean radiant temperature and the solar radiation absorbed by the surface are the same at the external and the internal surfaces of the component.

##### 5.3.2.2.2 Adjacent to rooms with pre-defined internal conditions

At the surface opposite to the room under consideration the boundary conditions are the hourly values of the air temperature of the adjacent room. The heat flow rate by long-wave radiation is calculated from the temperature of the opposite surface component and the air temperature of the adjacent room by a long wave radiation heat transfer coefficient assumed to be constant. The heat flow rate due to short wave radiation is assumed to be zero.

##### 5.3.2.2.3 Component with known surface temperature

In this case the temperature of both surfaces of the component are known. If only the room-facing surface temperature is fixed (cooling surface), the temperature of the opposite surface depends on the location of the component. If it is an external component, the boundary conditions of 5.3.2.1 apply. If it is an internal component, the boundary conditions of 5.3.2.2.1 or 5.3.2.2.2 apply.

### 5.3.3 Heat transfer coefficients

The following values shall be used:

#### a) Convective surface heat transfer coefficients

- external surface:  $h_{c,e} = 8,0 \text{ W/(m}^2\cdot\text{K)}$
- internal surface of no-cooling component:  $h_{c,i} = 2,5 \text{ W/(m}^2\cdot\text{K)}$
- internal surface of cooling surface:
  - vertical:  $h_{c,i} = 2,5 \text{ W/(m}^2\cdot\text{K)}$

- horizontal (heat flow upwards):  $h_{c,i} = 5,0 \text{ W}/(\text{m}^2 \cdot \text{K})$
- horizontal (heat flow downwards):  $h_{c,i} = 0,7 \text{ W}/(\text{m}^2 \cdot \text{K})$

NOTE The external convective surface heat transfer coefficient for cooling load calculations is intentionally lower than for energy calculations, representing low wind speed conditions as a safe assumption

b) Long-wave radiative heat transfer coefficients

- internal surface:  $h_{lr,i} = 5,5 \text{ W}/(\text{m}^2 \cdot \text{K})$
- external surface:  $h_{lr,e} = 5,5 \text{ W}/(\text{m}^2 \cdot \text{K})$

NOTE Given values are typical for high emissivity  $\varepsilon=0,9$  and  $T_m = 300\text{K}$

c) The correction heat flux density for the longwave radiation from the external walls to the sky is given by:

- external vertical components:  $q_{sk} = 0 \text{ W}/(\text{m}^2 \cdot \text{K})$
- external horizontal components:  $q_{sk} = 70 \text{ W}/(\text{m}^2 \cdot \text{K})$
- tilted components:  $q_{sk} = 70 \cos(\gamma) \text{ W}/(\text{m}^2 \cdot \text{K})$

where  $\gamma$  is the tilt angle from the horizontal.

### **5.3.4 Geometrical and thermophysical parameters of the room envelope**

#### **5.3.4.1 Opaque components**

For each component the following data are required:

- area (calculated from internal dimensions);
- thermal characteristics.

The procedure for evaluating the sunlit factor due to external obstruction  $f_s$  may be defined at national level.

Otherwise, a suitable procedure is given in Annex C of EN ISO 13791:2004.

#### **5.3.4.2 Transparent components**

For each transparent component the following data are required:

- area, including the frame;
- thermal characteristics;
- optical characteristics;
- sunlit fraction due to external obstructions  $f_s$ .

The thermal inertia of window glazing can usually be neglected.

### Solar to air factor $f_{sa}$

The solar to air factor,  $f_{sa}$ , takes into account that a proportion of the radiation entering through the window is immediately transformed in a heat flow rate for the internal air. This fraction depends on the presence of internal elements with very low thermal capacity as carpets, furniture, etc. It is assumed to be time independent and it should be defined on a national basis; alternatively the value of  $f_{sa} = 0,1$  may be used.

### Solar loss factor $f_{lf}$

The solar loss factor,  $f_{lf}$ , takes into account that a proportion of the solar radiation entering through the window is reflected back outside. It depends on the geometrical characteristics and solar properties of the glazing system, the exposure of the window, the solar angle and the room geometry. It is assumed to be time independent. Values of  $f_{lf}$  should be defined on a national basis; alternatively the value of  $f_{lf} = 0$  may be used.

### Solar distribution factor $f_{df}$

The heat flow rate due to the solar radiation entering through the glazing system is absorbed by the internal surface of each envelope component. According to the assumptions of Clause 4, the distribution of the solar radiation is time independent. The distribution factor is defined, for each surface, as the fraction of the solar shortwave absorbed by that surface. It depends on the solar reflectivity of each internal surface.

For the purposes of this standard the distribution factors should be calculated using the expressions in Table 1, as a function of the type of the system, the floor colour and the area of the envelope components.

**Table 1 — Solar distribution factors  $f_{df}$**

	Floor	Vertical walls	Ceiling	Window
cooled floor of dark colour	$2 A_f / (A_t + A_f)$	$A_{wa} / (A_t + A_f)$	$A_c / (A_t + A_f)$	0
all other cases	$A_f / A_t$	$A_{wa} / A_t$	$A_c / A_t$	0

$A_f$  is the floor area;

$A_t$  is the total area except window ( $= A_f + A_{wa} + A_c$ );

$A_{wa}$  is the vertical wall area except window;

$A_c$  is the ceiling area.

## 5.4 Cooling system device

### 5.4.1 General

The following systems are considered:

- convective device;
- cool surface device;

— both convective device and cool surface device.

**5.4.2 Convective device**

A convective device means that heat is removed from the space by an air terminal device (unit) with negligible radiative effects (i.e. fan coil or air inlet). In this situation the room cooling load is represented by the heat to be removed from the space in order to maintain the prescribed internal conditions defined by the system control.

**5.4.3 Cooled surface device**

A cooled surface device means that the heat rate is removed from the space by the cooled surface by convection and radiation. In this case the cooling rate is represented by the total heat to be removed by the surface of the cooled element in order to maintain the prescribed internal conditions. The cooled surface can be an embedded system according to EN 15377 where the surface temperature is calculated.

**5.5 Classification of the cooling load calculation method**

Calculation methods are classified according to their ability to model different types of cooling system and control methods, according to Tables 2 and 3.

**Table 2 — Classification of calculation methods**

Cooling systems within capability of method		Class of calculation method			
		1	2	3	4
Pure convective system	Infinite cooling capacity, continuous operation	v	v	v	v
	Infinite cooling capacity, continuous or intermittent operation		v	v	v
	Limited cooling capacity + moveable shading			v	v
Surface + convective system					v

For each main class of method (from 1 to 4) there are two sub-classifications, according to the types of the system control that the method can model.

**Table 3 — Sub-classification of calculation method**

Control type within capability of method	Sub-class	
	a	b
Air temperature	v	v
Operative temperature		v

**EXAMPLE** A calculation method of class 3b is able to handle pure convective systems with infinite cooling capacity, continuous or intermittent operation, fixed cooling capacity, moveable shadings, and control of the room air or room operative temperature. It is not able to model cooled surfaces.

## 6 Report of the calculation

### 6.1 General

According to this standard, the calculation report of cooling load shall include at least the input data specified in 6.2, and the output data as given in 6.3.

### 6.2 Input data

- a) the climatic data (hourly values of the external air temperature, solar radiation intensity, external radiant temperature);
- b) building characteristics: description of the building and the rooms investigated;
- c) for each room:
  - 1) volume, in  $\text{m}^3$ ;
  - 2) hourly values of:
    - i) ventilation air flow rate, in  $\text{m}^3/\text{s}$ ;
    - ii) infiltration air flow rate, in  $\text{m}^3/\text{s}$ ;
- d) inlet temperature (external air and air from central ventilation system), in  $^{\circ}\text{C}$ ;
- e) schedules of internal heat gains related to:
  - 1) lighting per floor area;
  - 2) presence of people;
  - 3) electrical appliances;
- f) for each element of the envelope, according to the calculation method:
  - area, thermal and optical characteristics used for the calculations;
- g) design temperature: schedule of air or operative temperature, depending on the control strategy;
- h) system device
  - convective: maximum cooling capacity;
  - cool surface device: minimum surface temperature;  
area of surface;  
boundary conditions.

### 6.3 Output data

The results of the calculation are the hourly values of the room cooling load and the air, mean radiant and operative temperatures.



## 7 Validation procedures

### 7.1 General

For validation of any existing or new numerical solution program they shall:

- a) comply with the maximum simplification allowed in this standard as described in the previous clauses;
- b) produce results for the test cases described below within the error bands specified in 7.6;
- c) comply with the validation procedure for the sunlit factor due to external obstructions given in 6.3 of EN ISO 13792:2005.

The tests defined in this clause are for the calculation of the room cooling load and the internal temperatures under cyclic conditions for several cases, and comparison of the calculated values with those in this standard.

### 7.2 Reference room

The interior dimensions of the room are: length = 3,6 m; depth = 5,5 m; height = 2,8 m. The external wall including the glazing is exposed to the West. The areas of the reference room components are given in Table 4. The window frame fraction is assumed to be zero.

**Table 4 — Areas of the reference room components**

	External wall	Glazing	Internal wall left	Internal wall right	Internal wall back	Floor	Ceiling
Area (m <sup>2</sup> )	3,08	7,0	15,4	15,4	10,08	19,8	19,8

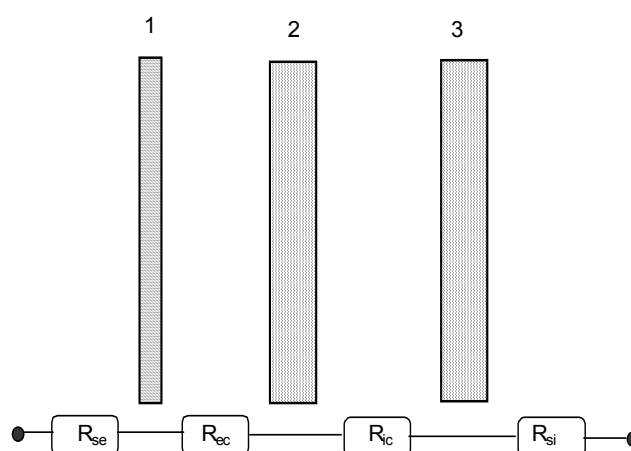
The solar parameters (considered here as independent of the solar angle) of the glazing component are given in Table 5:

**Table 5 — Solar characteristics of the glazed components for all incident angles**

Component	$\tau_e$	$\rho_e$
Pane	0,84	0,08
Shade	0,20	0,50

The thermophysical characteristics of the glazing system are:

a) SDP – Double pane glazing with external shading device (Figure 1):



**Figure 1 — Double pane glazing with external shading device**

Thermal resistances:

— external surface	$R_{se} = 0,074 \text{ m}^2 \text{ K/W}$
— cavity between external blind and external pane	$R_{ec} = 0,080 \text{ m}^2 \text{ K/W}$
— cavity between external pane and internal pane	$R_{ic} = 0,173 \text{ m}^2 \text{ K/W}$
— internal surface	$R_{si} = 0,125 \text{ m}^2 \text{ K/W}$

Thermal transmittance of the glazing system  $U_g = 2,21 \text{ W/(m}^2\text{K)}$

Solar parameters of the glazing system:

— absorption coefficient external blind	$\alpha_{eb} = 0,309$
— absorption coefficient external pane	$\alpha_{ep} = 0,0167$
— absorption coefficient internal pane	$\alpha_{ip} = 0,0145$
— solar transmittance	$\tau_e = 0,1525$
— total solar energy transmittance (solar factor)	$g = 0,20$

b) DP – Double pane glazing without external shading device (Figure 2):

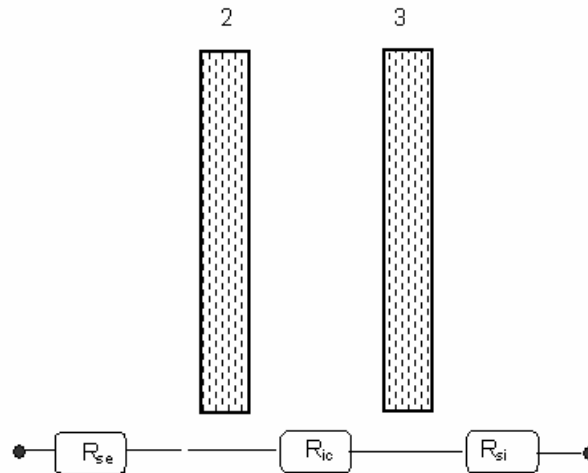


Figure 2 — Double pane glazing without shading devices

Thermal resistances:

- external surface  $R_{se} = 0,074 \text{ m}^2 \text{ K/W}$
- cavity between external pane and internal pane  $R_{ic} = 0,173 \text{ m}^2 \text{ K/W}$
- internal surface  $R_{si} = 0,125 \text{ m}^2 \text{ K/W}$

Thermal transmittance of the glazing system  $U_g = 2,69 \text{ W/(m}^2\text{K)}$

Solar parameters of the window system:

- absorption coefficient external pane  $\alpha_{ep} = 0,0854$
- absorption coefficient internal pane  $\alpha_{ip} = 0,0676$
- solar transmittance  $\tau_e = 0,710$
- total solar energy transmittance (solar factor)  $g = 0,77$

Opaque component

- solar absorption of all external wall surfaces  $\alpha_{sr} = 0,6$

For the validation the thermophysical characteristics of the walls, ceiling and floor given in Table 6. are used.

For the external surfaces, the view factor towards the sky is zero.

The solar loss factor  $f_{lf}$  is zero, and the solar to air factor  $f_{sa}$  is 0,1.

**Table 6 — Thermophysical properties of the opaque components**  
(order of layers from external to internal)

	$d$ m	$\lambda$ W/(m·K)	$\rho$ kg/m <sup>3</sup>	$c_p$ kJ/(kg·K)
<b>Type 1 (external wall)</b>				
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
<b>Type 2 (internal wall)</b>				
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
<b>Type 3c (ceiling)</b>				
plastic covering	0,004	0,23	1500	1,5
cement floor	0,06	1,40	2000	0,85
insulating layer	0,04	0,04	50	0,85
concrete	0,18	2,10	2400	0,85
<b>Type 3f (floor)</b>				
concrete	0,18	2,10	2400	0,85
insulating layer	0,04	0,04	50	0,85
cement floor	0,06	1,40	2000	0,85
plastic covering	0,004	0,23	1500	1,5
<b>Type 4c (ceiling)</b>				
plastic covering	0,004	0,23	1500	1,5
cement floor	0,06	1,40	2000	0,85
insulating layer	0,04	0,04	50	0,85
concrete	0,18	2,10	2400	0,85
insulating layer	0,10	0,04	50	0,85
acoustic board	0,02	0,06	400	0,84
<b>Type 4f (floor)</b>				
acoustic board	0,02	0,06	400	0,84
insulating layer	0,10	0,04	50	0,85
concrete	0,18	2,10	2400	0,85
insulating layer	0,04	0,04	50	0,85
cement floor	0,06	1,40	2000	0,85
plastic covering	0,004	0,23	1500	1,5

### 7.3 Climatic data

The hourly instantaneous values of the external air temperature and the solar radiation are given in Table 7 and Table 8, representing a summer day in July 15<sup>th</sup> at a latitude of 52° N. The evolution during an hour is assumed to be linear between the previous and subsequent hour (see Figure 3). The climatic input data for each calculation method have to be adapted following these assumptions.

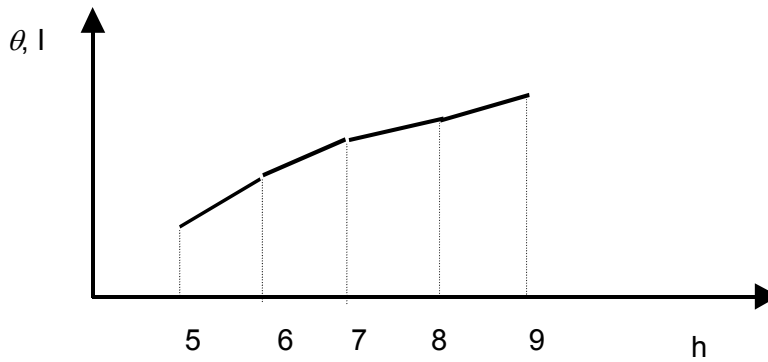


Figure 3 — Linear variation of the climatic data within each hour

Table 7 — Instantaneous external air temperature (°C)

Hour	$\theta_{a,e}$	Hour	$\theta_{a,e}$	Hour	$\theta_{a,e}$	Hour	$\theta_{a,e}$
1	14,08	7	13,12	13	26,24	19	22,56
2	13,28	8	14,56	14	27,52	20	21,44
3	12,64	9	16,64	15	28,00	21	18,72
4	12,16	10	19,04	16	27,52	22	17,12
5	12,00	11	21,76	17	26,40	23	15,84
6	12,32	12	24,32	18	24,64	24	14,88

For the purposes of these validation tests the total solar radiation impinging on the external surfaces has been pre-calculated and is given in Table 8.

**Table 8 — Instantaneous total solar radiation on the exposure of the wall (W/m<sup>2</sup>)**

Hour	Vertical west wall	Hour	Vertical west wall
04:00	0	13:00	366
05:00	22	14:00	558
06:00	55	15:00	703
07:00	80	16:00	778
08:00	101	17:00	756
09:00	117	18:00	604
10:00	128	19:00	271
11:00	135	20:00	0
12:00	150		

External radiant temperature is assumed to be equal to external air temperature.

For the air, the following parameters are used:

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

— air density: 1,139 kg/m<sup>3</sup>

#### 7.4 Test cases

Up to 15 tests shall be undertaken as specified in Table 9, depending on the class of the calculation method as defined in 5.5.

**Table 9 — Required tests according to class of calculation method**

Class of method	Test cases														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1a	X	X	X	X											
1b	X	X	X	X	X										
2a	X	X	X	X		X	X	X	X	X					
2b	X	X	X	X	X	X	X	X	X	X					
3a	X	X	X	X		X	X	X	X	X	X		X		
3b	X	X	X	X	X	X	X	X	X	X	X	X	X		
4a	X	X	X	X		X	X	X	X	X	X		X	X	X
4b	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

**Test 1 (for program of class 1a or higher) : reference case**

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
1	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup>, convective, 30 W/m<sup>2</sup>, radiative, per floor area, from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control (26°C); continuous operation

glazing system: with external shade (SDP)

**Test 2 (class 1a) : reference case + modification of the thermal inertia**

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
2	1	SDP	2	3c	3f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area, from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; continuous operation

glazing system: with external shade (SDP)

**Test 3 (class 1a) : reference case + modification of the internal gains**

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
3	1	SDP	2	4c	4f

internal gains : 20 W/m<sup>2</sup> convective, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; continuous operation

glazing system: with external shade (SDP)

**Test 4 (class 1a)** : reference case + modification of the type of glazing system

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
4	1	DP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; continuous operation

glazing system: no external shade (DP)

**Test 5 (class 1b)** : reference case + modification of the system control

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
5	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with operative temperature control; continuous operation

glazing system: with external shade (SDP)

**Test 6 (class 2a)** : reference case + intermittent operation of the system

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
6	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

glazing system: with external shade (SDP)



**Test 7 (class 2a)** : test 6 + modification of the thermal inertia

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
7	1	SDP	2	3c	3f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

glazing system: with external shade (SDP)

**Test 8 (class 2a)** : test 6 + modification of the internal gains

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
8	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

glazing system: with external shade (SDP)

**Test 9 (class 2a)** : test 6 + modification of the shading of the glazing system

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
9	1	DP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

glazing system: without external shade (DP)

**Test 10 (class 2a)** : test 6 + modification of the ventilation

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
10	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 8:00 to 18:00

ventilation: 2 air changes per hour of air at external temperature from 21:00 to 08:00, otherwise 0

system: air system with air temperature control; operation from 8:00 to 18:00

glazing system: with external shade (SDP)

**Test 11 (class 3a)** : test 6 + modification of the maximum cooling power

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
11	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

$$P_{\max} = 1400 \text{ W}$$

glazing system: with external shade (SDP)

**Test 12 (class 3b)** : test 6 + modification of system control

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
12	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with operative temperature control; operation from 08:00 to 18:00

glazing system: with external shade (SDP)

**Test 13 (class 3a)** : test 6 + modification of the functioning of the shading system

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Adiabatic floor
13	1	SDP	2	4c	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: air system with air temperature control; operation from 08:00 to 18:00

glazing system: with external shade (SDP) from 13:00 to 18:00 only

**Test 14 (class 4a)** : cooled floor at fixed temperature

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Adiabatic ceiling	Floor surface
14	1	SDP	2	4c	-

internal gains : 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: cooled floor at fixed temperature without thermal mass and external losses; continuous operation over 24 h without room temperature control

glazing system: with external shade (SDP)

temperature of the cooled surface: fixed at 18°C

floor solar reflectivity: 0,5

**Test 15 (class 4a)** : cooled ceiling with the control of the internal air temperature

Test	External opaque wall	Glazing system	Adiabatic vertical internal wall	Ceiling surface	Adiabatic floor
15	1	SDP	2	-	4f

internal gains: 20 W/m<sup>2</sup> convective, 30 W/m<sup>2</sup> radiative, per floor area from 08:00 to 18:00

ventilation: 0 air changes per hour of air at external temperature

system: cooled ceiling with air temperature control and continuous operation over 24 h, the ceiling has no thermal mass and no external losses

glazing system: with external shade (SDP)

temperature of the cooled surface: controlled with lower limit 18°C

## 7.5 Parameters to be calculated

For each test the following parameters shall be calculated:

- 1) Maximum hourly operative temperature during occupancy. The average hourly value shall be calculated if the method time step is less than 1 hour.
- 2) Maximum hourly cooling power (W). The average hourly value shall be calculated if the method time step is less than 1 hour.
- 3) Average cooling power for the 24 h cycle.

## 7.6 Test results

The reference results are given in Table 10.

**Table 10 — Reference results**

<b>Test</b>	<b>Maximum operative temperature</b> $\theta_{op,max,ref}$ °C	<b>Maximum cooling power</b> $P_{max,ref}$ W	<b>Average cooling power</b> $P_{av,ref}$ W
1	28,7	1683	585
2	28,1	1431	584
3	27,6	1191	358
4	32,6	3619	1259
5	26,0	1906	609
6	28,8	1742	554
7	28,6	1623	552
8	27,8	1238	340
9	33,3	3837	1125
10	28,6	1608	396
11	31,5	1400	523
12	26,0	1909	574
13	28,7	1796	646
14	30,5	1967	700
15	25,9	2218	723

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A method complies with this standard if each of the following three conditions are fulfilled for each test:

- 1)  $\text{abs} (\theta_{\text{op,max}} - \theta_{\text{op,max,ref}}) \leq 0,5 \text{ K}$
- 2)  $\text{abs} (P_{\text{max}} - P_{\text{max,ref}}) / P_{\text{max,ref}} \leq 0,05$
- 3)  $\text{abs} (P_{\text{av}} - P_{\text{av,ref}}) / P_{\text{av,ref}} \leq 0,05$

where abs is the absolute value.

## Annex A (informative)

### Example of solution model

#### A.1 Introduction

This annex gives an example of a simple method for the calculation of the required cooling load according to the type of input defined in the standard.

The calculation method is based on a network of resistances and capacity (HC three-nodes model) of the heat transfers between the internal and external environment.

#### A.2 Calculation of internal air and operative temperatures for a given value of applied cooling power

##### A.2.1 Presentation

The calculation model is based on the simplifications of the heat transfer between the internal and external environments illustrated in Figure A.1.

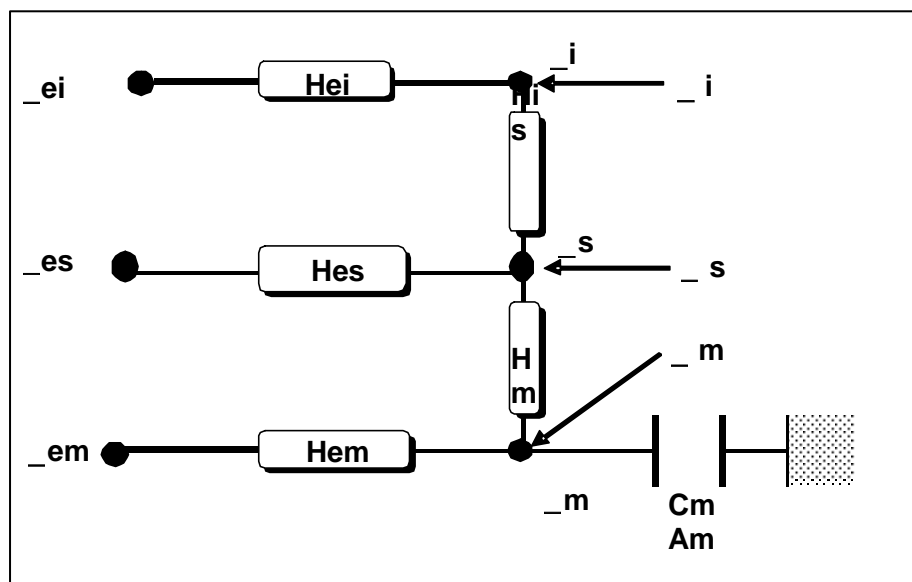


Figure A.1 — HC network

According to this representation as an electric analogue, the envelope elements are divided into:

- light opaque external elements
- heavy opaque external elements

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- glazing elements
- internal elements

The relevant nodes are defined related to:

- $\theta_i$  internal air temperature;
- $\theta_s$  star temperature,
- $\theta_m$  mass temperature;
- $\theta_{e,i}$  external air temperature;
- $\theta_{es}, \theta_{em}$  equivalent external sol-air temperature of external components.

The equivalent conductances  $H$ , in W/K, and thermal capacity  $C$ , in J/K, between the internal and the external environment are:

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

The heat flows (W) are:

- $\Phi_i$  heat flow to  $\theta_i$  node;
- $\Phi_s$  heat flow to  $\theta_s$  node;
- $\Phi_m$  heat flow to  $\theta_m$  node.

For each component the following parameters are required:

light opaque external components (thickness $\leq 120$ mm)	thermal transmittance	$U$
	solar factor	$S_f$
	solar radiation	$I_{si}$
	area	$A$
heavy opaque external components (thickness $> 120$ mm)	thermal transmittance	$U$
	solar factor	$S_f$
	solar radiation	$I_{si}$
	area	$A$

glazing components	thermal transmittance	$U$
	solar direct transmittance ( $\tau_e$ in EN 410)	$S_{f1}$
	secondary heat transfer factor towards the inside ( $q_i$ in EN 410)	$S_{f2}$
	tertiary heat transfer coefficient	$S_{f3}$
	solar radiation	$I_{si}$
	area	$A$
all components	areal thermal capacity	$C$
	area	$A$
room	air flow rate $\times$ room volume	$n V$

### A.2.2 Determination of the air and operative temperatures

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

$$\theta_{m,t} = \theta_{m,t-1} ( C_m / 3600 - 0.5 (H_3 + H_{em}) + \Phi_{mtot} ] / [ C_m / 3600 + 0.5 (H_3 + H_{em}) ] \quad (A.1)$$

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

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

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

$$\theta_1 = [H_{is} \theta_s + H_{ei} \theta_{ei} + \Phi_1] / (H_{is} + H_{ei}) \quad (A.4)$$

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

$$\theta_{op} = [\theta_1 + (1 + h_{ci} / h_{rs}) \theta_s - h_{ci} \theta_1 / h_{rs}] / 2 \quad (A.5)$$

with

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

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

$$H_2 = H_1 + H_{es}$$

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

$$\Phi_{mtot} = \Phi_m + H_{em} \theta_{em} + H_3 [ \Phi_s + H_{es} \theta_{es} + H_1 ( \Phi_1 / H_{ei} + \theta_{ei} ) ] / H_2$$



where

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

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

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

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

$H_{em}$  is a 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 thermal capacity of the envelope components given by Equation (A.11);

$\theta_{es}$  is the equivalent sol-air external temperature of the light external components given by Equation (A.13);

$\theta_{em}$  is the equivalent sol-air external temperature of the heavy external components given by Equation (A.14);

$\Phi_1$  is the heat flow to air node due to internal gains or direct solar radiation or convective heat gains due to window ventilated inner air layer given by Equation (A.17);

$\Phi_s$  is the heat flow to star node due to internal gains or direct solar radiation given by Equation (A.18);

$\Phi_m$  is the heat flow to mass node due to internal gains or direct solar radiation given by Equation (A.19).

The calculation is repeated for several days until the convergence on the internal temperature and cooling power values is obtained. Convergence is reached when the difference between  $\theta_m$  at 24 h 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.

#### Thermal transmission factors

Thermal transmission factor due to the air ventilation:

$$H_{ei} = c_a \rho_a n V / 3600 \quad (A.6)$$

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

with

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

where

$n$  is the number of air changes per hour;

$V$  is the room volume;

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

$$H_{es} = H_{Tl} + H_{Tw} \quad (\text{A.8})$$

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

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

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

$$H_{ms} = h_{is} A_m \quad (\text{A.9})$$

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

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

$H_{Th}$  corresponds to heavy external opaque components.

The heat capacity of the component  $C_m$  is calculated according to EN ISO 13786 for a 24 h period variation.

$$C_m = \sum_{i=1}^c A_i C_i \quad (\text{A.11})$$

where

$C_i$  is the equivalent internal thermal capacity of the component;

$A_i$  is the area of the component;

$c$  is the number of components facing the internal environment (including both internal and external components).

The equivalent thermal mass area  $A_m$  is given by:

$$A_m = \frac{C_m^2}{\sum_{i=1}^c A_i C_i^2} \quad (\text{A.12})$$

### Equivalent external sol-air temperatures

$$\theta_{es} = \theta_{ei} + \Phi_{sl} / H_{es} \quad (\text{A.13})$$

$$\theta_{em} = \theta_{ei} + \Phi_{sh} / H_{Th} \quad (\text{A.14})$$

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 vault sky losses by the light components (opaque and transparent) is given by:

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

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

$$\Phi_{sh} = \sum_{y=1}^h [A(S_f I_{sr} + q_{er} U / h_e)]_y$$

### Heat flows to node temperatures

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

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

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

$$\Phi_{svl} = \sum_{j=1}^w [A S_{f3} I_{sr}]_j$$

The heat flows due to internal heat gains are given by:

$$\Phi_{intc} = \sum_{i=1}^s \Phi_{intc,i} \tag{A.15}$$

$$\Phi_{intr} = \sum_{i=1}^s \Phi_{intr,i} \tag{A.16}$$

where

$s$  is the number of internal heat gains;

$\Phi_{\text{intc}}$  is the convective heat flow from each internal source;

$\Phi_{\text{intr}}$  is the radiative heat flow from each internal source.

The heat flows due to the cooling system, are given by:

$$\Phi_{\text{csc}} = f_{\text{scc}} \Phi_{\text{cs}}$$

$$\Phi_{\text{csr}} = (1 - f_{\text{scc}}) \Phi_{\text{cs}}$$

where

$f_{\text{scc}}$  is the convective fraction for the cooling system (see Table A.1)

$\Phi_{\text{cs}}$  is the total cooling power of the cooling system

**Table A.1 — Convective fraction**

	Convective fraction $f_{\text{scc}}$
Air system	1
Cooled ceiling	0,50
Cooled vertical surface	0,1
Cooled floor	0,1

NOTE The values of  $f_{\text{scc}}$  are derived from the heat transfer coefficient as defined in 5.3.3.

The heat flows to temperature nodes are given by:

$$\Phi_i = \Phi_{\text{svl}} + f_{\text{sa}} \Phi_{\text{sd}} + \Phi_{\text{intc}} + \Phi_{\text{csc}} \quad (\text{A.17})$$

$$\Phi_s = P_{\text{rs}} (1 - f_{\text{sa}}) (\Phi_{\text{intr}} + \Phi_{\text{csr}}) + P_{\text{rsd}} \Phi_{\text{sd}} \quad (\text{A.18})$$

$$\Phi_m = P_{\text{rm}} (1 - f_{\text{sa}}) (\Phi_{\text{intr}} + \Phi_{\text{csr}}) + P_{\text{rmd}} \Phi_{\text{sd}} \quad (\text{A.19})$$

where  $P_{\text{rs}}$  and  $P_{\text{rm}}$  are the parts of the internal radiative heat gains respectively to  $\theta_s$  and  $\theta_m$  nodes

$$P_{\text{rs}} = (A_t - A_m - H_{\text{es}} / h_{\text{is}}) / A_t$$

$$P_{\text{rm}} = A_m / A_t$$

$P_{\text{rsd}}$  and  $P_{\text{rmd}}$  are the parts of the direct solar radiative gains respectively to  $\theta_s$  and  $\theta_m$  nodes, assuming that the solar short wave radiation back to the window is already taken into account in the solar loss factor  $f_{\text{f}}$ .

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

$$P_{\text{rmd}} = A_m / (A_t - A_w)$$

$A_w$  is the total window area, given by:

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

where

$w$  is the number of glazing components;

$h$  is the number of heavy opaque components;

$l$  is the number of light 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 solar factor;

$I_{sr}$  is the intensity of the solar radiation reaching the surface;

$f_{if}$  is the solar loss factor for windows;

$f_s$  is the sunlit factor due to external obstructions, derived from EN ISO 13791;

$f_{sa}$  is the solar to air factor defined in 5.3.4.2;

$q_{er}$  is the density of heat flow from the external environment to the vault sky.

## A.3 Calculation of internal temperatures and required cooling power

### A.3.1 General description

The calculation of the internal temperatures and required cooling power is based on the calculation of the room behaviour on the one hand (for a given time step, the internal room temperature is a function of the applied cooling power), and on the cooling system behaviour on the other hand (through its control device, the applied cooling power is linked to the internal room temperature). The combination of both enables the calculation of the internal temperatures and actual cooling power for each time step.

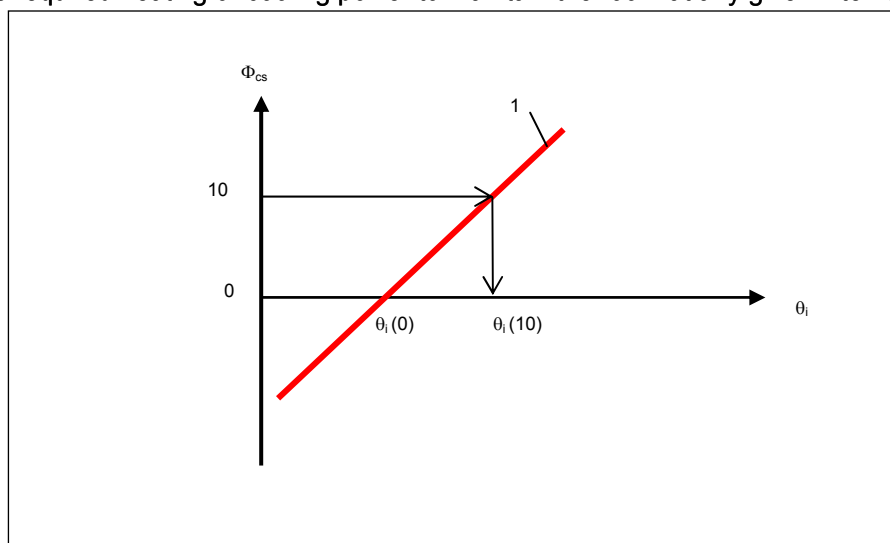
#### A.3.1.1 Room behaviour

For each hour, the RC network enables to calculate the internal air temperature  $\theta_i$  for any applied system power  $\phi_{cs}$ . The resolution scheme is such that  $\theta_i$  is a linear function of  $\phi_{cs}$ .

For a given hour, the room behaviour line is then known by applying Equations (A.4) and (A.5) described in A.2 for two values of  $\phi_{cs}$  (0 and 10 W/m<sup>2</sup>).

For each of the two values of cooling power, the corresponding internal temperatures are called  $\theta_i(0)$  free floating conditions for  $\phi_{cs} = 0$  and  $\theta_i(10)$  internal temperature for 10 W/m<sup>2</sup> applied system power.

This makes it possible to calculate the internal temperature for any heating or cooling power or, conversely, to calculate the required heating or cooling power to maintain the room at any given internal temperature.



### Key

$\Phi_{cs}$	applied system power, in $W/m^2$
$\theta_i$	room air temperature, in $^{\circ}C$
$\theta_i(0)$	room air temperature at free floating conditions $\Phi_{cs}=0 W/m^2$ , in $^{\circ}C$
$\theta_i(10)$	room air temperature with applied system power $\Phi_{cs}=10 W/m^2$ , in $^{\circ}C$
1	room behaviour line

Figure A.2 — Room behaviour

### A.3.1.2 Cooling system behaviour

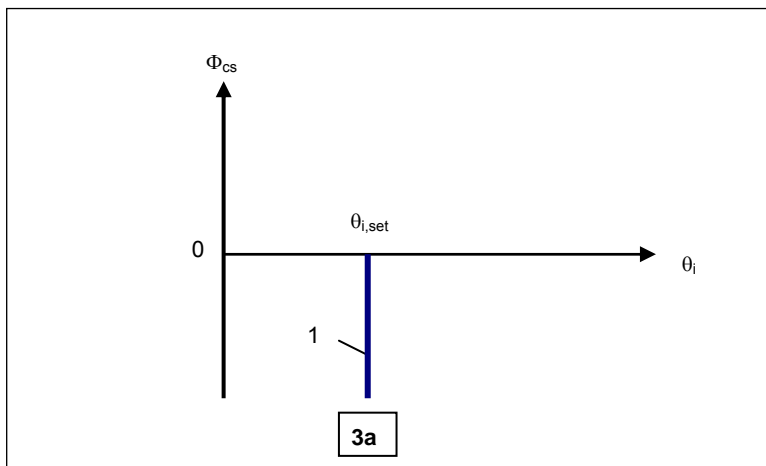
The available cooling power can be represented on the same graph by the set temperature,  $\theta_{i,set}$ , and the maximum available cooling power (which can vary for each hour)

Different situations can occur:

- a) There is no limitation to the cooling power (case 3a)

In this case, the system behaviour is just a vertical line : the internal temperature will never be higher than the  $\theta_{i,set}$  value.

For internal temperatures lower than  $\theta_{i,set}$ , the applied cooling power is equal to 0.

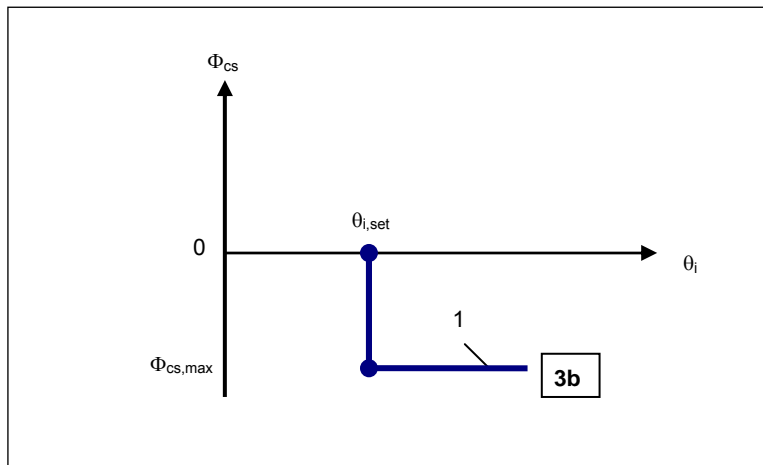


**Key**

- $\Phi_{cs}$  applied system power, in  $W/m^2$
- $\theta_i$  room air temperature, in  $^{\circ}C$
- 1 system behaviour line for unlimited cooling power

**Figure A.3 — System behaviour: unlimited cooling capacity**

b) The cooling power is limited at a given value (case 3b)



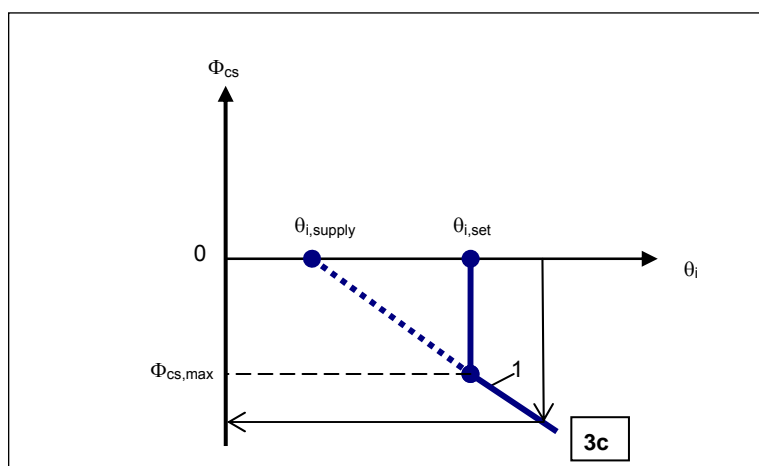
**Key**

- $\Phi_{cs}$  applied system power, in  $W/m^2$
- $\theta_i$  room air temperature, in  $^{\circ}C$
- 1 system behaviour line for limited cooling power  $\Phi_{cs, max}$

**Figure A.4 — System behaviour: fixed maximum cooling capacity**

In this case the cooling power will be limited at its maximum value even for internal temperatures higher than the  $\theta_{i, set}$  value

- c) The cooling power is limited at a maximum value increasing with the internal temperature (case 3c)



### Key

- $\Phi_{cs}$  applied system power, in  $W/m^2$   
 $\theta_i$  room air temperature, in  $^{\circ}C$   
 1 line for air system with a fixed air supply temperature  $\theta_{i, supply}$

**Figure A.5 — System behaviour: maximum cooling capacity increasing with internal temperature**

This can happen with air system supplied at a maximum constant air flow and a fixed temperature. In this case, the cooling power increases with the internal temperature (on the other hand, it is equal to zero if the internal air temperature is equal to the supplied air temperature).

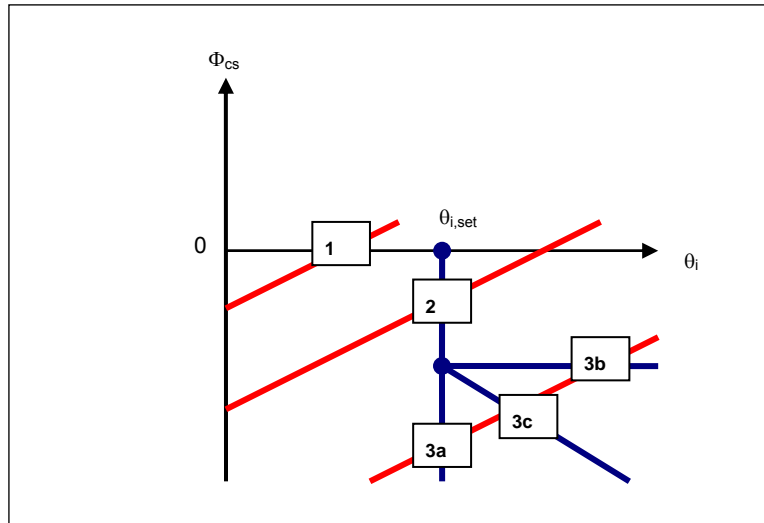
### A.3.1.3 Resulting internal temperatures and cooling power

The resulting internal temperatures and cooling demand is the intersection of the room behaviour line, and the system behaviour curve.

Three situations can occur:

- case 1 : The room requires no cooling (free floating conditions). No cooling is applied, and the internal temperatures are calculated.
- case 2 and 3a : The room requires cooling and the cooling power is sufficient. The internal temperature is equal to  $\theta_{i, set}$  and the calculated cooling demand is lower than its maximum value.
- case 3b and 3c : The room requires cooling and the cooling power is not sufficient. The cooling demand is limited to the maximum available cooling power. The calculated internal temperature is higher than the cooling set point  $\theta_{i, set}$ .





**Key**

- $\Phi_{cs}$  applied system power, in  $W/m^2$
- $\theta_i$  room air temperature, in  $^{\circ}C$
- $\theta_{i,set}$  room air setpoint temperature, in  $^{\circ}C$
- 1 line with no cooling needed, free floating conditions
- 2 line with sufficient cooling power available, room air temperature fixed at  $\theta_{i,set}$
- 3a line with unlimited cooling power available, room air temperature fixed at  $\theta_{i,set}$
- 3b line with limited cooling power available, room air temperature higher than  $\theta_{i,set}$
- 3c line for air system with a fixed air supply temperature  $\theta_{i,supply}$ , room air temperature higher than  $\theta_{i,set}$

**Figure A.6 —Room behaviour versus system behaviour**

**A.3.2 Calculation procedure for control on air temperature**

The aim is to calculate  $\theta_{i,ac}$  actual internal temperature, and  $\Phi_{cs,ac}$  actual cooling demand. In all cases, the  $\theta_{m,t}$  value must be also calculated and stored, as it will be used for the next time step.

Step 1 : check if cooling must be used (case 1 of A.3.1.3)

Take  $\Phi_{cs} = 0$  and calculate  $\theta_i$

Name  $\theta_i$  as  $\theta_{i0}$  ( $\theta_{i0}$  is the air temperature in free floating conditions)

If  $\theta_{i0} \leq \theta_{i,set}$ : no cooling is required then

$$\Phi_{cs,ac} = 0 \text{ and } \theta_{i,ac} = \theta_{i0}$$

and the calculation is done.

Otherwise apply step 2

Step 2 : calculate the required cooling demand

Apply the procedure in A 2 taking  $\Phi_{cs} = \Phi_{cs10}$  with  $\Phi_{cs10} = 10 A_f$  where  $A_f$  is the floor area.

Name  $\theta_i$  as  $\theta_{10}$  ( $\theta_{10}$  is the air temperature for a heating power of 10 W/m<sup>2</sup>).

Calculate  $\Phi_{\text{csun}}$  (unlimited cooling demand to obtain the set point requirement; negative for cooling)

$$\Phi_{\text{csun}} = \Phi_{\text{cs10}} (\theta_{i,\text{set}} - \theta_{10}) / (\theta_{10} - \theta_{10})$$

Step 3 : check if the available cooling is enough (cases 2 and 3a )

If  $\Phi_{\text{csun}} > \Phi_{\text{csmax}}$  (maximum cooling power) (situations 2 or 4),

$$\Phi_{\text{cs,ac}} = \Phi_{\text{csun}} \text{ and } \theta_{i,\text{ac}} = \theta_{i,\text{set}}$$

and the calculation is done.

Otherwise apply step 4.

Step 4 : calculate the actual cooling power and corresponding internal temperatures (cases 3b and 3c)

*Case 3b : fixed maximum cooling power*

$$\text{Set } \Phi_{\text{cs,ac}} = \Phi_{\text{cs,max}}$$

Calculate the internal temperatures with this value and the calculation is done.

*Case 3c : maximum cooling power related to internal temperature*

$$\Phi_{\text{cs}} = \Phi_{\text{csmax}} (\theta_i - \theta_{\text{sc0}}) / (\theta_{i,\text{set}} - \theta_{\text{sc0}})$$

where  $\theta_{\text{sc0}}$  is the value for which the cooling power is equal to 0 (cooling source value in general)

Calculate the actual cooling power by

$$\Phi_{\text{cs,ac}} = \Phi_{\text{csmax}} (\theta_{i,\text{ac}} - \theta_{\text{sc0}}) / (\theta_{i,\text{set}} - \theta_{\text{sc0}})$$

with

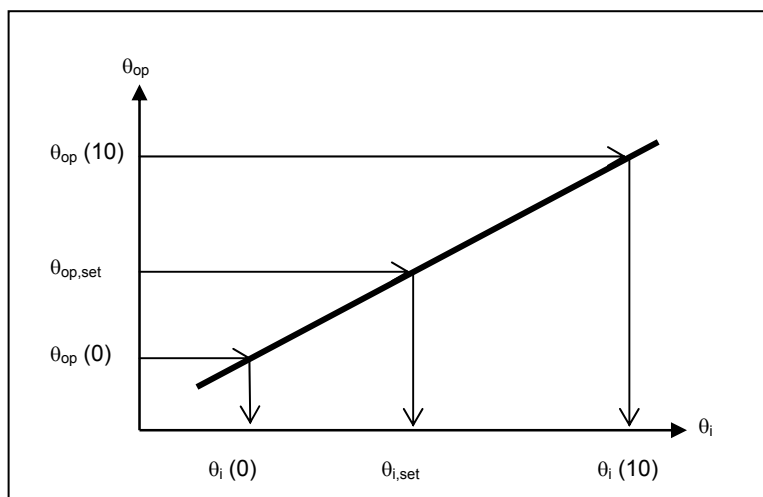
$$\theta_{i,\text{ac}} = [10 \theta_{10} (\theta_{i,\text{set}} - \theta_{\text{sc0}}) - \Phi_{\text{csmax}} (\theta_{\text{sc0}} (\theta_{10} - \theta_{10}))] / [10 (\theta_{i,\text{set}} - \theta_{\text{sc0}}) - \Phi_{\text{csmax}} (\theta_{10} - \theta_{10})]$$

Calculate internal temperatures with this value and the calculation is done.

Note in both cases, the setpoint temperature will not be maintained.

### A.3.3 Calculation procedure for control on operative temperature

An initial calculation is done relating for the given hour the value of  $\theta_i$  and  $\theta_{\text{op}}$  by applying step 1 and calculating the corresponding value of  $\theta_{\text{op0}}$  ( $\theta_{\text{op}}$  in free floating conditions) and  $\theta_{\text{op10}}$  ( $\theta_{\text{op}}$  for 10 W/m<sup>2</sup> cooling power).



**Key**

- $\theta$  room air temperature, in °C
- $\theta_{op}$  operative temperature, in °C
- $\theta_{i,set}$  indoor air setpoint temperature, in °C
- $\theta_{op,set}$  operative setpoint temperature, in °C
- $\theta(0)$  room air temperature at free floating conditions  $\phi_{cs}=0 \text{ W/m}^2$ , in °C
- $\theta(10)$  room air temperature with applied system power  $\phi_{cs}=10 \text{ W/m}^2$ , in °C
- $\theta_{op}(0)$  operative temperature at free floating conditions  $\phi_{cs}=0 \text{ W/m}^2$ , in °C
- $\theta_{op}(10)$  operative temperature with applied system power  $\phi_{cs}=10 \text{ W/m}^2$ , in °C

**Figure A.7 — Room air temperature versus operative temperature**

This enables to calculate the  $\theta_{i,set}$  value corresponding to the  $\theta_{op,set}$  required value.

Then the procedure in A.2.2 is applied.