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Foreword

This document has been prepared by Working Committee NA 005-52-22 AA *Konstruktiver baulicher Brandschutz (Spiegelausschuss zu Teilbereichen von CEN/TC 250)* of the *Normenausschuss Bauwesen* (Building and Civil Engineering Standards Committee).

This document is the National Annex to DIN EN 1991-1-2:2010-12, *Eurocode 1: Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire.*

European Standard EN 1991-1-2 allows national safety parameters, referred to as Nationally Determined Parameters (NDPs), to be specified for a number of points. The NDPs cover alternative verification methods, the provision of individual values and the selection of classes from designated classification systems. The relevant parts of the text are identified in the European Standard by references to the possibility of national choice and are listed in Clause NA.2.1.

This National Annex also includes non-contradictory complementary information (NCI) for the application of DIN EN 1991-1-2:2010-12, as permitted by Guidance Paper L "Application and use of Eurocodes" of the European Commission, as well as information on the application of the informative annexes of DIN EN 1991-1-2.

The provisions of this National Annex are based on investigations made and on the results of fire design analyses in accordance with DIN 4102-4 and are intended to maintain the national safety level in terms of fire safety.

This National Annex is an integral part of DIN EN 1991-1-2:2010-12.

Annexes AA and BB of this National Annex are normative; Annex CC is informative.

NA.1 Scope

This National Annex contains national provisions relating to actions on structures for the purposes of structural fire design that are to be taken into consideration when applying DIN EN 1991-1-2:2010-12 in Germany.

This National Annex is only valid in conjunction with DIN EN 1991-1-2:2010-12.

NA.2 National provisions for the application of DIN EN 1991-1-2:2010-12

NA.2.1 General

DIN EN 1991-1-2:2010-12 refers to the option of choosing Nationally Determined Parameters (NDPs) at the following places in the text.

— 2.4(4)

— 3.1(10)

— 3.3.1.1(1)

— 3.3.1.2(1)

— 3.3.1.2(2)

— 3.3.1.3(1)

— 3.3.2(1)

— 3.3.2(2)

— 4.2.2(2)

— 4.3.1(2)

In addition, NA.2.2 includes non-contradictory complementary information for the application of DIN EN 1991-1-2:2010-12. This information is preceded by the letters "NCI".

For the purposes of this document the terms and definitions in DIN EN 1991-1-2 apply.

NA.2.2 National provisions

In the following, the clauses are numbered as in DIN EN 1991-1-2:2010-12.

NCI re 1.2 Normative references

DIN 18230-1, *Structural fire protection in industrial buildings — Part 1: Analytically required fire resistance time*

DIN 18230-3, *Structural fire protection in industrial buildings — Part 3: Values for calculation*

DIN EN 1991-1-2:2010-12, *Eurocode 1: Actions on structures — Part 1-2: General actions — Actions on structures exposed to fire*

NDP re 2.4(4) Temperature analysis

Re NOTE 1 The specified period of time may be given in the national regulations or obtained from Annex F following the specifications of the National Annex.

The period of time in connection with the standard temperature-time curve (STTC) according to 3.2.1 is given in the building regulations of the German *Laender* and related ordinances and guidelines. Annex F shall not be applied.

Re NOTE 2 Limited periods of fire resistance may be set in the National Annex.

Generally, the temperature analysis shall be made for the full duration of the fire, including the cooling phase.

NCI re 2.4 Temperature analysis and 2.5 Mechanical analysis

For temperature analysis of a member and mechanical analysis in a fire scenario, advanced calculation methods may be applied.

If a computer programme is used for the evaluation of structures or parts of structures in terms of fire protection by means of advanced calculation methods, it is assumed that this software has been validated. Annex CC includes appropriate examples of validation methods.

The national annexes of the parts of Eurocodes 2 to 4 concerning fire protection each refer to the informative Annex CC of this National Annex.

NOTE Background information on the validation of computer programmes for the fire behaviour of members and structures is given in [5].

NDP re 3.1(10) Thermal actions for temperature analysis

Re NOTE The use of the nominal temperature-time curves according to 3.2 or, as an alternative, the use of the natural fire models according to 3.3 may be specified in the National Annex.

The standard temperature-time curve according to 3.2.1 should generally be applied for provision of the obligatory verifications of the fire protection of buildings.

For verification of the integrity of non-loadbearing external walls und top-mounted parapets, the external fire curve according to 3.2.2 may be applied for fire exposure from outside and the standard temperature-time curve according to 3.2.1 may be applied for fire exposure from inside.

The external fire curve according to 3.2.2 may also be applied for structural parts of buildings that are situated in their entirety in front of the façade of a building, if the thermal actions are not determined according to Annex B.

The hydrocarbon fire curve according to 3.2.3 shall not be applied to buildings with a conventional mixed fire load.

Natural fire models according to 3.3.1 and 3.3.2 should only be applied in conjunction with a fire protection concept or fire protection verification (in accordance with the legal requirements of the respective German *Land*).

The information relating to simplified and advanced fire models in the following sections is to be observed.

NDP re 3.3.1.1(1) Simplified fire models — General

Re NOTE For the calculation of the design fire load density $q_{f,d}$ a method is given in Annex E.

The informative Annex E shall not be applied. The required information on the calculation of the design fire load density and the design rate of heat release is given in Annex BB.

NDP re 3.3.1.2(1) Compartment fires

Re NOTE 1 The National Annex may specify the procedure for calculating the heating conditions.

Re NOTE 2 For internal members of fire compartments, a method for the calculation of the gas temperature in the compartment is given in Annex A.

The informative Annex A shall not be applied. For determination of the ambient gas temperature in a fire compartment, the method given in Annex AA may be applied taking into account the specified limits of applicability.

NDP re 3.3.1.2(2) External members

Re NOTE For external members exposed to fire through openings in the façade, a method for the calculation of the heating conditions is given in Annex B.

The heating conditions may be calculated by means of the method given in Annex B, taking into account the information given in the NCI to Annex B.

NDP re 3.3.1.3 Localised fires

Re NOTE The National Annex may specify the procedure for calculating the heating conditions.

The heating conditions of members in the zone of influence of a localised fire may be calculated by means of the method given in Annex C with the deviations set out in the NCI "re Annex C".

NDP re 3.3.2(2) Advanced fire models

Re NOTE The National Annex may specify the procedure for calculating the heating conditions. A method for the calculation of thermal actions in case of one-zone, two-zone or computational fluid dynamic models is given in Annex D.

Annex D may be applied. However, instead of applying the design fire load and the design value of the rate of heat release according to Annex E, the provisions of Annex BB of this National Annex shall be applied, taking into account the information given in the NCI to Annex D.

NDP re 4.2.2(2) Additional actions

Re NOTE The choice of additional actions may be specified in the National Annex.

Impact loading according to DIN 4102-3 on members separating fire compartments (including specially protected fire compartments in industrial buildings) shall be considered an additional action.

NDP re 4.3.1(2) Combination rules for actions — General rule

Re NOTE The use of the quasi-permanent value $\psi_{2,1}\,Q_{k,1}$ or the frequent value $\psi_{1,1}\,Q_{k,1}$ may be specified in the National Annex. The use of $\psi_{2,1}\,Q_{k,1}$ is recommended.

Generally, the quasi-permanent value $\psi_{2,1}\,Q_{k,1}$ may be used. This does not apply to members with wind as the leading action, in which case the frequent value $\psi_{1,1}\,Q_{k,1}$ shall be used for action due to wind.

Re Annex A Parametric temperature-time curves

Annex A shall not be applied in Germany.

Parametric temperature-time curves for fully developed room fires shall be determined as set out in Annex AA.

NOTE Background information on the determination and use of parametric temperature-time curves is given in [1].

Re Annex B Thermal actions for external members — Simplified calculation method

Annex B may be applied with the following modifications:

- Clause B.4.2 (Forced draught) shall not be applied;
- Equation (B.6) shall not be used. The length of the flame may be determined using Equation (B.7);
- Equation (B.16) shall not be used. Regardless of the thickness of the flame, an emissivity value of $\varepsilon_f = 1{,}0$ shall be used for the flame.

NOTE The design aids in [2] may be used for a simplified determination of the heating conditions.

Re Annex C Localized fires

Annex C may be applied with the following modifications:

- the method according to Annex C only applies to localized fire loads with $RHR_f \geq 250$ kW/m² (RHR = Rate of Heat Release);
- in addition to Equation (C.2) the following applies: $\Theta\,(z) = 900$ °C for $z \leq 1{,}0$ m.

NOTE Background information on the scope and the limits of applicability of this simplified method is given in [3].

Re Annex D Advanced fire models

The calculation methods of Annex D may be used.

Computer programmes for the determination of actions during natural fire exposure should only be used if they are validated for the respective applications.

NOTE Explanations of the scope and the limits of applicability of natural fire models and the basic validation criteria are given in [3].

Re Annex E Fire load densities

Annex E shall not be applied. It is replaced by Annex BB of this National Annex.

NOTES Background information on the safety concept of Annex BB is given in [5].

Re Annex F Equivalent time of fire exposure

Annex F shall not be applied.

For applications in industrial building the method according to DIN 18230-1 is given.

Re Annex G Configuration factor

Annex G may be applied.

NCI

Annex AA
(normative)

Simplified natural fire model for fully developed room fires

AA.1 General

Simplified natural fire models enable the design in terms of fire protection of members and structures for natural fires by means of a simple manual calculation or spreadsheet analysis based on a performance-dependent determination of physical actions, without the need for heat balance or CFD field models. As opposed to nominal temperature-time curves, simplified natural fire models take into account the significant factors influencing the time curve of a natural fire, such as the fire load density, ventilation conditions, geometry of the fire compartment and thermal properties of the enclosing members. A design fire usually serves as the basis for simplified natural fire models.

When using the simplified natural fire model, the temperature-time curve of a natural fire may be determined by means of equations, taking into account the ventilation conditions, the fire load density, the geometry of the fire compartment and thermal properties of the enclosure. The method is based on a realistic design fire, which is defined by the rate of heat release and is described in detail in [1].

AA.2 Limits of applicability

The following simplified natural fire model applies to fires in rooms with a floor area up to 400 m^2 and height up to 5 m with vertical vent openings of 12,5 % to 50 % of the floor area and a fire load density of 100 MJ/m^2 to 1 300 MJ/m^2. The thermal actions determined become more conservative the bigger and/or higher the rooms.

AA.3 Design fire

Generally, the time curve of the rate of heat release according to BB.4 serves as the design fire.

For ventilation controlled fires in residential buildings, office buildings or buildings with comparable occupancies, the characteristic value of the maximum rate of heat release in the fire compartment may be determined by approximation using Equation (AA.1):

$$\dot{Q}_{\text{max,v,k}} = 1{,}21 \cdot A_{\text{w}} \cdot \sqrt{h_{\text{w}}} \quad \text{in MW} \tag{AA.1}$$

where

A_{w} is the area of the vent openings in m^2;

h_{w} is the mean height of the vent openings in m.

Equation (AA.1) only applies to rates of heat release that are effective inside a fire compartment. For flame action outside a fire compartment, $\dot{Q}_{\text{max,v,k}} = \dot{Q}_{\text{inside}} + \dot{Q}_{\text{outside}}$ shall be used, as otherwise the flame action will be underestimated.

For fuel controlled fires in residential buildings, office buildings or buildings with comparable occupancies, as a simplification the characteristic value of the rate of heat release may be obtained using Equation (AA.2):

$$\dot{Q}_{max,f,k} = 0.25 \cdot A_f \quad \text{in MW} \tag{AA.2}$$

where

A_f is the maximum fire area in m^2, generally, the floor area of the area of fire.

The characteristic value of the maximum rate of heat release is the lower value of the two maximum rates of heat release for a ventilation controlled fire or fuel controlled fire respectively:

$$\dot{Q}_{max,k} = MIN\left\{\dot{Q}_{max,v,k}\,;\,\dot{Q}_{max,f,k}\right\}. \tag{AA.3}$$

Equation (AA.3) may be used to determine whether the fire is ventilation controlled or fuel controlled.

The design values of the highest rate of heat release $\dot{Q}_{max,k}$ are defined as

$$\dot{Q}_{max,v,d} = \dot{Q}_{max,v,k} \cdot \gamma_{fi,Q} \tag{AA.4}$$

$$\dot{Q}_{max,f,d} = \dot{Q}_{max,f,k} \cdot \gamma_{fi,Q} \tag{AA.5}$$

$$\dot{Q}_{max,d} = \dot{Q}_{max,k} \cdot \gamma_{fi,Q} \tag{AA.6}$$

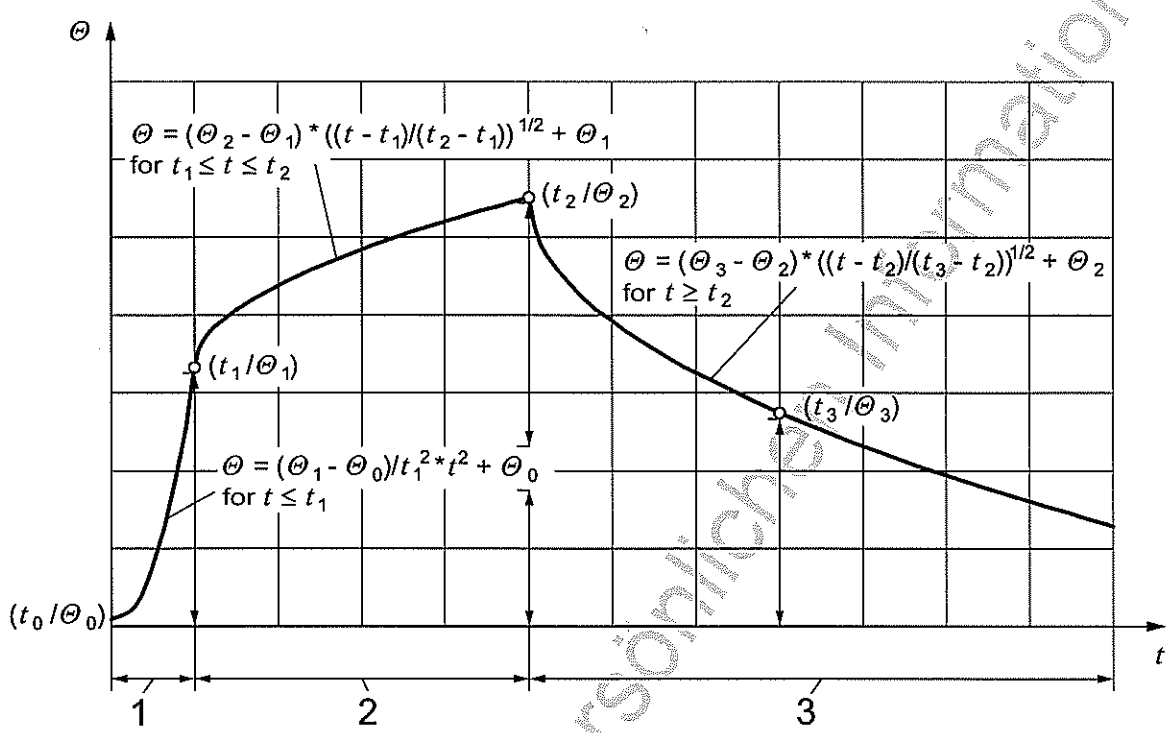
where

$\gamma_{fi,Q}$ is the partial factor according to BB.5.3.

AA.4 Parametric temperature-time curves

The temporal congruence with the rate of heat release enables the temperature-time curve of a natural fire to be described in all of its stages, from the stage of fire growth to the stage of a fully developed fire (see Figure AA.1).

The curve sections for the above three stages are delineated by distinctive points at the points in time t_0, t_1, t_2 und t_3, which are obtained from the time curve of the rate of heat release. To determine the related temperature values Θ_1, Θ_2 and Θ_3, a distinction needs to be made between ventilation controlled and fuel controlled fires (see AA.3).



Key

1 Section 1
2 Section 2
3 Section 3
t Time in min
Θ Temperature in °C

Figure AA.1 — Schematic diagram of the temperature-time curve according to the simplified natural fire model with points given as mathematical expressions (t_i, Θ_i) and the intermediate curve sections

For ventilation controlled fires and a reference fire load density of q = 1 300 MJ/m²:

$t_1 = t_\alpha \cdot \sqrt{\dot{Q}_{\mathrm{max,v,d}}}$	in s		(AA.7)
$\Theta_{1,\mathrm{v}} = -8{,}75 \cdot 1/O - 0{,}1 \cdot b + 1\,175$	in °C		(AA.8)
$t_2 = t_1 + \dfrac{Q_2}{\dot{Q}_{\mathrm{max,v,d}}}$	in s	with $Q_2 = 0{,}7 \cdot Q_\mathrm{d} - \dfrac{t_1^3}{3 \cdot t_\alpha^2}$	(AA.9)
$\Theta_{2,\mathrm{v}} = (0{,}004 \cdot b - 17) \cdot 1/O - 0{,}4 \cdot b + 2\,175$	in °C	≤ 11 340 °C	(AA.10)
$t_3 = t_2 + \dfrac{2 \cdot Q_3}{\dot{Q}_{\mathrm{max,v,d}}}$	in s	with $Q_3 = 0{,}3 \cdot Q_\mathrm{d}$	(AA.11)
$\Theta_{3,\mathrm{v}} = -5{,}0 \cdot 1/O - 0{,}16 \cdot b + 1\,060$	in °C		(AA.12)

where

t_α	is the factor to describe the fire growth according to Table BB.2. For residential and office occupancies it may be taken to be $t_\alpha = 300$ s;
b	is the heat storage capacity of the entire enclosure in $\mathrm{J}/\left(\mathrm{m}^2 \cdot \sqrt{\mathrm{s}} \cdot \mathrm{K}\right)$ according to AA.5;
$O = A_\mathrm{w}\sqrt{h_\mathrm{w}}/A_\mathrm{t}$	is the opening factor in $\mathrm{m}^{1/2}$;
A_w	is the area of the vent openings in m^2;
h_w	is the mean height of the vent openings in m;
A_t	is the total area of the enclosure including openings areas in m^2;
$Q_\mathrm{d} = q \cdot A_\mathrm{f}$	is the total fire load in the fire compartment in MJ with a reference fire load density of $q = 1\,300$ MJ/ m^2.

For fuel controlled fires and a reference fire load density of $q = 1\,300$ MJ/m^2:

$$t_1 = t_\alpha \cdot \sqrt{\dot{Q}_{\mathrm{max,f,d}}} \quad \text{in s} \tag{AA.13}$$

$$\Theta_{1,\mathrm{f}} = 24\,000 \cdot k + 20 \quad \text{in °C} \quad \text{for } k \leq 0{,}04 \text{ and } \Theta_{1,\mathrm{f}} = 980 \text{ °C for } k > 0{,}04 \tag{AA.14}$$

$$t_2 = t_1 + \frac{Q_2}{\dot{Q}_{\mathrm{max,f,d}}} \quad \text{in s} \quad \text{with } Q_2 = 0{,}7 \cdot Q_\mathrm{d} - \frac{t_1^3}{3 \cdot t_\alpha^2} \tag{AA.15}$$

$$\Theta_{2,\mathrm{f}} = 33\,000 \cdot k + 20 \quad \text{in °C} \quad \text{for } k \leq 0{,}04 \text{ and } \Theta_{2,\mathrm{f}} = 1340 \text{ °C for } k > 0{,}04 \tag{AA.16}$$

$$t_3 = t_2 + \frac{2 \cdot Q_3}{\dot{Q}_{\mathrm{max,f,d}}} \quad \text{in s} \quad \text{with } Q_3 = 0{,}3 \cdot Q_\mathrm{d} \tag{AA.17}$$

$$\Theta_{3,\mathrm{f}} = 16\,000 \cdot k + 20 \quad \text{in °C} \quad \text{for } k \leq 0{,}04 \text{ and } \Theta_{3,\mathrm{f}} = 660 \text{ °C for } k > 0{,}04 \tag{AA.18}$$

where

$$k = \left(\frac{\dot{Q}_{\mathrm{max,f,d}}^{\,2}}{A_\mathrm{w} \cdot \sqrt{h_\mathrm{w}}\left(A_\mathrm{t} - A_\mathrm{w}\right) \cdot b}\right)^{1/3} \tag{AA.19}$$

Based on the temperature-time curve for the reference fire load density ($q = 1\,300$ MJ/m^2), temperature-time curves may be determined for any fire load densities $q_{\mathrm{x,d}} \leq 1\,300$ MJ/m^2. The increasing branch of the temperature-time curve at the stage of fire growth and the stage of a fully developed fire (Section 1 and Section 2 in Figure AA.1) is independent of the fire load density. The point in time $t_{2,\mathrm{x}}$ at which the maximum temperature $\Theta_{2,\mathrm{x}}$ is reached is dependent on the fire load. It may be determined directly from the approach for the rate of heat release.

Where $Q_1 < 0{,}7 \cdot Q_{x,d}$, the following is obtained:

$$t_{2,x} = t_1 + \frac{\left(0{,}7 \cdot Q_{x,d}\right) - \left(t_1^3 / \left(3 \cdot t_\alpha^2\right)\right)}{\dot{Q}_{max,d}} \quad \text{in s} \qquad \text{(AA.20)}$$

The related temperature $\Theta_{2,x}$ is given by:

$$\Theta_{2,x} = \left(\Theta_2 - \Theta_1\right) \cdot \sqrt{\frac{\left(t_{2,x} - t_1\right)}{\left(t_2 - t_1\right)}} + \Theta_1 \quad \text{in °C} \qquad \text{(AA.21)}$$

where

t_α is the factor to describe the fire growth according to Table BB.2. For residential and office occupancies it may be taken to be $t_\alpha = 300$ s;

$Q_1 = \frac{t_1^3}{3 \cdot t_\alpha^2}$ in MW;

$Q_{x,d} = q_{x,d} \cdot A_f$ with $q_{x,d}$ according to Equation (BB.1)

$Q_1 \geq 0{,}7 \cdot Q_{x,d}$ results in:

$$t_{1,x} = t_{2,x} = \sqrt[3]{0{,}7 \cdot Q_{x,d} \cdot 3 \cdot t_\alpha^2} \quad \text{in s} \qquad \text{(AA.22)}$$

The related temperature $\Theta_{2,x}$ is given by:

$$\Theta_{2,x} = \frac{\left(\Theta_1 - 20\right)}{t_1^2} \cdot t_{1,x}^2 + 20 \quad \text{in °C} \qquad \text{(AA.23)}$$

At the point in time $t_{3,x}$ the temperature $\Theta_{3,x}$ may be defined by a logarithmic function through ($t = 0$; Θ_0) and (t_3; Θ_3) for various fire load densities $q_{x,d}$:

$$\Theta_{3,x} = \Theta_3 \cdot \frac{\log_{10}\left(\frac{t_{3,x}}{60} + 1\right)}{\log_{10}\left(\frac{t_3}{60} + 1\right)} \quad \text{in °C} \qquad \text{(AA.24)}$$

where

$$t_{3,x} = \frac{0{,}6 \cdot Q_{x,d}}{\dot{Q}_{max,d}} + t_{2,x} \quad \text{in s} \qquad \text{(AA.25)}$$

Between $t = 0$ and t_1 (Section 1 according to Figure AA.1) the temperature increases quadratically:

$$\Theta(t) = \frac{\left(\Theta_1 - 20\right)}{t_1^2} \cdot t^2 + 20 \quad \text{in °C} \quad \text{for } 0 \leq t \leq t_1 \qquad \text{(AA.26)}$$

The temperature increase in Section 2 is described by Equation (AA.27):

$$\Theta(t) = (\Theta_{2,x} - \Theta_1) \cdot \sqrt{\frac{(t - t_1)}{(t_{2,x} - t_1)}} + \Theta_1 \quad \text{in °C} \quad \text{for } t_1 \leq t \leq t_2 \tag{AA.27}$$

The decreasing branch in Section 3 is described by Equation (AA.28):

$$\Theta(t) = (\Theta_{3,x} - \Theta_{2,x}) \cdot \sqrt{\frac{(t - t_{2,x})}{(t_{3,x} - t_{2,x})}} + \Theta_{2,x} \quad \text{in °C} \quad \text{for } t > t_2 \tag{AA.28}$$

If a flashover $t_{1,\mathrm{fo}}$ occurs, in which the rate of heat release suddenly increases to its maximum, the point in time at which the flashover occurs can be obtained using Equation (AA.29):

$$t_{1,\mathrm{fo}} = \sqrt{t_\alpha^2 \cdot \dot{Q}_{\mathrm{fo}}} \quad \text{in s} \tag{AA.29}$$

where $\dot{Q}_{\mathrm{fo}}$ can be obtained by means of Equation (AA.30):

$$\dot{Q}_{\mathrm{fo}} = 0{,}007\,8 \cdot A_t + 0{,}378 \cdot A_w \cdot \sqrt{h_w} \quad \text{in MW} \tag{AA.30}$$

AA.5 Calculation of heat storage capacity b

The heat storage capacity b can be calculated as the weighted mean based on the surface of the enclosure. In order to consider the different heat storage capacities, b_i, of the walls, ceiling and floor, b can be obtained using Equation (AA.31):

$$b = \left(\left(\sum_{i=1}^{n} (b_i \cdot A_i)\right) / (A_t - A_w)\right) \tag{AA.31}$$

where

b_i is the heat storage capacity of the enclosure i, in J/(m^2 · $\sqrt{s}$ · K);

A_i is the surface of the enclosure i, in m^2.

The examples in Table AA.1 may be used for guidance to determine the heat storage capacity b by simplified means.

Table AA.1 — Influence groups as a function of heat storage capacity b

Line	Influence group	Heat storage capacity b J/(m^2 · $\sqrt{s}$ · K)
1	1	2 500
2	2	1 500
3	3	750

Influence group 1:

Members or materials with high heat dissipation, such as glazing, aluminium, glass, steel.

Influence group 2:

Members or materials with medium heat dissipation, such as concrete, lightweight concrete with an apparent density > 1 000 kg/m^3, calcium silicate masonry, clay masonry.

Influence group 3:

Members or materials with low heat dissipation, such as materials with an apparent density ≤ 1 000 kg/m^3 (e.g. fibre insulating materials, cellular concrete, timber, wood wool slabs, light-weight concrete, insulating plaster, composite members).

AA.6 Calculation procedure

Figure AA.2 shows a schematic procedure to calculate the parametric temperature-time curve in the form of a flow chart.

The method may also be applied to room unit fires [1]; here the successive fire propagation from one module to another is simplified.

limits of applicability

$A_w;\ h_w;\ A_f;\ q;\ b;\ A_t;\ k;\ Q;\ Q_x$

$\dot{Q}_{max,v} = 1{,}21 \cdot A_w \cdot \sqrt{h_w}$ $\quad \dot{Q}_{max,f} = 0{,}25 \cdot A_f$ $\quad q = 1\,300\ \text{MJ/m}^2$ $\quad q_x = Q_x / A_f$

$$k = \left(\frac{\dot{Q}^2}{A_w \cdot \sqrt{h_w} \cdot A_T \cdot b} \right)^{1/3}$$

$\dot{Q}_{max} = \text{MIN}\,[\dot{Q}_{max,v}, \dot{Q}_{max,f}]$

$\dot{Q}_{max,v} < \dot{Q}_{max,f}$

yes → ventilation controlled fire

fire load density $q = 1\,300\ \text{MJ/m}^2$

$t_1 = 300 \cdot \sqrt{\dot{Q}_{max,v}}$ $\qquad Q_1 = \dfrac{t_1^3}{3 \cdot 300^2}$

$\theta_{1,v} = -8{,}75 \cdot \dfrac{1}{O} - 0{,}1 \cdot b + 1\,175$ in °C

$Q_2 = 0{,}7 \cdot Q - Q_1$ $\qquad t_2 = t_1 + \dfrac{Q_2}{\dot{Q}_{max,v}}$

$\theta_{2,v} = (0{,}004 \cdot b - 17) \cdot \dfrac{1}{O} - 0{,}4 \cdot b + 2\,175$ in °C $\leq 1\,340$ °C

$Q_3 = 0{,}3 \cdot Q$ $\qquad t_3 = t_2 + \dfrac{2 \cdot Q_3}{\dot{Q}_{max,v}}$

$\theta_{3,v} = -5{,}0 \cdot \dfrac{1}{O} - 0{,}16 \cdot b + 1\,060$ in °C

no → fuel controlled fire

fire load density $q = 1\,300\ \text{MJ/m}^2$

$t_1 = 300 \cdot \sqrt{\dot{Q}_{max,f}}$ $\qquad Q_1 = \dfrac{t_1^3}{3 \cdot 300^2}$

$\theta_{1,f} = 24\,000 \cdot k + 20$ in °C for $k \leq 0{,}04$ and
$\theta_{1,f} = 980$ °C for $k > 0{,}04$

$Q_2 = 0{,}7 \cdot Q - Q_1$ $\qquad t_2 = t_1 + \dfrac{Q_2}{\dot{Q}_{max,f}}$

$\theta_{2,f} = 33\,000 \cdot k + 20$ in °C for $k \leq 0{,}04$ and
$\theta_{2,f} = 1\,340$ °C for $k > 0{,}04$

$Q_3 = 0{,}3 \cdot Q$ $\qquad t_3 = t_2 + \dfrac{2 \cdot Q_3}{\dot{Q}_{max,f}}$

$\theta_{3,f} = 16\,000 \cdot k + 20$ in °C for $k \leq 0{,}04$ and
$\theta_{3,f} = 660$ °C for $k > 0{,}04$

existing fire load density: $q_{x,d} = Q_{x,d} \cdot A_f$ wrong

$Q_1 < 0{,}7 \cdot Q_{x,d}$

yes:

existing fire load density $q_x = x\ \text{MJ/m}^2$

$$t_{2,x} = t_1 + \frac{(0{,}7 \cdot Q_{x,d}) - \left(\dfrac{t_1^3}{3 \cdot 300^2} \right)}{\dot{Q}_{max}}$$

$$t_{3,x} = t_{2,x} + \frac{0{,}6 \cdot Q_{x,d}}{\dot{Q}_{max}}$$

$$\theta_{2,x} = (\theta_2 - \theta_1) \cdot \sqrt{\frac{t_{2,x} - t_1}{t_2 - t_1}} + \theta_1$$

$$\theta_{3,x} = \left(\frac{\theta_3}{\log_{10}(t_3/60 + 1)} \right) \cdot \log_{10}(t_{3,x}/60 + 1)$$

no:

existing fire load density $q_x = x\ \text{MJ/m}^2$

$$t_1 = t_{1,x} = t_{2,x} = \sqrt[3]{0{,}7 \cdot Q_{x,d} \cdot 3 \cdot 300^2}$$

$$t_{3,x} = t_{2,x} + \frac{0{,}6 \cdot Q_{x,d}}{\dot{Q}_{max}}$$

$$\theta_{2,x} = \frac{(\theta_1 - 20)}{t_1^2} \cdot t_{1,x}^2 + 20$$

$$\theta_{3,x} = \left(\frac{\theta_3}{\log_{10}(t_3/60 + 1)} \right) \cdot \log_{10}(t_{3,x}/60 + 1)$$

Figure AA.2 — Schematic procedure for determining the temperature-time curve of a natural fire using a simplified natural fire model for residential buildings, office buildings and comparable occupancies with $t_\alpha = 300$ s

NCI

Annex BB
(normative)

Input data for the application of natural fire models

BB.1 General

This annex replaces Annex E of DIN EN 1991-1-2:2010-12. The provisions of this annex for fire load densities in buildings of different occupancies and for rates of heat release for different design fire scenarios take national and international findings into account. The defined design values for the parameters of the fire exposure also take into account the required reliability of the members and structures to be designed in the accidental fire situation according to the safety concept in [4]. This ensures that the required national safety level is maintained when applying the different natural fire models for the design of members and structures in terms of fire protection.

BB.2 Limits of applicability

The following input data for the description of the fire exposure for natural fires generally apply to all simplified and advanced fire models according to DIN EN 1991-1-2:2010-12, 3.3, in conjunction with the informative Annex D as well as Annex AA to this National Annex.

BB.3 Fire load density

BB.3.1 General

The fire load density with its design value shall be used as the leading input variable for determining fire exposure.

The design value of the fire load density $q_{f,d}$ is generally defined as:

$$q_{f,d} = \cdot \chi \cdot \gamma_{fi,q} \quad \text{in MJ/m}^2 \tag{BB.1}$$

where

$q_{f,k}$ is the characteristic fire load density related to floor area A_f of the fire compartment or occupancy unit in MJ/m^2;

χ is the efficiency of combustion; for typical mixed fire loads in office buildings, residential buildings and comparable occupancies where the fire load consists mainly of cellulosic material, χ = 0,7 may be taken as a fixed value;

$\gamma_{fi,q}$ is a partial factor that considers the probability of occurrence of a fully developed fire in the occupancy unit as well as the required reliability of the members according to BB.5.

The fire load density can either be determined as a fixed value from a fire load classification according to occupancy (see BB.3.2) or by investigating the individual fire loads for a particular project (see BB.3.3).

If the fire load density is determined from a fire load classification according to occupancy, a distinction shall be made between the fire loads from the type of occupancy (covered by the classification) and, if applicable, additional fire loads due to the construction of the building (supports, linings and finishings), which are not included in the classification.

BB.3.2 Determination of fire load density according to classification of occupancies

Mean fire load densities, which are related to the floor area A_f of the fire compartment or the occupancy unit, can be assigned to the usual building occupancies.

The 90 % quantile shall be used as the characteristic value of the fire load density $q_{f,k}$. It may be taken from Table BB.1, column 3.

Table BB.1 — Fire load densities (in MJ/m²) for different occupancies

Line	Occupancy	Fire load density MJ/m²		
		Mean value	**Standard deviation**	**90 % quantile**
		1	2	3
1	Residential building	780	234	1 085
2	Office building	420	126	584
3	Hospital (room)	230	69	320
4	Hotel (room)	310	93	431
5	Library	1 500	450	2 087
6	School (classroom)	285	85.5	397
7	Shop, shopping centre	600	180	835
8	Place of public assembly (theatre, cinema)	300	90	417
9	Public transport	100	30	139

The fire load densities specified in Table BB.1 only apply to spaces which are typical for the specific occupancy, such as office rooms in office buildings. Special rooms, such as archives or store rooms in office buildings, are to be considered separately as described in BB.3.3.

Fire loads due to the construction of a building (supports, linings and finishings) shall be determined separately according to BB.3.3 and added to the fire loads according to Table BB.1.

NOTE 1 When modifying the occupancy of rooms and the underlying fire load densities, a new assessment is generally required.

NOTE 2 Since fire load densities in industrial buildings largely depend on the specific occupancy, specifying fixed mean values is not advisable. Reference is made to the DIN 18230 series of standards for determining values individually (according to BB.3.3).

BB.3.3 Individual determination of fire load density

BB.3.3.1 General

If a classification according to occupancy is neither possible nor advisable, the fire load densities for the particular object shall be determined, taking the occupancy into consideration.

The fire loads and their local configuration shall be determined considering the intended function and the furniture, furnishings and installations as well as possible variations over time due to unfavourable developments or other occupancies.

If possible, an investigation of the fire load shall be performed on a comparable existing project, such that only the differences between the intended and the existing project are to be indicated by the client. Once the building is occupied, the assumed fire loads shall be verified. This also applies when the type of occupancy changes.

In addition to the fire loads due to the occupancy, combustible material making up the building (construction elements, linings/claddings, coatings, insulation) shall also be identified.

The design value of the fire load density $q_{\mathrm{f,d}}$ is defined as:

$$q_{\mathrm{f,d}} = \frac{\sum M_{\mathrm{k,i}} \cdot H_{\mathrm{ui}} \cdot \chi_{\mathrm{i}} \cdot \psi_{\mathrm{i}}}{A_{\mathrm{f}}} \cdot \gamma_{\mathrm{fi,q}} \geq q_{\mathrm{f,d,min}} \quad \text{in MJ/m}^2 \tag{BB.2}$$

where

$M_{\mathrm{k,i}}$	is the amount of combustible material in kg;
H_{ui}	is the net calorific value in MJ/kg, see BB.3.3.3;
χ_{i}	is the efficiency of combustion;
ψ_{i}	is a factor to take protected fire loads into account, see BB.3.3.2;
A_{f}	is the floor area of the fire compartment or occupancy unit in m^2;
$q_{\mathrm{f,d,min}}$	is the minimum value of fire load density in MJ/m^2.

Permanent fire loads which are not expected to vary during the service life of a building should be represented by their expected values.

Variable fire loads, which may be expected to vary during their service life, should be represented by values which are not expected to be exceeded during 90 % of the service life (90 % quantile).

As a simplification, the varying burning behaviour of the combustible materials as a function of their type and configuration is taken into account by the efficiency of combustion χ_{i}. For the mixed fire loads typical of office buildings, residential buildings and comparable occupancies, which mainly consist of cellulosic material, $\chi = 0{,}7$ may be taken as a fixed value. Otherwise, $\chi = 0{,}8$ shall be conservatively taken for solids and $\chi = 1{,}0$ for fluids and gases. For common solids, fluids and gases the efficiency of combustion χ_{i} may be taken from [4], for example.

For a very low calculated fire load density, a minimum design value $q_{\mathrm{f,d,min}} = 50$ MJ/m^2 shall be assumed taking unexpected fire loads into consideration.

BB.3.3.2 Protected fire loads

Fire loads in containments which are designed such that their integrity is maintained during fire exposure need not be considered.

Fire loads in non-combustible containments with no specific fire design, but which are known from experience to remain intact during fire exposure, may be considered as follows:

The greatest fire load, which is at least 10 % of the protected fire load, is taken into account by the value $\psi_i = 1{,}0$.

If this fire load plus the unprotected fire load is not sufficient to heat up the remaining protected fire load above the ignition temperature, the remaining protected fire load may be taken into account by using $\psi_i = 0{,}0$. In all other cases, ψ_i values shall be determined individually.

BB.3.3.3 Net calorific value

The net calorific value should be determined according to DIN EN ISO 1716.

The moisture content of materials may be taken into account as follows:

$$H_u = H_{u0} (1 - 0{,}01\, u) - 0{,}025\, u \quad \text{in MJ/kg} \tag{BB.3}$$

where

u is the moisture content in % (m/m), relative to the dry weight;

H_{u0} is the net calorific value of dry materials.

The net calorific value may be taken from DIN 18230-3 for common solids, fluids and gases, with 1 kWh = 3,6 MJ.

BB.4 Rate of heat release

The characteristic value of the rate of heat release $\dot{Q}_k$ at the stage of fire growth and fire propagation may be calculated by means of the following equation:

$$\dot{Q}_k = (t/t_\alpha)^2 \tag{BB.4}$$

where

t is the time after the outbreak of a fire, in s;

t_α is the time needed to reach a rate of heat release of 1 MW, in s.

The parameters t_α for different occupancies are given in Table BB.2. These are characteristic values approximately corresponding to a 90 % quantile of the statistic distribution.

t_α = 75 s shall be assumed for extremely fast fire propagation.

Table BB.2 — Parameters t_α for the stage of fire growth and maximum rate of heat release per unit area RHR_f for the stationary stage (steady state) for different occupancies (characteristic values)

Line	Occupancy	Fire propagation	t_α s	RHR_f MW/m²
		1	2	3
1	Residential building	medium	300	0,25
2	Office building	medium	300	0,25
3	Hospital (room)	medium	300	0,25
4	Hotel (room)	medium	300	0,25
5	Library	medium	450	0,25 to 0,50
6	School (classroom)	medium	300	0,15
7	Shop, shopping centre	fast	150	0,25
8	Place of public assembly (theatre, cinema)	fast	150	0,50
9	Public transport	slow	600	0,25

The rate of heat release is limited by a horizontal plateau corresponding to the fully developed fire in its stationary stage with the characteristic value $\dot{Q}_{\mathrm{max,k}}$.

For fuel controlled fires, the characteristic value of the maximum rate of heat release can be obtained using Equation (BB.5):

$$\dot{Q}_{\mathrm{max,f,k}} = RHR_f \cdot A_f \quad \text{in MW} \tag{BB.5}$$

where

RHR_f is the characteristic value of the rate of heat release per unit area according to Table BB.2 in MW/m²; RHR_f is the maximum rate of heat release reached by a fuel controlled fire per 1 m²;

A_f is the maximum fire area (generally, the floor area of the fire compartment) in m².

For ventilation controlled fires in rooms with a floor area up to 400 m², the maximum rate of heat release in the fire compartment may be determined by approximation according to Equation (BB.6):

$$\dot{Q}_{\mathrm{max,v,k}} = 0{,}1 \cdot \chi \cdot H_u \cdot A_w \cdot \sqrt{h_w} \quad \text{in MW} \tag{BB.6}$$

where

A_w is the area of the vent openings in m²;

h_w is the mean clear height of the vent openings in m;

H_u is the net calorific value of the relevant fire load in MJ/kg; in buildings the value H_u = 17,3 MJ/kg may usually be used for wood;

χ is the efficiency of combustion; in building construction χ = 0,7 may be taken as a fixed value for normal mixed fire loads, otherwise see [4], for example.

NOTE For rooms with a floor area of more than 400 m^2, the rate of heat release according to Equation (BB.6) is increasingly conservative. In such cases the use of an advanced fire model according to Annex D is recommended. Taking the limits of applicability into account (diameter of the fire area < 10 m, rate of release < 50 MW) the thermal action for a localized fire may be determined according to Annex C, if applicable.

The maximum rate of heat release is the maximum value of the ventilation controlled or fuel controlled fire, whichever is lower:

$$\dot{Q}_{\mathrm{max,k}} = \min\{\dot{Q}_{\mathrm{max,f,k}}; \dot{Q}_{\mathrm{max,v,k}}\} \tag{BB.7}$$

The design value of the maximum rate of heat release is given by Equation (BB.8):

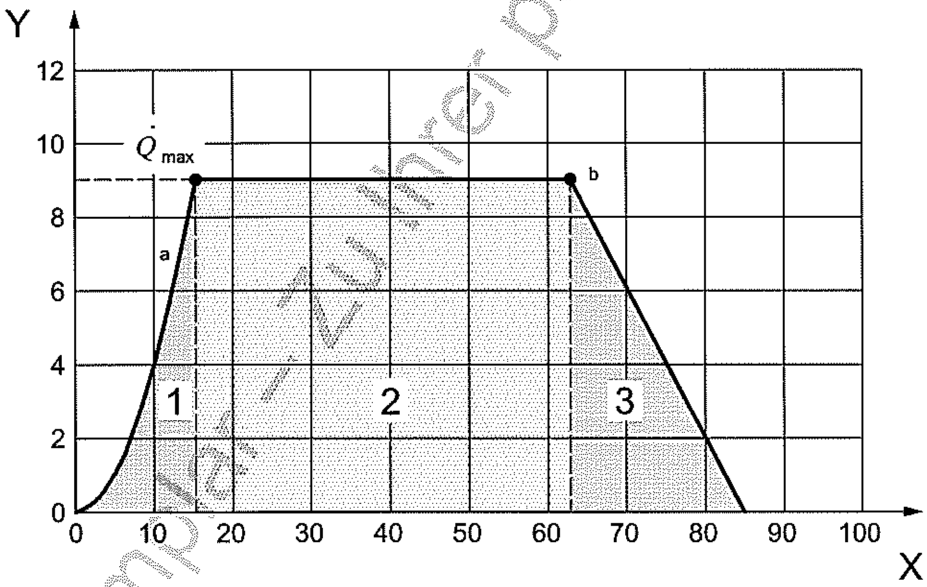
$$\dot{Q}_{\mathrm{max,d}} = \dot{Q}_{\mathrm{max,k}} \cdot \gamma_{\mathrm{fi,Q}} \tag{BB.8}$$

where

$\gamma_{\mathrm{fi,Q}}$ is the partial factor according to BB.5.3.

The horizontal plateau of the rate of heat release ends when 70 % of the total fire load has been consumed. As a simplification, the subsequent decay stage may be assumed to progress linearly.

The total progression of the rate of heat release as a function of time is schematically represented in Figure BB.1.



Key

1 Stage of fire growth
2 Stationary stage
3 Decay stage
a t^2 slope
b 70 % of the fire load consumed
X Time in min
Y Rate of heat release

Figure BB.1 —Rate of heat release as a function of time, including stage of fire growth, stationary stage (fully developed fire) and decay stage

BB.5 Safety concept

BB.5.1 Probability of occurrence of a fire

The required reliability of load bearing and/or separating members of a building in a fire scenario depends on the probability of occurrence of a damaging fire in an occupancy unit of a building and the associated consequences of damage due to the failure of members as a result of the fire.

The probability of occurrence p_{fi} of a damaging fire in an occupancy unit, which is effectively separated in terms of fire protection, with a floor area A_f within a reference period of 1 year can be obtained using Equation (BB.9):

$$p_{fi} = p_1 \cdot p_2 \cdot p_3 \tag{BB.9}$$

where

p_1 is the annual probability of occurrence of an initial fire in an occupancy unit, in a^{-1};

p_2 is the probability of failure of manual fire fighting;

p_3 is the probability of failure of fire fighting by an automatic fire extinguishing system on demand.

The annual probability of occurrence p_1 of at least one initial fire in an occupancy unit can be determined according to Equation (BB.10), taking into consideration the mostly disproportionately increasing rate of fire outbreaks in relation to the floor area A_f:

$$p_1 = 1 - \exp\,(a \cdot A^b) \approx a \cdot A^b \tag{BB.10}$$

where

A_f is the floor area of the occupancy unit separated in terms of fire protection in m^2;

a is the base value of the related rate of fire outbreaks per square metre in $(m^2 \cdot a)^{-1}$;

b is the exponent dependent on the occupancy and the division of the occupancy unit (room units).

Values of a und b for different occupancies are specified in Table BB.3.

As a simplification, the mean probability of occurrence p_1 of at least one initial fire in an occupancy unit per year may be taken from the last column of Table BB.3. These values apply to mean floor areas A_f of areas with appropriate occupancies.

Table BB.3 — Probability of occurrence p_1 of at least one initial fire per occupancy unit and year as a function of occupancy

Line	Occupancy	Probability of occurrence per occupancy unit and year		
		$p_1 \approx a \cdot A^b$		p_1
		a $1/(\mathrm{m}^2 \cdot a)$	b	$1/a$
		1	2	3
1	Residential building	4,8E-5	0,9	3,0E-3
2	Office building	5,9E-5	0,9	6,2E-3
3	Hospital, nursing home	7,0E-4	0,75	3,0E-1
4	Hotel, accommodation	8,0E-5	1,0	3,7E-2
5	School, educational institution	2,0E-4	0,75	4,0E-2
6	Shop, shopping centre	6,6E-5	1,0	8,4E-3
7	Place of public assembly (theatre, cinema) Other places of assembly (e.g. club)	9,7E-5	0,75 1,0	2,0E-2 1,2E-1

The probability of failure p_2 of manual fire fighting takes into account both users' self-help measures and the fire extinguishing operations carried out by the fire services:

$$p_2 = p_{2,1} \cdot p_{2,2} \quad \text{(BB.11)}$$

The probability of failure of manual fire fighting by users may generally be taken to be $p_{2,1} = 0,5$.

On the one hand the probability of failure of the fire extinguishing operations of the fire services depends on the time of performance (= alerting time + response time) and the strength of the fire services; on the other hand it depends on the fire propagation before the fire extinguishing operations commence. For a public fire brigade with an average time of performance of up to 15 min, $p_{2,2} = 0,2$ may be taken as a fixed value for calculations. For a corporate or industrial fire brigade, $p_{2,2}$ may be significantly reduced since this has a shorter time of performance, its strength is commensurate with the particular object, and the equipment at its disposal is also suited to the particular object.

Values of $p_{2,2}$ for fire fighting by a public and a corporate fire brigade respectively are given in Table BB.4. Values between the specified times of performance may be obtained by linear interpolation.

The probability of failure p_3 of fire fighting by an automatic fire extinguishing system depends on the type and design of the fire extinguishing system and the point in time at which it is activated.

Values of p_3 for the probability of failure of different fire extinguishing systems are given in Table BB.4.

Table BB.4 — Probability of failure $p_{2,2}$ and p_3 of fire fighting on demand

Line	Fire fighting by	Probability of failure on demand	
		$p_{2,2}$	p_3
		1	2
1 1a 1b	Public fire brigade with a time of performance < 15 min > 20 min	 0,2 0,5	
2 2a 2b	Corporate fire brigade with a time of performance[a] < 10 min (four fire brigade units) < 10 min (two fire brigade units)	 0,02 0,05	
3 3a 3b 3c 3d	Automatic fire extinguishing system sprinkler system according to VdS/CEA standard in other cases other water extinguishing system gas extinguishing system		 0,02 0,05 0,1 0,1

[a] Operation of automatic fire detection and fire alarm systems is assumed.

BB.5.2 Required reliability in a fire scenario

A permitted conditional probability of failure $p_{\mathrm{f,fi}}$ in a fire scenario and the related reliability index β_{fi} may be determined from the permitted probability of failure p_{f} of members for all load cases and the annual probability of occurrence p_{fi} of at least one damaging fire in the respective occupancy unit according to Equation (BB.10) as follows:

$$p_{\mathrm{f,fi}} = \Phi\ (-\beta) \tag{BB.12}$$

$$p_{\mathrm{f,fi}} = \frac{p_{\mathrm{f}}}{p_{\mathrm{fi}}} \tag{BB.13}$$

$$\beta_{\mathrm{fi}} = -\Phi^{-1}\left(p_{\mathrm{f,fi}}\right) \tag{BB.14}$$

where Φ ( ) is the function of the standardized normal distribution and Φ^{-1} is its inverse function.

Values of p_{f} in Equation (BB.13) and of the reliability index β according to Equation (BB.12) respectively are given in Table BB.5 as a function of the occupancy and the consequences of damage in the event of member failure. If no further details are given, the values for medium consequences of damage shall be used.

Table BB.5 — Guideline values for the reliability index β and the related probability of failure p_f (over a reference period of 1 year) for different occupancies

Line	Occupancy	Consequences of damage					
		high		medium		low	
		β	p_f	β	p_f	β	p_f
		1a	1b	2a	2b	3a	3b
1	Residential building, office building or comparable occupancy	4,7	1,3E-6	4,2	1,3E-5	3,7	1,1E-4
	Building classes according to *Musterbauordnung* (Model building code)				4 + 5		2 + 3
2 3 4 5 6 7	Hospital, nursing home Accommodation, hotel School Shop Places of public assembly High-rise building	5,2	1,0E-7	4,7	1,3E-6	4,2	1,3E-5
8	Agricultural building	—	—	4,2	1,3E-5	3,7	1,1E-4

BB.5.3 Partial factors γ_{fi} for the parameters of fire exposure

The design values for the relevant parameters of fire exposure, fire load density q and rate of heat release $\dot{Q}$ can be defined using the conditional probability of failure in a fire scenario $p_{f,fi}$ according to Equation (BB.13) and the associated reliability index β_{fi} according to Equation (BB.14) respectively.

NOTE The fire load density according to BB.2 and BB.3 governs the duration of the fire and hence the temperature in the fire compartment, which increases with the duration of the fire. At the early stage of the fire the rate of heat release according to BB.4 is the relevant parameter.

According to Equation (BB.1) the design value of the fire load density is obtained from the characteristic value $q_{f,k}$ (90 % quantile) and a partial factor $\gamma_{fi,q}$.

When the fire load density is determined according to the classification of occupancies according to BB.3.2, the partial factor $\gamma_{fi,q}$ is obtained from Equation (BB.15) as a function of the required reliability index β_{fi}:

$$\gamma_{fi} = \frac{1 - V \cdot 0{,}78 \cdot \left[0{,}577\,2 + \ln\left(-\ln\left(\Phi\left(\alpha \cdot \beta_{fi}\right)\right)\right)\right]}{1 - V \cdot 0{,}78 \cdot \left[0{,}577\,2 + \ln\left(-\ln(0{,}9)\right)\right]} \qquad \text{(BB.15)}$$

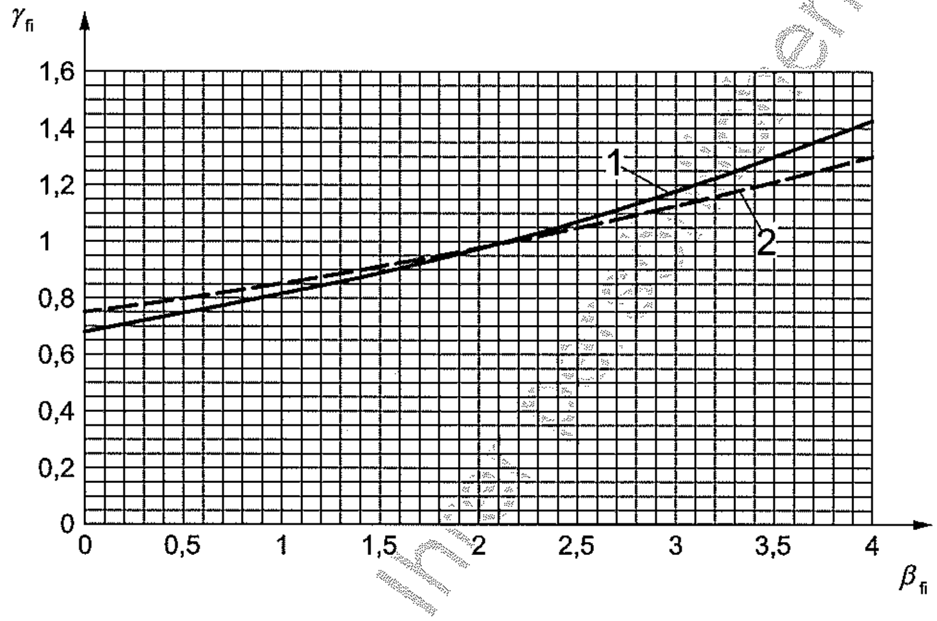
where $\Phi(\ )$ is the function of the standard normal distribution. For V, the coefficient of variation of the fire load density shall be taken to be $V_q = 0{,}3$; the sensitivity factor α (as a measure of the variance) is taken to be $\alpha = 0{,}6$.

The partial factor $\gamma_{fi,q}$ may also be taken from curve 1 in Figure BB.2.

For the individual determination of the fire load density according to BB.3.3, the partial factor $\gamma_{\mathrm{fi,q}}$ is obtained by means of Equation (BB.15), taking the reduced coefficient of variation $V_{\mathrm{q}} = 0{,}2$ as V and retaining the sensitivity factor $\alpha = 0{,}6$. The partial factor $\gamma_{\mathrm{fi,q}}$ may also be read off from Figure BB.2, curve 2.

The partial factor for the rate of heat release $\dot{Q}$ according to BB.4 is obtained from Equation (BB.15) with the coefficient of variation $V_{\dot{\mathrm{Q}}} = 0{,}2$ and the sensitivity factor $\alpha = 0{,}6$. Thus it corresponds to the partial factor $\gamma_{\mathrm{fi,q}}$ used for the individual determination of the fire load density according to BB.3.3.

The partial factor $\gamma_{\mathrm{fi},\dot{\mathrm{Q}}}$ may also be read off from Figure BB.2, curve 2.



$p_{\mathrm{f,fi}}$	β_{fi}
5,0E-01	0,00
4,0E-01	0,25
3,1E-01	0,50
2,3E-01	0,75
1,6E-01	1,00
1,1E-01	1,25
6,7E-02	1,50
4,0E-02	1,75
2,3E-02	2,00
1,2E-02	2,25
6,2E-03	2,50
3,0E-03	2,75
1,3E-03	3,00
5,8E-04	3,25
2,3E-04	3,50
8,8E-05	3,75
3,2E-05	4,00

Key

1 Fire load density according to BB.3.2

2 Rate of heat release according to BB.4 and fire load density according to BB.3.3

Figure BB.2 — Partial factors for the parameters of a natural fire related to the defined characteristic values (90 % quantile)

NCI

Annex CC
(informative)

Testing and validation of computer programmes for fire protection verifications by means of advanced calculation methods

CC.1 General

The physical, mathematical and mechanical elements of computer programmes used for verifying adequate fire protection by means of advanced calculation methods should be validated with regard to thermal analysis, cross-sectional analysis and system analysis. The purpose of this Annex CC is to verify the applicability of programmes for the design of members and structures in terms of fire protection engineering on the basis of an adequate number of validation examples and to assess the degree to which these programmes are applicable to real structures.

The individual steps of the verification procedure are validated one by one using defined evaluation criteria. With the aid of a test matrix the computational accuracy of the programme is analysed for the respective evaluation criterion. For the purpose of comparison, the test matrix lists either existing analytical solutions or results from calculations of recognized programmes for the respective example. The results obtained from the computer programme to be verified are compared with these values. Deviations should be within allowed tolerances.

If the allowed tolerances cannot be met for all evaluation criteria, it is also possible to limit the scope of the programme. For example, programmes which cannot precisely determine the behaviour of the structural system (e.g. support conditions, loading) cannot be used for the fire protection design of statically indeterminate systems and/or systems at risk of becoming unstable. However, these programmes can be used for the fire protection design of statically determinate flexural members.

The examples have been compiled as part of a research project [6] and adapted to the latest versions of those parts of the Eurocode that deal with fire protection (DIN EN 1991-1-2 to DIN EN 1996-1-2). Deviations from the latest DIN EN standards are indicated in the examples.

CC.2 Limits of applicability

This Annex CC applies to the verification of computer programmes on the basis of the advanced calculation methods described in those parts of the Eurocodes dealing with fire protection (DIN EN 1992-1-2, DIN EN 1993-1-2, EN 1994-1-2, DIN EN 1995-1-2, DIN EN 1996-1-2 and DIN EN 1999-1-2).

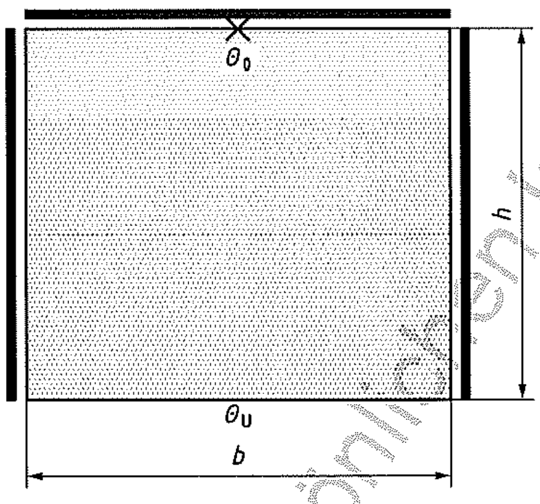
CC.3 Use and documentation

The originator of a computer programme developed for providing verification according to advanced calculation methods should independently calculate the validation examples prior to using the programme for fire protection verifications to prove compliance with building regulations. The input data and calculation assumptions should be used exactly according to the programme description.

The calculations and their results should be presented using the tables given in the compilation of examples. All deviations from the results of the sample calculations should be within the specified tolerances.

CC.4 Validation examples

CC.4.1 Example 1



Key

▬ Adiabatic boundary

Figure CC.1 — Heat transfer (cooling process)

Table CC.1 — Material properties and boundary conditions

Material		Imaginary value
Thermal conductivity λ	W/(m · K)	1
Specific heat c_p	J/(kg · K)	1
Apparent density ρ	kg/m^3	1 000
Boundary conditions		
Dimensions h, b	m	1
Heat transfer coefficient α_c	W/(m^2 · K)	1
Emissivity $\varepsilon_{res} = \varepsilon_m \cdot \varepsilon_f$	—	0
Initial conditions		
Ambient temperature Θ_U	°C	0
Temperature in the cross section	°C	1 000
Reference value		
Temperature Θ_O at point X	°C	

Table CC.2 — Reference and calculated values for heat transfer (cooling)

Time s	Reference value Θ_0 Temperature °C	Calculated value Θ_0' Temperature °C	Deviation $(\Theta_0' - \Theta_0)/\Theta_0 \cdot 100$ % $(\Theta_0' - \Theta_0)$ K	Tolerance	Notes
0	1 000			± 1 % and ± 5,0 K	
60	999,3				
300	891,8				
600	717,7				
900	574,9				
1 200	460,4				
1 500	368,7				
1 800	295,3				

Programmes whose calculated values deviate from the reference values by more than the tolerance specified in Table CC.2 (the lower value is to be applied in each case) shall be considered unsuitable for the thermal analysis of members on the basis of the Eurocode.

However, such programmes may be used within a limited scope for the thermal analysis of members (e.g. for certain materials) if their suitability for this limited scope can be verified on the basis of example 1.

CC.4.2 Example 2

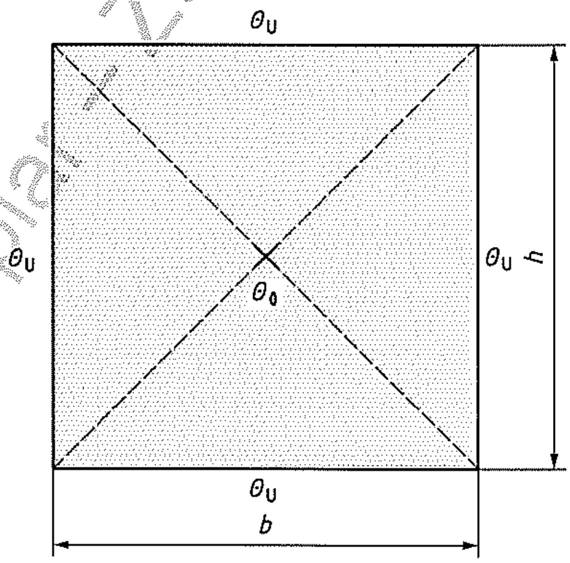


Figure CC.2 — Heat transfer (heating process)

Table CC.3 — Material properties and boundary conditions

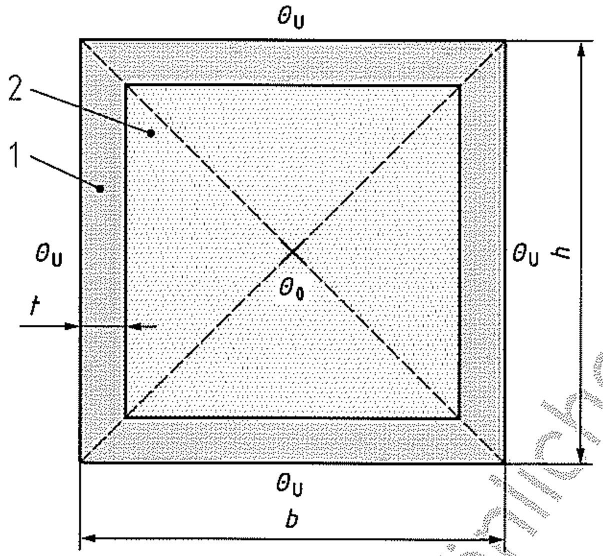
Material		Imaginary value	
		Θ	$\lambda\,(\Theta)$
Thermal conductivity λ (linear progression)	W/(m · K)	0	1,5
		200	0,7
		1 000	0,5
Specific heat c_p	J/(kg · K)	1 000	
Apparent density ρ	kg/m^3	2 400	
Boundary conditions			
Dimensions h, b	m	0,2	
Heat transfer coefficient α_c	W/(m^2 · K)	10	
Emissivity $\varepsilon_{res} = \varepsilon_m \cdot \varepsilon_f$	—	0,8	
Initial conditions			
Ambient temperature Θ_U	°C	1 000	
Temperature in the cross section	°C	0	
Reference value			
Temperature Θ_O at point X	°C		

Table CC.4 — Reference and calculated values for heat transfer (heating process)

Time min	Reference value Θ_0 Temperature °C	Calculated value Θ_0' Temperature °C	Deviation $(\Theta_0' - \Theta_0)/\Theta_0 \cdot 100$ % $(\Theta_0' - \Theta_0)$ K	Tolerance	Notes
30	36,9				
60	137,4			for $t \leq 60$ min	
90	244,6			± 5 K	
120	361,1			for $t > 60$ min	
150	466,2			± 3 %	
180	554,8				

Programmes in which the calculated values deviate from the reference values by more than the tolerance specified in Table CC.4 shall be considered unsuitable for the thermal analysis of members.

CC.4.3 Example 3



Key

1 Steel
2 Fill

Figure CC.3 — Thermal transmittance through multiple layers (steel hollow section with fill)

Table CC.5 — Material properties and boundary conditions

Material		Steel	Fill
Thermal conductivity λ	W/(m · K)	DIN EN 1993-1-2	0,05
Specific heat c_p	J/(kg · K)	DIN EN 1993-1-2	1 000
Apparent density ρ	kg/m^3	DIN EN 1993-1-2	50
Boundary conditions			
Dimensions h, b, t	m	$h = b = 0{,}201$;	$t = 0{,}000\,5$
Heat transfer coefficient α_c	W/(m^2 · K)	10	
Emissivity $\varepsilon_{res} = \varepsilon_m \cdot \varepsilon_f$	—	0,8	
Initial conditions			
Ambient temperature Θ_U	°C	1 000	
Temperature in the cross section	°C	0	0
Reference value			
Temperature Θ_O at point X	°C		

Table CC.6 — Reference and calculated values for thermal transmittance through multiple layers

Time min	Reference value Θ_0 Temperature °C	Calculated value Θ_0' Temperature °C	Deviation $(\Theta_0' - \Theta_0)/\Theta_0 \cdot 100$ % $(\Theta_0' - \Theta_0)$ K	Tolerance	Notes
30	340,5			± 1 % and ± 5 K	
60	717,1				
90	881,6				
120	950,6				
150	979,3				
180	991,7				

Programmes in which calculated values deviate from the reference values by more than the tolerance specified in Table CC.6 (the lower value is to be applied in each case) are unsuitable for the thermal analysis of (lined) members comprising multiple layers of material on the basis of the Eurocode.

CC.4.4 Example 4

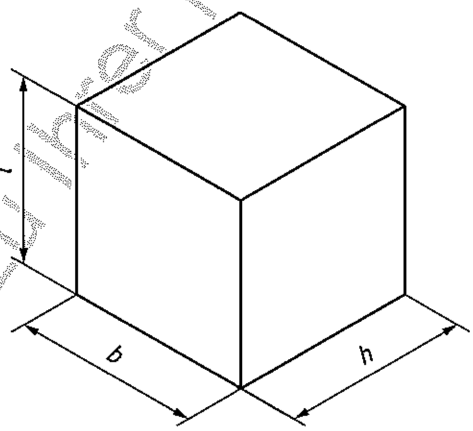


Figure CC.4 — Member (with statically determinate conditions of support)

Table CC.7 — Material properties and boundary conditions

Boundary conditions		Structural steel
Dimensions l, h, b	mm	100
Stress-strain relationships		DIN EN 1993-1-2
Strength $f_{yk(20°C)}$	N/mm²	355
Initial conditions	°C	20
Homogeneous temperature of member Θ	°C	100 300 500 600 700 900
Thermal expansion	—	DIN EN 1993-1-2
Reference value		
Thermal elongation Δl	mm	

Table CC.8 — Reference and calculated values for the thermal elongation of structural steel

Θ °C	**Reference value** Δl mm	**Calculated value** $\Delta l'$ mm	**Deviation** $(\Delta l' - \Delta l)/\Delta l \cdot$ **100** **%** $(\Delta l' - \Delta l)$ mm	**Tolerance**	**Notes**
100	0,099 84			for $\Theta \leq 300$ °C ± 0,05 mm for $\Theta > 300$ °C ± 1 %	
300	0,371 84				
500	0,675 84				
600	0,839 84				
700	1,011 84				
900	1,180 00				

Programmes in which calculated values deviate from the reference values by more than the tolerance specified in Table CC.8 shall be considered unsuitable for the mechanical analysis of members on the basis of the Eurocode.

CC.4.5 Example 5

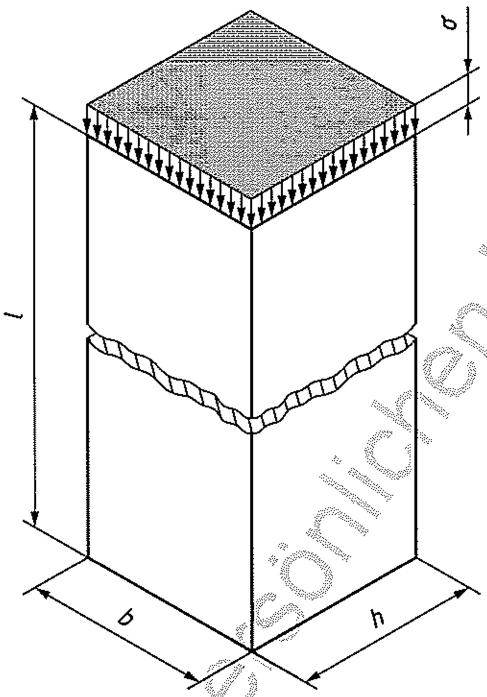


Figure CC.5 — Member (Euler case 2; the support conditions shall be such as to eliminate any possibility of loss of stability)

Table CC.9 — Material properties and boundary conditions (concrete with aggregate mainly containing quartzite and 3 % moisture (*m/m*))

Boundary conditions		Structural steel	Concrete
Dimensions $l / h / b$	mm	100 / 10 / 10	100 / 31,6 / 31,6
Stress-strain relationships		DIN EN 1993-1-2	DIN EN 1992-1-2
Strength $f_{yk(20°C)}, f_{ck(20°C)}$	N/mm²	355	20
Thermal expansion		DIN EN 1993-1-2	DIN EN 1992-1-2
Initial conditions	°C	20	
Homogeneous temperature of member Θ	°C	20 200 400 600 800	
Load $\sigma_{s\Theta} / f_{yk(\Theta)}$ and $\sigma_{c\Theta} / f_{ck(\Theta)}$ respectively (only for example 5)		0,2 0,6 0,9	
Reference value			
Linear deformation Δl (example 5)	mm		
Normal force $N_{R,fi,k}$ (example 6)	kN		

Table CC.10 Reference and calculated values for stress-strain relationships of structural steel

Temperature Θ °C	Load $\sigma_{s(\Theta)} / f_{yk(\Theta)}$	Reference value Δl mm	Calculated value $\Delta l'$ mm	Deviation $(\Delta l' - \Delta l)/\Delta l \cdot 100$ %	Tolerance %	Notes
20	0,2	−0,034				
	0,6	−0,101				
	0,9	−0,152				
200	0,2	+0,194				
	0,6	+0,119				
	0,9	−0,159				
400	0,2	+0,472				
	0,6	+0,293			± 3	
	0,9	−0,451				
600	0,2	+0,789				
	0,6	+0,581				
	0,9	−0,162				
800	0,2	+1,059				
	0,6	+0,914				
	0,9	+0,170				

Table CC.11 — Reference and calculated values for stress-strain relationships of concrete with aggregate mainly containing quartzite

Temperature Θ °C	Load $\sigma_{c(\Theta)} / f_{ck(\Theta)}$	Reference value Δl mm	Calculated value $\Delta l'$ mm	Deviation $(\Delta l' - \Delta l)/\Delta l \cdot 100$ %	Tolerance %	Notes
20	0,2	−0,033 4				
	0,6	−0,104				
	0,9	−0,176				
200	0,2	+0,107				
	0,6	−0,047 4				
	0,9	−0,207 5				
400	0,2	+0,356				
	0,6	+0,075			± 3	
	0,9	−0,216				
600	0,2	+0,685				
	0,6	−0,016 7				
	0,9	−0,744				
800	0,2	+1,066				
	0,6	+0,365				
	0,9	−0,363				

Programmes in which calculated values deviate from the reference values by more than the tolerance specified in Table CC.10 and Table CC.11 shall be considered unsuitable for the mechanical analysis of members on the basis of the Eurocode.

CC.4.6 Example 6

For boundary conditions and material properties see Figure CC.5 and Table CC.9.

Table CC.12 — Reference and calculated values for the ultimate loadbearing capacity of structural steel

Temper-ature Θ °C	**Reference value** $N_{R,fi,k}$ kN	**Calculated value** $N_{R,fi,k}'$ kN	**Deviation** $(N_{R,fi,k}' - N_{R,fi,k}) / N_{R,fi,k} \cdot 100$ % $(N_{R,fi,k}' - N_{R,fi,k})$ kN	**Tolerance**	**Notes**
20	–35,5				
200	–35,5			± 3,0 %	
400	–35,5			and	
600	–16,7			± 0,5 kN	
800	–3,9				

Table CC.13 — Reference and calculated values for the ultimate loadbearing capacity of concrete with aggregate mainly containing quartzite

Temper-ature Θ °C	**Reference value** $N_{R,fi,k}$ kN	**Calculated value** $N_{R,fi,k}'$ kN	**Deviation** $(N_{R,fi,k}' - N_{R,fi,k}) / N_{R,fi,k} \cdot 100$ % $(N_{R,fi,k}' - N_{R,fi,k})$ kN	**Tolerance**	**Notes**
20	–20,0				
200	–19,0			± 3,0 %	
400	–15,0			and	
600	–9,0			± 0,5 kN	
800	–3,0				

Programmes in which calculated values deviate from the reference values by more than the tolerances specified in Tables CC.12 and CC.13 (the lower value is to be applied in each case) shall be considered unsuitable for the mechanical analysis of members on the basis of the Eurocode.

CC.4.7 Example 7

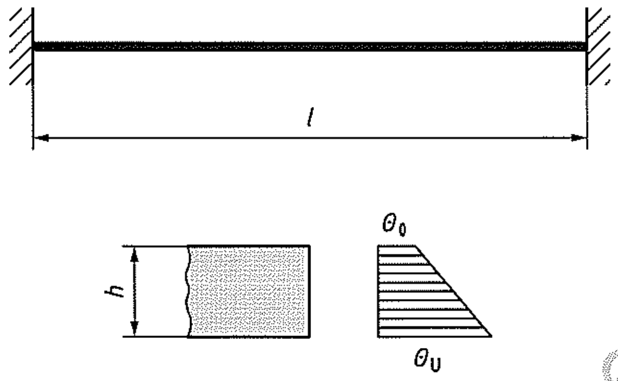


Figure CC.6 — System and cross section

Table CC.14 — Boundary and initial conditions

Boundary conditions		Structural steel	
Dimensions l / h / b	mm	1 000 / 100 / 100	
Nominal stress-strain relationships		DIN EN 1993-1-2	
Strength $f_{yk(20°C)}$	N/mm²	650[a]	
Modulus of elasticity $E_{a(20°C)}$	N/mm²	210 000	
Thermal expansion		DIN EN 1993-1-2	
Initial conditions			
Temperature of member Θ_o	°C	120	20
Temperature of member Θ_u	°C	120	220
Reference value			
Secondary effects N_{Zw}, M_{Zw}	kN, kNm		
Restraint σ_{Zw} at the lower boundary	N/mm²		

[a] Structural steel according to DIN EN 1993-1-1 with the imaginary yield strength $f_{yk(20°C)}$ = 650 N/mm² (not high-tensile steel) and thermomechanical properties according to DIN EN 1993-1-2

Table CC.15 — Reference and calculated values for the formation of restraint forces

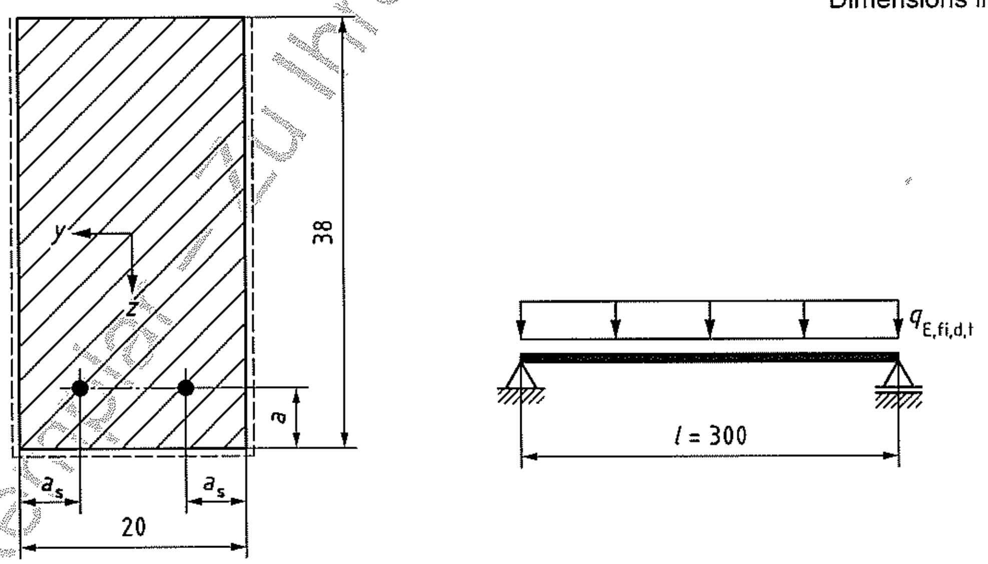
Temperature load case		Reference value X	Calculated value X'	Deviation $(X' - X)/X \cdot 100$ %	Tolerance %
120/120	N_{Zw} kN	−2 585			N_{zw}: ±1 M_{zw}: ± 1 σ_{zw}: ± 5
	M_{Zw} kNm	0		--------------	
	σ_{Zw} N/mm^2	−258,5			
20/220	N_{Zw} kN	−2 511			
	M_{Zw} kNm	−40,3			
	σ_{Zw} N/mm^2	−479			

Programmes in which calculated values deviate from the reference values by more than the tolerance specified in Table CC.15 shall be considered unsuitable for the mechanical analysis of members, on the basis of the Eurocode.

CC.4.8 Example 8 — Lightly reinforced concrete flexural beam

A lightly reinforced concrete beam designed as a flexural beam with a cross section b/h = 20 cm/38 cm and a span l = 3,0 m (see Figure CC.7) is exposed on three sides. The centre-to-centre spacing of the reinforcement is that for fire resistance class R 90 according to Table CC.16.

Dimensions in centimetres



Key

_ _ _ _ Exposed face

Figure CC.7 — Lightly reinforced concrete flexural beam — cross section and system

Table CC.16 — Section properties, material properties and boundary conditions

Reinforced concrete flexural beam (lightly reinforced)				R 90
Dimensions		l / b / h	in cm	300 / 20 / 38
Centre-to-centre spacing		a / a_s	in cm	4.5 / 5.5
Load		$q_{E,fi,d,t}$	in kN/m	29
C20/25 concrete (3 % moisture (m/m))		$f_{ck(20°C)}$	in N/mm^2	20
B500 reinforcing steel		$f_{yk(20°C)}$	in N/mm^2	500
Nominal stress-strain relationships		Concrete[a]		DIN EN 1992-1-2
		Reinforcing steel[b]		
Thermal stress		STTC (three sides)		DIN EN 1991-1-2
Heat transfer coefficient		α_c	in W/(m^2 · K)	25
Emissivity		ε_m		0,70
Thermal and physical material values	Concrete	λ, ρ, c_p, $\varepsilon_{th,c}$		DIN EN 1992-1-2
	Reinforcing steel	λ_a, ρ, c_a, $\varepsilon_{th,s}$		DIN EN 1994-1-2

[a] With aggregate mainly containing quartzite and an apparent density ρ = 2 400 kg/m^3

[b] Class N, hot-rolled

Table CC.17 — Reference and calculated value for a lightly reinforced concrete beam

Fire resistance class	Reference value A_s cm^2	Calculated value A'_s cm^2	Deviation $(A'_s - A_s)/A_s \cdot 100$ %	Tolerance %	Notes
90	3,56			± 10	

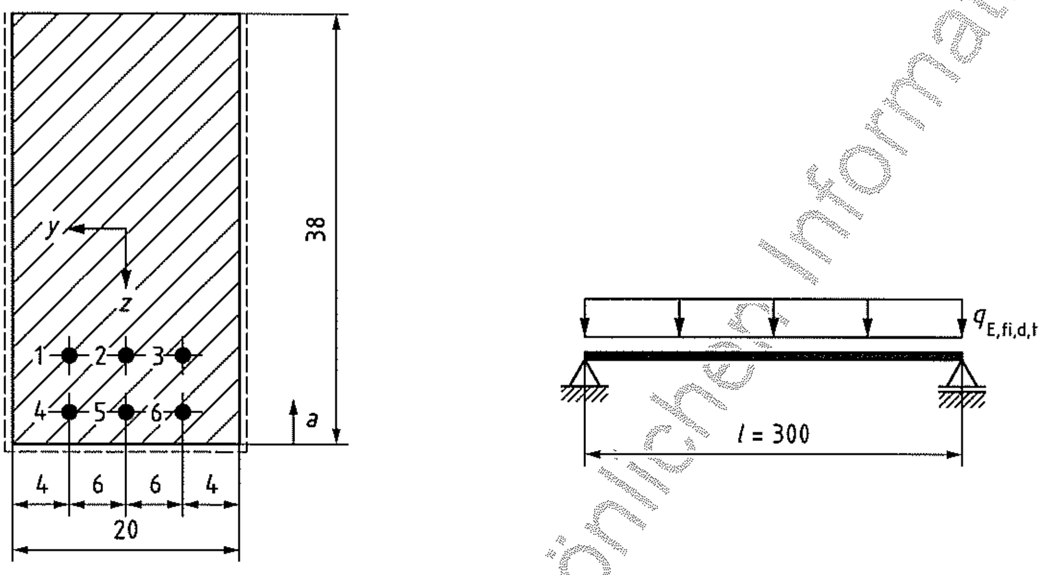
NOTE After fire exposure time t = 90 min the temperature in the reinforcement is Θ_s = 562 °C.

Programmes in which the calculated cross-sectional area of the reinforcement deviates from the reference value in Table CC.17 by more than the specified tolerance shall be considered unsuitable for the analysis of reinforced concrete flexural beams in terms of fire protection on the basis of the Eurocode.

CC.4.9 Example 9 — Heavily reinforced concrete flexural beam

A heavily reinforced flexural beam with a cross section b/h = 20 cm/38 cm and a span l = 3,0 m (Figure CC.8) is exposed on three sides. The centre-to-centre spacing of the reinforcement is that for resistance class R 90 according to Table CC.18.

Dimensions in centimetres



Key

____ Exposed face

Figure CC.8 —Heavily reinforced concrete flexural beam — cross section and system

Table CC.18 — Section properties, material properties and boundary conditions

Reinforced concrete flexural beam (heavily reinforced)			R 90
Dimensions	l / b / h	in cm	300 / 20 / 38
Centre-to-centre spacing	$a_{1,2,3}$	in cm	7
	$a_{4,5,6}$	in cm	4
Load	$q_{E,fi,d,t}$	in kN/m	62,9
C20/25 concrete (3 % moisture (m/m))	$f_{ck(20°C)}$	in N/mm²	20
B500 reinforcing steel	$f_{yk(20°C)}$	in N/mm²	500
Nominal stress-strain relationships	Concrete[a]		DIN EN 1992-1-2
	Reinforcing steel[b]		
Thermal stress	STTC (three sides)		DIN EN 1991-1-2
Heat transfer coefficient	α_c	in W/(m² · K)	25
Emissivity	ε_m		0,70
Thermal and physical material values — Concrete	λ, ρ, c_p, $\varepsilon_{th,c}$		DIN EN 1992-1-2
Thermal and physical material values — Reinforcing steel	λ_a, ρ, c_a, $\varepsilon_{th,s}$		DIN EN 1994-1-2

[a] With aggregate mainly containing quartzite and an apparent density ρ = 2 400 kg/m

[b] Class N, hot-rolled

Table CC.19 — Reference and calculated value for a heavily reinforced concrete beam

Fire resistance class	Reference value A_s cm^2	Calculated value A'_s cm^2	Deviation $(A'_s - A_s)/A_s \cdot 100$ %	Tolerance %	Notes
90	9,76			± 10	

NOTE After fire exposure time t = 90 min the temperature in the reinforcement is:

— $\Theta_{s,1} = \Theta_{s,3}$ = 539 °C;

— $\Theta_{s,2}$ = 372 °C;

— $\Theta_{s,4} = \Theta_{s,6}$ = 656 °C;

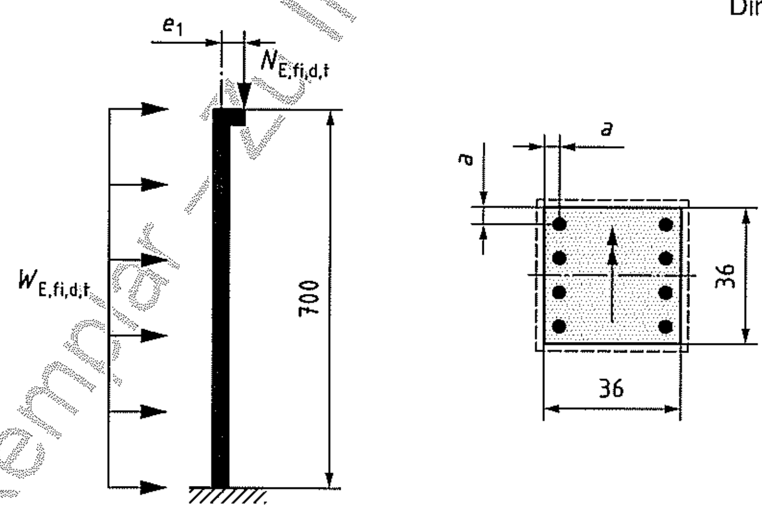
— $\Theta_{s,5}$ = 525 °C.

Programmes in which the calculated cross-sectional area of the reinforcement deviates from the reference value in Table CC.19 by more than the specified tolerance shall be considered unsuitable for the analysis of reinforced concrete flexural beams in terms of fire protection on the basis of the Eurocode.

CC.4.10 Example 10 — Reinforced concrete cantilevered column

A reinforced concrete cantilevered column with a cross section $b = h$ = 36 cm and a length l = 7,0 m (Figure CC.9) is exposed on four sides. The C20/25 concrete column is reinforced with B500 steel with an area of cross section A_s = 18,85 cm^2 (6 ∅ 20 mm) and is subjected to a longitudinal force with a load eccentricity e_1 = 3,5 cm and to a line load (wind load) in the fire situation (see Table CC.20).

Dimensions in centimetres



Key

---- Exposed side

Figure CC.9 — Reinforced concrete cantilevered column — cross section and system

Table CC.20 — Dimensions, load and material properties

Dimensions		$l / b / h$	in cm	700 / 36 / 36
Buckling length in the fire situation		$l_{0,\text{fi}}$	in m	14,0
Load eccentricity in the fire situation		e_1	in cm	3,5
Centre-to-centre spacing		a	in mm	55
Load		$N_{\text{E,fi,d,t}}$	in kN	–79
		$w_{\text{E,fi,d,t}}$	in kN/m	1,74
C20/25 concrete (3 % moisture (m/m))		$f_{\text{ck(20°C)}}$	in N/mm^2	20
B500 reinforcing steel		$f_{\text{yk(20°C)}}$	in N/mm^2	500
Nominal stress-strain relationships		Concrete[a]		DIN EN 1992-1-2
		Reinforcing steel[b]		
Thermal stress		STTC (four sides)		DIN EN 1991-1-2
Heat transfer coefficient		α_c	in W/(m^2 · K)	25
Emissivity		ε_m		0,70
Thermal and physical material values	Concrete	λ, ρ, c_p, $\varepsilon_{\text{th,c}}$		DIN EN 1992-1-2
	Reinforcing steel	λ, ρ, c_a, $\varepsilon_{\text{th,s}}$		DIN EN 1994-1-2

a With aggregate mainly containing quartzite and an apparent density ρ = 2 400 kg/m^3

b Class N, hot-rolled

NOTE The load eccentricity includes imperfections according to DIN EN 1992-1-1:2005-10, 5.2.

The reinforced concrete cantilevered column is analysed in the major bending direction.

Table CC.21 — Reference and calculated values for the reinforced concrete cantilevered column

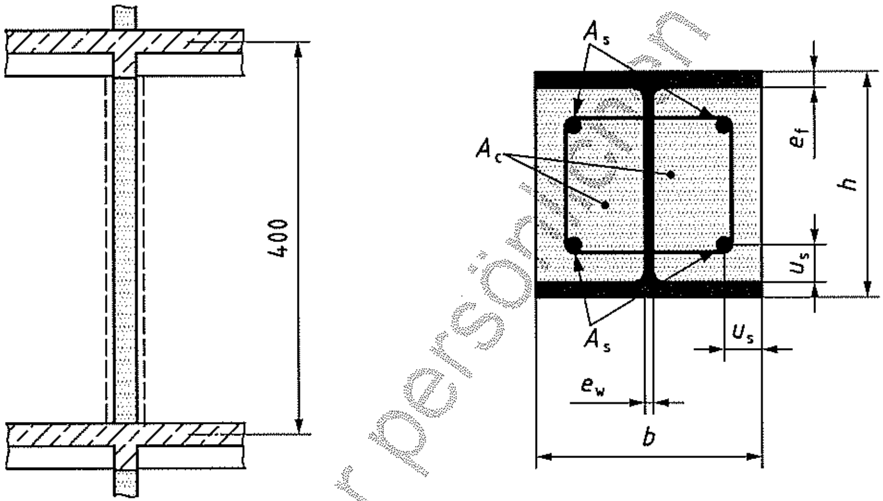
	Reference value X	Calculated value X'	Deviation $(X'-X)/X \cdot 100$ %	Tolerance %
Failure time t_u in min	93			± 3
Horizontal displacement at the column head w_z in mm after fire exposure time $t = 90$ min	381			± 15
Moment at the column base $M_{E,fi,d}$ in kNm after fire exposure time $t = 90$ min	75,5			± 5
NOTE After fire exposure time $t = 90$ min the temperature in the reinforcement is: — $\Theta_s = 502$ °C (corner reinforcement); — $\Theta_s = 319$ °C (reinforcement in the centre).				

Programmes in which the calculated values deviate from the reference values in Table CC.21 by more than the specified tolerance shall be considered unsuitable for the analysis of reinforced concrete columns in terms of fire protection on the basis of the Eurocode.

CC.4.11 Example 11 — Composite column with concrete encasement

A concrete-encased composite column with cross-sectional dimensions $b = h = 30$ cm and a length $l = 4.0$ m (Figure CC.10) is exposed on four sides. The cross section of the column consists of a HE-B 300 section of S 235 structural steel, C25/30 concrete encasement and B500 reinforcing steel 4 ∅ 28. Neither column end is free to rotate in the fire situation. The composite column is subjected to a concentric longitudinal force $N_{E,fi,d,t}$ (Table CC.22) in the fire situation; the geometrical imperfection is determined via a stress-free parabolic pre-deformation with the peak value l/1 000.

Dimensions in centimetres



Key

----- Column exposed on four sides

Figure CC.10 — Encased composite column — cross section and system

Table CC.22 — Dimensions, load and material properties

Dimensions	$l / b / h$	in cm	400 / 30 / 30
	u_s	in mm	50
	e_f	in mm	19
	e_w	in mm	11
Buckling length in the fire situation	$l_{0,fi}$	in cm	200
Load	$N_{E,fi,d,t}$	in kN	–1 700
Concrete C25/30 (3 % moisture (m/m))	$f_{ck(20°C)}$	in N/mm²	25
Reinforcing steel B500	$f_{yk(20°C)}$	in N/mm²	500
Structural steel S 235	$f_{ak(20°C)}$	in N/mm²	235
Nominal stress-strain relationships	Concrete[a]		DIN EN 1994-1-2
	Reinforcing steel[b]		
	Structural steel		
Thermal stress	STTC (four sides)		DIN EN 1991-1-2
Heat transfer coefficient	α_c	in W/(m² · K)	25
Emissivity	ε_m		0,7
Thermal and physical material values — Concrete	λ, ρ, c_p, $\varepsilon_{th,c}$		DIN EN 1994-1-2
Thermal and physical material values — Steel	λ, ρ, c_a, $\varepsilon_{th,s}$, $\varepsilon_{th,a}$		DIN EN 1994-1-2

[a] With aggregate mainly containing quartzite and an apparent density ρ = 2 400 kg/m³

[b] Hot-rolled

Table CC.23 — Reference and calculated values for the concrete-encased composite column

		Reference value X	Calculated value X'	Deviation $(X' - X)/X \cdot 100$ %	Tolerance %
Failure time t_u	in min	92			± 5
Total horizontal displacement w_z in mm at centre of column after fire exposure time t =	30 min	4,4			
	60 min	5,5			

NOTE After fire exposure time t = 90 min the temperature is:

— Θ_s = 535 °C in the reinforcement;

— Θ_s = 447 °C in the centroid of the steel section.

Programmes in which the calculated values deviate from the reference values in Table CC.23 by more than the specified tolerance shall be considered unsuitable for the analysis of concrete encased composite columns in terms of fire protection, on the basis of the Eurocode.

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