Annex for The Netherlands

Steel Design 2

Fire

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bouwen met staal

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Annex for the Netherlands to *Fire* (Steel Design 2)

This annex has been prepared by dr.ir. A.F. Hamerlinck and is based on the original Dutch version of *Fire*, published in 2010 (and updated in 2015) by Bouwen met Staal as *Brand* by the same author.
References are made to each NA symbol in *Fire* – where relevant – the corresponding clause in the Eurocode.
Annexes to *Fire* (Steel Design 2) are also available for Belgium, Luxembourg and Switzerland and can be downloaded free of charge from the website of Bouwen met Staal.

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Eurocodes in The Netherlands

Dutch Building Decree and Eurocodes

The Dutch Building Decree (in Dutch: Bouwbesluit) includes, amongst other things, minimum requirements regarding structures, which every structure in The Netherlands – including those for residential buildings, offices and bridges – has to meet. Fulfilling these requirements is required by law in order to obtain a building permit. In addition to new building structures, renovations and existing structures are also regulated by the Dutch Building Decree.

The Dutch Building Decree is a General Administrative Order (in Dutch: Algemene maatregel van bestuur) which belongs to the Dutch Housing Law. The first version came into force in 1992. The latest Dutch Building Decree – which came into force on April 1, 2012 – was published in the *Law Gazette* (in Dutch: *Staatsblad*) (2011) 416. The Dutch Building Decree 2012 was last amended on November 4, 2020.

The Environmental Structures Decree (in Dutch: Besluit bouwwerken leefomgeving) will replace the Dutch Bulding Decree as of 1-1-2022. The regulation of the structural and fire safety remains generally unchanged.

The Dutch Building Decree 2012 only concerns the public law aspects of newly built or existing structures. Private law aspects – such as serviceability requirements concerning deflections, or execution aspects – should always be agreed between the parties involved. The requirements of the Dutch Building Decree are organized into five categories:

– *safety*: preventing or limiting of danger for users of the building or for other parties;
– *health*: preventing or limiting of harmful or inconvenient consequences for users of the building;
– *usability*: facilitating performance of the characteristic activities for the building;
– *energy efficiency*: contributing to an efficient use of energy in the building;
– *environment*: avoiding too much irreversible damage to the environment (soil, air, water) due to the building.

There are also requirements for installations, which are not divided into these categories. The Dutch Building Decree also contains requirements regarding fire safety, construction, and demolition activities.

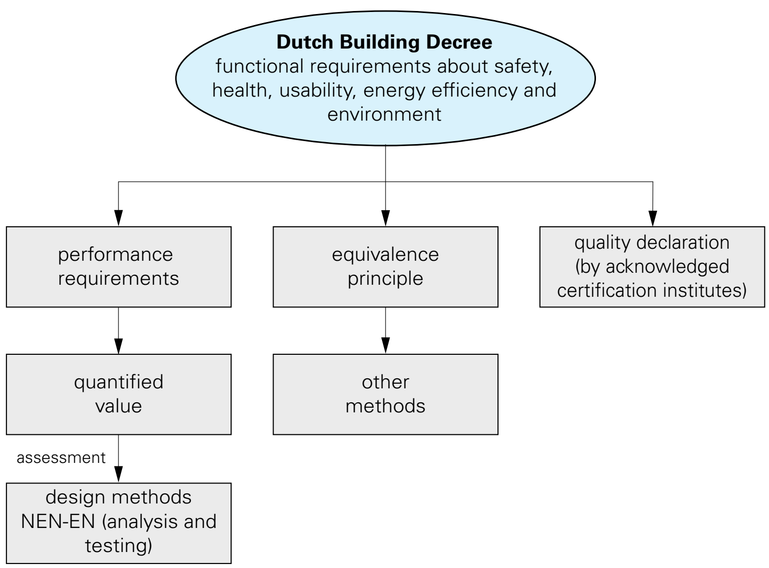
The requirements of the Dutch Building Decree are formulated as performance requirements. A performance requirement is derived from functional requirements, and is quantified through a limiting value as a minimum requirement. For the assessment of a building structure requirements regarding (fire) safety are of particular importance. The Dutch Building Decree refers to the Eurocodes for checking the resistance of structures, both under normal temperatures as well as

in the event of fire. Apart from performance requirements in the form of limiting values (e.g. the requirement to the fire resistance of structures, expressed in minutes), the Dutch Building Decree also provides so-called determination methods. These determination methods can be used to establish if a building structure or part of a structure meets the limiting values of the performance requirements. The determination methods are provided in codes, for structures in the Eurocodes (for fire the subsequent parts -1-2 of the Eurocodes). If an application for a building permit is based on, and meets, the requirements of the (Euro)codes designated in the Dutch Building Decree, then the applicant may assume that the building permit will be granted so far as technical requirements are concerned.
To allow innovations the Dutch Building Decree also has a so-called equivalence principle, apart from the system of performance requirements and determination methods. Based on this equivalence principle, building structures which cannot simply be assessed using the determination methods of the Eurocodes can still be designed and built. The applicant should in such cases show by means of other methods – for example tests or advanced calculation methods – that the structure preforms as intended by the prescribed performance requirements.
Recognized quality declarations have a separate status within the Dutch Building Decree. In this case, recognized means that the quality declaration has been prepared and issued by an accredited certification institution. A quality declaration is generally linked to a construction product in a particular application. The quality declaration implicitly demonstrates that the construction product meets the performance requirements, or has an equivalent quality.

Figure NL1 shows schematically the way in which the requirements of the Dutch Building Decree can be met.

Dutch guidelines for steel structures in the event of fire

When a designer makes use of national Dutch guidelines (generally issued by Bouwen met Staal (Dutch Steel Association), the assessment of a steel structure against the requirements of the Dutch Building Decree should always be based on the equivalence principle, see figure NL1.



NL1 Relation scheme Dutch Building Decree.

Fire safety

Annex NL

p. 1-6 ***Dutch Building Decree, cl. 1.3***

The requirements for the fire resistance of the structure can be reduced by using a sprinkler system, see e.g. [15], or even eliminated by using the 'equivalence safety principle' of the Dutch Building Decree, e.g. by application of [16].

p. 1-9 ***Dutch Building Decree, cl. 1.3***

To get a building permit, the applicant must show the equivalence of safety, e.g. by using the proposed technical installation measures compared to that achieved with passive measures.

p. 1-10

No additional requirements to this general detailing conditions, which are usually approved by fire tests.

p. 1-12 ***EN 1994-1-2, cl. 4.3.5.3 and Annex H***

Instead of using the EN 1994-1-2 version of Potfire, the version of Potfire based on the more advanced method applied in the French National Annex can be used on the basis of the 'equivalent safety principle', see [14].

p. 1-14

In The Netherlands, it is common – as an alternative to [2] – to use the Bouwen met Staal guideline, see [13], to approve the quality of application of the intumescent coating.

p. 1-16 (a) ***Dutch Building Decree, cl. 1.3***

A monitoring concept offers the possibility of reducing the fire resistance requirement for structural elements and can be the best option if the normal use of the building requires minimum partitioning. It is particularly appropriate when there is a small fire load in low-rise buildings – where a fire usually develops slowly – so sufficiently fast and effective action by the fire fighters is assured. To get a building permit, the applicant must show the 'equivalence of safety', e.g. by using the proposed technical installation measures compared to that achieved with passive measures.

p. 1-16 (b)

No additional requirements in The Netherlands.

p. 1-17 (a) ***sprinklers***

Certified sprinklers are required and the operation has to be guaranteed by an approved inspection and maintenance scheme.

p. 1-17 (b) ***sprinklers***

Granting permission to decrease the fire resistance requirements based on the 'principle of equivalence' is up to the local authority.

p. 1-18 (a) ***sprinklers***

In The Netherlands it is possible to include in the sprinkler certificate that the sprinkler system is designed in such a way that the steel structure is cooled explicitly during a fire. This makes the sprinkler installation a demonstrably equivalent solution based on the limitation of the steel temperature. This is a more rational approach compared to lowering the fire resistance requirement by 30 or 60 minutes.

p. 1-18 (b)

No additional requirements in The Netherlands.

p. 1-19 ***EN 1991-1-2, cl. 3.1 and annex E***

The Dutch National Annex allows for two choices: either the application of a nominal, standard fire curve (under all circumstances allowed for buildings) or a natural, physical fire curve (under certain conditions allowed for buildings), see remarks to p. 3-10 (a).

p. 1-20 (a)

No additional requirements in The Netherlands.

p. 1-20 (b) ***Dutch Building Decree, cl. 2.10.1, 2.84.1 and 2.104.7***

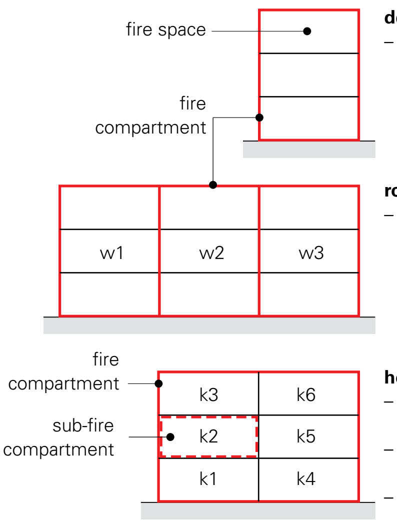
In The Netherlands the required fire resistance of the structure of escape routes is 30 minutes, according to the Dutch Building Decree, cl. 2.10.1. However, the fire has not to be considered in the escape route itself, but in another smoke (c.q. sub-fire) compartment. In buildings with staircases with a height more than 8 m, the fire separating requirements to the staircase of 60 minutes, usually also increase the structural fire resistance requirement to 60 minutes, according to the Dutch Building Decree, cl. 2.104.7 and 2.84.1.

A sub-fire compartment is (a part of) a fire compartment which can be evacuated fast (within 30 seconds) during a fire in the compartment. There are requirements as to the maximum walking distance and height within a sub-fire compartment. After leaving the sub-fire compartment where the fire is located, the occupants must have a smoke-free escape route. During a fire in a sub-fire compartment, the escape routes in other sub-fire compartments are not allowed to collapse within 30 minutes caused by the collapse of the burning sub-fire compartment. As a consequence, this principle comes down to the assessment of the structural effect of the fire in a sub-fire compartment on the structure in other sub-fire compartments (that are not on fire). If the effect is the collapse of the structure in another sub-fire compartment, then the fire resistance requirement is 30 minutes. In all other cases there are no fire resistance requirements. This scenario needs to be assessed for every separate sub-fire compartment and additional requirements may apply to the structure.

p. 1-20 (c) ***Dutch Building Decree, cl. 2.10***

In The Netherlands the required fire resistance of the main load-bearing structure depends on the occupancy and the height of the building, see figure NL1.1.

The structural engineer usually considers the complete structure as main load-bearing structure under fire conditions. However, this is usually incorrect because the effect of failure of the structure during fire has to be assessed at the level of fire compartments. The structure of the fire compartment may fail as long as the other fire compartments (where there is no fire) remain intact. This means that buildings with only one fire compartment – like detached houses and small office buildings or single-storey buildings – do not have to fulfil fire resistance requirements with respect to progressive collapse of the structures in other fire compartments (see fig. NL1.1).



detached house or small office
– no main load-bearing structure

row house
– no main load-bearing structure, provided that failure of, for example, dwelling w2 does not result in failure of dwellings w1 or w3

hotel (room)
– k1 has a main load-bearing structure if failure of k1 causes failure of k3, k5 or k6
– k2 has a main load-bearing structure if failure of k2 causes failure of k4 or k6
– k3 has a main load-bearing structure if failure of k3 causes failure of k1, k4 or k5

NL1.1 Dutch fire resistance requirements for the main load-bearing structure of new non-residential and residential buildings, dependent on the occupancy and the height of the highest floor level above the connecting terrain (measured at the main entrance).

In residential buildings the requirements of figure NL1.1 do not apply if the structural collapse is limited to the apartment on fire and to the apartment(s) directly adjacent to that apartment. In that case only the fire resistance requirement of the walls and floors between the apartments (being independent fire compartments), usually 60 minutes, have to be fulfilled. If more apartments are involved in the collapse, the higher requirements of 90 or 120 minutes may apply (for residential buildings with floors higher than 7 m).

The fire resistance requirements for the main load-bearing structure may be lowered by 30 minutes (to the red values in fig. NL1.1) if the permanent fire load is lower than 500 MJ (or 26 kg spruce timber) per square meter floor area. The permanent fire load includes the combustion of all construction parts of the buildings that are required to get a building permit. The interior construction parts such as plinths, ceilings, non load-bearing walls need not be taken into account here. Also the fire load of the furniture and other goods which are added by the user need not be taken into account (which has already been taken into account in the fire resistance requirements). The fire resistance requirements can be reduced in case of a small permanent fire load because the fire exposure time is shorter.

p. 1-21 ***Dutch Building Decree, cl. 1.3***

In The Netherlands, it is allowed to determine the fire resistance of the structure on other fire curves than the standard fire curve by using the 'equivalent safety principle', see remarks to p. 3-10 (a).

p. 1-22 (a) ***Dutch Building Decree, cl. 1.3***

In The Netherlands, this is possible by using the 'equivalent safety principle'.

p. 1-22 (b) ***Dutch Building Decree, cl. 1.3***

In The Netherlands, this is possible by using the 'equivalent safety principle'.

p. 1-24 ***EN 1991-1-2, cl. 2.4.1***

No additional requirements in The Netherlands.

p. 1-25 ***EN 1990, cl A1.3.2***

The recommended values of γ_G = 1,0 and γ_Q = 1,0 are adopted.

p. 1-26 ***EN 1990, cl A1.3.2***

The Dutch National Annex, see [17], specifies:

– ψ_2 shall be used for imposed (variable) loads on floors and roofs;

– ψ_1 = 0,2 shall be used for wind loads in the case of a structural element which failure causes the collapse of a structural element in another fire compartment (progressive collapse or disproportional damage). In other cases ψ_2 = 0 shall be used for wind loads.

p. 1-30 ***Literature***

Additional literature specific for The Netherlands.

13. A.F. Hamerlinck, *Kwaliteitsrichtlijn applicatie brandwerende coating* (in English: Quality guideline for the application of intumescent coating), Bouwen met Staal, Zoetermeer 2010 (2nd edition). Free to download at: gratis-publicaties.bouwenmetstaal.nl.
14. A.F. Hamerlinck en L. Twilt, 'Ruimere mogelijkheden berekening betongevulde slain buis-kolommen' (in English: 'Extended application of the calculation of concrete-filled steel tubes'), *Bouwen met Staal* 222 (2011), pp. 56-60. Free to download at: www.brandveiligmetstaal.nl/upload/File/BmS222.pdf.
15. HM Government, *The Building Regulations 2010. Fire safety. Approved document B, volume 1 (Dwellings) and volume 2 (Buildings other than dwellings)*, 2019. Free to dowload at: www.gov.uk/government/publications/fire-safety-approved-document-b.
16. J.C. Hogeweg and R.J.M. van Mierlo, *Sprinklerinstallaties en brandwerendheid op bezwijken van staalconstructies* (in English: Sprinklers and the fire resistance of steel structures), DGMR/Efectis report F.2015.0122.00.R001, Arnhem 2017. Free to download at: www.brandveiligmetstaal.nl/pag/211/sprinklerinstallaties.html (scroll down to 'Richtlijnen' and then click 'hier').
17. *NEN-EN 1990+A1+A1/C2* (Eurocode. Grondslagen van het constructief ontwerp), 2019 + NB, 2019.
18. *NEN-EN 1991-1-2+C3* (Eurocode 1. Belastingen op constructies. Deel 1-2. Algemene belastingen. Belasting bij brand), 2019 + NB, 2019.
19. *NEN-EN 1993-1-2+C2* (Eurocode 3. Ontwerp en berekening van staalconstructies. Deel 1-2. Algemene regels. Ontwerp en berekening van constructies bij brand), 2011 + NB, 2015.
20. *NEN-EN 1994-1-2+C1/A1* (Eurocode 4. Ontwerp en berekening van staal-betonconstructies. Deel 1-2. Algemene regels. Ontwerp en berekening van constructies bij brand), 2014 + NB, 2007.

Calculation of the fire resistance

p. 2-4 ***EN 1990, cl. A1.3.2***

The Dutch National Annex specifies y_2 shall be used for imposed (variable) loads on floors and roofs, so the applied ψ_2 = 0,3 (as well as γ_G = 1,2 for the permanent and γ_Q = 1,5 for the variable action) in the text and equations (2.3) and (2.4) are valid for The Netherlands.
On the basis of these national choices, conservative values have been derived for tendering (assuming the degree of utilization μ_o is equal to the reduction factor for the design load level in the fire situation η_{fi} (i.e. for a unity check 1,0 in the fundamental combination), see [14].

p. 2-17 ***EN 1993-1-1, cl. 6.1 and EN 1993-1-2, cl. 2.3***

The Dutch National Annexes specify $\gamma_{M,0} = \gamma_{M,fi}$ = 1,0, so the simplified equations presented in this section are valid.

p. 2-18 ***EN 1993-1-2, Annex D***

According to the Dutch National Annex Annex D of EN 1993-1-2 has a normative status. The method with specific, local section factors presented in this section, can be derived on the basis of the principles given in EN 1993-1-2.

p. 2-20 ***EN 1990, cl. A1.3.2***

The Dutch National Annex specifies ψ_1 = 0,2 shall be used for wind loads in the case of a structural element which failure causes the failure of a structural element in another fire compartment (progressive collapse or disproportional damage). Together with γ_Q = 1,5 for the variable action, the text is valid for The Netherlands.

p. 2-23 ***EN 1990, cl. A1.3.2***

The recommended value ψ_2 = 0,8 is accepted.

p. 2-25 ***EN 1990, cl. A1.3.2***

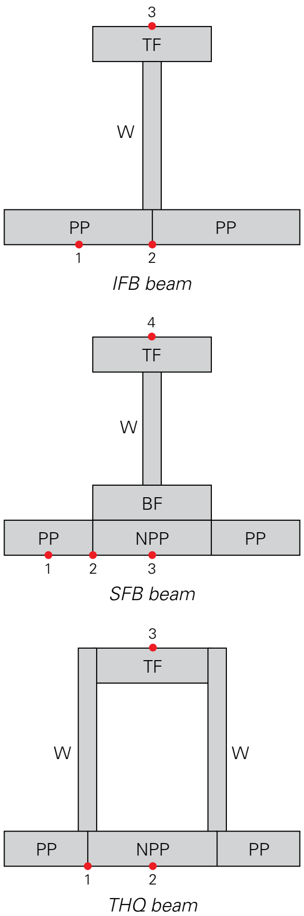
The recommended value ψ_2 = 0,3 is accepted.

p. 2-29 ***EN 1990, cl. A1.3.2***

The recommended value ψ_2 = 0,3 is accepted.

p. 2-32 ***EN 1990, cl. A1.3.2***

See remarks to p. 2-25.



NL2.1 Location of the characteristic points.

p. 2-35 ***advanced calculation method***

Temperature distribution in the cross-section

As a modification of the advanced calculation method in section 2.8.3, in The Netherlands the temperature distribution in the cross-section can be determined on the basis of research performed by Efectis Nederland, see [12]. This temperature distribution – as well as the described method in the text, see [1, 13, 15] – is incorporated in the software program GLigger 1.11 published by Bouwen met Staal, see [11].

The Efectis calculation rules were developed on the basis of a finite element program in which the temperature distribution in the cross-section depends on the time of exposure to the standard fire curve (see fig. 2.1). Based on simulations, design tables with characteristic temperatures were drawn up that can be used in the calculation of the bending moment capacity. These tables comprise the characteristic temperatures at which the resistance in a transverse direction is assessed, i.e. the transfer of the support reaction from the floor to the beam web via the lower plate of the beam. The temperatures in the tables have been determined for 30, 60, 90 and 120 minutes of exposure to the standard fire.

The characteristic temperatures obtained from finite element simulations serve as input for the calculation rules. These temperatures are determined for the characteristic points in the cross-section. The location of these points in the cross-section is shown in figure NL2.1.

The characteristic points are used in the calculation as shown in table NL2.2. The temperatures determined with the simulations are available in tabular form, see table NL2.3 for a selection of SFB beams and [12] for the complete set of tables. The calculated temperatures are very similar to the ones measured in fire tests, as has been demonstrated by Efectis [12]. Because measurements show some scatter, the predicted temperatures can sometimes be higher or lower than the measured temperatures. But in general, the predicted temperatures give an accurate indication of the heat transfer in the cross-section.

		IFB	SFB	THQ
PP	transverse bending bottom plate	2	2	1
(N)PP	cross-sectional reduction longitudinal moment capacity	2	2	1
PP	contribution to longitudinal moment capacity	1	1	1
NPP	contribution to longitudinal moment capacity	–	3	2
BF	transverse bending bottom flange (temperature by linear interpolation)	–	3-4	–
BF	cross-sectional reduction longitudinal moment capacity bottom flange (temperature by linear interpolation)	–	3-4	–
W	web (temperature by linear interpolation)	2-3	3-4	2-3
TF	top flange or plate	3	4	3

NL2.2 Indication of the characteristic points.

The calculation method for determining the load-bearing capacity of integrated beams in the event of fire uses the characteristic temperatures to calculate the longitudinal plastic moment capacity. These plastic moments are available in tabular form, see [12]. They can be used when the criterion in the transverse direction is met, see (equation 2.31). Table NL2.4 gives a selection of SFB beams taken form [12]. In these Efectis tables the longitudinal plastic moment capacity as a function of the fire resistance requirement (in minutes) are given for C = 0,0 and C = 1,0 (from equation 2.31) for each profile. These moment capacites are displayed as a percentage of the plastic moment capacity at room temperature.

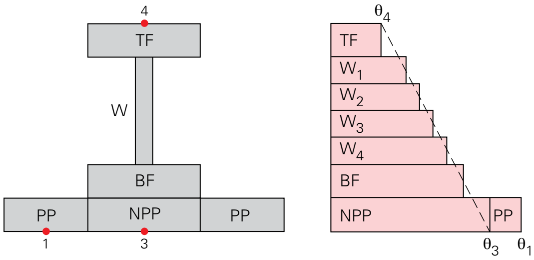
beam type	t = 30 minutes				t = 60 minutes			
	1	2	3	4	1	2	3	4
SFB 160-HEM 140-350x10	557	486	438	58	800	745	700	152
SFB 160-HEM 140-350x15	523	468	425	55	780	735	694	148
SFB 160-HEB 160-360x10	581	531	480	46	821	785	739	119
SFB 180-HEM 160-370x15	519	462	413	47	777	730	684	128
SFB 180-HEB 180-380x10	578	527	472	36	821	785	736	91
SFB 200-HEM 180-390x10	551	477	418	40	798	741	687	105
SFB 200-HEB 200-400x15	540	497	445	29	800	768	721	68
SFB 220-HEM 200-410x10	549	473	411	33	798	741	683	84
SFB 220-HEB 220-420x10	572	517	456	26	819	782	728	56
SFB 240-HEM 220-430x10	546	470	404	29	797	739	679	67
SFB 240-HEB 240-440x10	567	510	441	26	816	776	713	53
SFB 270-HEM 240-450x25	451	404	345	26	724	685	629	55

NL2.3 Characteristic temperatures (in ˚C) for characteristic points in a selection of SFB beams.

type	C = 0,0[(a)]				C = 1,0[(a)]			
	fire resistance (min)				fire resistance (min)			
	30	60	90	120	30	60	90	120
SFB 160-HEM 140-350x10	95,1	55,1	28,5	18,7	90,7	46,3	24,7	16,4
SFB 160-HEM 140-350x15	95,6	62,6	31,1	20,0	90,7	52,0	26,4	17,2
SFB 160-HEB 160-360x10	94,8	51,4	28,0	19,6	91,5	42,2	23,7	16,9
SFB 180-HEM 160-370x15	96,0	64,1	32,1	21,2	91,4	53,4	27,3	18,3
SFB 180-HEB 180-380x10	95,4	50,6	27,7	19,8	92,3	41,7	23,7	17,2
SFB 200-HEM 180-390x10	96,1	57,0	29,7	20,6	91,2	47,9	25,9	18,3
SFB 200-HEB 200-400x15	96,1	60,9	30,7	21,7	92,5	49,1	25,7	18,5
SFB 220-HEM 200-410x10	96,4	57,4	29,6	20,9	91,2	48,3	26,0	18,6
SFB 220-HEB 220-420x10	96,1	49,9	27,0	19,6	92,9	41,3	23,3	17,2
SFB 220-HEB 220-430x10	96,7	57,8	29,7	21,0	91,2	48,7	26,1	18,7
SFB 240-HEB 240-440x10	96,5	51,9	27,5	20,0	93,2	42,9	23,7	17,6
SFB 270-HEM 240-450x25	97,6	80,5	41,0	25,3	92,7	68,5	34,2	21,8

a. These values have been reduced by 2% compared to the values in the Efectis report, because this report assumes a slightly lower decrease in the yield stress of steel in the event of a fire than according to the present Eurocode.

NL2.4 Reduction of the longitudinal plastic moment capacity (in %) of some SFB beams at different fire requirements.



NL2.5 Determination of the steel temperatures and reduced yield strengts in a cross-section of an SFB beam subdivided into different parts.

p. 2-40

Example 2.6

- *Given*. An office building with integrated beams SFB 200-HEB 200-400x15 (fig. 2.31) in steel S355 grade with W_{pl} = 822-10^3 mm^3 and hollow core slabs with a support length of 80 mm. The weight of the integrated beams is G_k = 1,1 kN/m; they have at centre-to-centre distance a = 7,2 m spanning L = 4,5 m. The weight of the hollow core slabs is G_k = 5,5 kN/m^2. They are designed for a variable load Q_k = 4 kN/m^2 with ψ_2 = 0,3.
- *Question*. Check whether a fire resistance of 60 minutes is achieved with the modification according to the Efectis method which is accepted in The Netherlands.
- *Answer*. The load on the beam in the event of fire is $q_{\theta,d} = (G_{k,floor} + \psi_2 Q_k)a + G_{k,beam}$ = (5,5 + 0,3·4)·7,2 +1,1 = 49,3 kN/m and the corresponding bending moment $M_{\theta,d} = q_{\theta,d}L^2/8$ = 49,3·4,5^2/8 = 125 kNm. The load from the floor on the beams on one side is $q_{\theta,max} = 0{,}5q_{\theta,d}$ = 0,5$(G_{k,floor} + \psi_2 Q_k)$a = 0,5·(5,5 + 0,3·4)·7,2 = 24,1 kN/m.

For a fire resistance of 60 minutes, the temperatures of the characteristic points (fig. NL2.5) can be read from table NL2.3. Equation (2.2) defines the (effective) yield strength for each of these points. The results are:

		point	1	2	3	4
θ_n (60 min)	(˚C)		800	768	721	68
$f_{y,\theta n}$	(N/mm^2)		43,0	53,3	72,8	355

Verification of the bottom plate

For point 2: $f_{y,\theta} = f_{y,\theta 2}$ = 53,3 N/mm^2. C_p follows from equation (2.31):

$$C_p = 1 - \sqrt{1 - 2\cdot\frac{e_1 - e_2}{t_p^2}\cdot\frac{q_{max}}{f_{y,\theta}}} + \frac{q_{max}\sqrt{3}}{f_{y,\theta}t_p}$$

$$= 1 - \sqrt{1 - 2\cdot\frac{320 - 200}{15^2}\cdot\frac{24{,}1}{53{,}3}} + \frac{24{,}1\cdot\sqrt{3}}{53{,}3\cdot 15} = 0{,}333 \leq 1$$

Verification of the bottom flange

For the bottom flange, the temperature is determined by linear interpolation between points 3 and 4:

$$\theta_f = \theta_3 - \frac{\frac{1}{2}t_f + t_p}{h_{tot}}\left(\theta_3 - \theta_4\right) = 721 - \frac{\frac{1}{2}\cdot 15 + 15}{215}\cdot\left(721 - 68\right) = 653\ ˚C$$

For the lower flange: $f_{y,\theta} = f_{y,\theta f}$ = 115 N/mm^2. C_f then follows from equation (2.31), where the term $(e_1 - e_2)$ has to be replaced by e_2 and t_p by t_f:

$$C_f = 1 - \sqrt{1 - 2 \cdot \frac{e_2}{t_f^2} \cdot \frac{q_{max}}{f_{y,\theta}}} + \frac{q_{max}\sqrt{3}}{f_{y,\theta} t_f} = 1 - \sqrt{1 - 2 \cdot \frac{200}{15^2} \cdot \frac{24{,}1}{115}} + \frac{24{,}1 \cdot \sqrt{3}}{115 \cdot 15} = 0{,}232 \leq 1$$

Verification of the plastic moment capacity of the cross-section with the table

Table NL2.4 shows the reduction of the longitudinal plastic moment capacity for C = 0,0 and C = 1,0. A safe approach is to determine the moment capacity for C = 0,333 (the highest value of C_p and C_f) using linear interpolation.
From table NL2.4 it follows for C = 0,0: $M_{\theta,pl} = 0{,}609 W_{pl} f_y = 0{,}609 \cdot 822 \cdot 103 \cdot 355 \cdot 10^{-6} = 178$ kNm.
For C = 1,0 it follows: $M_{\theta,pl} = 0{,}491 W_{pl} f_y = 0{,}491 \cdot 822 \cdot 103 \cdot 355 \cdot 10^{-6} = 143$ kNm $> M_{\theta,d} = 125$ kNm.
For C = C_p = 0,333, $M_{\theta,pl}$ = 166 kNm is found by interpolation.
When the C value for the lower plate is significantly higher than the C value for the lower flange, the interpolation is very safe and in that case it is better to use the manual calculation.

Verification of the plastic moment capacity of the cross-section by a manual cross-section calculation

The cross-sectional reduction is:

$$A_{PP,eff} = \left(b_p - e_2 - \frac{1}{6} C_p \left(e_1 - e_2\right)\right) t_p$$
$$= \left(400 - 200 - \frac{1}{6} \cdot 0{,}333 \cdot (320 - 200)\right) \cdot 15 = 2900 \text{ mm}^2$$

$$A_{NPP,eff} = \left(1 - \frac{1}{2} C_p\right) t_p e_2 = \left(1 - \frac{1}{2} \cdot 0{,}333\right) \cdot 15 \cdot 200 = 2501 \text{ mm}^2$$

$$A_{BF,eff} = \left(1 - \frac{1}{6} C_p\right) t_f e_2 = \left(1 - \frac{1}{6} \cdot 0{,}333\right) \cdot 15 \cdot 200 = 2884 \text{ mm}^2$$

For each part of the cross-section, see figure NL2.5, the plastic normal force can be determined:

	A_{eff} (mm^2)	θ (°C)	$f_{y.\theta}$ (N/mm^2)	$N_{\theta,pl}$ (kN)	z (mm)	$M_{\theta,pl}$ (kNm)
TF	3000	68	355	1065	–25,2	26,8
W1 (compression)	188	178	355	67	8,8	0,6
W1 (tension)	264	178	355	94	12,4	1,2
W2	452	307	355	160	46,1	7,4
W3	452	436	331	150	88,6	13,3
W4	452	565	199	90	131,1	11,8
BF	2884	653	114	330	159,8	52,8
NPP	2501	721	72,8	182	174,8	31,9
PP	2900	800	43,0	125	174,8	21,9

The total plastic normal force is the sum of the plastic normal forces in the individual parts and amounts to 2263 kN. Half of this force (1132 kN) is slightly more than the force provided by the top flange (1065 kN). Therefore the neutral is in web part W1. The location of the neutral line from the top of the profile z_{na} is:

$$z_{na} = t_f + \frac{0{,}5N_{\theta,pl,tot} - N_{\theta,pl,TF}}{N_{\theta,pl,W1}} \cdot \frac{h - 2t_f}{4} = 15 + \frac{1132 - 1065}{161} \cdot \frac{200 - 2 \cdot 15}{4} = 32{,}7 \text{ mm}$$

The sum of the contributions to the plastic moment of the normal forces multiplied by the distance z to the neutral axis results in $M_{\theta,pl}$ = 168 kNm > $M_{\theta,d}$ = 125 kNm.

Conclusion

Both the transverse load-bearing capacity (of the bottom plate and bottom flange) and the longitudinal moment capacity $M_{\theta,pl}$ are sufficient in the fire design situation. The SFB 200-HEB 200-400x15 beam has therefore a fire resistance of 60 minutes, without protecting the bottom plate.

p. 2-44 ***EN 1990, cl. A1.3.2***

The recommended value ψ_2 = 0,3 is accepted.

p. 2-46 ***Literature***

Additional literature specific for The Netherlands.

11. Baaij Software Engineering, *GLigger 1.11 (Berekenen van geïntegreerde liggers)* (in English: Design of integrated beams), Bouwen met Staal, Zoetermeer 2014. See publicaties.bouwenmetstaal.nl/1589/GLigger-1.11-(berekenen-van-geïntegreerde-liggers)/.
12. A.J. Breunesse and J.H.H. Fellinger, *Brandwerendheid van geïntegreerde liggers* (in English: Fire resistance of integrated beams) (TNO report 2002-CVB-R06136), Delft 2002.
13. A.J. Breunese, A.F. Hamerlinck and J.H.H. Fellinger, 'Geïntegreerde liggers 60 minuten brandwerend zonder bekleding?' (in English: 'Integrated beams 60 minutes fire resistant without protection'), *Bouwen met Staal* 169 (2002), p. 46-53. Free to download at: www.brandveiligmetstaal.nl/upload/File/liggers/169_46.pdf.
14. A.F. Hamerlinck, *Veilige waarden voor de kritieke staaltemperatuur bij ontwerp en aanbesteding* (in English: Safe values for the critical steel temperature for design and tendering), Bouwen met Staal, Zoetermeer 2015. Free to download at: gratis-publicaties.bouwenmetstaal.nl.
15. A.F. Hamerlinck and B. Potjes, 'Nieuwe richtlijn voor succcesvol vloerconcept' (in English: 'New guideline for a successful floor concept of integrated beams and hollow core slabs'), *Bouwen met Staal* 191 (2006), p. 26-29.
16. *NEN-EN 1990+A1+A1/C2* (Eurocode. Grondslagen van het constructief ontwerp), 2019 + NB, 2019.

17. *NEN-EN 1991-1-2+C3* (Eurocode 1. Belastingen op constructies. Deel 1-2. Algemene belastingen. Belasting bij brand), 2019 + NB, 2019.
18. NEN-EN 1993-1-1+C2+A1 (Eurocode 3. Ontwerp en berekening van staalconstructies.Deel 1-1. Algemene regels en regels voor gebouwen), 2016 + NB, 2016.
19. *NEN-EN 1993-1-2+C2* (Eurocode 3. Ontwerp en berekening van staalconstructies. Deel 1-2. Algemene regels. Ontwerp en berekening van constructies bij brand), 2011 + NB, 2015.

Annex NL 3

Fire safety engineering

p. 3-8 ***EN 1991-1-2, annex C***

In The Netherlands, this is possible by using the ‘equivalent safety principle’ of the Dutch Building Decree, cl. 1.3. According to the Dutch National Annex, Annex C of EN 1991-1-2 has an informative status. The principles of the LOCAFI research project and design rules will be incorporated in Annex C of the next version of EN 1991-1-2.

p. 3-9 ***EN 1991-1-2, annex C***

In The Netherlands, design recommendations have been given in [26], In this Dutch guideline the local fire scenario in an open, naturally ventilated car park depends on the fire resistance requirement according to the building regulations (in minutes).

p. 3-10 (a) ***EN 1991-1-2, annex E***

In The Netherlands, the application of the natural fire safety concept – including for instance active fire safety measures (such as sprinkler and dectection systems) – is accepted *because* Annex E of EN 1991-1-2 has a normative status (for steel structures in which the effect of restraint forces is neglegible or taken into account in the design), see [35].

The situation with respect to the application of fire safety engineering (natural local and compartment fires as well as system behaviour of structures) is described in the Legal Context documents of [8], for all member states. The Dutch version can als be found in [29].

Fire resistance with respect to the load-bearing function used to be described (up to 2012) with reference to the standard fire exposure (see fig. 2.1). Since the Dutch Building Decree 2012 has been enforced, however, the fire resistance is no longer explicitly connected to the standard fire. Chapter 2.2 of the Dutch Building Decree 2012 more neutrally describes (as well as the new Dutch Environmental Structures Decree as of 2022 will describe) the requirement as ‘the structure does not collapse within ... minutes’. As to the determination of the fire resistance, the Dutch Building Decree defines that the Eurocodes shall be used, see [29].

Since the Eurocodes are mandatory, the ‘load case fire’ has to be treated according to NEN-EN 1991-1-2 + National Annex (together with NEN-EN 1993-1-2 + National Annex (steel) and NEN-EN 1994-1-2 + National Annex (composite), respecively). EN 1991-1-2 enables the structural designer to choose between a ‘traditional fire design’ of a single member on the basis of standard fire exposure or a ‘fire engineering design’ of a single member or ‘fire safety engineering design’ of a structural system on the basis of a natural fire, so called system behaviour, see figure 3.2.

The first method is straightforward. The latter method refers primarily to Annexes B-E of EN 1991-1-2, in which the procedures to design external members, localised fires, advanced fire

models and natural (compartment) fires are described. However, some of these EN annexes are informative and therefore have a lower status than the traditional approach with the standard fire curve. In the present version of the Dutch National Annex to EN 1991-1-2 the status of the Annexes C-D is informative. This means that local authorities are not obliged to accept a design that is in accordance with these annexes and they have some freedom to reject such designs or at least ask for further prove or explanation of the design and the equal fire safety. Annex E the Dutch National Annex about the fire safety engineering of natural compartment fires, however, is normative (for steel structures in which the effect of restraint forces is negligible or taken into account in the design). In the design attention has to be paid to specific aspects not taken in to account in the traditional design, e.g. the cooling phase, connections and thermal deformations. The normative status of annex E means an important step forward in the application of 'fire engineering design'.
A more detailed description of the physical one and two zone models on which the natural fire concept in EN 1991-1-2 is based can be found in [34]. Backgrounds of the National Annex [35] can be found in [25, 27, 28, 30, 32, 33].

p. 3-10 (b) ***EN 1991-1-2, annex E***

No additional requirements in The Netherlands. In some cases the Dutch National Annex [35] gives additional values for the fire load density of specific occupancies.

p. 3-12 (a) ***EN 1991-1-2, annex E***

In the Dutch National Annex a number of adaptations to Annex E of EN 1991-1-2 has been made.

1. EN 1991-1-2, cl. E.1 describes a simplified method with partial risk factors. The introduction of separate partial risk factors (as is currently the case with EN 1991-1-2) can, when multiplied, lead to deviations from the original European method [5]. The Dutch National Annex therefore applies the original method. This resulted in a number of extra tables (table NB.2 to NB.4) that show the partial probabilities p_i, each corresponding to the individual partial risk factors in EN 1991-1-2. These partial probabilities are multiplied with each other from which the reference probability for the specific situation follows. The corresponding global risk factor δ_{qf} is then determined using table NB.1. This factor multiplies the characteristic fire load in order to take into account the activation risk: the risk of a fire threatening the structure, depending on the size of the fire compartment p_1, the occupancy p_2 and the effect of the active fire safety measures p_{ni} (see equations NB.1, NB. 3 and NB.4):

   $$q_{f,r} = q_{f,d} \cdot \delta_{qf} = q_{f,k} \cdot m \cdot \delta_{qf}$$

2. An additional correction factor p_{cc} according to the consequence class CC (p_{cc} = 0,005 for CC1, p_{cc} = 0,03 for CC2 and p_{cc} = 0,2 for CC3), see table NB.5, has been introduced.
3. Tables NB.2 to NB.5 with values of the partial probabilities are used to calulate the reference probability p_{tot} by equation (NB.4):

   $$p_{tot} = p_1 \cdot p_2 \cdot \Pi p_{ni} \cdot p_{cc}$$

4. An additional equation NB.2 to take into account the activation risk and the effect of the active fire safety measures in a physically more feasible way (compared to EN 1991-1-2), by application of the overall risk factor δ_{qf} on the rate of heat release, being the primary physical parameter:

   $$RHR_{f,\rho}(t) = RHR_{f,\delta}(t) \cdot \delta_{qf}$$

   $RHR_{f,r}(t)$ is the rate of heat release curve to be taken into account in the calculation and $RHR_{f,d}(t)$ is the design curve of the the rate of heat release in the fire compartment (this can be both the fuel and the ventilation controlled situation). This means that it is not only the effect on the fire load that is considered, but on the effect of the rate of heat release as well. The fire load is the derivation of the rate of heat release, i.e. the area below the rate of heat release curve (see fig. 3.15). This adjustment is an improvement compared to EN 1991-1-2, because it is not the fire load density that is the most important, primary thermal parameter, but the rate of heat release. The effect of a sprinkler system, among other things, is better expressed in this way.

In order to study the effect of the use of compartment fires with one and two zone models according to the Eurocodes and to compare the results with the current classification system based on fire resistance requirements according to the standard fire, the Dutch normalization institute NEN started the project 'Physical fire model' in 2006. The goal was the alignment of risk levels with public law and regulations. The first phase of this project was completed in 2009 [27] with the conclusion that the calculations according to NEN-EN 1991-1-2 with the National Annex provide 'robust' solutions. This means that overall there is a sufficient and equivalent level of safety.
In order to better reflect the probabilistic philosophy of the Eurocode – and also to consider the mechanical response to the thermal actions and response – the second phase has been carried out and this was delivered in 2014. After this, the National Annex has been adapted by achieving a better connection to the philosophy of the Eurocodes with consequence classes and, in the meantime, maintaining a good and robust approach to the intended safety level of the building regulations.
The NEN working group 'Fire safety engineering' of the standardization committee 'Fire safety of construction works' has produced an extensive series of background documents [25, 27, 28, 32, 33] in which the insights gained and discussions are described. These documents form the basis for the text of the National Annex and they provide also the justification for the choices made. A natural fire calculation has also been made for four occupancies (office, residential, hotel and shop), which gives a nuanced picture of the fire temperatures in relation to the size of the fire compartment and the level of fire safety measures. A more extensive comparison was then made between calculations with a natural fire and with the standard fire for low buildings up to and including high-rise buildings [27].

A physical fire model based on a natural fire concept is described in the new design standard NEN 6055 [34]. This model also contains one and two zone models, but not the risk factors from

EN 1991-1-2. NEN 6055 is suitable for a broader purpose than merely assessing whether or not load-bearing structures will collapse in the event of a fire. However, the Dutch National Annex is only suitable for this purpose. If the physical fire model is also used to assess whether safe evacuations or safe repression is possible, the risk approach according to the Dutch National Annex cannot be followed. In this case, other normative scenarios should be considered, possibly with a general probabilistic approach (scenarios with probability of occurrence and effect on victims or damage). The physical fire model according to NEN 6055 is then applied without global risk factor on the fire load and/or the rate of heat release as indicated in EN 1991-1-2.

p. 3-12 (b) ***EN 1991-1-2, annex E***

See remarks to p. 3-12 (a).

p. 3-14 ***EN 1991-1-2, annex B and EN 1993-1-2, annex B***

In The Netherlands, the determination of thermal actions on a steel structure outside the façade (taking radiation and convection into account) is possible *because* Annex B of EN 1991-1-2 and Annex B of EN 1993-1-2 (for the fire safety engineering of external steel structures) both have the normative status. In some cases (e.g. where direct flame contact can be excluded because of the distance between the windows and the structure) a conservative design is possible by adopting the external fire curve of EN 1991-1-2, cl. 3.2.2.

p. 3-17 ***EN 1993-1-2, cl. 4.1***

According to the Dutch National Annex of EN 1991-1-2, cl. 4.1, advanced calculation models according to EN 1991-1-2, cl. 4.3 are allowed (using the 'equivalent safety principle' of the Dutch Building Decree, cl. 1.3). The principles and design rules of the MACS research project satisfy the requirements of EN 1991-1-2, cl. 4.3 and will be incorporated in the next version of EN 1993-1-2. Besides the refences of section 3.5 [2, 9, 17], reference is made to an early publication about realistic behaviour of steel structures in the event of fire, see [31].

p. 3-22 ***Literature***

Additional literature specific for The Netherlands.

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26. A.F. Hamerlinck, A. Breunese, L. Noordijk, D.W.L. Jansen and N.J. van Oerle, *Richtlijn brandveiligheid stalen parkeergarages* (in English: Guideline for the fire safety of steel car parks), Bouwen met Staal, Zoetermeer 2011. Free to download at: www.brandveiligmetstaal.nl/upload/File/actueel/Richtlijn_Brandv_Parkeerg_BmS_1e_editie_nov2011.pdf.
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30. Nieman Raadgevende Ingenieurs, *Risicogebaseerde brandveiligheid van draagconstructies. Afstemming thermische belasting (natuurlijk brandconcept) en mechanische respons op veiligheidsniveau van de publiekrechtelijke regelgeving (2e fase)* (in English: Risk based fire safety of structures. Alignment to the fire safety level of the with public law regulations of the thermal actions (physical fire model) (2nd phase)) (rapport Wu040430abA0.rhe), Zwolle 2014.
31. L. Twilt and C. Both, 'Werkelijk gedrag van een staalconstructie bij brand onderzocht' (in English: 'Actual behaviour of a steel structure in the event of fire'), *Bouwen met Staal* 141 (1998), p. 27-31.
32. N. Voogd and R.A.P. van Herpen, *Fysisch brandmodel. Achtergronden. Normalisatie fysisch brandmodel. Basismodel* (in English: Physical fire model. Backgrounds. Standardization of physical fire model. Basic model) (research report Wu040430aaA1.rhe), Adviesbureau Nieman, Zwolle 2007.
33. N. Voogd and R.A.P. van Herpen, *Fysisch brandmodel. Achtergronden. Normalisatie fysisch brandmodel. Submodellen* (in English: Physical fire model. Backgrounds. Standardization of physical fire model. Submodels) (rapport Wu040430aaA2.rhe), Adviesbureau Nieman, Zwolle 2007.
34. *NEN 6055* (Thermische belasting op basis van het natuurlijk brandconcept. Bepalingsmethode) (in English: Thermal exposure based on the natural fire concept. Assessment method), 2011.
35. *NEN-EN 1991-1-2+C3* (Eurocode 1. Belastingen op constructies. Deel 1-2. Algemene belastingen. Belasting bij brand), 2019 + NB, 2019.
36. *NEN-EN 1992-1-2+C1* (Eurocode 2. Ontwerp en berekening van betonconstructies. Deel 1-2. Algemene regels. Ontwerp en berekening van constructies bij brand), 2011 + NB, 2011.
37. *NEN-EN 1993-1-2+C2* (Eurocode 3. Ontwerp en berekening van staalconstructies. Deel 1-2. Algemene regels. Ontwerp en berekening van constructies bij brand), 2011 + NB, 2015.
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Design tables

p. 4-7 ***EN 1990, cl. A1.3.2***

The Dutch National Annex specifies:

- ψ_2 shall be used for imposed (variable) loads on floors and roofs;
- ψ_1 (= 0,2) shall be used for wind loads in the case of a structural element which collapse causes the collapse of a structural element in another fire compartment (progressive collapse or disproportional damage). In other cases ψ_2 (= 0) shall be used for wind loads.

p. 4-8 ***EN 1990, cl. A1.3.2***

See remarks to p. 4-7.