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English version

Eurocode 1 – Actions on Structures

Part 1-2 : General Actions – Actions on structures exposed to fire

FINAL DRAFT

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Eurocode 1 – Actions sur les structures – Partie 1-2 : Actions Générales – Actions sur les structures exposées au feu

Eurocode 1 – Einwirkungen auf Tragwerke – Teil 1-2: Allgemeine Einwirkungen – Einwirkungen im Brandfall

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Contents

page

European foreword

This document (EN 1991-1-2:20xx) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI.

This document is a working document

Introduction

Introduction to EN1991-2

EN 1991-1-2 gives design guidance and application rules in connection to thermal and mechanical actions on structures exposed to fire.
EN 1991-1-2 is intended for clients, designers, contractors and relevant authorities.
EN 1991-1-2 is intended to be used with EN 1990, the other Parts of EN 1991 and EN 1992-1999 for the design of structures.

Verbal forms used in the Eurocodes

The verb “shall" expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.
The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.
The verb “may" expresses a course of action permissible within the limits of the Eurocodes.
The verb “can" expresses possibility and capability; it is used for statements of fact and clarification of concepts.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National annex (informative).
A National Annex can only contain information on those parameters, known as Nationally Determined Parameters (NDPs), that are left open in the Eurocodes for national choice. These NDPs are to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e.:

- values and/or classes where alternatives are given in the Eurocode,
- values to be used where a symbol only is given in the Eurocode,
- country specific data (geographical, climatic, etc.), e.g. snow map,
- the procedure to be used where alternative procedures are given in the EN Eurocode.

The National Annex can also contain

- decisions on the application of informative annexes,
- references to non-contradictory complementary information (NCCI) to assist the user to apply the Eurocodes.

Additional information specific to EN 1991-1-2

EN 1991-1-2 describes the thermal and mechanical actions for the structural design of buildings exposed to fire, including requirements and design procedures.

Safety requirements

The general objectives are to limit risks with respect to the individual and society, neighbouring property, and where required, environment or directly exposed property, in the case of fire.

Construction Products Regulation (EU) No 305/2011 gives the following requirement for the limitation of the consequence in case of fire:

"The construction works must be designed and built in such a way, that in the event of an outbreak of fire

- the load bearing capacity of the construction can be assumed for a specified period of time,
- the generation and spread of fire and smoke within the works are limited,
- the spread of fire to neighbouring construction works is limited,
- the occupants can leave the works or can be rescued by other means,
- the safety of rescue teams is taken into consideration".

According to the Interpretative Document N°2 "Safety in Case of Fire[1]" the essential requirement may be observed by following various possibilities for fire safety strategies prevailing in the Member States like conventional fire scenarios (nominal fires) or "natural" (Physically based) fire scenarios, including passive and/or active fire protection measures.

Required functions and levels of performance can be specified either in terms of nominal (standard) fire resistance rating, generally given in national fire regulations or, where allowed by national fire regulations, by referring to fire safety engineering for assessing passive and active measures.

The fire parts of Structural Eurocodes deal with specific aspects of passive fire protection in terms of designing structures and parts thereof for adequate load bearing resistance and for limiting fire spread as relevant.

Numerical values for partial factors and other reliability elements are given as recommended values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and of quality management applies.

This document does not cover the supplementary requirements concerning, for example:

- the possible installation and maintenance of sprinkler systems;
- conditions on occupancy of building or fire compartment;
- the use of approved insulation and coating materials, including their maintenance

, because they are subject to specification by the relevant authority.

Design procedures

A full analytical procedure for structural fire design would take into account the behaviour of the structural system at elevated temperatures, the potential heat exposure and the beneficial effects of active and passive fire protection systems, together with the uncertainties associated with these three features and the importance of the structure (consequences of failure).

At the present time, it is possible to undertake a procedure for determining adequate performance which incorporates some, if not all, of the above parameters and to demonstrate that the structure, or its components, will give adequate performance in a real building fire. However, where the procedure is based on a nominal (standard) fire, the classification system, which calls for specific periods of fire resistance, takes into account (though not explicitly) the features and uncertainties described above.

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[1] See 2.2, 3.2(4) and 4.2.3.3 of ID N°2.

Figure 1 illustrates the two design procedures provided by the Part 1-2 of EN 1991,i.e. the prescriptive approach and the performance-based approach. The prescriptive approach uses nominal (standard) fires to generate thermal actions. The performance-based approach, using fire safety engineering, refers to thermal actions based on physical and chemical parameters.

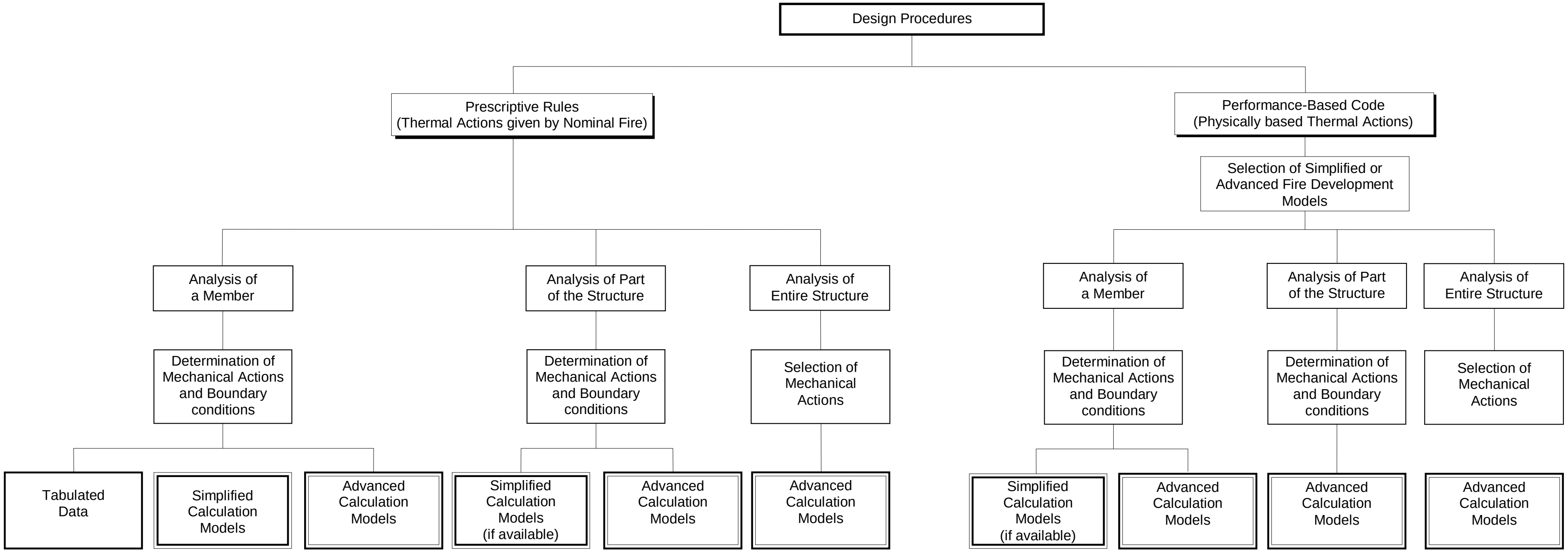


Figure 1 — Alternative design procedures

National annex for EN 1991-2

This standard gives values within notes indicating where national choices can be made. Therefore the National Standard implementing EN 1991-2 can have a National Annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.
National choice is allowed in EN 1991-2 through clauses:

- 2.4(4)
- 3.1(10)
- 3.3.1.2(1)
- 3.3.1.3(1)
- 3.3.2(2)
- 4.2.2(2)
- 4.3.1(2)

National choice is allowed in EN 1991-2 on the use of informative annexes.

1 Scope

1.1 Scope of EN 1991

(1) XXXXX

1.2 Scope of EN 1991-1-2

(1) ~~This Part 1-2 of EN 1991~~ The methods given in this Part of EN 1991 are ~~is~~ applicable to buildings and civil engineering works, with a fire load related to the building and its occupancy.

(2) This Part ~~1-2~~ of EN 1991 deals with thermal and mechanical actions on structures exposed to fire. It is intended to be used in conjunction with the fire design Parts of EN 1992 to EN 1996 and EN 1999 which give rules for designing structures for fire resistance.

(3) This Part ~~1-2~~ of EN 1991 contains thermal actions either ~~related to~~ nominal ~~and~~ or physically based ~~thermal actions~~. More data and models for physically based thermal actions are given in annexes.

(4) This Part ~~1-2~~ of EN 1991 does not cover the assessment of the damage of a structure after a fire~~.~~

1.3 Assumptions

(1)P In addition to the general assumptions of EN 1990 the following assumptions apply:

- any active and passive fire protection systems taken into account in the design will be adequately maintained;
- the choice of the relevant design fire scenario is made by appropriate qualified and experienced personnel, or is given by the relevant national regulation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 13501-2, Fire classification of construction products and building elements - Part 2: Classification using data from fire resistance tests, excluding ventilation services.

EN 1990:2002, *Eurocode: Basis of structural design.*

EN 1991, *Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight and imposed loads.*

EN 1991, *Eurocode 1: Actions on structures - Part 1-3: General actions - Snow loads.*

EN 1991, *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind loads.*

EN 1992, *Eurocode 2: Design of concrete structures.*

EN 1993, *Eurocode 3: Design of steel structures.*

EN 1994, *Eurocode 4: Design of composite steel and concrete structures.*

EN 1995, *Eurocode 5: Design of timber structures.*

EN 1996, *Eurocode 6: Design of masonry structures.*

EN 1999, *Eurocode 9: Design of aluminium structures.*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this ~~European Standard~~ Part of EN 1991, the ~~terms and~~ definitions ~~given in~~ of EN 1990 ~~and the following apply.~~ apply with the following additional definitions.

3.1.1 Common terms used in Eurocode Fire parts

3.1.1.1

equivalent time of fire exposure
time of exposure to the standard temperature-time curve supposed to have the same heating effect as a real fire in the compartment

3.1.1.2
external member
structural member located outside the building that may be exposed to fire through openings in the building enclosure

3.1.1.3
compartment, fire compartment
space within a building, extending over one or several floors, which is enclosed by separating elements such that fire spread beyond the compartment is prevented during the relevant fire exposure

3.1.1.4
fire resistance
ability of a structure, a part of a structure or a member to fulfil its required functions (load bearing function and/or fire separating function) for a specified load level, for a specified fire exposure and for a specified period of time

3.1.1.5
fully developed fire
state of full involvement of all combustible surfaces in a fire within a specified space

3.1.1.6
global structural analysis (for fire)
structural analysis of the entire structure, when either the entire structure, or only a part of it, are exposed to fire. Indirect fire actions are considered throughout the structure

3.1.1.7
indirect fire actions
internal forces and moments caused by thermal expansion

3.1.1.8
integrity (E)
ability of a separating element of building construction, when exposed to fire on one side, to prevent the passage through it of flames and hot gases and to prevent the occurrence of flames on the unexposed side

3.1.1.9
insulation (I)
ability of a separating element of building construction when exposed to fire on one side, to restrict the temperature rise of the unexposed face below specified levels

3.1.1.10
load bearing function (R)
ability of a structure or a member to sustain specified actions during the relevant fire, according to defined criteria

3.1.1.11
member
basic part of a structure (such as beam, column, but also assembly such as stud wall, truss~~,~~...) considered as isolated with appropriate boundary and support conditions

3.1.1.12
member analysis (for fire)

thermal and mechanical analysis of a structural member exposed to fire in which the member is assumed as isolated, with appropriate support and boundary conditions. Indirect fire actions are not considered, except those resulting from thermal gradients

3.1.1.13
normal temperature design
ultimate limit state design for ambient temperatures according to Part 1-1 of EN 1992 to EN 1996 or EN 1999

3.1.1.14
separating function
ability of a separating element to prevent fire spread (e.g. by passage of flames or hot gases – cf. integrity) or ignition beyond the exposed surface (cf. insulation) during the relevant fire

3.1.1.15
separating element
load bearing or non-load bearing element (e.g. wall) forming part of the enclosure of a fire compartment

3.1.1.16
standard fire resistance
ability of a structure or part of it (usually only members) to fulfil required functions (load-bearing function and/or separating function), for the exposure to heating according to the standard temperature-time curve for a specified load combination and for a stated period of time

3.1.1.17
structural members
load-bearing members of a structure including bracings

3.1.1.18
temperature analysis
procedure of determining the temperature development in members based on the thermal actions (net heat flux) and the thermal material properties of the members and of protective surfaces, where relevant

3.1.1.19
thermal actions
actions on the structure described by the net heat flux to the members

3.1.2 Special terms relating to design in general

3.1.2.1
advanced fire model
design fire based on mass conservation and energy conservation aspects

3.1.2.2
computational fluid dynamics model
fire model able to solve numerically the partial differential equations giving, in all points of the compartment, the thermo-dynamical and aero-dynamical variables

3.1.2.3
fire wall
separating element that is a wall separating two spaces (e.g. two buildings) that is designed for fire resistance and structural stability, and may include resistance to horizontal loading such that, in case of fire and failure of the structure on one side of the wall, fire spread beyond the wall is avoided

3.1.2.4
one-zone model
fire model where homogeneous temperatures of the gas are assumed in the compartment

3.1.2.5
simplified fire model
design fire based on a limited application field of specific physical parameters

3.1.2.6
two-zone model
fire model where different zones are defined in a compartment: the upper layer, the lower layer, the fire and its plume, the external gas and walls. In the upper and lower layers, uniform temperature of the gas is assumed

3.1.3 Terms relating to thermal actions

3.1.3.1
combustion factor
factor representing the efficiency of combustion, varying between 1 for complete combustion to 0 for combustion fully inhibited

3.1.3.2
design fire
quantitative description of assumed fire characteristics within a design fire scenario specified

3.1.3.3
design fire load density
fire load density considered for determining thermal actions in fire design

3.1.3.4
design fire scenario
specific fire scenario on which an analysis will be conducted

3.1.3.5
external fire curve
nominal temperature-time curve intended for the outside of separating (EI) external walls and parapets which can be exposed to fire from ~~different parts of the facade, i.e. directly from the inside of the respective fire compartment or from~~ a compartment situated below or adjacent to the respective external wall

3.1.3.6
fire activation risk
parameter taking into account the probability of ignition, function of the compartment area and the occupancy

3.1.3.7
fire load density
fire load per unit area related to the floor area q_f, or related to the surface area of the total enclosure, including openings, q_t

3.1.3.8
fire load
Quantity of energy which is released by complete combustion of all combustible materials in a compartment or a localised fire area (building contents and construction elements)

3.1.3.9
fire scenario
qualitative description of the course of a fire with time identifying key events that characterize the fire and differentiate it from other possible fires. It typically defines the ignition and fire growth process, the fully developed stage and decay stage together as well as systems that impact the course of the fire and the nature of local environment

3.1.3.10
flash-over
simultaneous ignition of all the fire loads in a compartment

3.1.3.11
hydrocarbon fire curve
nominal temperature-time curve for representing effects of a hydrocarbon type fire

3.1.3.12
localised fire
fire involving only a limited area of the compartment

3.1.3.13
opening factor
factor representing the amount of ventilation depending on the area of openings in the compartment walls, on the height of these openings and on the total area of the enclosure surfaces

3.1.3.14
rate of heat release
heat (energy) released by a combustible product as a function of time

3.1.3.15
standard temperature-time curve
nominal curve defined in EN 13501-2 for representing a model of a fully developed fire in a compartment

3.1.3.16
temperature-time curves
gas temperature in the environment of member surfaces as a function of time. They may be:

- **nominal**: conventional curves, adopted for classification or verification of fire resistance, e.g. the standard temperature-time curve, external fire curve, hydrocarbon fire curve;
- **physically based**: determined on the basis of fire models and the specific physical parameters defining the conditions in the fire compartment

3.1.4 Terms relating to heat transfer analysis

3.1.4.1
configuration factor
configuration factor for radiative heat transfer from surface A to surface B is defined as the fraction of diffusely radiated energy leaving surface A that is incident on surface B

3.1.4.2
convective heat transfer coefficient
convective heat flux to the member related to the difference between the bulk temperature of gas bordering the relevant surface of the member and the temperature of that surface

3.1.4.3
emissivity
equal to absorptivity of a surface, i.e. the ratio between the radiative heat absorbed by a given surface and that of a black body surface

3.1.4.4
net heat flux
energy, per unit time and surface area, definitely absorbed by members

3.2 Symbols and abbreviations

For the purpose of this Part ~~1-2~~ of EN 1991, the following symbols apply.

Latin upper case letters

A	area of the fire compartment
$A_{ind,d}$	design value of indirect action due to fire
A_f	floor area of the fire compartment
A_{fi}	fire area
A_h	area of horizontal openings in roof of compartment
$A_{h,v}$	total area of openings in enclosure ($A_{h,v} = A_h + A_v$)
A_j	area of enclosure surface j, openings not included
A_t	total area of enclosure (walls, ceiling and floor, including openings)
A_v	total area of vertical openings on all walls ($A_v = \sum_i A_{v,i}$)
$A_{v,i}$	area of window "i"
C_i	protection coefficient of member face i
D	depth of the fire compartment, diameter of the fire
E_d	design value of the relevant effects of actions from the fundamental combination according to EN 1990
$E_{d,fi}$	constant design value of the relevant effects of actions in the fire situation
$E_{d,fi,t}$	design value of the relevant effects of actions in the fire situation at time t
E_g	internal energy of gas
H	distance between the fire source and the ceiling
H_u	net calorific value including moisture
H_{u0}	net calorific value of dry material
H_{ui}	net calorific value of material i
L_c	length of the core
L_f	flame length along axis
L_H	horizontal projection of the flame (from the facade)
L_h	horizontal flame length
L_L	flame height (from the upper part of the window)

L_x	axis length from window to the point where the calculation is made
$M_{k,i}$	amount of combustible material i
O	opening factor of the fire compartment $\left(O = A_v \sqrt{h_{eq}} / A_t\right)$
O_{lim}	reduced opening factor in case of fuel controlled fire
P_{int}	the internal pressure
Q	rate of heat release of the fire
Q_c	convective part of the rate of heat release Q
$Q_{fi,k}$	characteristic fire load
$Q_{fi,k,i}$	characteristic fire load of material i
Q_D^*	heat release coefficient related to the diameter D of the local fire
Q_H^*	heat release coefficient related to the height H of the compartment
$Q_{k,1}$	characteristic leading variable action
Q_{max}	maximum rate of heat release
Q_{in}	rate of heat release entering through openings by gas flow
Q_{out}	rate of heat release lost through openings by gas flow
Q_{rad}	rate of heat release lost by radiation through openings
Q_{wall}	rate of heat release lost by radiation and convection to the surfaces of the compartment
R	ideal gas constant (= 287 [J/kgK])
R_d	design value of the resistance of the member at normal temperature
$R_{fi,d,t}$	design value of the resistance of the member in the fire situation at time t
RHR_f	maximum rate of heat release per square meter
T	the temperature [K]
T_{amb}	the ambient temperature [K]
T_0	initial temperature
T_f	temperature of the fire compartment [K]
T_g	gas temperature [K]
T_w	flame temperature at the window [K]

T_z	flame temperature along the flame axis [K]
W	width of wall containing window(s)
W_1	width of the wall 1, assumed to contain the greatest window area
W_2	width of the wall of the fire compartment, perpendicular to wall W_1
W_a	horizontal projection of an awning or balcony
W_c	width of the core

Latin lower case letters

b	thermal absorptivity for the total enclosure ($b = \sqrt{(\rho c \lambda)}$)
b_i	thermal absorptivity of layer i of one enclosure surface
b_j	thermal absorptivity of one enclosure surface j
c	specific heat
d_{eq}	geometrical characteristic of an external structural element (diameter or side)
d_f	flame thickness
d_i	cross-sectional dimension of member face i
g	the gravitational acceleration
h_{eq}	weighted average of window heights on all walls $\left(h_{eq} = \left(\sum_i (A_{v,i}\, h_i) \right) / A_v \right)$
h_i	height of window i
$\dot{h}$	heat flux to unit surface area
$\dot{h}_{net}$	net heat flux to unit surface area
$\dot{h}_{net,c}$	net heat flux to unit surface area due to convection
$\dot{h}_{net,r}$	net heat flux to unit surface area due to radiation
$\dot{h}_{tot}$	total heat flux to unit surface area
$\dot{h}_i$	heat flux to unit surface area due to fire i
k	correction factor
k_b	conversion factor
k_c	correction factor
m	mass, combustion factor
$\dot{m}$	mass rate

$\dot{m}_{in}$	rate of gas mass coming in through the openings
$\dot{m}_{out}$	rate of gas mass going out through the openings
$\dot{m}_{fi}$	rate of pyrolysis products generated
q_f	fire load per unit area related to the floor area A_f
$q_{f,d}$	design fire load density related to the floor area A_f
$q_{f,k}$	characteristic fire load density related to the surface area A_f
q_t	fire load per unit area related to the surface area A_t
$q_{t,d}$	design fire load density related to the surface area A_t
$q_{t,k}$	characteristic fire load density related to the surface area A_t
r	horizontal distance between the vertical axis of the fire and the point along the ceiling where the thermal flux is calculated
s_i	thickness of layer i
s_{lim}	limit thickness
t	time
$t_{e,d}$	equivalent time of fire exposure
$t_{d,fi}$	design fire resistance (property of the member or structure)
$t_{fi,requ}$	required fire resistance time
t_{lim}	time for maximum gas temperature in case of fuel controlled fire
t_{max}	time for maximum gas temperature
t_{α}	fire growth rate coefficient
u	wind speed, moisture content
w_i	width of window "i"
w_t	sum of window widths on all walls ($w_t = \Sigma w_i$); ventilation factor referred to A_t
w_f	width of the flame; ventilation factor
y	coefficient parameter
z	height
z_0	virtual origin of the height z
z'	vertical position of the virtual heat source

Greek upper case letters

Φ	configuration factor
Φ_f	overall configuration factor of a member for radiative heat transfer from an opening
$\Phi_{f,i}$	configuration factor of member face i for a given opening
Φ_z	overall configuration factor of a member for radiative heat transfer from a flame
$\Phi_{z,i}$	configuration factor of member face i for a given flame
Γ	time factor function of the opening factor O and the thermal absorptivity b
Γ_{lim}	time factor function of the opening factor O_{lim} and the thermal absorptivity b
Θ	temperature [°C]; Θ [°C] = T [K] - 273
$\Theta_{cr,d}$	design value of the critical material temperature [°C]
Θ_d	design value of material temperature [°C]
Θ_g	gas temperature in the fire compartment, or near the member [°C]
Θ_m	temperature of the member surface [°C]
Θ_{max}	maximum temperature [°C]
Θ_r	effective radiation temperature of the fire environment [°C]
Ω	$(A_f \cdot q_{f,d}) / (A_v \cdot A_t)^{1/2}$
Ψ_i	protected fire load factor

Greek lower case letters

α_c	coefficient of heat transfer by convection
α_h	area of horizontal openings related to the floor area
α_v	area of vertical openings related to the floor area
δ_{ni}	factor accounting for the existence of a specific fire-fighting measure i
δ_{q1}	factor taking into account the fire activation risk due to the size of the compartment
δ_{q2}	factor taking into account the fire activation risk due to the type of occupancy
ε_m	surface emissivity of the member
ε_f	emissivity of flames, of the fire
η_{fi}	reduction factor
$\eta_{fi,t}$	load level for fire design
λ	thermal conductivity
ρ	density

ρ_g	internal gas density
σ	Stephan Boltzmann constant (= 5,67 · 10^{-8} [W/(m^{2}K^4)])
τ_F	free burning fire duration
ψ_0	combination factor for the characteristic value of a variable action
ψ_1	combination factor for the frequent value of a variable action
ψ_2	combination factor for the quasi-permanent value of a variable action

4 Structural fire design procedure

4.1 General

(1) A structural fire design analysis shall include the following steps as relevant:

– selection of the relevant design fire scenarios;

– determination of the corresponding design fires;

– calculation of temperature evolution within the structural members;

– calculation of the mechanical behaviour of the structure exposed to fire.

NOTE Mechanical behaviour of a structure depends on:

- thermal actions and their effect on material properties

- indirect fire actions

- the direct and indirect effects of mechanical actions.

(2) Structural fire design should involve the application of actions for temperature analysis and actions for mechanical analysis according to this Part and other Parts of EN 1991.

(3) Actions on structures from fire exposure shall be classified as accidental actions, see EN 1990:2002, 6.4.3.3(4).

4.2 Design fire scenario

(1) To identify the accidental design situation, the relevant design fire scenarios and the associated design fires should be determined on the basis of a fire risk assessment.

(2) For structures where particular risks of fire arise as a consequence of other accidental actions, this risk should be considered when determining the overall safety concept.

(3) Time- and load-dependent structural behaviour prior to the accidental situation ~~should~~ need not be considered, unless (2) applies.

4.3 Design fire

(1) For each design fire scenario, a design fire, in a fire compartment, should be ~~estimated~~ determined according to section 5 of this Part of EN 1991 or with available physical models with justification.

(2) The design fire should be applied only to one fire compartment of the building at a time, unless otherwise specified in the design fire scenario.

(3) For structures, where the national authorities specify structural fire resistance requirements, it may be assumed that the relevant design fire is given by the standard fire, unless specified otherwise.

4.4 Temperature Analysis of members

(1) When performing temperature analysis of a member, the position of the design fire in relation to the member shall be taken into account.

(2) For external members, fire exposure through openings in facades and roofs should be considered.

(3) For separating external walls fire exposure from inside (from the respective fire compartment) and alternatively from outside (from other fire compartments) should be considered when required.

(4) Depending on the design fire chosen in section 5, the following procedures should be used:

- with a nominal ~~temperature-time~~ fire curve, the temperature analysis of the structural members is made for a specified period of time, without any cooling phase;

NOTE 1 ~~Guidance on the calculation of the equivalent time of standard fire exposure is given in Annex F.~~ The specified period of time may be given in the national regulations. If allowed by the national regulations, the specified period of time can be obtained from Annex F following the specifications of the national annex

- with a physically based model, the temperature analysis of the structural members is made for the full duration of the fire, including the cooling phase.

NOTE 2 ~~Limited periods of fire resistance may be set in the national Annex.~~ The national Annex may refer to national regulations in which limited periods of fire resistance are specified.

4.5 Mechanical Analysis of members

(1) The mechanical analysis shall be performed for the same duration as used in the temperature analysis.

(2) Verification of fire resistance should be carried out in the time domain:

$$t_{\mathrm{d,fi}} \geq t_{\mathrm{requi,fi}} \tag{2.1}$$

or in the strength domain:

$$R_{\mathrm{d,fi,t}} \geq E_{\mathrm{d,fi,t}} \tag{2.2}$$

or in the temperature domain:

$$\Theta_{\mathrm{d}} \leq \Theta_{\mathrm{cr,d}} \tag{2.3}$$

where

$t_{\mathrm{d,fi}}$ is the design value of the fire resistance

$t_{\mathrm{requ,fi}}$ is the required fire resistance time

$R_{\mathrm{d,fi,t}}$ is the design value of the resistance of the member in the fire situation at time t

$E_{\mathrm{d,fi,t}}$ is the design value of the relevant effects of actions in the fire situation at time t

Θ_{d} is the design value of material temperature

$\Theta_{\mathrm{cr,d}}$ is the design value of the critical material temperature

5 Thermal actions for temperature analysis

5.1 Heat flux

(1) Thermal actions shall be represented by the net heat flux $\dot{h}_{\text{net}}$ [W/m^2] to the surface of the member.

(2) On the fire exposed surfaces the net heat flux $\dot{h}_{\text{net}}$ should be determined by considering heat transfer by convection and radiation as shown in Formula (5.1):

$$\dot{h}_{\text{net}} = \dot{h}_{\text{net,c}} + \dot{h}_{\text{net,r}} \qquad [\text{W/m}^2] \qquad (5.1)$$

where

$\dot{h}_{\text{net,c}}$ is the net convective heat flux component given by e.q. (5.2)

$\dot{h}_{\text{net,r}}$ is the net radiative heat flux component given by e.q. (5.3)

(3) The net convective heat flux component should be determined by:

$$\dot{h}_{\text{net,c}} = \alpha_{\text{c}} \cdot (\Theta_{\text{g}} - \Theta_{\text{m}}) \qquad [\text{W/m}^2] \qquad (5.2)$$

where

α_{c} is the coefficient of heat transfer by convection [W/(m^{2}K)]

Θ_{g} is the gas temperature in the fire compartment ~~of~~ near the member [°C]

Θ_{m} is the surface temperature of the member, according to the fire design Parts of EN 1992 to EN 1996 and EN 1999, as relevant [°C]

(4) On the fire exposed surface, the coefficient of heat transfer by convection α_{c} relevant for nominal temperature-time curves should be as indicated in 5.2.

(5) On the unexposed side of separating members, the net heat flux $\dot{h}_{\text{net}}$ should be determined by using equation (5.1), with the coefficient of heat transfer α_{c} as follows:

- $\alpha_{\text{c}} = 9$ ~~[~~W/(m^{2}K)~~]~~ when assuming it contains the effects of heat transfer by radiation
- $\alpha_{\text{c}} = 4$ ~~[~~W/(m^{2}K)~~]~~ in all other cases

(6) The net radiative heat flux component per unit surface area is determined by:

$$\dot{h}_{\text{net,r}} = \Phi \cdot \varepsilon_{\text{m}} \cdot \varepsilon_{\text{f}} \cdot \sigma \cdot [(\Theta_{\text{r}} + 273)^4 - (\Theta_{\text{m}} + 273)^4] \qquad [\text{W/m}^2] \qquad (5.3)$$

where

Φ is the configuration factor

ε_{m} is the surface emissivity of the member

ε_{f} is the emissivity of the fire

σ is the Stephan Boltzmann constant (= 5,67 · 10^{-8} W/(m^{2}K^4))

Θ_{r} is the effective radiation temperature of the fire environment [°C]

Θ_{m} is the surface temperature of the member [°C]

NOTE 1 Unless given in the material related fire design Parts of EN 1992 to EN 1996 and EN 1999, the value $\varepsilon_m = 0,8$ ~~shall~~ should be used.

NOTE 2 The emissivity of the fire is taken in general as $\varepsilon_f = 1,0$.

(7) ~~Unless otherwise given in Part or the fire design Parts of EN 1992 to EN 1996 and EN 1999,~~ Where this Part or the fire part of EN 1992 to EN 1996 and EN 1999 give no specific data, the configuration factor should be taken as $\Phi = 1,0$. A lower value of the configuration factor may be chosen to take account of position and shadow effects.

NOTE For the calculation of the configuration factor Φ a method is given in Annex G. This Annex also clarifies position and shadow effects.

(8) In case of fully fire engulfed members, the radiation temperature Θ_r may be represented by the gas temperature Θ_g around that member.

(9) Gas temperatures Θ_g may be ~~adopted as~~ taken from nominal ~~temperature-time~~ fire curves according to 3.2, or ~~adopted~~ calculated according to the physically based fire models ~~according to~~ given in 5.3.

5.2 Nominal ~~temperature-time fire~~ curves

5.2.1 Standard ~~temperature-time~~ fire curve

(1) The standard ~~temperature-time~~ fire curve is given by Formula (5.4):

$$\Theta_g = 20 + 345 \log_{10} (8\,t + 1) \qquad [°\mathrm{C}] \qquad (5.4)$$

where

Θ_g is the gas temperature in the fire compartment [°C]

t is the time [min]

(2) The coefficient of heat transfer by convection α_c for the standard temperature-time curve should be taken as $\alpha_c = 25$ W/(m^{2}K).

5.2.2 External fire curve

(1) The external fire curve is given by Formula (5.5):

$$\Theta_g = 660\,(1 - 0,687\, e^{-0,32\,t} - 0,313\, e^{-3,8\,t}) + 20 \qquad [°\mathrm{C}] \qquad (5.5)$$

where

Θ_g is the gas temperature near the member [°C]

t is the time [min]

(2) The coefficient of heat transfer by convection α_c for the external fire ~~standard temperature-time~~ curve should be taken as $\alpha_c = 25$ W/(m^{2}K).

5.2.3 Hydrocarbon fire curve

(1) The hydrocarbon fire ~~temperature-time~~ curve is given by Formula (5.6):

$$\Theta_g = 1\,080\ (1 - 0{,}325\ e^{-0{,}167\,t} - 0{,}675\ e^{-2{,}5\,t}) + 20 \qquad [°C] \qquad (5.6)$$

where

Θ_g is the gas temperature in the fire compartment [°C]

t is the time [min]

(2) The coefficient of heat transfer by convection for the hydrocarbon curve should be taken as $\alpha_c = 50$ W/(m^{2}K).

5.3 Physically based models

5.3.1 Simplified fire models

5.3.1.1 General

(1) Simplified fire models ~~should be~~ are based on specific physical parameters with a limited field of application.

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

(2) A uniform temperature distribution as a function of time should be assumed for fully developed compartment fires. A non-uniform temperature distribution as a function of time should be assumed in case of localised fires.

(3) When simplified fire models are used, the coefficient of heat transfer by convection should be taken as $\alpha_c = 35$ ~~[~~W/(m^{2}K)~~]~~.

5.3.1.2 Compartment fires

(1) Gas temperatures should be determined on the basis of physical parameters considering at least the fire load density and the ventilation conditions.

NOTE-1 For internal members of fire compartments, a method for the calculation of the gas temperature in the compartment is given in Annex A and Annex E of this Part of EN 1991.

NOTE 2 For external members exposed to fire through openings in the facade, a method for the calculation of the heating conditions is given in Annex B of this Part of EN 1991..

5.3.1.3 Localised fires

(1) A Localised fire should be taken into account in a compartment where flash-over is unlikely to occur or in the early stage of a fire

NOTE A method for the calculation of thermal actions from localised fires is given in Annex C.

5.3.2 Advanced fire models

(1) Advanced fire models should take into account the following:

- gas properties;
- mass exchange;
- energy exchange.

NOTE For the calculation of the design fire load density $q_{f,d}$,the fire growth rate and the rate of heat release Q, methods are given in Annex E.

(2) One of the following models should be used:

- one-zone models assuming a uniform, time dependent temperature distribution in the compartment;
- two-zone models assuming an upper layer with time dependent thickness and with time dependent uniform temperature, as well as a lower layer with a time dependent uniform and lower temperature;
- Computational Fluid Dynamics models giving the temperature evolution in the compartment in a completely time dependent and space dependent manner.

NOTE 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.

(3) The coefficient of heat transfer by convection should be taken as $\alpha_c = 35$ ~~[~~W/(m^{2}K)~~]~~, unless more detailed information is available.

(4) In order to calculate more accurately the temperature distribution along a member, in case of a localised fire, a combination of results obtained with a two-zone model and a localised fire approach may be considered. The temperature field in the member may be obtained by considering the maximum effect at each location given by the two fire models~~.~~

6 Mechanical actions for structural analysis

6.1 General

(1) Imposed and constrained expansions and deformations caused by temperature changes due to fire exposure result in effects of actions, e.g. forces and moments, which shall be considered with the exception of those cases where they:

- may be recognized a priori to be either negligible or favourable;
- are accounted for by conservatively chosen support models and boundary conditions, and/or implicitly considered by conservatively specified fire safety requirements.

(2) For an assessment of indirect actions the following should be considered:

- constrained thermal expansion of the members themselves, e.g. columns in multi-storey frame structures with stiff walls;
- differing thermal expansion within statically indeterminate members, e.g. continuous floor slabs;
- thermal gradients within cross-sections giving internal stresses;
- thermal expansion of adjacent members, e.g. displacement of a column head due to the expanding floor slab, or expansion of suspended cables;
- thermal expansion of members affecting other members outside the fire compartment.

(3) Design values of indirect actions due to fire $A_{\mathrm{ind,d}}$ should be determined on the basis of the design values of the thermal and mechanical material properties given in the fire design Parts of EN 1992 to EN 1996 and EN 1999 and the relevant fire exposure.

(4) Indirect actions from adjacent members should not be considered when fire safety requirements refer to members under standard fire conditions.

6.2 Simultaneity of actions

6.2.1 Actions from normal temperature design

(1) Actions that are likely to act in the fire situation shall be considered as for normal temperature design

(2) Representative values of variable actions, accounting for the accidental design situation of fire exposure, should be introduced in accordance with EN 1990.

(3) Decrease of imposed loads due to combustion should not be taken into account.

(4) Cases where snow loads should not be considered in combination with fire, due to the melting of snow, should be assessed individually.

(5) Actions resulting from industrial operations should not be taken into account.

6.2.2 Additional actions

(1) Simultaneous occurrence of fire with other independent accidental actions should not be considered.

(2) Depending on the accidental design situations to be considered, additional actions induced by the fire may need to be applied during fire exposure, e.g. impact due to collapse of a structural member or heavy machinery.

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

(3) Fire walls may be required to resist a horizontal impact load according to EN 1363-2.

6.3 Combination rules for actions

6.3.1 General rule

(1) For obtaining the relevant effects of actions $E_{\mathrm{fi,d,t}}$ during fire exposure, the mechanical actions shall be combined in accordance with EN 1990 for accidental design situations.

(2) The representative value of the variable action Q_1 may be considered as the quasi-permanent value $\psi_{2,1}\, Q_1$, or as an alternative the frequent value $\psi_{1,1}\, Q_1$.

NOTE The representative value of the variable action Q_1 is the quasi-permanent value $\psi_{2,1}\, Q_1$, unless the National Annex specifies the frequent value $\psi_{1,1}\, Q_1$.

6.3.2 Simplified rules

(1) Where indirect fire actions need not be explicitly considered, effects of actions may be determined by analysing the structure for combined actions according to 4.3.1 for $t = 0$ only. These effects of actions $E_{\mathrm{fi,d}}$ may be applied as constant throughout fire exposure.

NOTE This clause applies, for example, to effects of actions at boundaries and supports, where an analysis of parts of the structure is performed in accordance with the fire design Parts of EN 1992 to EN 1996 and EN 1999.

(2) As a further simplification to (1), effects of actions may be deduced from those determined in normal temperature design:

$$E_{\mathrm{fi,d,t}} = E_{\mathrm{fi,d}} = \eta_{\mathrm{fi}} \cdot E_{\mathrm{d}} \qquad (6.1)$$

where

E_{d} is the design value of the relevant effects of actions from the fundamental combination according to EN 1990;

$E_{\mathrm{fi,d}}$ is the corresponding constant design value in the fire situation;

~~η_{fi} is a reduction factor defined in the fire design Parts of EN 1992 to EN 1996 and EN 1999.~~

(3) For load combination (6.10) in EN 1990, the reduction factor η_{fi} should be taken as:

$$\eta_{\mathrm{fi}} = \frac{G_{\mathrm{k}} + \psi_{\mathrm{fi}}\, Q_{\mathrm{k,1}}}{\gamma_{\mathrm{G}}\, G_{\mathrm{k}} + \gamma_{\mathrm{Q,1}}\, Q_{\mathrm{k,1}}} \qquad (6.2)$$

or, for load combinations (6.10a) and (6.10b) in EN 1990, as the smallest value given by the following two expressions:

$$\eta_{\mathrm{fi}} = \frac{G_{\mathrm{k}} + \psi_{\mathrm{fi}}\, Q_{\mathrm{k},1}}{\gamma_{\mathrm{G}}\, G_{\mathrm{k}} + \gamma_{\mathrm{Q},1}\, Q_{\mathrm{k},1}} \qquad (6.3)$$

$$\eta_{\mathrm{fi}} = \frac{G_{\mathrm{k}} + \psi_{\mathrm{fi}}\, Q_{\mathrm{k},1}}{\xi\, \gamma_{\mathrm{G}}\, G_{\mathrm{k}} + \gamma_{\mathrm{Q},1}\, Q_{\mathrm{k},1}} \qquad (6.4)$$

where

$Q_{\mathrm{k},1}$	is the characteristic value of the leading variable action 1;
G_{k}	is the characteristic value of the permanent action;
γ_{G}	is the partial factor for the permanent action;
$\gamma_{\mathrm{Q},1}$	is the partial factor for the leading variable action 1;
ψ_{fi}	is the combination factor for variable actions in the fire situation, given either by $\psi_{1,1}$ or $\psi_{2,1}$, see EN 1991-1-2;
ξ	is a reduction factor for the unfavourable permanent action G_k.

NOTE 1: The choice of load combinations between expression (6.2) and expressions (6.3) and (6.4) may be found in the national annex of EN1990.

NOTE 2: An example of the variation of the reduction factor η_{fi} versus the load ratio $Q_{\mathrm{k},1}/G_{\mathrm{k}}$ for different values of the combination factor ψ_{fi} according to expression (6.2) is shown in figure 6.1 with the following assumptions: γ_{G} = 1,35 and $\gamma_{\mathrm{Q},1}$ = 1,5. Partial factors are specified in the relevant national annexes of EN 1990. Expressions (6.3) and (6.4) give slightly higher values.

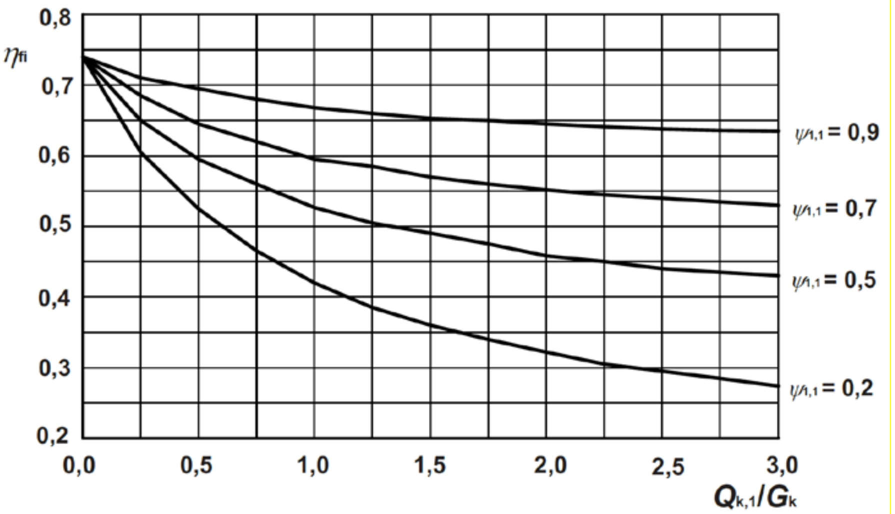


Figure 6.1 – Examples of reduction factor η_{fi} versus load ratio $Q_{\mathrm{k},1}/G_{\mathrm{k}}$ according to expression (6.2)

(4) As a simplification, recommended values of η_{fi} may be used as defined in the relevant material Eurocode. The choice of recommended values for the reduction factor η_{fi} may be found in the national annex.

6.3.3 Load level

(1) Where tabulated data are specified for a reference load level, this load level should be taken as:

$$E_{\mathrm{fi,d,t}} = \eta_{\mathrm{fi,t}} \cdot R_{\mathrm{d}} \tag{6.2}$$

where

R_{d} is the design value of the resistance of the member at normal temperature, determined according to EN 1992 to EN 1996 and EN 1999;

$\eta_{\mathrm{fi,t}}$ is the load level for fire design.

Annex A
(informative)

Parametric temperature-time curves

(1) The following temperature-time curves are valid for fire compartments up to 500 m^2 of floor area, without openings in the roof and for a maximum compartment height of 4 m. It is assumed that the fire load of the compartment is completely burnt out.

(2) If fire load densities are specified without specific consideration to the combustion behaviour (see annex E), then this approach should be limited to fire compartments with mainly cellulosic type fire loads.

(3) The temperature-time curves in the heating phase are given by:

$$\Theta_g = 20 + 1\,325\,(\,1 - 0{,}324\,e^{-0{,}2t^*} - 0{,}204\,e^{-1{,}7t^*} - 0{,}472\,e^{-19t^*}\,) \qquad \text{(A.1)}$$

where

Θ_g	is the gas temperature in the fire compartment	[°C]	
t^*	$= t \cdot \Gamma$	[h]	(A.2a)

with

t	time	[h]
Γ	$= [O/b]^2 / (0{,}04/1\,160)^2$	[-]
b	$= \sqrt{(\rho c \lambda)}$	
	with the following limits: $100 \leq b \leq 2\,200$	[$J/m^2s^{1/2}K$]
ρ	density of boundary of enclosure	[kg/m^3]
c	specific heat of boundary of enclosure	[J/kgK]
λ	thermal conductivity of boundary of enclosure	[W/(mK)]
O	opening factor: $A_v \sqrt{h_{eq}} / A_t$	[$m^{1/2}$]
	with the following limits: $0{,}02 \leq O \leq 0{,}20$	
A_v	total area of vertical openings on all walls	[m^2]
h_{eq}	weighted average of window heights on all walls	[m]
A_t	total area of enclosure (walls, ceiling and floor, including openings)	[m^2]

(4) For the calculation of the b factor, the density ρ, the specific heat c and the thermal conductivity λ of the boundary may be taken at ambient temperature.

(5) To account for an enclosure surface with different layers of material, $b = \sqrt{(\rho c \lambda)}$ should be introduced as:

– If $b_1 < b_2$, $b = b_1$ (A.3)

– If $b_1 > b_2$, a limit thickness $s_{\lim}$ is calculated for the exposed material according to:

$$s_{\lim} = \sqrt{\frac{3\,600\, t_{\max}\, \lambda_1}{c_1\, \rho_1}} \quad \text{with } t_{\max} \text{ given by eq. A.7 .} \qquad [\text{m}] \qquad (A.4)$$

If $s_1 > s_{\lim}$ then $b = b_1$ (A.4a)

If $s_1 < s_{\lim}$ then $b = \frac{s_1}{s_{\lim}} b_1 + \left(1 - \frac{s_1}{s_{\lim}}\right) b_2$ (A.4b)

where

~~the~~ index 1 represents the layer directly exposed to the fire, ~~the~~ index 2 the next layer…

s_i is the thickness of layer i

b_i = $\sqrt{(\rho_i c_i \lambda_i)}$

ρ_i is the density of~~the~~ layer i

c_i is the specific heat of~~the~~ layer i

λ_i is the thermal conductivity of ~~the~~ layer i

(6) To account for different b factors in walls, ceiling and floor, $b = \sqrt{(\rho c \lambda)}$ should be introduced as:

$$b = (\Sigma(b_j A_j)) / (A_t - A_v) \qquad (A.5)$$

where

A_j is the area of enclosure surface j, openings not included

b_j is the thermal property of enclosure surface j according to equations (A.3) and (A.4)

(7) The maximum temperature $\Theta_{\max}$ in the heating phase happens for $t^* = t^*_{\max}$

$$t^*_{\max} = t_{\max} \cdot \Gamma \qquad [\text{h}] \qquad (A.6)$$

$$\text{with } t_{\max} = \max\, [(0{,}2 \cdot 10^{-3} \cdot q_{t,d} / O)\ ;\ t_{\lim}] \qquad [\text{h}] \qquad (A.7)$$

where

$q_{t,d}$ is the design value of the fire load density related to the total surface area A_t of the enclosure whereby $q_{t,d} = q_{f,d} \cdot A_f / A_t$ [MJ/m^2]. The following limits should be observed: $50 \leq q_{t,d} \leq 1\,000$ [MJ/m^2].

$q_{f,d}$ is the design value of the fire load density related to the surface area A_f of the floor [MJ/m^2] taken from annex E.

$t_{\lim}$ is given by (10) in [h].

NOTE The time $t_{\max}$ corresponding to the maximum temperature is given by $t_{\lim}$ in case the fire is fuel controlled. If $t_{\max}$ is given by $(0{,}2 \cdot 10^{-3} \cdot q_{t,d} / O)$, the fire is ventilation controlled.

(8) When $t_{\max} = t_{\lim}$, t^* used in equation (A.1) is replaced by:

$$t^* = t \cdot \Gamma_{\lim} \qquad [\text{h}] \qquad (A.2b)$$

with $\Gamma_{\text{lim}} = [O_{\text{lim}} / b]^2 / (0{,}04/1\,160)^2$ (A.8)

where $O_{\text{lim}} = 0{,}1 \cdot 10^{-3} \cdot q_{\text{t,d}} / t_{\text{lim}}$ (A.9)

(9) If ($O > 0{,}04$ and $q_{\text{t,d}} < 75$ and $b < 1\,160$), Γ_{lim} in (A.8) has to be multiplied by k given by:

$$k = 1 + \left(\frac{O - 0{,}04}{0{,}04}\right)\left(\frac{q_{\text{t,d}} - 75}{75}\right)\left(\frac{1160 - b}{1160}\right) \qquad \text{(A.10)}$$

(10) In case of slow fire growth rate, $t_{\text{lim}} = 25$ min; in case of medium fire growth rate, $t_{\text{lim}} = 20$ min and in case of fast fire growth rate, $t_{\text{lim}} = 15$ min.

NOTE For advice on fire growth rate, see Table E.6 in Annex E.

(11) The temperature-time curves in the cooling phase are given by:

$\Theta_{\text{g}} = \Theta_{\text{max}} - 625\,(t^* - t^*_{\text{max}} \cdot x)$ for $t^*_{\text{max}} \leq 0{,}5$ (A.11a)

$\Theta_{\text{g}} = \Theta_{\text{max}} - 250\,(3 - t^*_{\text{max}})\,(t^* - t^*_{\text{max}} \cdot x)$ for $0{,}5 < t^*_{\text{max}} < 2$ (A.11b)

$\Theta_{\text{g}} = \Theta_{\text{max}} - 250\,(t^* - t^*_{\text{max}} \cdot x)$ for $t^*_{\text{max}} \geq 2$ (A.11c)

where t^* is given by (A.2a)

$t^*_{\text{max}} = (0{,}2 \cdot 10^{-3} \cdot q_{\text{t,d}} / O) \cdot \Gamma$ (A.12)

$x = 1{,}0$ if $t_{\text{max}} > t_{\text{lim}}$, or $x = t_{\text{lim}} \cdot \Gamma / t^*_{\text{max}}$ if $t_{\text{max}} = t_{\text{lim}}$

Annex B
(informative)

Thermal actions for external members - Simplified calculation method

B.1 Scope

(1) This method allows the determination of:

- the maximum temperatures of a compartment fire;
- the size and temperatures of the flame from openings;
- radiation and convection parameters.

(2) This method considers steady-state conditions for the various parameters. The method is valid only for fire loads $q_{f,d}$ higher than 200 MJ/m².

B.2 Conditions of use

(1) When there is more than one window in the relevant fire compartment, the weighted average height of windows h_{eq}, the total area of vertical openings A_v and the sum of window widths ($w_t = \Sigma w_i$) are used.

(2) When there are windows in only wall 1, the ratio D/W is given by:

$$D/W = \frac{W_2}{W_1} \tag{B.1}$$

(3) When there are windows on more than one wall, the ratio D/W should be obtained as follows:

$$D/W = \frac{W_2}{W_1}\frac{A_{v1}}{A_v} \tag{B.2}$$

where

W_1 is the width of the wall 1, assumed to contain the greatest window area;

A_{v1} is the sum of window areas on wall 1;

W_2 is the width of the wall perpendicular to wall 1 in the fire compartment.

(4) When there is a core in the fire compartment, the ratio D/W should be obtained as follows:

- limits given in (7) apply;
- L_c and W_c are the length and width of the core;
- W_1 and W_2 are the length and width of the fire compartment:

$$D/W = \frac{(W_2 - L_c)\,A_{v1}}{(W_1 - W_c)\,A_v} \tag{B.3}$$

(5) All parts of an external wall that do not have the fire resistance (REI) required for the stability of the building should be classified as window areas.

(6) The total area of windows in an external wall is:

- the total area, according to (5), if it is less than 50 % of the area of the relevant external wall of the compartment;
- firstly the total area and secondly 50 % of the area of the relevant external wall of the compartment if, according to (5), the area is more than 50 %. These two situations should be considered for calculation. When using 50 % of the area of the external wall, the location and geometry of the open surfaces should be chosen so that the most severe case is considered.

(7) The size of the fire compartment should not exceed 70 m in length, 18 m in width and 5 m in height.

(8) The flame temperature should be taken as uniform across the width and the thickness of the flame.

B.3 Effects of wind

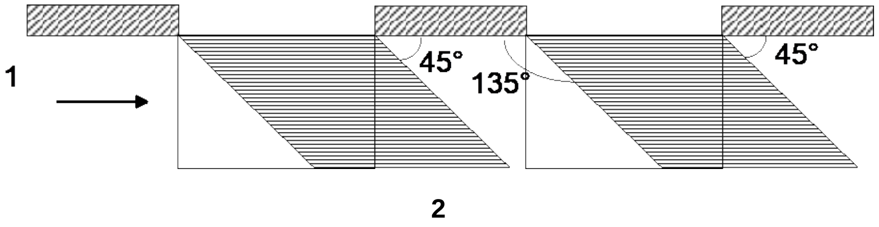
B.3.1 Mode of ventilation

(1)P If there are windows on opposite sides of the fire compartment or if additional air is being fed to the fire from another source (other than windows), the calculation shall be done with forced draught conditions. Otherwise, the calculation is done with no forced draught conditions.

B.3.2 Flame deflection by wind

(1) Flames from an opening should be assumed to be leaving the fire compartment (see Figure B.1):

- perpendicular to the facade;
- with a deflection of 45° due to wind effects.



Key
1 Wind
2 Horizontal cross section

Figure B.1 — Deflection of flame by wind

B.4 Characteristics of fire and flames

B.4.1 No forced draught

(1) The rate of burning or the rate of heat release is given by:

$$Q = \min\left((A_\mathrm{f} \cdot q_\mathrm{f,d}) / \tau_\mathrm{F}\, ;\, 3{,}15\,(1 - \mathrm{e}^{-0{,}036/O})\, A_\mathrm{v} \left(\frac{h_\mathrm{eq}}{D/W} \right)^{1/2} \right) \qquad [\mathrm{MW}] \qquad (\mathrm{B.4})$$

Where τ_F is assumed to be equal to 1 200 [s]

(2) The temperature of the fire compartment should be given by:

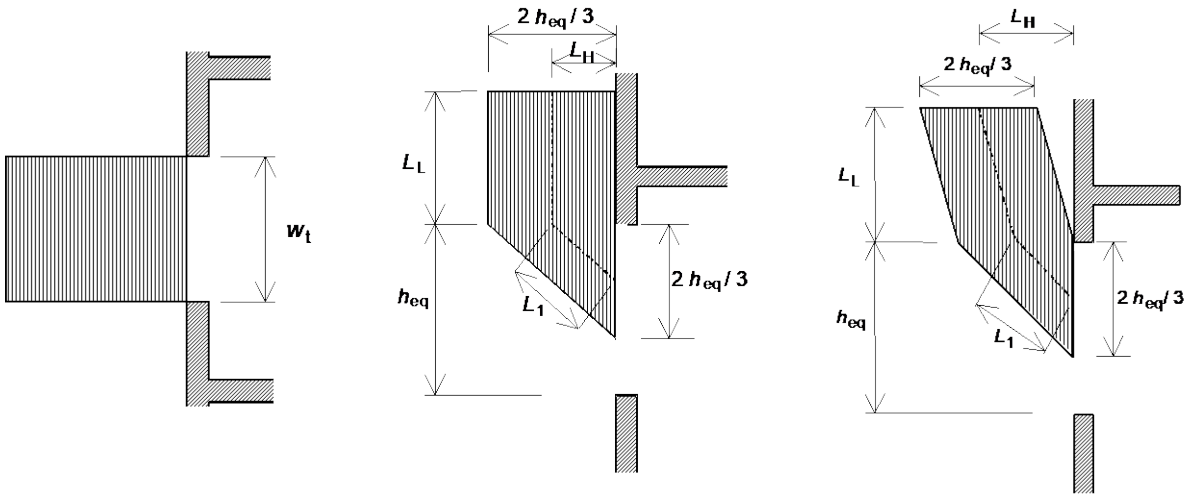
$$T_\mathrm{f} = 6\,000\,(1 - \mathrm{e}^{-0{,}1/O})\, O^{1/2}\, (1 - \mathrm{e}^{-0{,}00286\,\Omega}) + T_0 \qquad (\mathrm{B.5})$$

(3) The flame height (see Figure B.2) should be given by:

$$L_\mathrm{L} = \max\left(0\, ;\, h_\mathrm{eq} \left(2{,}37 \left(\frac{Q}{A_\mathrm{v}\, \rho_\mathrm{g}\, (h_\mathrm{eq}\, g)^{1/2}} \right)^{2/3} - 1 \right) \right) \qquad (\mathrm{B.6})$$

NOTE With ρ_g = 0,45 kg/m^3 and g = 9,81 m/s^2 , this equation may be simplified to:

$$L_\mathrm{L} = 1{,}9 \left(\frac{Q}{w_\mathrm{t}} \right)^{2/3} - h_\mathrm{eq} \qquad (\mathrm{B.7})$$



horizontal cross section **vertical cross section** **vertical cross section**

$L_H = \frac{h_{eq}}{3} \Rightarrow L_1 = \sqrt{L_\mathrm{H}^2 + \frac{h_\mathrm{eq}^2}{9}} \cong \frac{h_\mathrm{eq}}{2}$	$L_1 \cong \frac{h_\mathrm{eq}}{2}$
$L_\mathrm{f} = L_\mathrm{L} + L_1$	$L_\mathrm{f} = \sqrt{L_\mathrm{L}^2 + \left(L_\mathrm{H} - \frac{h_\mathrm{eq}}{3} \right)^2} + L_1$
h_eq<1,25w_t and wall above	no wall above or h_eq>1,25w_t

Figure B.2 — Flame dimensions, no through draught

(4) The flame width should be taken as the window width (see Figure B.2).

(5) The flame depth should be taken as 2/3 of the window height: 2/3 h_{eq} (see Figure B.2).

(6) The horizontal projection of flames:

– in case of a wall existing above the window, should be taken as:

$L_H = h_{eq}/3$ if $h_{eq} \leq 1{,}25\ w_t$ (B.8)

$L_H = 0{,}3\ h_{eq}\ (h_{eq}\ /\ w_t)^{0{,}54}$ if $h_{eq} > 1{,}25\ w_t$ and distance to any other window $> 4\ w_t$ (B.9)

$L_H = 0{,}454\ h_{eq}\ (h_{eq}\ /2w_t)^{0{,}54}$ in other cases (B.10)

– in case of a wall not existing above the window, should be taken as:

$L_H = 0{,}6\ h_{eq}\ (L_L/\ h_{eq})^{1/3}$ (B.11)

(7) The flame length along axis should be taken as:

when $L_L > 0$

$L_f = L_L + h_{eq}\ /2$ if there is a wall above the window and if $h_{eq} \leq 1{,}25\ w_t$ (B.12)

$L_f = (L_L^{\ 2} + (L_H - h_{eq}\ /3\ )^2\ )^{1/2} + h_{eq}\ /2$ if there is no wall above the window or if $h_{eq} > 1{,}25\ w_t$ (B.13)

when $L_L = 0$, then $L_f = 0$

(8) The flame temperature at the window should be taken as:

$T_w = 520\ /\ (\ 1 - 0{,}4725\ (L_f \cdot w_t\ /Q)) + T_0$ [K] (B.14)

with $L_f \cdot w_t\ /Q < 1$

(9) The emissivity of flames at the window may be taken as $\varepsilon_f = 1{,}0$

(10) The flame temperature along the axis should be taken as:

$T_z = (T_w - T_0)\ (1 - 0{,}4725\ (L_x \cdot w_t\ /\ Q)) + T_0$ [K] (B.15)

with

$L_x \cdot w_t\ /Q < 1$

L_x is the axis length from the window to the point where the calculation is made

(11) The emissivity of flames may be taken as:

$\varepsilon_f = 1 - \ e^{-0{,}3d_f}$ (B.16)

where d_f is the flame thickness [m]

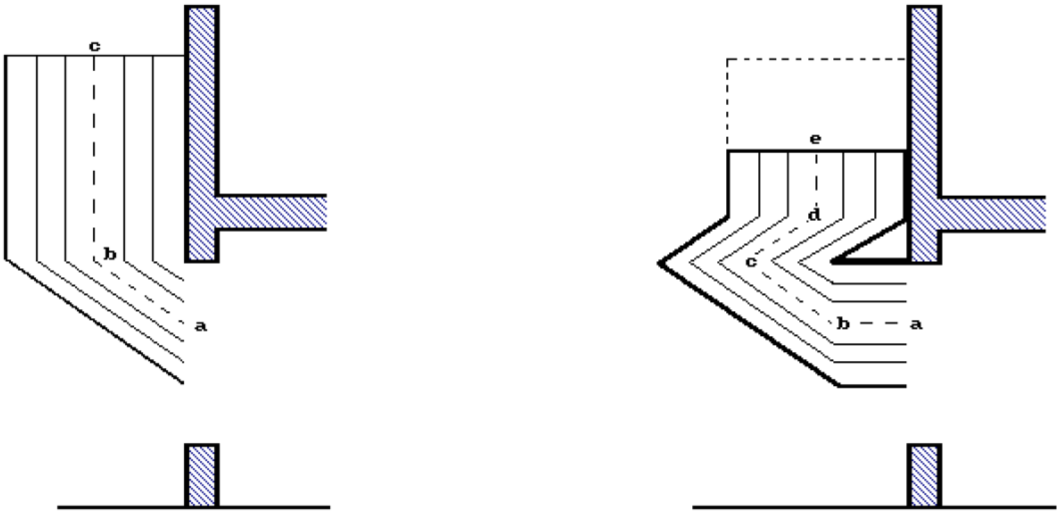
(12) The convective heat transfer coefficient is given by:

$\alpha_c = 4{,}67\ (1/d_{eq})^{0{,}4}\ (Q/A_v)^{0{,}6}$ (B.17)

(13) If an awning or balcony (with horizontal projection: W_a) is located at the level of the top of the window over its whole width (see Figure B.3), for the wall above the window and $h_{eq} \leq 1{,}25\ w_t$, the height and horizontal projection of the flame should be modified as follows:

– the flame height L_L given in (3) should be decreased by $W_a\ (1+\sqrt{2}\ )$;

– the horizontal projection of the flame L_H given in (6),should be increased by W_a.



a b c = L_f

vertical cross section

a b c d e = L_f and w_a = a b

vertical cross section

Figure B.3 — Deflection of flame by balcony

(14) With the same conditions for awning or balcony as mentioned in (13), in the case of no wall above the window or $h_{eq} > 1{,}25\ w_t$, the height and horizontal projection of the flame should be modified as follows:

– the flame height L_L given in (3) should be decreased by W_a;

– the horizontal projection of the flame L_H, obtained in (6) with the above mentioned value of L_L should be increased by W_a.

B.4.2 Forced draught

(1) The rate of burning or the rate of heat release should be given by:

$$Q = (A_f \cdot q_{f,d})\ /\ \tau_F \qquad [\mathrm{MW}] \qquad (B.18)$$

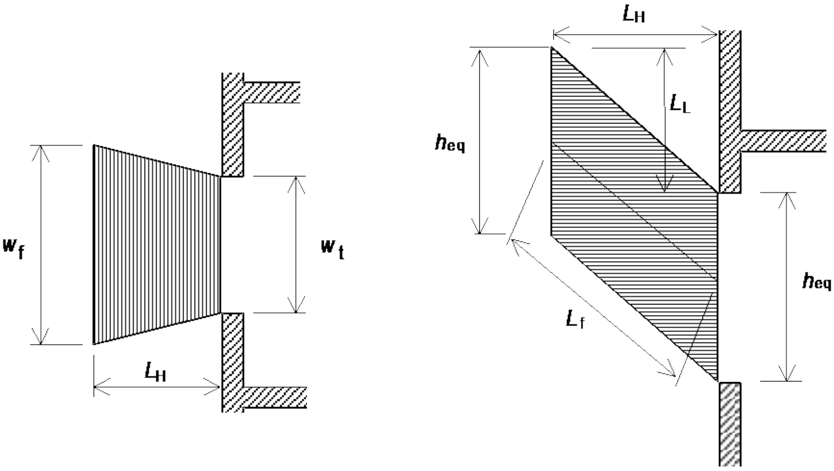
(2) The temperature of the fire compartment should be given by:

$$T_f = 1\ 200\ (1- e^{-0{,}00228\ \Omega}) + T_0 \qquad (B.19)$$

(3) The flame height (see Figure B.4) is given by:

$$L_L = \left(1{,}366 \left(\frac{1}{u} \right)^{0{,}43} \frac{Q}{A_v^{1/2}} \right) - h_{eq} \qquad (B.20)$$

NOTE With u = 6 m/s, $L_L \approx 0{,}63\ Q / A_v^{1/2} - h_{eq}$



horizontal cross section **vertical cross section**

$w_f = w_t + 0{,}4\ L_H$ $L_f = (L_L^2 + L_H^2)^{1/2}$

Figure B.4 — Flame dimensions, through or forced draught

(4) The horizontal projection of flames should be given by:

$$L_H = 0{,}605\ (u^2 / h_{eq})^{0{,}22}\ (L_L + h_{eq}) \qquad \text{(B.21)}$$

NOTE With u = 6 m/s, $L_H = 1{,}33\ (L_L + h_{eq}) / h_{eq}^{\ 0{,}22}$

(5) The flame width should be given by:

$$w_f = w_t + 0{,}4\ L_H \qquad \text{(B.22)}$$

(6) The flame length along axis should be given by:

$$L_f = (L_L^2 + L_H^2)^{1/2} \qquad \text{(B.23)}$$

(7) The flame temperature at the window should be given by:

$$T_w = 520 / (1 - 0{,}3325\ L_f\ (A_v)^{1/2} / Q) + T_0 \qquad [K] \qquad \text{(B.24)}$$

with $L_f\ (A_v)^{1/2} / Q < 1$

(8) The emissivity of flames at the window may be taken as $\varepsilon_f = 1{,}0$

(9) The flame temperature along the axis should be given by:

$$T_z = \left(1 - 0{,}3325 \frac{L_x\ (A_v)^{1/2}}{Q}\right)(T_w - T_0) + T_0 \qquad [K] \qquad \text{(B.25)}$$

where

L_x is the axis length from the window to the point where the calculation is made

(10) The emissivity of flames may be taken as:

$$\varepsilon_f = 1 - e^{-0,3 d_f} \tag{B.26}$$

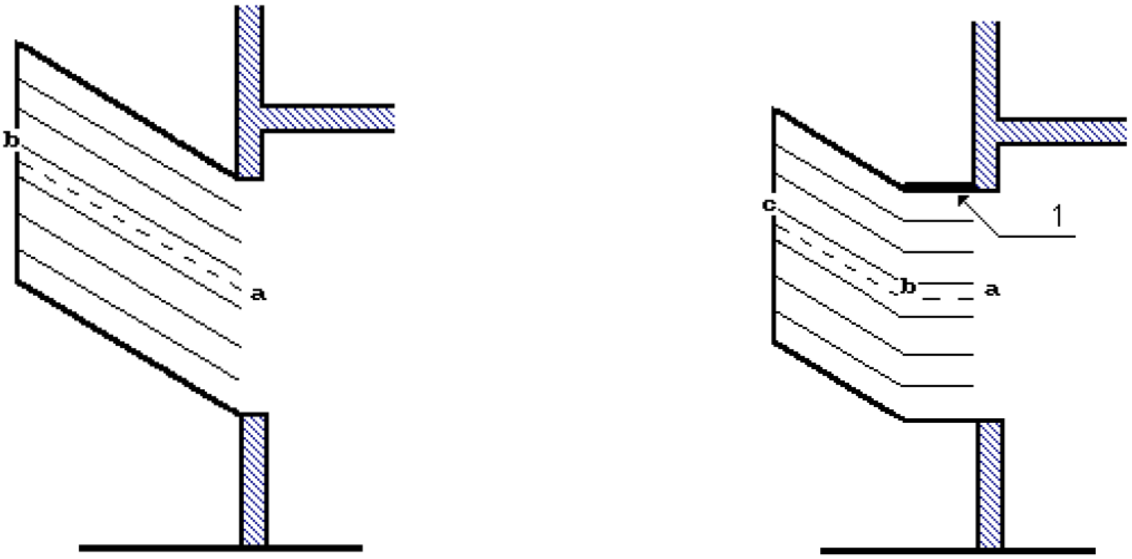
where d_f is the flame thickness [m]

(11) The convective heat transfer coefficient should be given by:

$$\alpha_c = 9,8\ (1\ /\ d_{eq})^{0,4}\ (\ Q/(17,5\ A_v\ ) + u/1,6\ )^{0,6} \tag{B.27}$$

NOTE With u = 6 m/s the convective heat transfer coefficient is given by:
$\alpha_c = 9,8\ (\ 1/d_{eq}\ )^{0,4}\ (\ Q/(17,5A_v\ ) + 3,75\ )^{0,6}$

(12) Regarding the effects of balconies or awnings, see Figure B.5, the flame trajectory, after being deflected horizontally by a balcony or awning, is the same as before, i.e. displaced outwards by the depth of the balcony, but with a flame length L_f unchanged.



a b = L_f

vertical cross section

a b c = L_f

Key
1 Awning

vertical cross section

Figure B.5 — Deflection of flame by awning

B.5 Overall configuration factors

(1) The overall configuration factor Φ_f of a member for radiative heat transfer from an opening should be determined from:

$$\Phi_f = \frac{(C_1 \Phi_{f,1} + C_2 \Phi_{f,2})\, d_1 + (C_3 \Phi_{f,3} + C_4 \Phi_{f,4})\, d_2}{(C_1 + C_2)\, d_1 + (C_3 + C_4)\, d_2} \tag{B.28}$$

where

$\Phi_{f,i}$ is the configuration factor of member face i for that opening, see annex G;

d_i is the cross-sectional dimension of member face i ;

C_i is the protection coefficient of member face i as follows:

- for a protected face: $C_i = 0$
- for an unprotected face: $C_i = 1$

(2) The configuration factor $\Phi_{f,i}$ for a member face from which the opening is not visible should be taken as zero.

(3) The overall configuration factor Φ_z of a member for radiative heat transfer from a flame should be determined from:

$$\Phi_z = \frac{(C_1 \Phi_{z,1} + C_2 \Phi_{z,2}) d_1 + (C_3 \Phi_{z,3} + C_4 \Phi_{z,4}) d_2}{(C_1 + C_2) d_1 + (C_3 + C_4) d_2} \quad \text{(B.29)}$$

where

$\Phi_{z,i}$ is the configuration factor of member face i for that flame, see annex G.

(4) The configuration factors $\Phi_{z,i}$ of individual member faces for radiative heat transfer from flames may be based on equivalent rectangular flame dimensions. The dimensions and locations of equivalent rectangles representing the front and sides of a flame for this purpose should be determined as given in annex B of EN 1993-1-2 sections B.2 for columns and B.3 for beams. ~~annex G.~~ For all other purposes, the flame dimensions given in B.4 of this annex should be used.

Annex C
(informative)

Localised fires

(1) The thermal action of a localised fire can be represented as a virtual solid flame, following the method described in this annex.
Differences should be made regarding

i) the relative height of the flame to the ceiling
ii) the position of the structural element to the geometry of the flame
iii) the position of the structural element to the ceiling level

The proposed methodology is valid if the following conditions are met:

i) - diameter of the fire is limited by $\leq 10m$;
ii) - rate of heat release of the fire is limited by $Q \leq 50MW$

(2) The virtual solid flame representing the thermal action of a localised fire is conical.

NOTE : The methodology does not consider the impact of the smoke layer see 3.3.2 (4)

(3) The height of the virtual solid flame L_f (see Figure C.1) is given by:

$$L_f = -1{,}02\,D + 0{,}0148\,Q^{2/5} \qquad \text{[m]} \qquad \text{(C.1)}$$

D is the diameter of the fire [m]

Q is the rate of heat release [W]

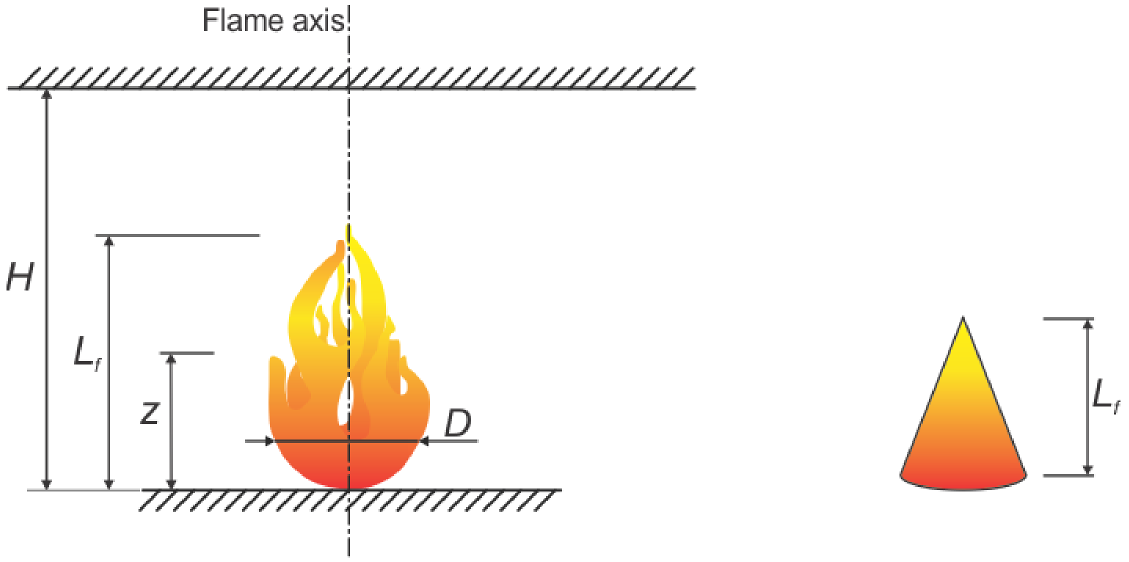


Figure C.1: Height of the virtual flame L_f

(4) When the virtual solid flame is impacting the ceiling, the shape of this virtual solid flame should be modified into a truncated cone (see Figure C.2).

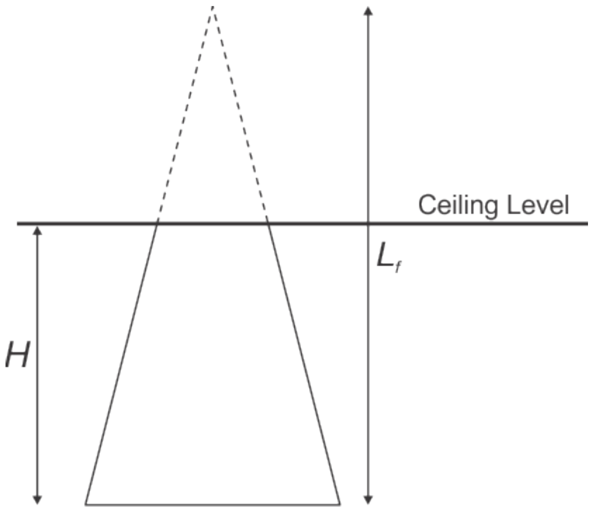


Figure C.2 : Adapted shape of conical virtual solid flames after truncation

(5) The temperature on the cone shall be constant at a vertical level z (see Figure C.3) and given by:

$$\Theta(z) = 20 + 0{,}25 Q_c^{2/3}(z - z_0)^{-5/3} \leq 900 \qquad [°C] \qquad (C.2)$$

where

Q_c is the convective part of the rate of heat release [W], with Q_c = 0,8 Q by default

~~Note: The application is not considered for low flame height to diameter ratio.~~

NOTE 1 The application is not considered for flame height to diameter ratio below 0,625.

NOTE 2 For low heat release rate, fire diameter may be reduced to fulfil the condition on Note 1.

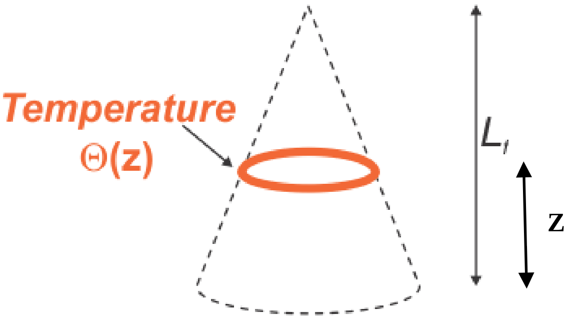


Figure C.3

(6) The virtual origin z_0 of the vertical axis is given by:

$$z_0 = -1{,}02D + 0{,}00524 Q^{2/5} \qquad [m] \qquad (C.3)$$

(7) If the virtual solid flame is impacting the ceiling and the structural element is situated at the ceiling level ($z \geq 0{,}9\,H$, see Figure C.6), the heat flux $\dot{\mathrm{h}}$ [W/m^2] received by the fire exposed unit surface area is given by:

$\dot{h} = 100000$ if $y \leq 0{,}30$

$\dot{h} = 136300 - 121000\,y$ if $0{,}30 < y < 1{,}0$ (C.4)

$\dot{h} = 15000\,y^{-3{,}7}$ if $y \geq 1{,}0$

where

y is a parameter [-] given by : $y = \frac{r+H+z'}{L_h+H+z'}$

r is the horizontal distance [m] between the vertical axis of the fire and the structural where the thermal flux is calculated, see Figure C.4

H is the distance [m] between the fire source and the ceiling, see Figure C.4

Where z’ is the vertical position of the virtual heat source [m] and is given by:

$$z' = 2{,}4D\left(Q_D^{*2/5} - Q_D^{*2/3}\right) \text{ when } Q_D^* < 1{,}0$$
$$z' = 2{,}4D\left(1{,}0 - Q_D^{*2/5}\right) \text{ when } Q_D^* \geq 1{,}0 \quad \text{(C.5)}$$

(8) In case the virtual solid flame is impacting the ceiling, the horizontal flame length L_h is given by:

$$L_h = (2{,}9\,H\,(Q_H^*)^{0{,}33}) - H \quad \text{[m]} \quad \text{(C.6)}$$

Where H is the distance [m] between the fire source and the ceiling, see Figure C.3

Where Q_H^* is a non-dimensional rate of heat release given by:

$$Q_H^* = Q\,/\,(1{,}11 \cdot 10^6 \cdot H^{2{,}5}) \quad \text{[-]} \quad \text{(C.7)}$$

where D is the diameter of the fire [m], see Figure C.4 and

$$Q_D^* = Q/(1{,}11 \cdot 10^6 \cdot D^{2{,}5}) \quad \text{[-]} \quad \text{(C.8)}$$

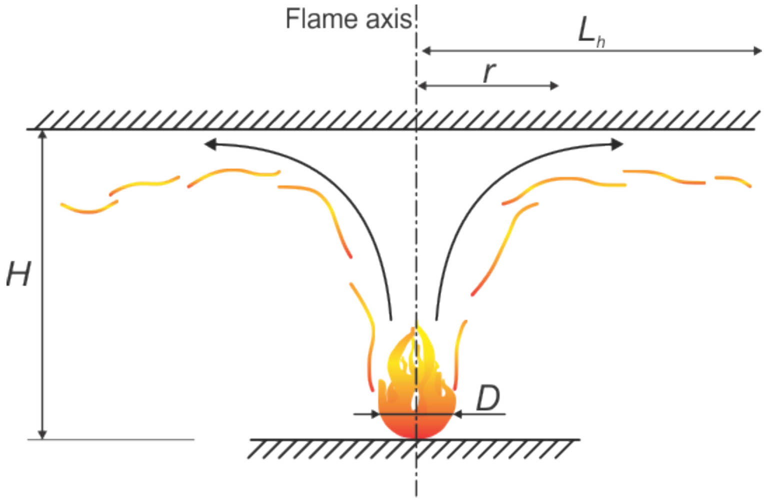


Figure C.4

(9) A structural element is considered as engulfed into the localised fire if the vertical projection of this element is included into the virtual flame basis. Therefore, this condition does not depend ~~if~~ on whether the virtual solid flame is considered as conical or cylindrical (see Figure C.5).

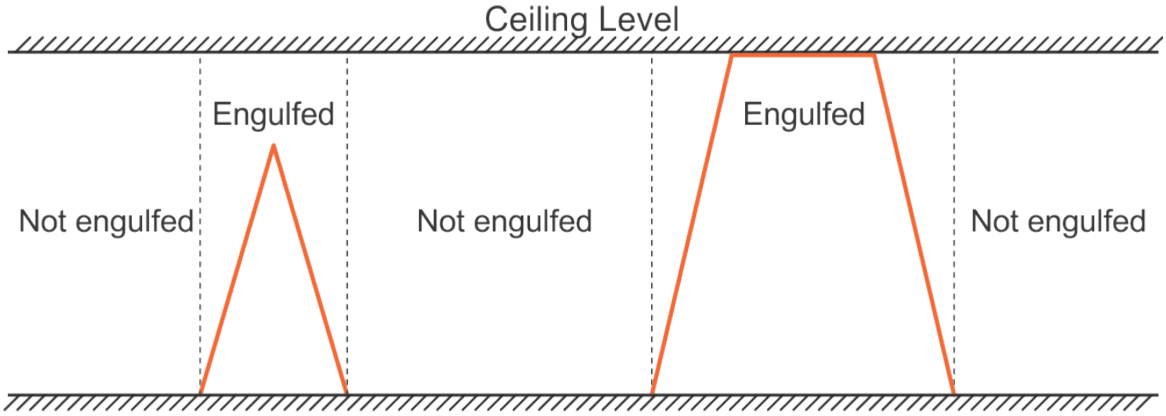


Figure C.5: Domains considered as engulfed and not-engulfed

(10) If the structural element is engulfed into the localised fire and not situated at the ceiling level ($z < 0{,}9\,H$, see Figure C.6), the heat flux $\dot{\mathrm{h}}$ [W/m^2] received by the fire exposed unit surface area is the heat flux given by Eq. C.9, where Θ(z) is the temperature of the virtual solid flame given by (C.2).

$$\dot{\mathrm{h}} = \alpha_c(\Theta(z) - 20) + \Phi \cdot \epsilon_m \cdot \epsilon_f \cdot \sigma \cdot [(\Theta(z) + 273)^4 - 293^4] \qquad \text{(C.9)}$$

The configuration factor Φ may be taken as 1.

(11) If both conditions (7) and (10) are not fulfilled (see Figure C.6), the total heat flux $\dot{\mathrm{h}}$ [W/m^2] received by the fire exposed unit surface area is the radiative heat flux received from the external surface of the solid flame.

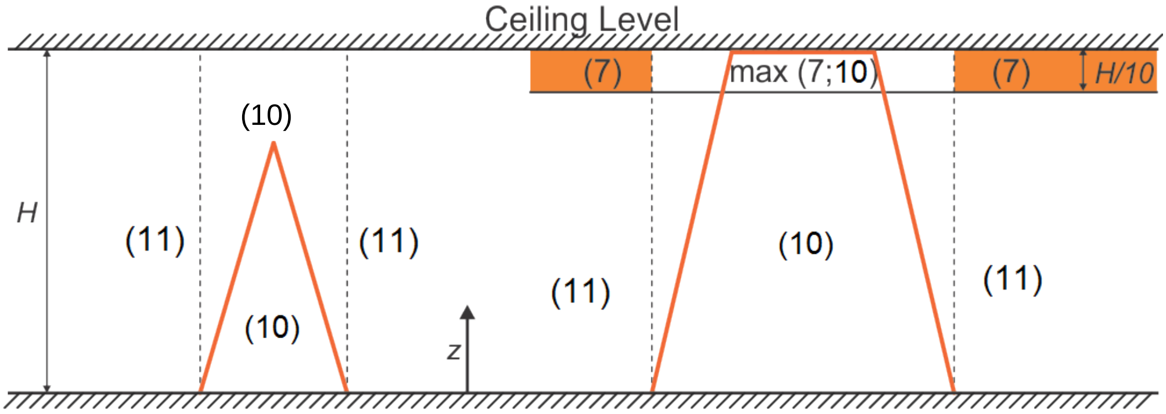


Figure C.6: Domains of application of clauses (7), (12) and (13)

(12) The virtual solid flame shall be divided into the successive elementary cylinders with different diameters. At each time step, the radiative heat flux emitted by intermediate horizontal rings situated below the fire exposed unit surface ($z > z_{ring,j}$, see Figure C.7) shall ~~not~~ be ~~neglected~~ considered (Eq. C.1~~1~~0).

$$\dot{\mathrm{h}} = \sum_{i=1}^{n} \Phi_{cylinder_i} \cdot \epsilon_m \cdot \epsilon_f \cdot \sigma \cdot [(\Theta(z_i) + 273)^4 - 293^4]$$
$$+ \sum_{j=1}^{m} \Phi_{ring_j} \cdot \epsilon_m \cdot \epsilon_f \cdot \sigma \cdot [(\Theta\left(z_{ring_j}\right) + 273)^4 - 293^4]$$

(C.1~~1~~0)

Where n is the number of elementary cylinders and m the number of visible rings

(13) The thickness of an elementary cylinder b_j ~~can~~ may not be larger than ~~50cm~~ 0.5m, see Figure C.7. The temperature Θ_j of an elementary cylinder is the temperature at the mid-thickness level z_j, using (C.2). If the virtual solid flame is considered as conical, the diameter of an elementary cylinder D_j will be the maximal diameter of the cone in this flame slice (see Figure C.7). Only rings below the element (directly visible from its point of view) are used (see Figure C.7). A method for the calculation of the configuration factor Φ is given in Annex G.

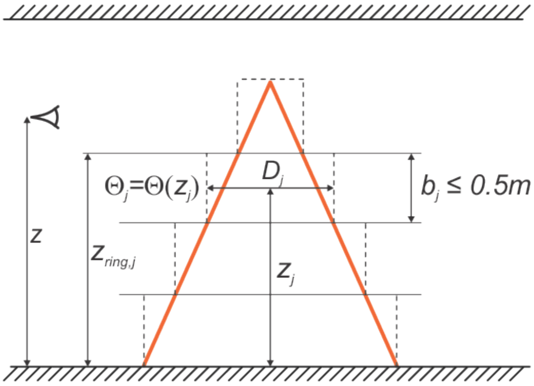


Figure C.7: Subdivision of conical or cylindrical solid flame into elementary cylinders

(14) The net heat flux $\dot{h}_{net}$ [W/m²] received by the fire exposed unit surface area is given by:

$$\dot{h}_{net} = \dot{h} - \alpha_c(\Theta_m - 20) - \Phi \cdot \epsilon_m \cdot \epsilon_f \cdot \sigma[(\Theta_m + 273)^4 - (293)^4] \qquad \text{(C.11)}$$

Where $\dot{h}$ is calculated according to (7), (10) or (11).

(15) In case of separate localised fires, the total heat flux received by the fire exposed unit surface area may be taken as:

$$\dot{h}_{tot} = \dot{h}_1 + \dot{h}_2 \ \ldots \ \leq 100000 \qquad \text{[W/m²]} \qquad \text{(C.12)}$$

Where the different individual heat fluxes $\dot{h}_1$, $\dot{h}_2$ ... received by the fire exposed unit surface area are calculated according to (7), (10) or (11).

Annex D
(informative)

Advanced fire models

D.1 One-zone models

(1) A one-zone model should apply for post-flashover conditions. Homogeneous temperature, density, internal energy and pressure of the gas are assumed in the compartment.

(2) The temperature should be calculated considering:

- the resolution of mass conservation and energy conservation equations;
- the exchange of mass between the internal gas, the external gas (through openings) and the fire (pyrolysis rate);
- the exchange of energy between the fire, internal gas, walls and openings.

(3) The ideal gas law considered is:

$$P_{\mathrm{int}} = \rho_{\mathrm{g}}\, R\, T_{\mathrm{g}} \qquad [\mathrm{N/m^2}] \qquad (D.1)$$

(4) The mass balance of the compartment gases is written as

$$\frac{\mathrm{d}m}{\mathrm{d}t} = \dot{m}_{\mathrm{in}} - \dot{m}_{\mathrm{out}} + \dot{m}_{\mathrm{fi}} \qquad [\mathrm{kg/s}] \qquad (D.2)$$

where

$\frac{\mathrm{d}m}{\mathrm{d}t}$	is the rate of change of gas mass in the fire compartment
$\dot{m}_{\mathrm{out}}$	is the rate of gas mass going out through the openings
$\dot{m}_{\mathrm{in}}$	is the rate of gas mass coming in through the openings
$\dot{m}_{\mathrm{fi}}$	is the rate of pyrolysis products generated

(5) The rate of change of gas mass and the rate of pyrolysis may be neglected. Thus

$$\dot{m}_{\mathrm{in}} = \dot{m}_{\mathrm{out}} \qquad (D.3)$$

These mass flows may be calculated based on static pressure due to density differences between air at ambient and high temperatures, respectively.

(6) The energy balance of the gases in the fire compartment may be taken as:

$$\frac{\mathrm{d}E_{\mathrm{g}}}{\mathrm{d}t} = Q - Q_{\mathrm{out}} + Q_{\mathrm{in}} - Q_{\mathrm{wall}} - Q_{\mathrm{rad}} \qquad [\mathrm{W}] \qquad (D.4)$$

where

E_g	is the internal energy of gas	[J]
Q	is the rate of heat release of the fire	[W]

Q_{out} $= \dot{m}_{out}\, c\, T_f$

Q_{in} $= \dot{m}_{in}\, c\, T_{amb}$

Q_{wall} $= (A_t - A_{h,v})\, \dot{h}_{net}$, is the loss of energy to the enclosure surfaces

Q_{rad} $= A_{h,v}\, \sigma\, T_f^{\,4}$, is the loss of energy by radiation through the openings

with:

c	is the specific heat	[J/kgK]
$\dot{h}_{net}$	is given by expression (3.1)	
$\dot{m}$	is the gas mass rate	[kg/s]
T	is the temperature	[K]

D.2 Two-zone models

(1) A two-zone model is based on the assumption of accumulation of combustion products in a layer beneath the ceiling, with a horizontal interface. Different zones are defined: the upper layer, the lower layer, the fire and its plume, the external gas and walls.

(2) In the upper layer, uniform characteristics of the gas may be assumed.

(3) The exchanges of mass, energy and chemical substance may be calculated between these different zones.

(4) In a given fire compartment with a uniformly distributed fire load, a two-zone fire model may develop into a one-zone fire in one of the following situations:

– if the gas temperature of the upper layer ~~gets higher than~~ exceeds 500 °C,

– if the upper layer ~~is growing so to cover~~ grows and covers 80% of the compartment height.

D.3 Computational fluid dynamics models

(1) A computational fluid dynamics model may be used to solve numerically the partial differential equations giving, in all points of the compartment, the thermo-dynamic and aero-dynamic variables.

NOTE Computational fluid dynamics (CFD) models analyse systems involving fluid flow, heat transfer and associated phenomena by solving the fundamental equations of the fluid flow. These equations represent the mathematical statements of the conservation laws of physics.

Annex E
(informative)

Fire load densities, Fire Growth Rates and Rate of Heat Releases

E.1 General

(1) The fire load density used in calculations should be a design value, either based on measurements or based on occupancy statistical distribution as provided in this Annex.

(2) The design value may be determined:

- from a national fire load classification of occupancies; and/or
- specific for an individual project by performing a fire load survey.

(3) The design value of the fire load $q_{f,d}$ is defined as:

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{q1} \cdot \delta_{q2} \cdot \delta_n \cdot \delta_{q3} \qquad [\mathrm{MJ/m^2}] \tag{E.1}$$

where

m	is the combustion factor (see E.3)
δ_{q1}	is a factor taking into account the fire activation risk due to the size of the compartment (see Table E.1)
δ_{q2}	is a factor taking into account the fire activation risk due to the type of occupancy (see Table E.1)
$\delta_n = \prod_{i=1}^{10} \delta_{ni}$	is a factor taking into account the different active fire fighting measures i (sprinkler, detection, automatic alarm transmission, firemen …). These active measures are generally imposed for life safety reason (see Table E.2 and ~~clauses~~ (4) and (5)).
δ_{q3}	is a factor taking into account the reliability class of the building, as defined in EN 1990 (see Table E.3).
$q_{f,k}$	is the characteristic fire load density per unit floor area [MJ/m²] (see e.g. Table E.4)

Table E.1 — Factors δ_{q1}, δ_{q2}

Compartment floor area A_f [m²]	Danger of Fire Activation δ_{q1}	Danger of Fire Activation δ_{q2}	Examples of Occupancies
25	1,10	0,78	artgallery, museum, swimming pool
250	1,50	1,00	offices,residence, hotel, paper industry
2 500	1,90	1,22	manufactory for machinery & engines
5 000	2,00	1,44	chemical laboratory, painting workshop
10 000	2,13	1,66	manufactory of fireworks or paints

Table E.2 — Factors δ_{ni}

δ_{ni} Function of Active Fire Fighting Measures																
Automatic Fire Suppression				Automatic Fire Detection & Alarm				Manual Fire Suppression								
Automatic Water Extinguishing System	Independent Water Supplies			Automatic Fire Detection & Alarm			Automatic Alarm Transmission To Fire Brigade	Fire Brigade		Safe Access Route			Fire Fighting Devices		Smoke Exhaust System	
	0	1	2	By heat	By smoke	By heat & smoke		Work FB	Off Site FB	Improved	Standard	Difficult	present	not present	present	not present
δ_{n1}	δ_{n2}			δ_{n3}			δ_{n4}	δ_{n5}		δ_{n6}			δ_{n7}		δ_{n8}	
0,61	1	0,87	0,7	0,9	0,73	0,73	0,87	0,61	0,78 / 0,84	0,9	1	1,5	1	1,5	1	1,5

(4) For the normal fire fighting measures required by national regulations, such as the safe access routes, fire fighting devices, and smoke exhaust systems in staircases, the δ_{ni} values of Table E.2 should be taken as 1,0. However, if these fire fighting measures have not been foreseen but required by national regulations, the corresponding δ_{ni} value should be taken as 1,5.

(5) If staircases are put under overpressure in case of fire alarm, the factor δ_{n8} of Table E.2 may be taken as 0,9.

(6) The preceding approach is based on the assumption that the requirements in the relevant European Standards on sprinklers, detection, alarm, smoke exhaust systems are met.

(7) The factor δ_{n5} of Table E.2 corresponding to "off-site fire brigade" translates the effect of a professional fire brigade: it may be taken as 0,78 or 0,84 if the brigade acts in maximum 20 minutes or 30 minutes after the fire alarm, respectively.

TABLE E.3 – Factor δ_{q3}

Reliability Class	Examples of buildings	δ_{q3}
RC3	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)	1.19
RC2	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)	1
RC1	Agricultural buildings, buildings where people do not normally enter (e.g. storage buildings, greenhouses)	0.83

E.2 Determination of fire load densities

E.2.1 General

(1) The fire load should consist of all combustible building contents and the relevant combustible parts of the construction, including linings and finishing. Combustible parts of the combustion which do not char during the fire ~~need not to be taken into account~~ may be ignored.

(2) The following clauses apply for the determination of fire load densities:

- from a fire load classification of occupancies (see E.2.5); and/or
- specific for an individual project (see E.2.6).

(3) Where fire load densities are determined from a fire load classification of occupancies, fire loads are distinguished as:

- fire loads from the occupancy, given by the classification;
- fire loads from the building (construction elements, linings and finishing) which are generally not included in the classification and are then determined according to the following clauses E.2.2, as relevant.

E.2.2 Definitions

(1) The characteristic fire load is defined as:

$$Q_{fi,k} = \Sigma\, M_{k,i} \cdot H_{ui} \cdot \Psi_i = \Sigma\, Q_{fi,k,i} \qquad [\text{MJ}] \qquad (E.2)$$

where

$M_{k,i}$ is the amount of combustible material [kg], according to (3) and (4)

H_{ui} is the net calorific value of material i [MJ/kg], see (E.2.4)

$[\Psi_i]$ is the optional factor for assessing protected fire loads, see (E.2.3)

(2) The characteristic fire load density $q_{f,k}$ per unit area is defined as:

$$q_{f,k} = Q_{fi,k} / A \qquad [\text{MJ/m}^2] \qquad (E.3)$$

where

A is the floor area (A_f) of the fire compartment or reference space, or inner surface area (A_t) of the fire compartment, giving $q_{f,k}$ or $q_{t,k}$

(3) Permanent fire loads, which are not expected to vary during the service life of a structure, should be introduced ~~by~~ with their expected values resulting from the survey.

(4) Variable fire loads, which may vary during the service life of a structure, should be represented by values, which are expected not to be exceeded during 80 % of the time.

E.2.3 Protected fire loads

(1) Fire loads in containments which are designed to survive fire exposure need not be considered.

(2) Fire loads in non-combustible containments with no specific fire design, but which remain intact during fire exposure, may be considered as follows:

The largest fire load, but at least 10 % of the protected fire loads, is associated with $\Psi_i = 1,0$.

If this fire load plus the unprotected fire loads are not sufficient to heat the remaining protected fire loads beyond ignition temperature, then the remaining protected fire loads may be associated with $\Psi_i = 0,0$.

Otherwise, Ψ_i values need to be assessed individually.

E.2.4 Net calorific values

(1) Net calorific values should be determined according to EN ISO 1716:2002.

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

$$H_u = H_{u0} (1 - 0,01\, u) - 0,025\, u \qquad [\mathrm{MJ/kg}] \qquad (E.4)$$

where

u is the moisture content expressed as percentage of dry weight

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

(3) Net calorific values of some solids, liquids and gases are given in Table E.4.

Table E.4 — Net calorific values H_u [MJ/kg] of combustible materials for calculation of fire loads

Solids	
Wood	17,5
Other cellulosic materials • Clothes • Cork • Cotton • Paper, cardboard • Silk • Straw • Wool	20
Carbon • Anthracit • Charcoal • Coal	30
Chemicals	
Paraffin series • Methane • Ethane • Propane • Butane	50
Olefin series • Ethylene • Propylen • Butene	45
Aromatic series • Benzene • Toluene	40
Alcohols • Methanol • Ethanol • Ethyl alcohol	30
Fuels • Gasoline, petroleum • Diesel	45
Pure hydrocarbons plastics • Polyethylene • Polystyrene • Polypropylene	40
Other products	
ABS (plastic)	35
Polyester (plastic)	30
Polyisocyanerat and polyurethane (plastics)	25
Polyvinylchloride, PVC (plastic)	20
Bitumen, asphalt	40
Leather	20
Linoleum	20
Rubber tyre	30

E.2.5 Fire load classification of occupancies

(1) The fire load densities should be classified according to occupancy, be related to the floor area, and be used as characteristic fire load densities $q_{f,k}$ [MJ/m²], as given in Table E.5.

Table E.5 — Fire load densities $q_{f,k}$ [MJ/m²] for different occupancies

Occupancy	Average	80% Fractile
Dwelling	780	948
Hospital (room)	230	280
Hotel (room)	310	377
Library, Archives	1 500	1 824
Densely loaded office (office including minimum 20 ~~maximum 30~~% archive’s surface)	744	905
Office	420	511
Sparsely loaded office (open space office with limited combustible furniture, paperless office without archives)	206	250
Classroom of a school	285	347
Commercial area	600	730
Theatre (cinema)	300	365
Public space: Circulation areas, walkways	100	122
NOTE Gumbel distribution is assumed		

(2) The values of the fire load density $q_{f,k}$ given in Table E.5 are valid in case of a factor δ_{q2} equal to 1,0 (see Table E.1).

(3) The fire loads in Table E.5 are valid for ordinary compartments in connection with the here given occupancies. Special rooms are considered according to E.2.2.

(4) Fire. loads from the building (construction elements, structures, linings and finishing) should be determined according to E.2.2. These should be added to the fire load densities of (1) if relevant

E.2.6 Individual assessment of fire load densities

(1) In the absence of occupancy classes, fire load densities may be specifically determined for an individual project by performing a survey of fire loads from the occupancy.

(2) The fire loads and their local arrangement should be estimated considering the intended use, furnishing and installations, variations with time, unfavourable trends and possible modifications of occupancy.

(3) Where available, a survey should be performed in a comparable existing project, such that only possible differences between the intended and existing project need to be specified by the client.

E.3 Combustion behaviour

(1) The combustion behaviour should be considered in depending on ~~function of~~ the occupancy and ~~of~~ the type of fire load.

(2) For mainly cellulosic materials, the combustion factor may be assumed as $m = 0{,}8$.

E.4 Rate of heat release Q

(1) The growing phase may be defined by the expression:

$$Q = 10^6 \left(\frac{t}{t_\alpha} \right)^2 \tag{E.5}$$

where

Q is the rate of heat release in [W]

t is the time in [s]

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

(2) The parameter t_α and the maximum rate of heat release RHR_f , for different occupancies, are given in Table E.6

Table E.6 — Fire growth rate and RHR_f for different occupancies

Max Rate of heat release RHR_f			
Occupancy	Fire growth rate	t_α [s]	RHR_f [kW/m^2]
Dwelling	Medium	300	250
Hospital (room)	Medium	300	250
Hotel (room)	Medium	300	250
Library, Archives	Fast	150	500
Densely loaded office (office including minimum 20 ~~maximum 30~~% archive’s surface)	Medium	300	250
Office	Medium	300	250
Sparsely loaded office (open space office with limited combustible furniture, paperless office without archives)	Medium	300	250
Classroom of a school	Medium	300	250
Commercial area	Fast	150	250
Theatre (cinema)	Fast	150	500
Public space: Circulation areas, walkways	Slow	600	250

(3) The values of the fire growth rate and RHR_f according to Table E.6 are valid in case of a factor δ_{q2} equal to 1,0 (see Table E.1).

(4) For an ultra-fast fire spread, t_α corresponds to 75 s.

(5) The growing phase is limited by a horizontal plateau corresponding to the stationary state and to a value of Q given by ($RHR_f \cdot A_{fi}$)

where

A_{fi} is the maximum area of the fire [m^2] which is the fire compartment in case of uniformly distributed fire load but which may be smaller in case of a localised fire.

RHR_f is the maximum rate of heat release produced by 1 m^2 of fire in case of fuel controlled conditions [kW/m^2] (see Table E.6).

(6) The horizontal plateau is limited by the decay phase which starts when 70 % of the total fire load has been consumed.

(7) The decay phase may be assumed to be a linear decrease starting when 70 % of the fire load has been burnt and completed when the fire load has been completely burnt.

(8) If the fire is ventilation controlled, this plateau level should be reduced following the available oxygen content, either automatically in case of the use of a computer program based on one zone model or by the simplified expression:

~~$Q_{max} = 0{,}10 \,.\, m \,.\, H_u \,.\, A_v \,.\, \sqrt{h_{eq}}$~~ $Q_{max} = 1{,}57 \,.\, m_{O2} \,.\, A_v \,.\, \sqrt{h_{eq}}$ [MW] (E.6)

where

A_v is the opening area [m^2]

h_{eq} is the mean height of the openings [m]

~~H_u is the net calorific value of wood with H_u = 17,5 MJ/kg~~

~~m is the combustion factor with m = 0,8~~

m_{O2} is the oxygen consumption factor with m_{O2} = 0,8.

(9) When the maximum level of the rate of heat release is reduced in case of ventilation controlled condition, the curve of the rate of heat release should be extended to correspond to the available energy given by the fire load. If the curve is not extended, it is then assumed that there is external burning, which induces a lower gas temperature in the compartment.

(10) As an alternative to (2), design based on probabilistic methods may be used when authorized by the relevant authority or agreed for a specific project by the relevant parties.

The design value of the rate of heat release $Q_{f,d}$ is defined as:

$Q_{f,d} = Q_{f,k} \cdot \delta_{Q1}$ [kW/m^2] (E.7)

where

δ_{Q1} is a probabilistic factor applied on the Rate of Heat Release Rate. Without a statistical distribution of the Rate of Heat Release and without a specific authorization by the relevant authorities, this factor shall be taken as 1.

$Q_{f,k}$ is the Rate of Heat Release density per unit floor area [kW/m^2] (see e.g.. Table E.6)

Annex F
(informative)

Equivalent time of fire exposure

(1) The following approach may be used where the design of members is based on tabulated data or other simplified rules, related to the standard fire exposure.

NOTE The method given in this annex is material dependent. It is not applicable to composite steel and concrete or timber constructions.

(2) If fire load densities are specified without specific consideration of the combustion behaviour (see annex E), then this approach should be limited to fire compartments with mainly cellulosic type fire loads.

(3) The equivalent time of standard fire exposure is defined by:

$$t_{e,d} = (q_{f,d} \cdot k_b \cdot w_f)\, k_c \quad \text{or}$$

$$t_{e,d} = (q_{t,d} \cdot k_b \cdot w_t)\, k_c \qquad \text{[min]} \qquad \text{(F.1)}$$

where

$q_{f,d}$ is the design fire load density according to annex E, whereby $q_{t,d} = q_{f,d} \cdot A_f / A_t$

k_b is the conversion factor according to (4)

w_f is the ventilation factor according to (5), whereby $w_t = w_f \cdot A_t / A_f$

k_c is the correction factor function of the material of the ~~composing~~ structural cross-sections, ~~and~~ defined in Table F.1.

Table F.1 — Correction factor k_c in order to cover various materials.
(*O* is the opening factor defined in annex A)

Cross-section material	Correction factor k_c
Reinforced concrete	1,0
Protected steel	1,0
Not protected steel	$13{,}7 \cdot O$

(4) Where no detailed assessment of the thermal properties of the enclosure is made, the conversion factor k_b may be taken as:

$$k_b = 0{,}07 \quad [\text{min} \cdot \text{m}^2/\text{MJ}] \quad \text{when } q_d \text{ is given in } [\text{MJ/m}^2] \qquad \text{(F.2)}$$

otherwise k_b may be related to the thermal property $b = \sqrt{(\rho c \lambda)}$ of the enclosure according to Table F.2. For determining b for multiple layers of material or different materials in walls, floor, ceiling, see annex A (5) and (6).

Table F.2 — Conversion factor k_b depending on the thermal properties of the enclosure

$b = \sqrt{\rho c \lambda}$ [J/m^{2}s$^{1/2}$K]	k_b [min · m^2/MJ]
$b > 2\,500$	0,04
$720 \leq b \leq 2\,500$	0,055
$b < 720$	0,07

(5) The ventilation factor w_f may be calculated as:

$$w_f = (6{,}0 / H)^{0{,}3} [0{,}62 + 90(0{,}4 - \alpha_v)^4 / (1 + b_v \alpha_h)] \geq 0{,}5 \qquad [-] \qquad (F.3)$$

where

$\alpha_v = A_v / A_f$ is the area of vertical openings in the façade (A_v) related to the floor area of the compartment (A_f) where the limit $0{,}025 \leq \alpha_v \leq 0{,}25$ should be observed

$\alpha_h = A_h / A_f$ is the area of horizontal openings in the roof (A_h) related to the floor area of the compartment (A_f)

$b_v = 12{,}5 (1 + 10 \alpha_v - \alpha_v^2) \geq 10{,}0$

H is the height of the fire compartment [m]

For small fire compartments [$A_f < 100$ m^2] without openings in the roof, the factor w_f may also be calculated as:

$$w_f = O^{-1/2} \cdot A_f / A_t \qquad (F.4)$$

where

O is the opening factor according to annex A

(6) It shall be verified that:

$$t_{e,d} < t_{fi,d} \qquad (F.5)$$

where

$t_{fi,d}$ is the design value of the standard fire resistance of the members, assessed according to the fire Parts of EN 1992 to EN 1996 and EN 1999.

Annex G
(informative)

Configuration factor

G.1 General

(1) The configuration factor Φ ~~is~~ defined in ~~1.5.4.1~~ 3.1.4.1, which in a mathematical form is given by:

$$dF_{d1-d2} = \frac{\cos\theta_1 \cos\theta_2}{\pi\, S_{1-2}^2} dA_2 \tag{G.1}$$

The configuration factor measures the fraction of the total radiative heat leaving a given radiating surface that arrives at a given receiving surface. Its value depends on the size of the radiating surface, on the distance from the radiating surface to the receiving surface and on their relative orientation (see Figure G.1).

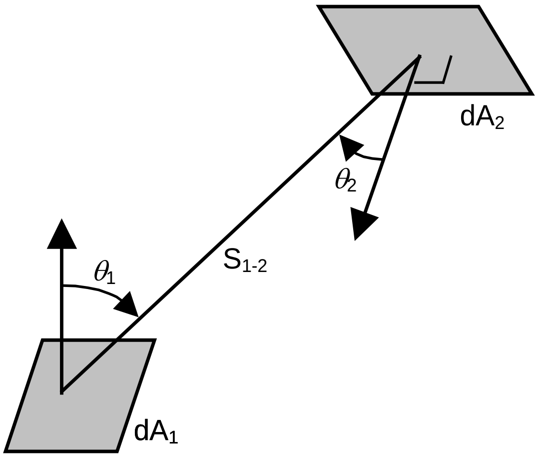


Figure G.1 — Radiative heat transfer between two infinitesimal surface areas

(2) In cases where the radiator has uniform temperature and emissivity, the definition can be simplified to : “the solid angle within which the radiating environment can be seen from a particular infinitesimal surface area, divided by 2π.”

(3) The radiative heat transfer to an infinitesimal area of a convex member surface is determined by the position and the size of the fire only (position effect).

(4) The radiative heat transfer to an infinitesimal area of a concave member surface is determined by the position and the size of the fire (position effect) as well as by the radiation from other parts of the member (shadow effects).

(5) Upper limits for the configuration factor Φ are given in Table G.1.

Table G.1 — Limits for configuration factor Φ

		Localised	Fully developed
position effect		$\Phi \leq 1$	$\Phi = 1$
shadow effect	convex	$\Phi = 1$	$\Phi = 1$
	concave	$\Phi \leq 1$	$\Phi \leq 1$

G.2 Shadow effects

(1) Specific rules for quantifying the shadow effect are given in the material orientated parts of the Eurocodes.

G.3 External members

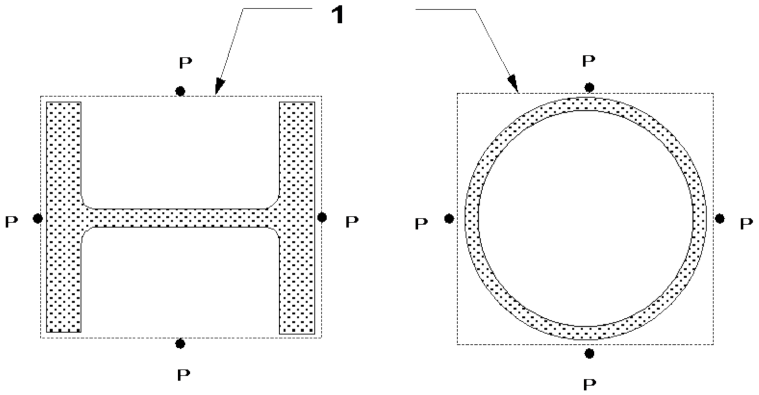
(1) For the calculation of temperatures in external members, all radiating surfaces may be assumed to be rectangular in shape. They comprise the windows and other openings in fire compartment walls and the equivalent rectangular surfaces of flames, see annex B.

(2) In calculating the configuration factor for a given situation, a rectangular envelope should first be drawn around the cross-section of the member receiving the radiative heat transfer, as indicated in Figure G.2 (This accounts for the shadow effect in an approximate way). The value of Φ should then be determined for the mid-point P of each face of this rectangle.

(3) The configuration factor for each receiving surface should be determined as the sum of the contributions from each of the zones on the radiating surface (normally four) that are visible from ~~the~~ point P on the receiving surface, as indicated in Figures G.3 and G.4. These zones should be defined relative to the point X where a horizontal line perpendicular to the receiving surface meets the plane containing the radiating surface. No contribution should be taken from zones that are not visible from ~~the~~ point P, such as the shaded zones in Figure G.4.

(4) If ~~the~~ point X lies outside the radiating surface, the effective configuration factor should be determined by adding the contributions of the two rectangles extending from X to the farther side of the radiating surface, then subtracting the contributions of the two rectangles extending from X to the nearer side of the radiating surface.

(5) The contribution of each zone should be determined as follows:



Key
1 Envelope

Figure G.2 — Envelope of receiving surfaces

a) receiving surface parallel to radiating surface:

$$\Phi = \frac{1}{2\pi}\left[\frac{a}{(1+a^2)^{0,5}}\tan^{-1}\left(\frac{b}{(1+a^2)^{0,5}}\right)+\frac{b}{(1+b^2)^{0,5}}\tan^{-1}\left(\frac{a}{(1+b^2)^{0,5}}\right)\right] \tag{G.2}$$

where

a = h / s

b = w / s

s is the distance from P to X;

h is the height of the zone on the radiating surface;

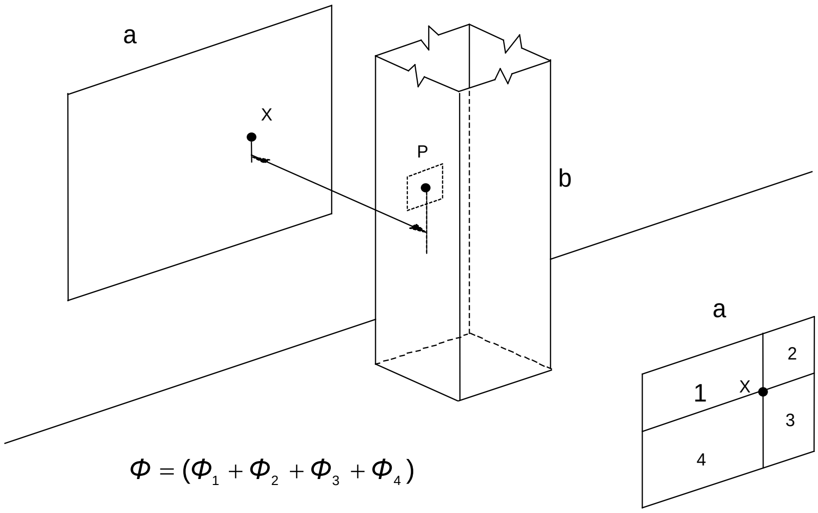
w is the width of that zone.

b) receiving surface perpendicular to radiating surface:

$$\Phi = \frac{1}{2\pi}\left[\tan^{-1}(a)-\frac{1}{(1+b^2)^{0,5}}\tan^{-1}\left(\frac{a}{(1+b^2)^{0,5}}\right)\right] \tag{G.3}$$

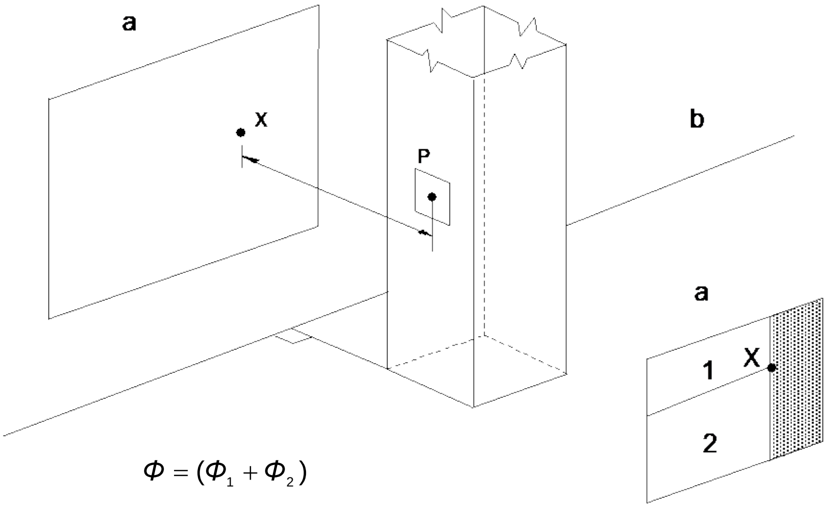
c) receiving surface in a plane at an angle θ to the radiating surface:

$$\Phi = \frac{1}{2\pi}\left[\tan^{-1}(a)-\frac{(1-b\cos\theta)}{(1+b^2-2b\cos\theta)^{0,5}}\tan^{-1}\left(\frac{a}{(1+b^2-2b\cos\theta)^{0,5}}\right)+\frac{a\cos\theta}{(a^2+\sin^2\theta)^{0,5}}\left[\tan^{-1}\left(\frac{(b-\cos\theta)}{(a^2+\sin^2\theta)^{0,5}}\right)+\tan^{-1}\left(\frac{\cos\theta}{(a^2+\sin^2\theta)^{0,5}}\right)\right]\right] \tag{G.4}$$



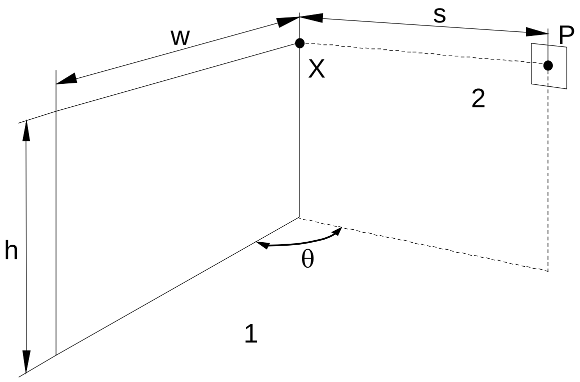
Key
a Radiating surface
b Receiving surface

Figure G.3 — Receiving surface in a plane parallel to that of the radiating surface



Key
a Radiating surface
b Receiving surface

Figure G.4 — Receiving surface perpendicular to the plane of the radiating surface



Key
1 Radiating surface
2 Receiving surface

Figure G.5 — Receiving surface in a plane at an angle θ to that of the radiating surface

G.4 Virtual solid flame

(1) As mentioned in Annex C, a localized fire may be represented by a succession of elementary cylinders having different diameters representing the cone and the total radiative flux [W/m^2] is the sum of the radiative flux emitted by the lateral surface of the cylinders and the radiative flux emitted by the rings situated at the top surface of each cylinder, see Figure G.6.

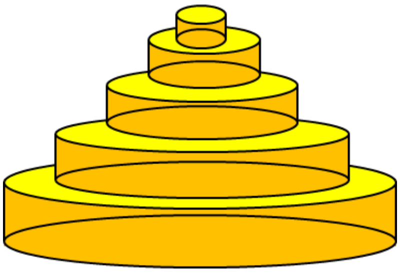


Figure G.6 - Division of a virtual solid flame into a succession of elementary cylinders and rings

(2) In calculating the configuration factor for a given localized fire, a rectangular envelope should first be drawn around the cross-section of the member receiving the radiative heat transfer, as indicated in Figure G.2. The value of Φ should then be determined for the mid-point P of each face of this rectangle.

(3) The contribution of each cylinder lateral surface should be determined using (G.5). If the plane of the receiving surface does intersect the cylinder, this cylinder shall be reduced to the largest cylinder included in the initial cylinder and situated integrally in the visible domain (Figure G.8).

a) The plane of the receiving surface does not intersect the cylinder:

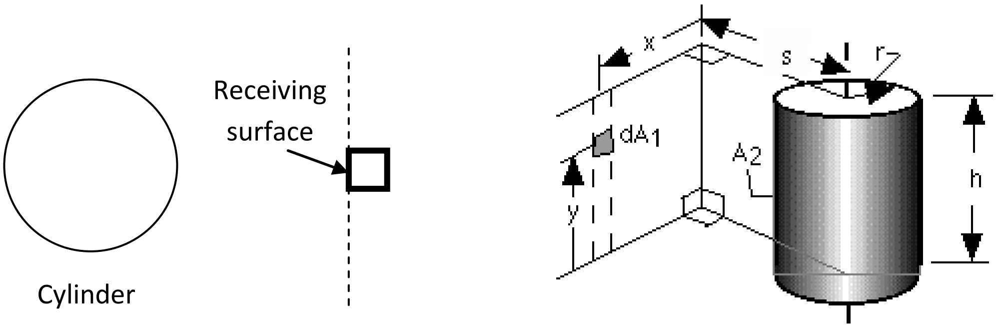


Figure G.7 - Plane of the receiving surface not intersecting the cylinder

$$F_{dA_1 \rightarrow A_2} = \frac{S}{B} - \frac{S}{2B\pi} \left\{ \begin{array}{c} cos^{-1}\left(\frac{Y^2-B+1}{A-1}\right) + cos^{-1}\left(\frac{C-B+1}{C+B-1}\right) \\ -Y\left[\frac{A+1}{\sqrt{(A-1)^2+4Y^2}} cos^{-1}\left(\frac{Y^2-B+1}{\sqrt{B}(A-1)}\right)\right] \\ -\sqrt{C}\frac{C+B+1}{\sqrt{(C+B-1)^2+4C}} cos^{-1}\left(\frac{C-B+1}{\sqrt{B}(C+B-1)}\right) \\ +Hcos^{-1}\left(\frac{1}{\sqrt{B}}\right) \end{array} \right\} \quad (G.5)$$

With $S = s/r, X = x/r, Y = y/r, H = h/r, A = X^2 + Y^2 + S^2, B = S^2 + X^2, C = (H - Y)^2$

b) If the plane of the receiving surface does intersect the cylinder (see Figure G.8):

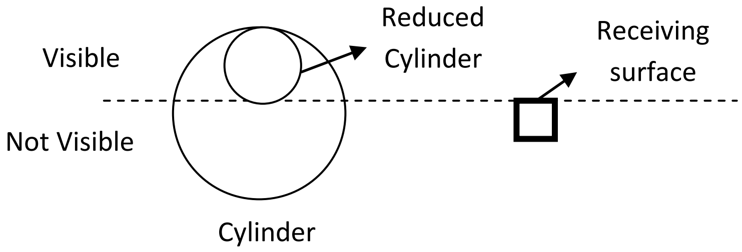


Figure G.8 - Plane of the receiving surface intersecting the cylinder

(4) As a conservative simplification, the radiative heat flux [W/m^2] received by a surface in a plane intersecting the cylinder can be evaluated as 50% of the radiated heat flux received by the principal surface. The principal surface is characterized by a normal vector pointing to the centre of the cylinder (principal surface is Face 1 on Figure G.9).

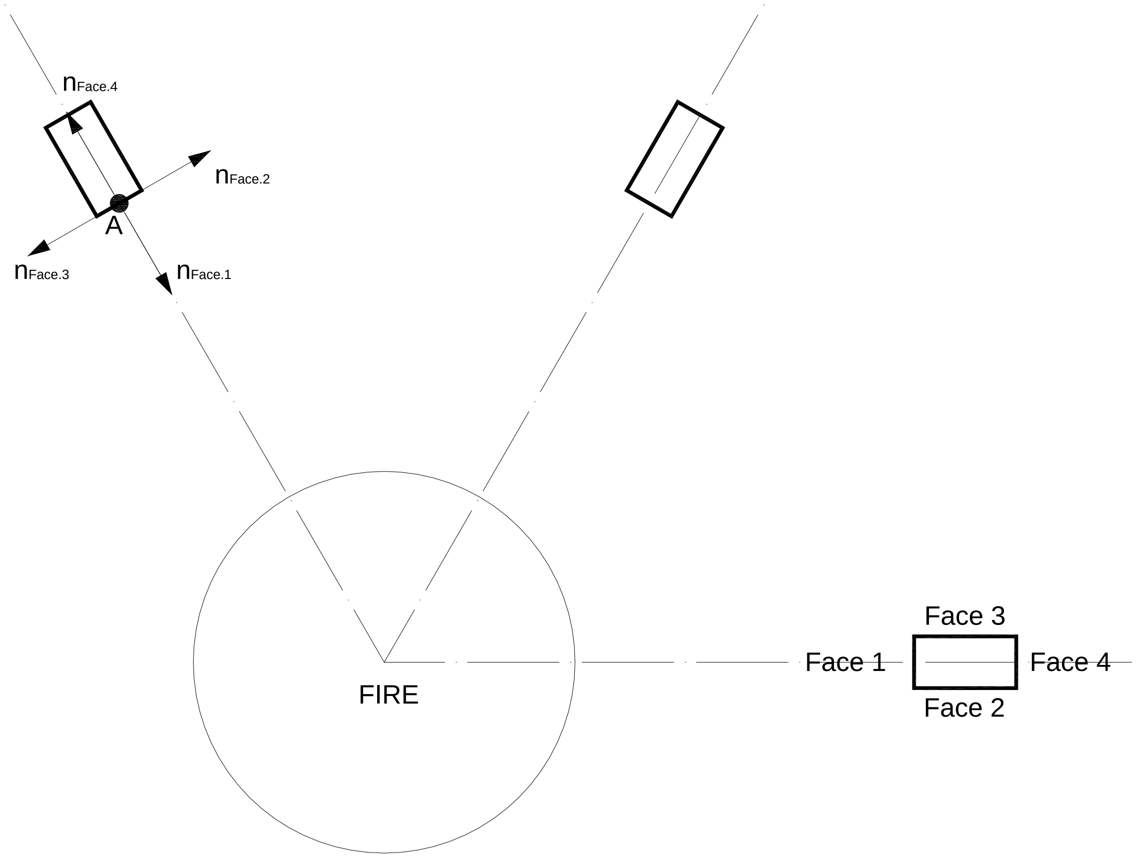
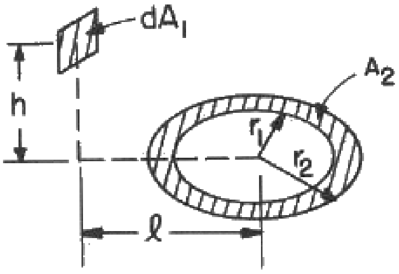


Figure G.9 - Principal surface for different positions of the receiving element

(5) The contribution of each ring should be determined using (G.6).



$$F_{dA_1 \to A_2} = \frac{H}{2}\left(\frac{H^2+R_2^2+1}{\sqrt{\left(H^2+R_2^2+1\right)^2-4R_2^2}} - \frac{H^2+R_1^2+1}{\sqrt{\left(H^2+R_1^2+1\right)^2-4R_1^2}}\right) \tag{G.6}$$

With $\mathrm{H} = \mathrm{h}/\mathrm{l}, \mathrm{R} = \mathrm{r}/\mathrm{l}$

Figure G.10 – Relative position of the receiving surface and the ring