Section 3 Eurocode 1 EN 1991-1-2

3.1 General

The methods given in this Part 1-2 of EN 1991 are applicable to buildings, with a fire load related to the building and its occupancy. 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 prEN 1992 to prEN 1996 and prEN 1999 which give rules for designing structures for fire resistance. This Part 1-2 of EN 1991 contains thermal actions related to nominal and physically based thermal actions. More data and models for physically based thermal actions are given in annexes.

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.

The rules given in EN 1990:2002, 1.4 apply. For the purposes of this European Standard, the terms and definitions given in EN 1990:2002, 1.5 and the following apply.

3.2 Terms relating to thermal actions

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.

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.

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.

EXTERNAL MEMBER. Structural member located outside the building that may be exposed to fire through openings in the building enclosure.

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.

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.

DESIGN FIRE SCENARIO. Specific fire scenario on which an analysis will be conducted.

EXTERNAL FIRE CURVE. Nominal temperature-time curve intended for the outside of separating external walls 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.

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.

FIRE LOAD. Sum of thermal energies which are released by combustion of all combustible materials in a space (building contents and construction elements).

HYDROCARBON FIRE CURVE. Nominal temperature-time curve for representing effects of an hydrocarbon type fire.

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.

STANDARD TEMPERATURE-TIME CURVE. Nominal curve defined in prEN 13501-2 for representing a model of a fully developed fire in a compartment.

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
- parametric: determined on the basis of fire models and the specific physical parameters defining the conditions in the fire compartment.

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.

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.

FLASH-OVER. Simultaneous ignition of all the fire loads in a compartment.

3.3 Structural Fire design procedure

A structural fire design analysis should take into account 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.

Mechanical behaviour of a structure is depending on thermal actions and their thermal effect on material properties and indirect mechanical actions, as well as on the direct effect of mechanical actions.

Structural fire design involves applying actions for temperature analysis and actions for mechanical analysis according to this Part and other Parts of EN 1991. Actions on structures from fire exposure are classified as accidental actions, see EN 1990:2002, 6.4.3.3(4).

3.4 Design fire scenario, design fire

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

For each design fire scenario, a design fire, in a fire compartment, should be estimated according to section 3 of this Part. 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.

3.5 Temperature Analysis

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

Depending on the design fire chosen in section 3, the following procedures should be used:

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

Note The specified period of time may be given in the national regulations or obtained from annex F following the specifications of the national annex.

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

Note Limited periods of fire resistance may be set in the national annex.

3.6 Thermal actions for temperature analysis (Section 3)

Thermal actions are given by the net heat flux $\dot{h}_{net}[W/m^2]$ to the surface of the member. On the fire exposed surfaces the net heat flux $\dot{h}_{net}$ should be determined by considering heat transfer by convection and radiation as:

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} \quad \textbf{(Eq. 3-1)}$$

where $\dot{h}_{net,c}$ is the net convective heat flux component and $\dot{h}_{net,r}$ is the net radiative heat flux component. The net convective heat flux component should be determined by:

$$\dot{h}_{net,c}\ [W/m^2] = \alpha_c \cdot (\theta_g - \theta_m) \quad \textbf{(Eq. 3-2)}$$

where:

- α_c is the coefficient of heat transfer by convection $[W/m^2K]$
- θ_g is the gas temperature in the vicinity of the fire exposed member [°C]
- θ_m is the surface temperature of the member [°C].

On the unexposed side of separating members, the net heat flux $\dot{h}_{net}$ should be determined by using equation 3-1, with $\alpha_c = 4\ [W/m^2K]$. The coefficient of heat transfer by convection should be taken as $\alpha_c = 9\ [W/m^2K]$, when assuming it contains the effects of heat transfer by radiation.

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

$$\dot{h}_{net,r}\ [W/m^2] = \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot [(\theta_r + 273)^4 - (\theta_m + 273)^4] \quad \textbf{(Eq. 3-3)}$$

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 $(5,67 \times 10^{-8}\ W/m^2K^4)$
- θ_r is the effective radiation temperature of the fire environment [°C]
- θ_m is the surface temperature of the member [°C].

Note Unless given in the material related fire design Parts of prEN 1992 to prEN 1996 and prEN 1999, $\varepsilon_m = 0,8$ may be used. The emissivity of the fire is taken in general as $\varepsilon_f = 1,0$.

Where this Part or the fire design Parts of prEN 1992 to prEN 1996 and prEN 1999 give no specific data, the configuration factor should be taken as $\Phi = 1$. A lower value may be chosen to take account of so called position and shadow effects.

Note For the calculation of the configuration factor Φ a method is given in annex G.

In case of fully fire engulfed members, the radiation temperature θ_r may be represented by the gas temperature θ_g around that member. The surface temperature θ_m results from the temperature analysis of the member according to the fire design Parts 1-2 of prEN 1992 to prEN 1996 and prEN 1999, as relevant.

Gas temperatures θ_g may be adopted as nominal temperature-time curves according to 3.2, or adopted according to the fire models given in 3.3.

Note The use of the nominal temperature-time curves according to 3.2 or, as an alternative, the use of the natural fire models according to 3.3 may be specified in the national annex.

3.7 Nominal temperature-time curves

STANDARD TEMPERATURE-TIME CURVE. The standard temperature-time curve is given by:

$$\theta_g = 20 + 345 \cdot \log_{10}(8t + 1) \qquad \textbf{(Eq. 3-4)}$$

where:

- θ_g is the gas temperature in the fire compartment [°C]
- t is the time [min].

The coefficient of heat transfer by convection is $\alpha_c = 25\ W/m^2K$.

EXTERNAL FIRE CURVE. The external fire curve is given by:

$$\theta_g = 20 + 660(1 - 0,687e^{-0,32t} - 0,313e^{-3,8t}) \qquad \textbf{(Eq. 3-5)}$$

where:

- θ_g is the gas temperature near the member [°C]
- t is the time [min].

The coefficient of heat transfer by convection is $\alpha_c = 25\ \mathrm{W/m^2K}$.

HYDROCARBON CURVE. The hydrocarbon temperature-time curve is given by:

$$\theta_g = 20 + 1080(1 - 0,325e^{-0,167t} - 0,675e^{-2,5t}) \qquad \textbf{(Eq. 3-6)}$$

where:

- θ_g is the gas temperature in the fire compartment [°C]
- t is the time [min].

The coefficient of heat transfer by convection is $\alpha_c = 50\ \mathrm{W/m^2K}$.

3.8 Verification tests

EN1991-1-2_(A).XLS. 6.4 MB. Created: 3 February 2013. Last/Rel.-date: 3 May 2013. Sheets:

— Splash

— CodeSec3

— Annex A.

NOTE: the code requires a reference to the "OLE Automation" type library

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EXAMPLE 3-R- Section 3.1 - Thermal actions for temperature analysis - **test 1**

Given: Determine the net heat flux on a fire exposed surface, in case of fully fire engulfed members ($\theta_r \approx \theta_g$ around the member). Suppose: $\alpha_c = 4,00\ \mathrm{W/m^2K}$ (coefficient of heat transfer by convection); $\theta_g = 700°\mathrm{C}$ (gas temperature in the vicinity of the fire exposed member); $\theta_m = 70°\mathrm{C}$ (surface temperature of the member); $\Phi = 1$ (configuration factor); $\varepsilon_m = 0,8$ (surface emissivity of the member); $\varepsilon_f = 1,0$ (emissivity of the fire); $\theta_r = 700°\mathrm{C}$ (effective radiation temperature of the fire environment).

[*Reference sheet:* CodeSec3]-[*Cell-Range: A1:O1-A64:O64*].

Solution: The net convective heat flux component is given by:

$$\dot{h}_{net,c} = \alpha_c \cdot (\theta_g - \theta_m) = 4,00 \cdot (700 - 70) = 2520\ \mathrm{W/m^2} = 2,52\ \mathrm{kW/m^2}.$$

The net radiative heat flux component is determined by:

$$\dot{h}_{net,r} = \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot [(\theta_r + 273)^4 - (\theta_m + 273)^4] = 1 \cdot 0,8 \cdot 1 \cdot \frac{5,67}{10^8} \cdot [(700 + 273)^4 - (70 + 273)^4]$$

$$\dot{h}_{net,r} = 1 \cdot 0,8 \cdot 1 \cdot \frac{5,67}{10^8} \cdot [8,963 \cdot 10^{11} - 0,138 \cdot 10^{11}] = 40 \cdot \frac{10^{11}}{10^8} = 40000\ \mathrm{W/m^2} = 40\ \mathrm{kW/m^2}$$

Therefore, the net heat flux (considering heat transfer by convection and radiation) is given by:

$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} = 2,52 + 40 = 42,52\ \mathrm{kW/m^2}.$$

Now, considering $\theta_r \approx \theta_g$ with (say) $\theta_m = 500°\mathrm{C}$, $\theta_g = 720°\mathrm{C}$, we get:

$$\dot{h}_{net,c} = \alpha_c \cdot (\theta_g - \theta_m) = 4,00 \cdot (720 - 500) = 880\ W/m^2 = 0,88\ kW/m^2$$

$$\dot{h}_{net,r} = \Phi \cdot \varepsilon_m \cdot \varepsilon_f \cdot \sigma \cdot [(\theta_r + 273)^4 - (\theta_m + 273)^4] = 1 \cdot 0,8 \cdot 1 \cdot \frac{5,67}{10^8} \cdot [(720 + 273)^4 - (500 + 273)^4]$$

$$\dot{h}_{net,r} = 1 \cdot 0,8 \cdot 1 \cdot \frac{5,67}{10^8} \cdot [9,723 \cdot 10^{11} - 3,570 \cdot 10^{11}] = 27,91 \cdot \frac{10^{11}}{10^8} = 27910\ W/m^2 = 27,91\ kW/m^2$$

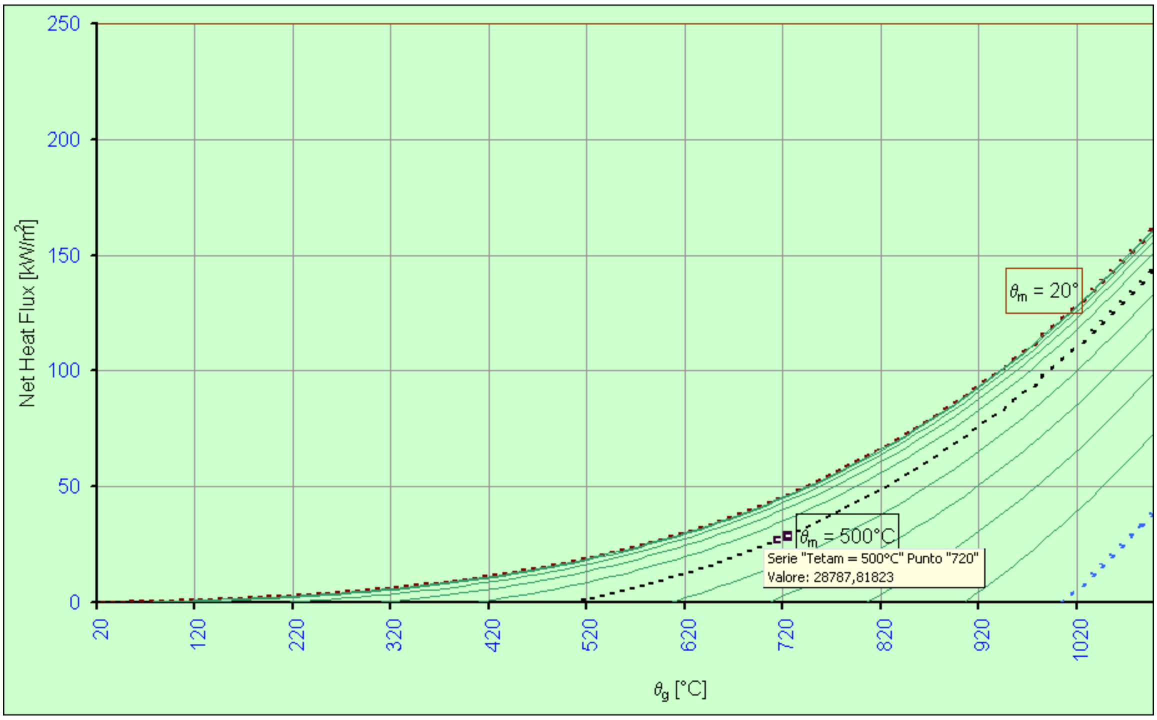

Figure 3.6 View Plot (from input). See cells Range H63:J65 - Sheet: CodeSec3.

Hence, we find: $\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r} = 0,88 + 27,91 = 28,79\ kW/m^2$ (see plot above).

example-end

EXAMPLE 3-S- Section 3.2 - Nominal temperature-time curves - **test 2**

Given: Determine the standard temperature-time curve at $t = 120$ min (time of the exposure), the external fire curve and the hydrocarbon temperature-time curve at $t = 15$ min.

[*Reference sheet:* CodeSec3]-[*Cell-Range: A68:O68-A190:O190*].

Solution: The standard temperature-time curve is given by (gas temperature in the fire compartment): $\theta_g = 20 + 345 \cdot \log_{10}(8t + 1)$.

Sobstituting $t = 120$ min, we get:

$$\theta_g = 20 + 345 \cdot \log_{10}(8t + 1) = 20 + 345 \cdot \log_{10}(8 \cdot 120 + 1) = 20 + 345 \cdot 2,983 = 1049°C .$$

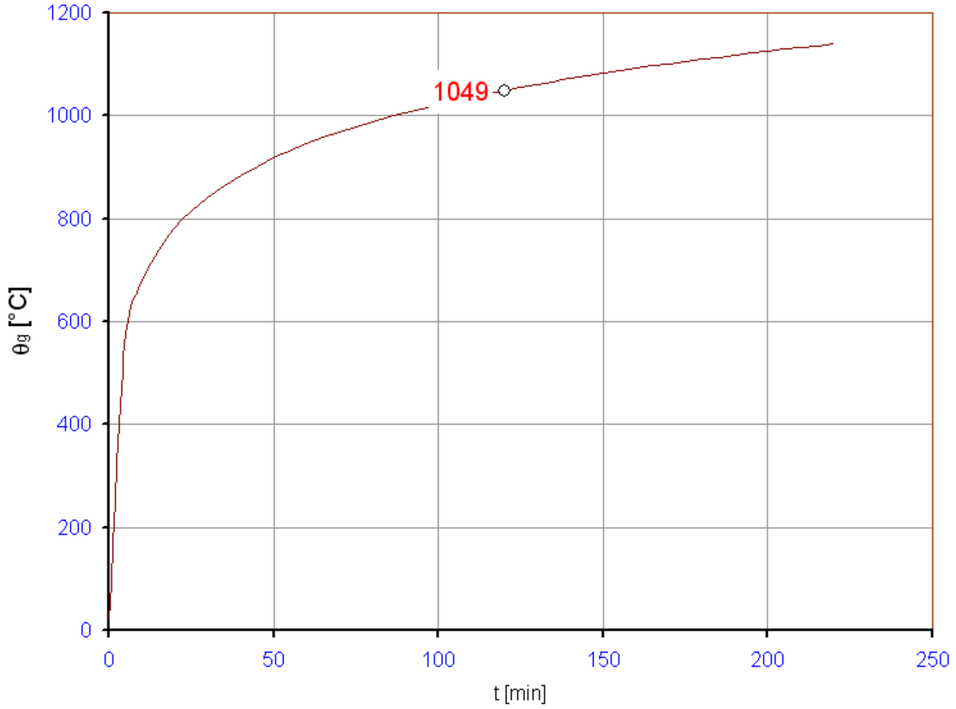

Figure 3.7 Standard temperature-time curve.

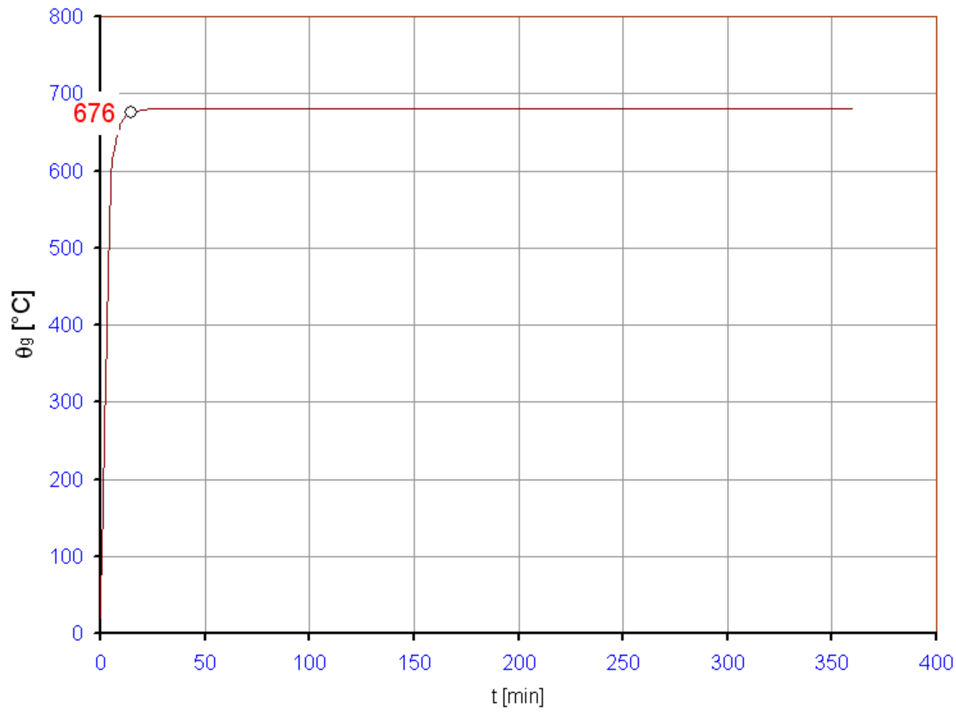

Figure 3.8 External fire curve.

The external fire curve is given by (gas temperature near the member):

$\theta_g = 20 + 660(1 - 0,687e^{-0,32t} - 0,313e^{-3,8t})$. Sobstituting $t = 15\ \text{min}$, we get:

$\theta_g = 20 + 660(1 - 0,687e^{-0,32(15)} - 0,313e^{-3,8(15)}) = 20 + 660(1 - 0,687e^{-4,8} - 0,313e^{-57})$

$\theta_g \approx 20 + 660(1 - 0,687 \cdot 0,00823 - 0) = 676,3°C$.

We find that: $\theta_g = 680°C = cost$ for $t > 40\ \text{min}$ approximately.

The hydrocarbon temperature-time curve is given by (gas temperature in the fire compartment): $\theta_g = 20 + 1080(1 - 0,325e^{-0,167t} - 0,675e^{-2,5t})$.

Sobstituting $t = 15\ \text{min}$, we get:

$\theta_g = 20 + 1080(1 - 0,325e^{-0,167(15)} - 0,675e^{-2,5(15)}) = 20 + 1080(1 - 0,325e^{-2,505} - 0,675e^{-(37,5)})$

$\theta_g \approx 20 + 1080(1 - 0,325e^{-2,505} - 0) = 20 + 1080(1 - 0,325 \cdot 0,0817 - 0) = 1071,3°C$.

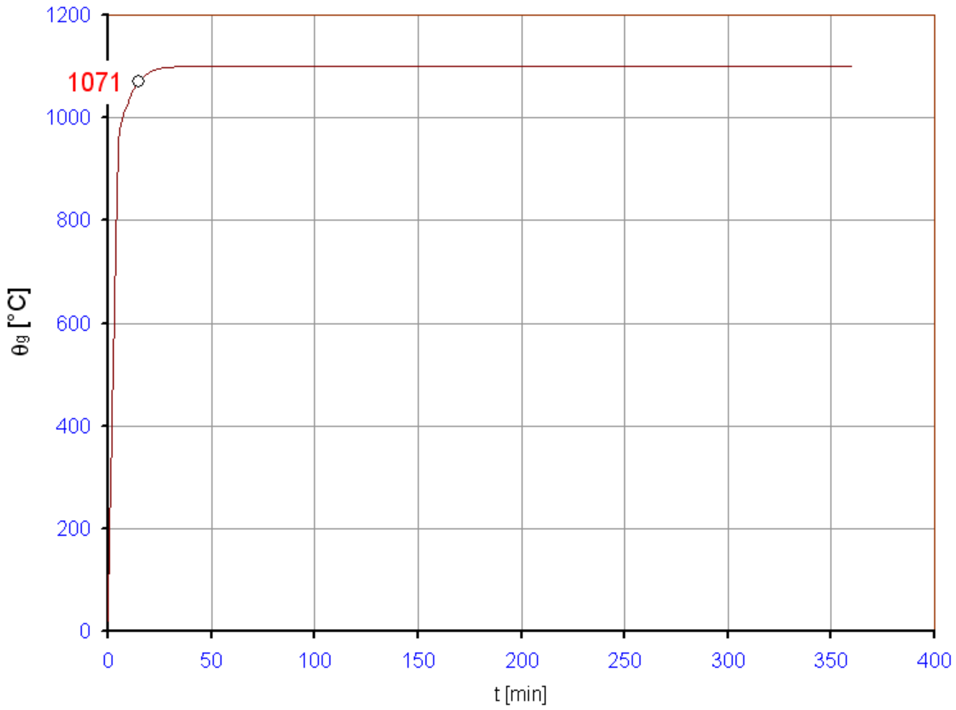

Figure 3.9 Hydrocarbon curve.

We find that: $\theta_g = 1100°C = cost$ for $t > 65\ \text{min}$ approximately.

example-end

EXAMPLE 3-T- Annex A - Parametric temperature-time curves - **test 3**

Given: For internal members of fire compartments, calculate the gas temperature in the compartment using the method given in informative Annex A of EC1 Part 1-2. The theory assumes that temperature rise is independent of fire load.

The temperature within the compartment is assumed to vary as a simple exponential function of modified time dependent on the variation in the ventilation area and the properties of the compartment linings from this "standard" compartment.

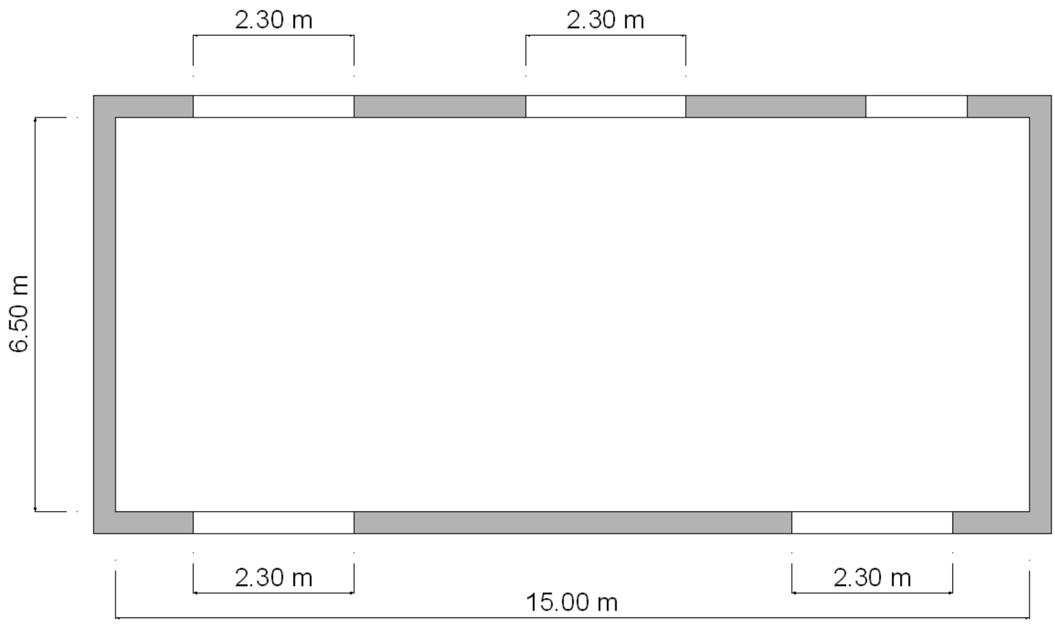

Figure 3.10 Plan of fire compartment (height = 3,60 m).

[*Reference sheet:* Annex A]-[*Cell-Range: A1:O1-A152:O152*].

Solution: Dimension of the compartment:

width = 6,50 m; lenght = 15,00 m; heigth = 3,60 m.

Dimension of windows:

number of windows = 4; width = 2,30 m (mean value); heigth = h_{eq} = 1,70 m (weighted average of window heights on all walls).

	ρ [kg/m^3]	c [J/kgK]	λ [W/mK]	$b = \sqrt{\rho c \lambda}$ [J/m^{2}s^{0,5}K]
CEILING	2400	1506	1,50	$\sqrt{2400 \cdot 1506 \cdot 1,50} = 2328$ (a)
WALLS	900	1250	0,24	$\sqrt{900 \cdot 1250 \cdot 0,24} = 519,6$
FLOOR	900	1250	0,24	$519,6$

Table 3.5 Thermal properties of enclosure surfaces.

(a). b (thermal absorptivity) with the following limits $100 \le b \le 2200$.

We assume: ceiling $b = 2200\ \mathrm{J/m^2 s^{0,5} K}$; walls and floor $b = 520\ \mathrm{J/m^2 s^{0,5} K}$.

Total area of vertical openings on all walls:

$A_v = 4 \cdot (2,30\ m) \cdot (1,70\ m) = 15,64\ m^2$.

Total area of enclosure (walls, ceiling and floor, including openings):

$A_t = 2 \cdot [(6,50 \cdot 15,00) + (6,50 + 15,00) \cdot 3,60] = 349,8\ m^2$.

Opening factor:

$$O = A_v \frac{\sqrt{h_{eq}}}{A_t} = (15,64)\frac{\sqrt{(1,70)}}{(349,8)} = 0,0583\ m^{1/2}$$

with the following limits: $0,02 \le O = 0,0583 \le 0,20$.

We find: ceiling $A_j = 6,50 \cdot 15,00 = 97,50\ m^2$ and floor $A_j = 97,50\ m^2$,
wall $A_j = 2 \cdot (6,50 + 15,00) \cdot 3,60 - 15,64 = 139,2\ m^2$. Hence, we get:

$$b = \frac{\sum b_j A_j}{(A_t - A_v)} = \frac{2200 \cdot 97,50 + 520 \cdot 139,2 + 520 \cdot 97,5}{(349,8 - 15,64)} = 1010\ J/m^2 s^{0,5} K.$$

with the following limits: $100 \le b = 1010 \le 2200$.

Time factor function:

$$\Gamma = \frac{[O/b]^2}{(0,04/1160)^2} = \frac{[(0,0583)/1010]^2}{(0,04/1160)^2} = 2,802.$$

Design value of the fire load density related to the surface area A_f of the floor:

$q_{f,d} = 700\ MJ/m^2$.

Floor area of the fire compartment: $A_f = 97,5\ m^2$.

Design value of the fire load density related to the total surface area A_t of the enclosure:

$$q_{t,d} = q_{f,d}\frac{A_f}{A_t} = 700 \cdot \frac{97,5}{349,8} = 195,11\ MJ/m^2.$$

Fire growth rate: say $t_{lim} = 20\ min \approx 0,333\ h$ (medium fire growth rate).

$0,2 \cdot 10^{-3} q_{t,d}/O = (0,2 \cdot 10^{-3} \cdot 195,11)/0,0583 = 0,67\ h$.

$t_{max} = max[0,2 \cdot 10^{-3} q_{t,d}/O;\ 0,333\ h] = max[0,67;\ 0,333] = 0,67\ h$.

$t_{max} > t_{lim}$ the fire is ventilation controlled.

The maximum temperature θ_{max} in the heating phase happens for $t^* = t^*_{max}$:

$t^*_{max} = t_{max} \cdot \Gamma = 0,67 \cdot 2,802 = 1,88\ h$.

Maximum temperature (heating phase):

$$\begin{cases} \theta_{max} = 20 + 1325 \cdot (1 - 0,324e^{-0,2t^*} - 0,204e^{-1,7t^*} - 0,472e^{-19t^*}) \\ t^*_{max} = 1,88\ h \end{cases}$$

$\theta_{max} = 20 + 1325 \cdot (1 - 0,324e^{-0,2(1,88)} - 0,204e^{-1,7(1,88)} - 0,472e^{-19(1,88)})$

$\theta_{max} \approx 20 + 1325 \cdot [1 - 0,324 \cdot (0,687) - 0,204 \cdot (0,041) - 0] = 1039°C$.

Cooling phase $t \ge t^*_{max}$:

with $t_{max} = 0,67\ h > t_{lim} = 0,33\ h$, we get: $x = 1$ (see eq. A.12).

With $t^{**}_{max} = \left(0,2\times10^{-3}\cdot\frac{q_{t,d}}{O}\right)\cdot\Gamma = \left(0,2\times10^{-3}\cdot\frac{195,11}{0,0583}\right)\cdot 2,802 = 0,669\cdot 2,802 = 1,88\ h$

$0,5\ h < \left(0,2\times10^{-3}\cdot\frac{q_{t,d}}{O}\right)\cdot\Gamma = 1,88\ h < 2\ h$, we get:

$\theta_g = \theta_{max} - 250\cdot(3 - t^{**}_{max})\cdot(t^* - t^{**}_{max}\cdot x)$,

$\theta_g = \theta_{max} - 250\cdot(3-1,88)\cdot(t^*-1,88) = 1039 - 250\cdot(3-1,88)\cdot(t^*-1,88)$.

For (say) $t = 1,10\ h \Rightarrow t^* = t\cdot\Gamma = 1,10\cdot 2,802 = 3,08\ h$, we find:

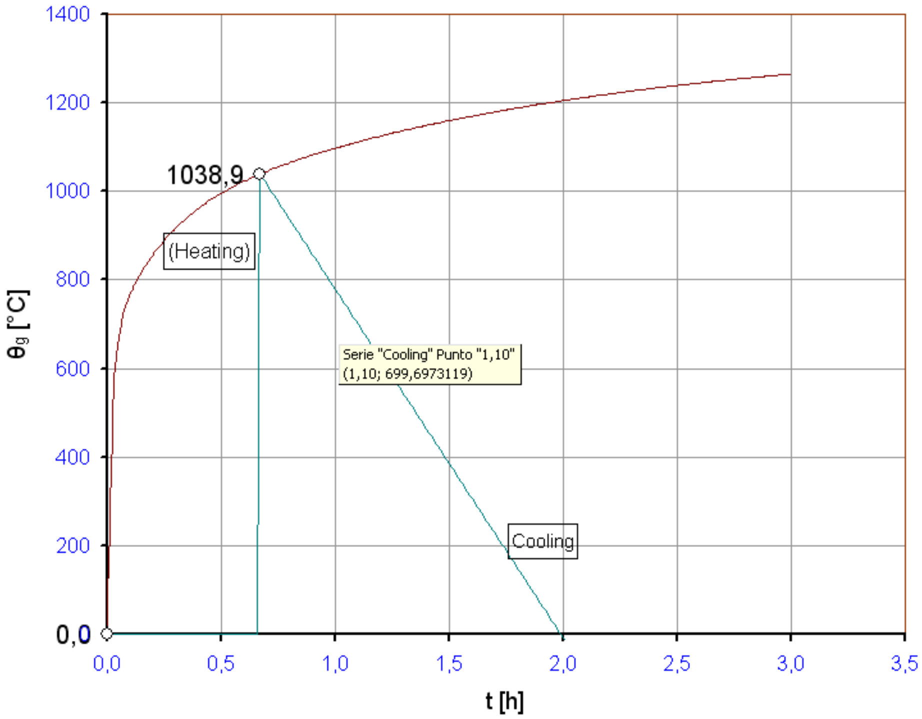

Figure 3.11 Parametric curve: heating, cooling.

$\theta_g = 1039 - 250\cdot(3-1,88)\cdot(t^*-1,88) = 1039 - 250\cdot(3-1,88)\cdot(3,08-1,88) = 703°C$.

Rounding error: 100 x (703 – 699,7)/699,7 = 0,5%.

example-end

EXAMPLE 3-U-- Annex A - Parametric temperature-time curves - **test 4**

Given: Maintaining the same assumptions in the previous example and assuming $q_{f,d} = 200\ MJ/m^2$, calculate the cooling phase.

[*Reference sheet:* Annex A]-[*Cell-Range: A107:O107-A152:O152*].

Solution: We find:

$$q_{t,d} = q_{f,d}\frac{A_f}{A_t} = 200 \cdot \frac{97,5}{349,8} = 55,75\ MJ/m^2$$

$$t_{max} = \max[0,2 \cdot 10^{-3} q_{t,d}/O;\ 0,333\ h] = \max[0,19;\ 0,333] = 0,333\ h$$

Time factor function (A.2b):

$$\Gamma_{lim} = \frac{[O_{lim}/b]^2}{(0,04/1160)^2} \approx \frac{[(0,0167)/1010]^2}{(0,04/1160)^2} = 0,23\text{, with}$$

$$O_{lim} = \frac{0,1}{10^3}\frac{q_{t,d}}{t_{lim}} = \frac{0,1}{10^3}\frac{(55,75)}{(0,333)} = 0,0167.$$

If ($O > 0{,}04$ and $q_{t,d} < 75$ and $b < 1160$), Γ_{lim} in (A.8) has to be multiplied by k given by:

$$k = 1 + \left(\frac{O - 0,04}{0,04}\right) \cdot \left(\frac{q_{t,d} - 75}{75}\right) \cdot \left(\frac{1160 - b}{1160}\right) = 1 + \left(\frac{0,0583 - 0,04}{0,04}\right) \cdot \left(\frac{55,75 - 75}{75}\right) \cdot \left(\frac{1160 - 1010}{1160}\right)$$

$$k = 1 + 0,4575 \cdot (-0,2567) \cdot (0,1293) = 0,98.$$

We get:

$$t^*_{max} = t_{max} \cdot k\Gamma_{lim} = 0,333 \cdot 0,98 \cdot 0,231 \approx 0,08\ h.$$

Maximum temperature (heating phase):

$$\begin{cases} \theta_{max} = 20 + 1325 \cdot (1 - 0,324 e^{-0,2t^*} - 0,204 e^{-1,7t^*} - 0,472 e^{-19t^*}) \\ t^*_{max} \approx 0,757\ h \end{cases}$$

$$\theta_{max} = 20 + 1325 \cdot (1 - 0,324 e^{-0,2(0,076)} - 0,204 e^{-1,7(0,076)} - 0,472 e^{-19(0,076)})$$

$$\theta_{max} \approx 20 + 1325 \cdot [1 - 0,324 \cdot (0,985) - 0,204 \cdot (0,879) - 0,472 \cdot (0,236)] = 537°C,$$

Rounding error: 100 x (537 – 536,1)/536,1 < 0,2%.

$$t^{**}_{max} = \frac{0,2}{10^3}\frac{q_{t,d}}{O}\Gamma = \frac{0,2}{10^3}\frac{(55,75)}{(0,0583)} \cdot 2,802 = 0,536\ h.$$

$t_{max} \le t_{lim} = 0,333\ h$ (the fire is fuel controlled):

$$x = \frac{t_{lim} \cdot \Gamma}{t^{**}_{max}} \approx \frac{(0,333) \cdot 2,802}{0,536} = 1,74.$$

For $0,5 < t^{**}_{max} < 2$:

$$\theta_g = \theta_{max} - 250 \cdot (3 - t^{**}_{max}) \cdot (t^* - t^{**}_{max} \cdot x) = \theta_{max} - 250 \cdot (3 - 0,536) \cdot (t^* - 0,536 \cdot 1,74).$$

For (say) $t = 0,50\ h \Rightarrow t^* = t \cdot \Gamma = 0,50 \cdot 2,802 = 1,40\ h$, we find:

$$\theta_g \approx 537 - 250 \cdot (3 - 0,536) \cdot (1,40 - 0,536 \cdot 1,74) = 249°C,$$

Rounding error: 100 x (249 – 248,4)/248,4 < 0,25%.

example-end

3.9 References [Section 3]

BS EN 1991-1-2. Eurocode 1: *Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire*. 26 November 2002

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