

# Temperature analysis cross section - TA

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## Application options

The TA application allows the calculation of temperature fields in rectangular and circular concrete cross sections exposed to fire in accordance with the appropriate National Annex to Eurocode. The cross sections may have any dimensions typical for reinforced concrete.

The fire load is taken into account via the standard temperature-time curve as per DIN EN 1991-1-2:2010-12.

Currently, the temperature analysis in the cross section is directly accessible out of the Frilo applications B2 Reinforced Concrete Design and B5/B5+ Reinforced Concrete Column.

Note: When calling TA from B5/B5+, only exposition to fire from four sides is currently possible.

## Basis of calculation

In the following paragraphs, we like to give a brief recapitulation of the physical fundamentals of heat transfer problems and the special assumptions of EN1992-1-2. The thermal analysis performed by TA uses these basic principles in the calculation of the time- and location-dependent temperature distribution in a component under fire.

### Heat conduction

In terms of mathematics, the transient heat conduction in a solid body is described with a partial differential equation of second order. The equation belongs to the group of parabolic differential equations.

$$\frac{\partial T}{\partial t} = \frac{\lambda}{c_p \cdot \rho} \Delta T$$

With:

T	temperature [K]
t	time [s]
$\lambda$	thermal conductivity [W/(mK)]
$c_p$	specific thermal capacity [J/(kg K)]
$\rho$	bulk density [kg/m <sup>3</sup> ]

The properties of the material themselves also depend on temperature in this process. [III. 1](#) shows in an exemplary manner the assumptions specified by EN1992-1-2 concerning the development of the specific heat capacity of concrete depending on the temperature (and moisture content) of the concrete. [III. 2](#) shows analogously the behaviour of the thermal conductivity, which diminishes with rising temperature.

Reinforcement is disregarded in temperature analyses of reinforced concrete cross sections, because the influence of the reinforcement steel is negligibly low (compare /3/4.3.2 (4)).

On the surface of a solid body, two other mechanisms of heat transfer have to be taken into account in addition to the described thermal conductivity. Thermal radiation and convection

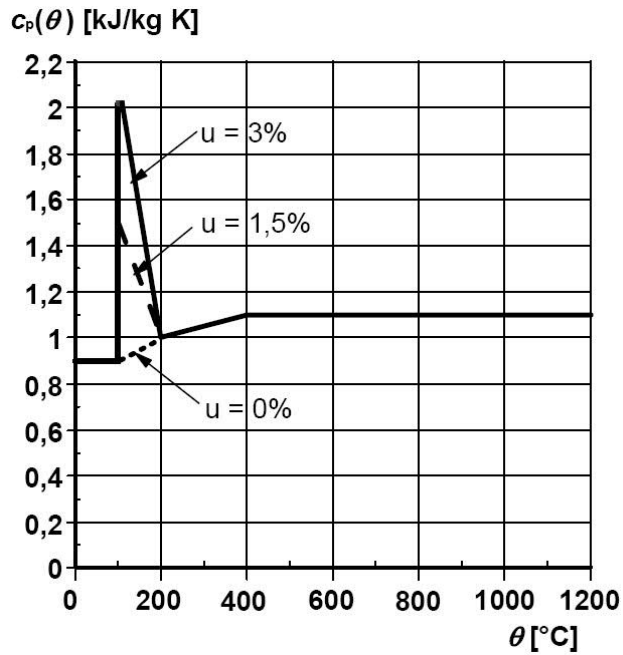


Illustration 1: Specific heat capacity of concrete (source: EN1992-1-2, illustration 3.6a)

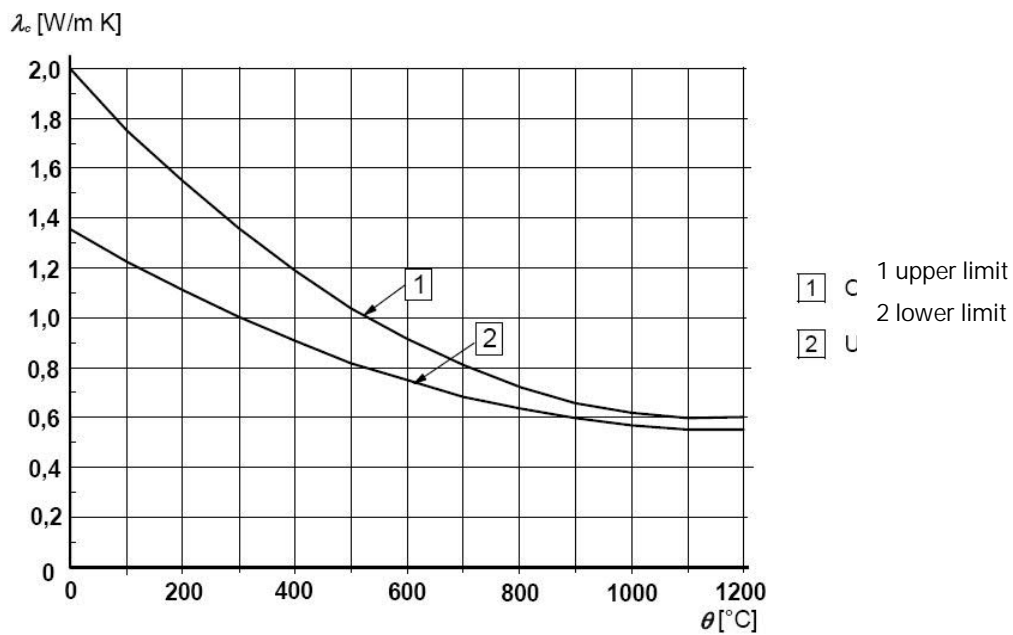


Illustration 2: Specific thermal conductivity of concrete (source: EN1992-1-2, illustration 3.7)

## Thermal radiation

Thermal radiation is an electromagnetic radiation emitted by each solid. The intensity of the thermal radiation increases with rising temperature. The heat flow density  $q$  results from the following equation:

$$q = \varepsilon \cdot \sigma \cdot T^4$$

With:

$\varepsilon$	emission coefficient [-]
$\sigma = 5,67 \cdot 10^{-8} \frac{W}{m^2 K^4}$	Stefan-Boltzmann constant

The emission coefficient  $\varepsilon$  describes the degree of absorption. A coefficient of  $\varepsilon = 0.7$  can be assumed for concrete (cf. /3/ 2.2(2)).

## Convection

Convection is the heat transfer caused by the motion of particles. It occurs only in fluids and gases. The heat flow density  $q$  results from the following equation:

$$q = -\alpha \cdot \Delta T$$

With:

$\alpha$	heat transfer coefficient [W/(m <sup>2</sup> K)]
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In temperature analyses of fire protection-related problems, a heat transfer coefficient of  $\alpha = 25 \text{ W/m}^2\text{K}$  is normally taken into account for the fire-exposed sides of the concrete cross section to be examined (cf. /3/ 3.2.1 (2)).

Because convection is considerably lower on the unexposed sides, a lower heat transfer coefficient of  $9 \text{ W/m}^2\text{K}$  is assumed here (cf. /5/ p. 169)

## Actions: Standard temperature-time curve

In accordance with DIN EN 1991-1-2, fire is considered as an accidental loading situation and, therefore, a superposition with other accidental actions is not required. The loading implemented in the software corresponds to the standard temperature-time curve as per /3/3.2.1 (1):

$$T = T_0 + 345 \cdot \log(8t + 1) \quad [^{\circ}\text{C}]$$

With:

$T_0$  initial temperature [ $^{\circ}\text{C}$ ]

$t$  time [min]

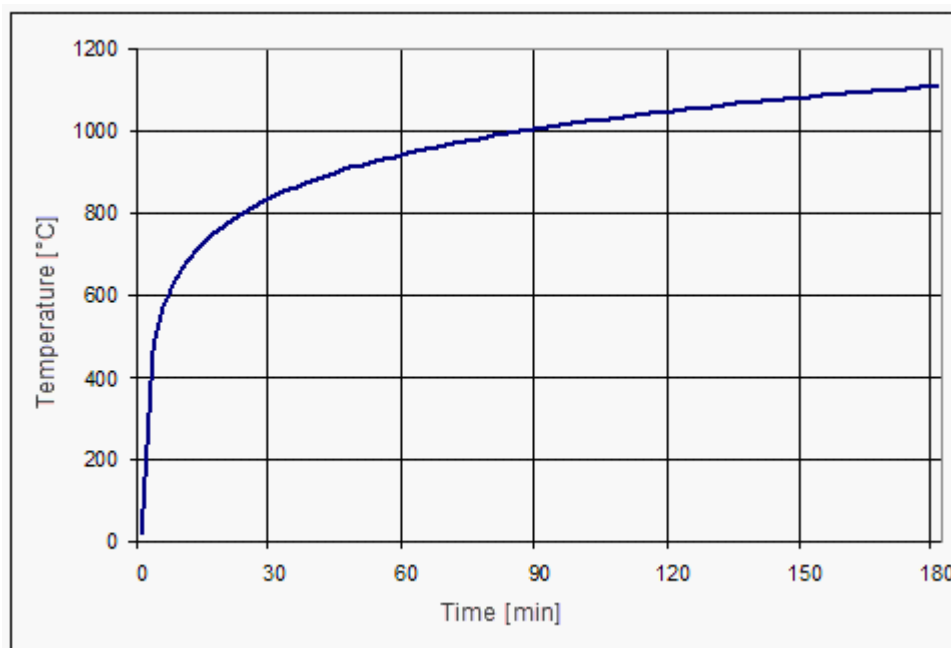


Illustration 3: Standard temperature-time curve

## Numerical solution

Because the material properties are non-linear, there is no analytical solution to the temperature problem. The present TA application uses the finite element method for the spatial discretization of the cross section.

The discretization in time is based on constant steps of one minute duration each. The implicit Euler method is used for the integration. In contrast to explicit methods, there are no requirements concerning the magnitude of the time step and the results are stable in all cases.

## Input

The input interface is divided into the sections:

- Geometry
- Thermal properties
- Fire exposure and border conditions
- Calculation

We are going to describe each section below:

### Geometry

Rectangular profiles are defined by specifying their **Width** and **Height**.

### Thermal properties

The thermal properties describe the temperature-related behaviour of the material and its interaction with the environment.

#### Concrete moisture

Selectable between 0 % (→ low thermal capacity) and 3 % (→ higher thermal capacity). Default value: 3.0 % (corresponds to the assumption in reference [/6/](#)) for instance.

#### Bulk density

Bulk density of the material. Default is 2,400 kg/m<sup>3</sup> (corresponds to the assumption in reference [/6/](#) for instance).

#### Heat transfer coefficient

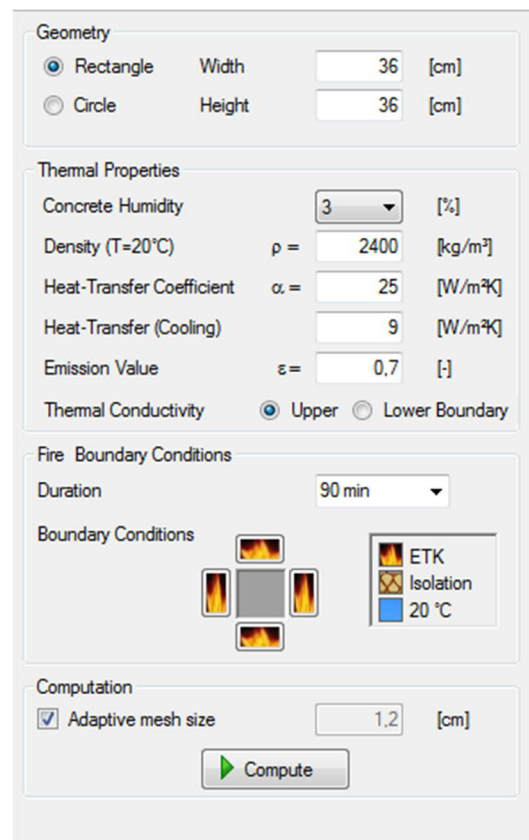
The convection on the flame-exposed sides (default: 25 W/m<sup>2</sup>K as per [/3/ 3.2.1 \(2\)](#)) is higher than that on cooling sides with a favourable effect (9 W/m<sup>2</sup>K as per [/5/ p. 169](#)).

#### Emission value

Degree of radiation absorption. Default is 0.7 in accordance with [/4/ 2.2 \(2\)](#).

#### Thermal conductivity

Selectable whether the upper or lower limiting value of the thermal conductivity should be used (in accordance with [/4/](#), the upper limiting value should be used).



The screenshot shows the software's input interface with the following sections and values:

- Geometry:**
  - Rectangle: Width = 36 [cm], Height = 36 [cm]
  - Circle
- Thermal Properties:**
  - Concrete Humidity: 3 [%]
  - Density (T=20°C):  $\rho = 2400$  [kg/m<sup>3</sup>]
  - Heat-Transfer Coefficient:  $\alpha = 25$  [W/m<sup>2</sup>K]
  - Heat-Transfer (Cooling): 9 [W/m<sup>2</sup>K]
  - Emission Value:  $\epsilon = 0.7$  [-]
  - Thermal Conductivity:  Upper  Lower Boundary
- Fire Boundary Conditions:**
  - Duration: 90 min
  - Boundary Conditions: ETK, Isolation, 20 °C
- Computation:**
  - Adaptive mesh size: 1.2 [cm]
  -

## Fire exposure and border conditions

The user can enter a freely selectable value or select steps of 30 minutes duration each. In this section, the user can define the border conditions separately for each side of the cross section:



Fire exposure as per standard temperature-time curve.



Assumption of a perfect isolation (no heat flow) or



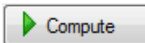
a cooling side (having a favourable effect) ( $T_a=20^\circ\text{C}$ ).

## Settings for the FE calculation

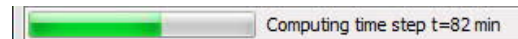
The TA application uses the finite element method for the spatial discretization. In general, a higher resolution of the FE mesh improves the quality of the results but costs more computing time. The (default) automatic assessment of the mesh resolution offers a good compromise between quality and duration in most cases. Alternatively, the user can define the element size.

## Calculation

The temperature analysis is started by activating the button



The non-linear calculation of the behaviour in time assesses the temperature fields in time steps of one minute each.



*Note: The computing time and work rises with the number of elements and time steps and may vary between several seconds and some minutes, depending on the hardware configuration of your computer.*

*Note: In order to avoid laborious new calculations, the calculated temperature fields are stored automatically. If a similar problem is defined, the results are loaded and displayed directly (see also [Further settings](#)).*

## Output

After completion of the calculation, the resulting temperature field is displayed. The user can change the representation via the "View" menu.

- Various colour models allow the optimization of the output for fast visual grasping of the temperature fields (RGB or HSV model) or printing of black & white copies.
- You can display the FE mesh to check your settings or hide it.
- In addition, you can activate the representation of Isotherms, which are lines of points with the same temperature. The isolines are generated and shown with a spacing of 100 degrees.

The Select temperature field option allows you to show also previous states at a time spacing of 30 minutes.

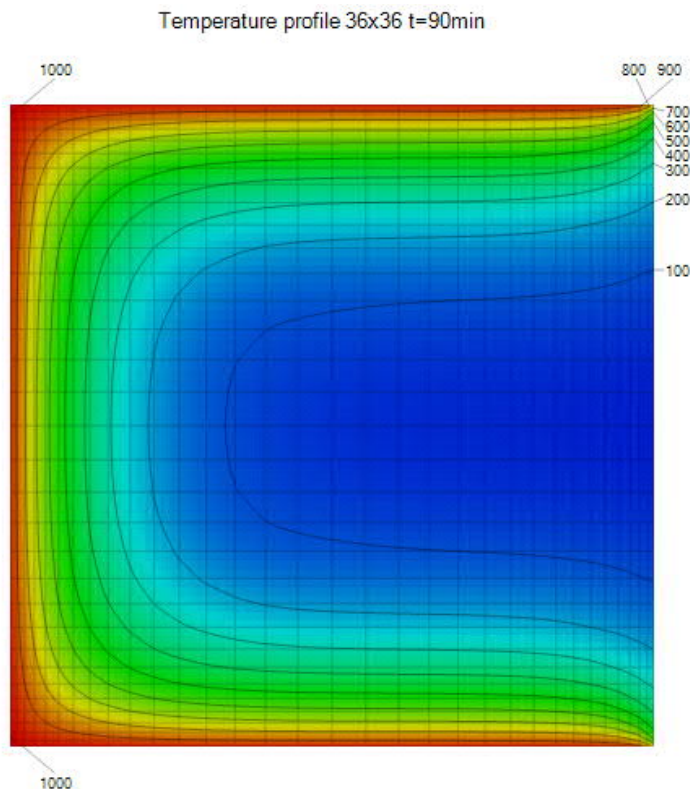


Illustration 4: Temperature field of a cross section exposed on three sides after 90 minutes

## Context menu

A click with the right mouse button on the graphical screen provides access to additional functions.



The user can activate view options for the selection of the colour model, the mesh or the indication of isolines quickly and easily via the context menu.



The Copy function allows you to copy the current result graphics to the windows clipboard and paste them into external documents in other applications, such as Microsoft Word.



The Export function allows you to save result graphics in a BMP or JPG file.

Drag & drop allows you in addition to transfer the graphics to many other applications. (Note: For the transfer to MS Word 2003, please use the copy command as described above.)



## Further settings

The TA application stores the calculated temperature fields in a cache memory. This helps to avoid repeated calculations of the same problem.

Activating the menu item Tools → Cache displays a dialog for the configuration of the cache memory (ill. 5).

Available options are:

- enable or disable caching
- select another directory for the storage
- verify the cache size
- remove data from the cache to make disk space available.

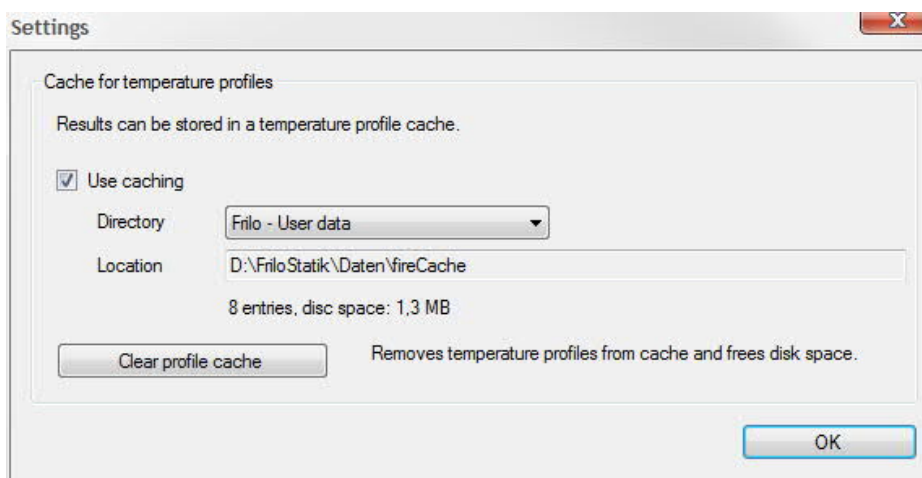


Illustration 5: Further settings for the configuration of the cache memory

## Reference literature

- / 1 / DIN EN 1992-1-2:2006
- / 2 / DIN 4102-2:1977-09 Fire behaviour of building materials and building components; Building components; definitions, requirements and tests
- / 3 / DIN EN 1991-1-2:2003
- / 4 / DIN EN 1992-1-2/NA:2009 (Draft)
- / 5 / VfDB Leitfadene Ingenieurmethoden des Brandschutzes 5/2009
- / 6 / Simplified method for analysing class R 90 reinforced normal-weight concrete cantilever columns in /4/