FIRE TESTING METHOD FOR PASSIVE FIRE PROTECTION EXPOSED TO NATURAL FIRE CURVES

STRUCTURES IN FIRE FORUM
SHEFFIELD UK, 10 APRIL 2026

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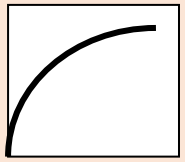
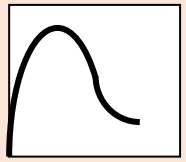
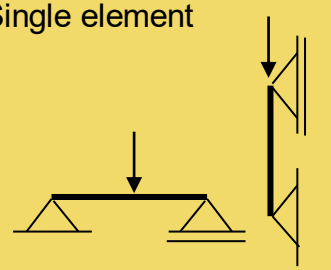
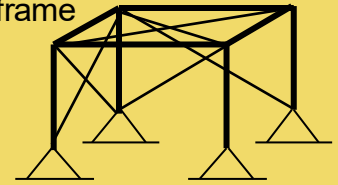
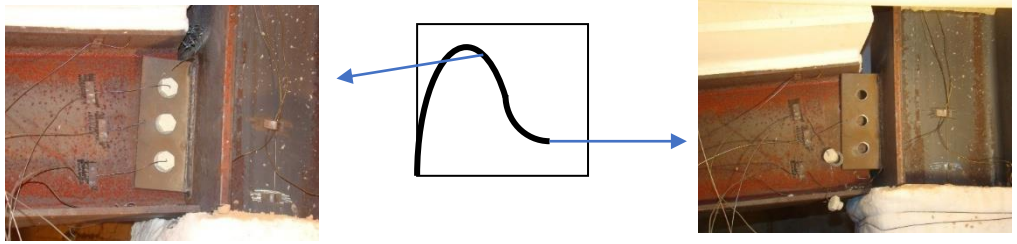
THE EUROCODE OFFERS THE POSSIBILITY TO PREDICT THE ACTUAL STRUCTURAL BEHAVIOUR USING SIMULATIONS

Schematisation of the fire → / Schematisation of the structure ↓	Nominal fire curves 	Parametric or natural fire curves 
Single element 	**Prescriptive design**	Not recommended (unbalanced)
(Partial) structural frame 	Not recommended (unbalanced)	**Performance based design**

Goals of such simulations can be for example:

- avoid structural collapse
- drive a certain collapse mechanism
- limit damage to the building



Failure due to framework action in the cooling down phase

Source: ECSC - COSSFIRE project, 2009
https://data.europa.eu/doi/10.2777/16400

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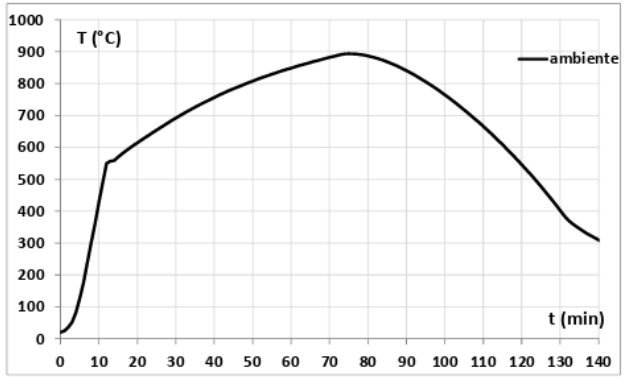
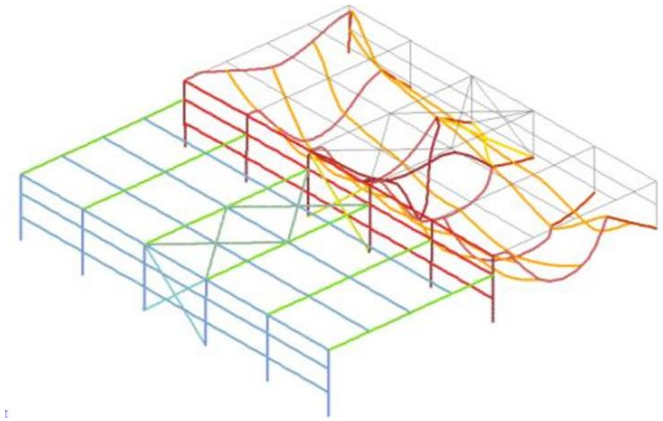
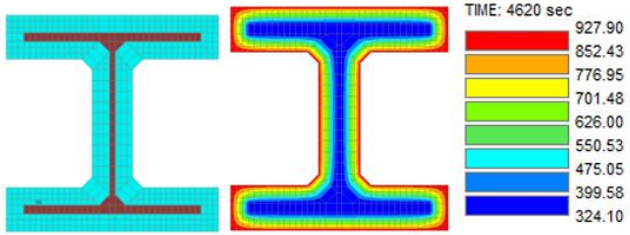
PERFORMANCE BASED DESIGN METHODS ARE ONLY ELABORATED FOR CONSTRUCTION MATERIALS BUT NOT FOR PASSIVE FIRE PROTECTION

- Also when using a natural fire curve, passive fire protection may be necessary
- Problem:
  - No test standard available
  - Standard fire curve thickness tables are not applicable
  - PFP may not be accepted in combination with natural fire curves
  - Fire engineers use PFP with natural curves at their own risk







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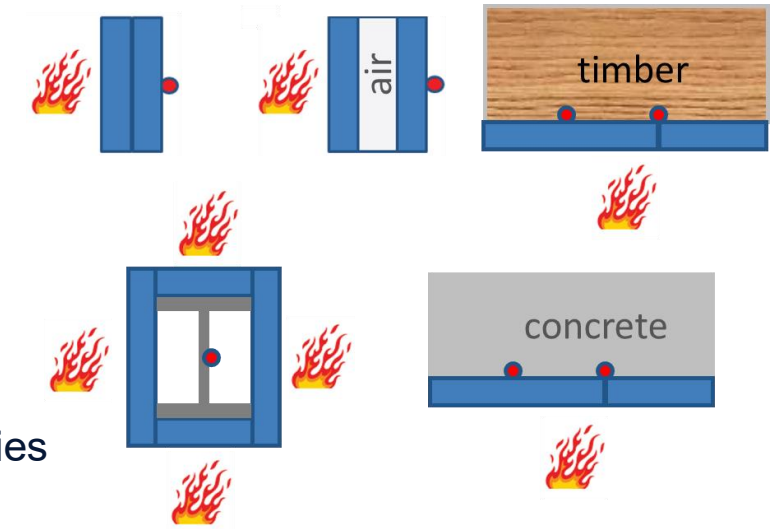
THERMAL PROPERTIES ON THE TDS ARE NOT SUITABLE FOR FEM!

- Thermal properties on a Technical Data Sheet:
  - Are determined on a small piece of material in **steady-state** temperature conditions
  - **Time-dependent effects** like evaporation of moisture, phase changes and chemical transitions are not represented
  - Values do not account for the **effects of the full system**: heat transfer through joints, cavities, fixings etc.

Technical data		
Colour		grey
Building material class	DIN 4102 EN 13501	A1, non-combustible
Classification temperature	°C	400
Bulk density	kg/m³	870
Shrinkage 400 °C - 12h	%	0.25
Thermal conductivity 20 °C 100 °C 200 °C	 W/m K W/m K W/m K	
Specific heat capacity 400 °C	kJ/kg K	0.92
Linear change in length 20-600 °C	K⁻¹	6.4x10⁻⁶
Alkalinity	pH value	approx. 13

For each situation, calibrated properties may differ!

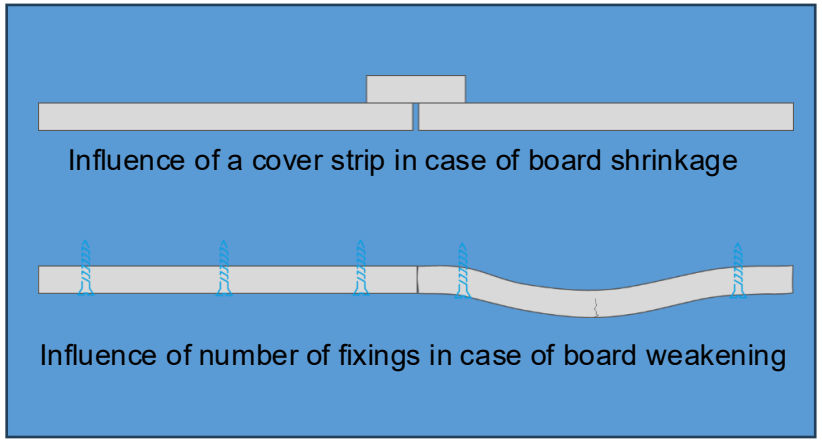


- To correctly model the fire protection of a real structural element, the properties need to account for **time-dependent effects** and **system effects**.
- Therefore, such **properties must be calibrated on actual fire tests**, and are **only valid for the tested system**.

DESIGNING PFP WITH NATURAL FIRE CURVES IS CHALLENGING

- The (fast or slow) heating rate will **influence the performance of the PFP system**, for example because of
  - **Mechanical effects**
    - Deformations
    - Shrinkage / expansion
    - Gaps / cracks

    } These depend also on the fixing method, fixing distances, cover strips, joint treatment, surface preparation etc.
  - **Physical and chemical effects**
    - Moisture evaporation and pore pressure
    - Reversible or irreversible phase changes
    - Chemical reactions



- During **cooling down phase, indirect thermal actions may reverse**
  - The behaviour of the fire protection during cooling down must be known and reproducible

PERFORMANCE OF PFP WITH NATURAL FIRE CURVES

A research project was done to **enable the use of passive fire protection in combination with natural fire curves**

- Efectis France
- University of Ghent
- Promat
- With subvention of the Flemish government

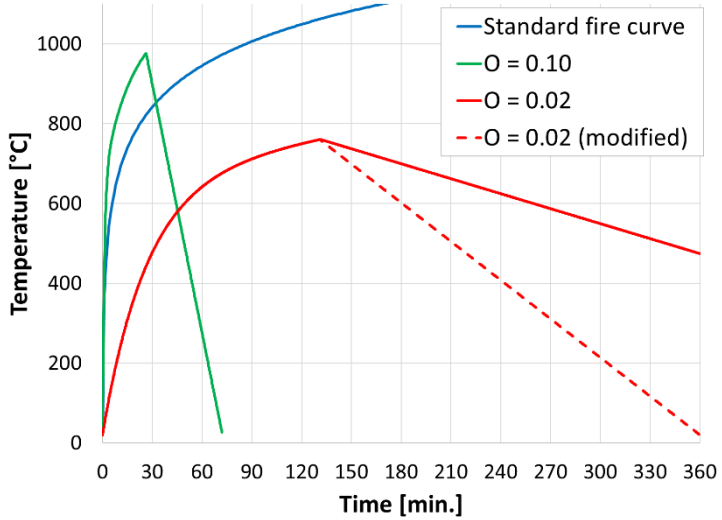
Project steps:

- **Furnace fire testing** with parametric fire curves (steel elements + PROMATECT®-H)
- **Modelling and validation**
- **Real fire test** (with **wooden cribs** instead of gas fire)
- **Guidance document**

PARAMETRIC FIRE CURVES AND STEEL SECTIONS FOR TESTING

- **Two new parametric fire curves**
- A **short and intense** parametric fire curve (opening factor 0.10) (almost 1000°C in less than 30 min.)
- A **long and slow** parametric fire curve (opening factor 0.02) (>120 min. heating to just over 750°C, cooling until 360 min.)

- **Steel sections for fire testing:**
- **Loaded beams** + reference beams to determine stickability
- Additional **unloaded short columns**
  - Different **combinations of board thickness & steel section factor** to be tested
  - **Finite element modelling** was used to determine relevant* combinations for the parametric fire curves
  - **Total number of short sections:**
    - **13x Standard (ISO) curve (as per EN 13381-4)**
    - **7x Short and intense fire curve**
    - **12x Long and slow fire curve**
- ** Combinations that would lead to steel temperatures << 500°C were considered not relevant*



Unloaded short sections	Thickness min	Thickness 0,2-0,5	Thickness 0,5-0,8	Thickness max
A/V min	ISO Short Long	ISO Long	ISO	
A/V 0,2-0,5	ISO Short Long	 Short Long	ISO Long	ISO Long
A/V 0,5-0,8	ISO Short Long	ISO	ISO Short Long	ISO Long
A/V max	 Short Long	ISO	ISO Short Long	ISO Long

HOW TO TRANSLATE TEST DATA INTO DESIGN INFO?

- For the **standard fire curve**, test results are translated into **thickness tables**
- Fire protection thickness tables are only valid for the standard fire curve, so **we can't use them for natural fire curves**

fire resistance 60 minutes required protection thickness in mm

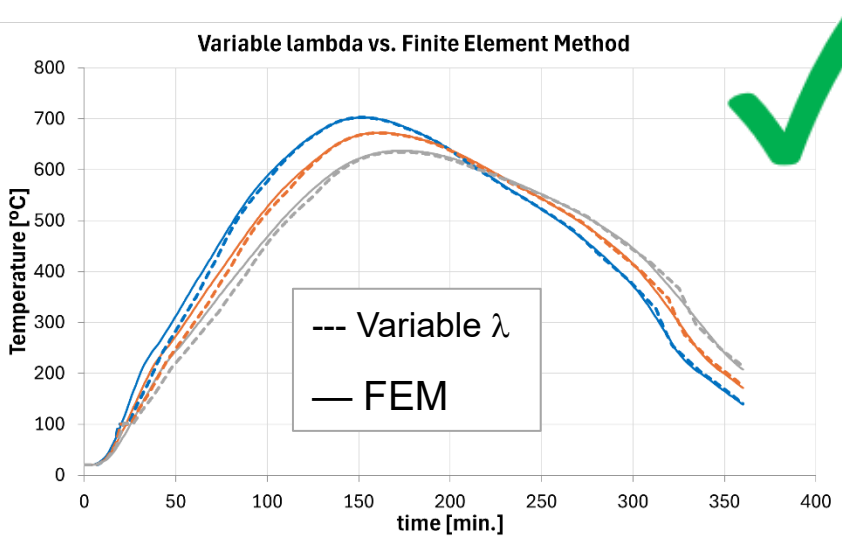
Section factor m-1	Critical steel temperature °C								
	350	400	450	500	550	600	650	700	
0	12.1	11.4	11.4	11.4	11.4	11.4	11.4	11	11.4
45.9	12.1	11.4	11.4	11.4	11.4	11.4	11.4	1	1.4
50	13.3	11.4	11.4	11.4	11.4	11.4	11.4		
60	15.7	12.2	11.4	11.4	11.4	11.4	11.4	4	11
70	17.8	14.1	11.4	11.4	11.4	11.4	11.4	4	11.4
80	19.5	15.8	13	11.4	11.4	11.4	11.4	4	11.4
90	20.9	17.3	14.4	12	11.4	11.4	11.4		11.4
100	22.1	18.6	15.7	13.3	11.4	11.4	11.4		11.4
110	23.2	19.7	16.8	14.4	12.3	11.4	11.4	11	11.4
120	24.2	20.7	17.8	15.4	13.3	11.5	11.4	11.4	
130	25	21.6	18.7	16.3	14.2	12.3	11.4	11.4	
140	25.7	22.4	19.5	17.1	15	13.2	11.5	11.4	11.4
150		23.1	20.3	17.9	15.8	13.9	12.3	11.4	11.4

- One of the methods in EN 13381-4 to make such tables is the "**variable lambda method**"

$$\Delta\theta_{a,t} = \left[\frac{\lambda_{p,t}}{c_a \rho_a} d_p \times \frac{A_m}{V} \times \left(\frac{1}{1+\phi/3}\right) \times (\theta_t - \theta_{a,t}) \Delta t\right] - \left[\left(e^{\phi/10} - 1\right) \Delta\theta_t\right]$$

- Test results are transformed into **thermal conductivities** (variable λ's), which depend on
  - Temperature
  - Fire protection thickness

Instead of creating thickness tables, the λ values can be used directly as **input for finite element models**



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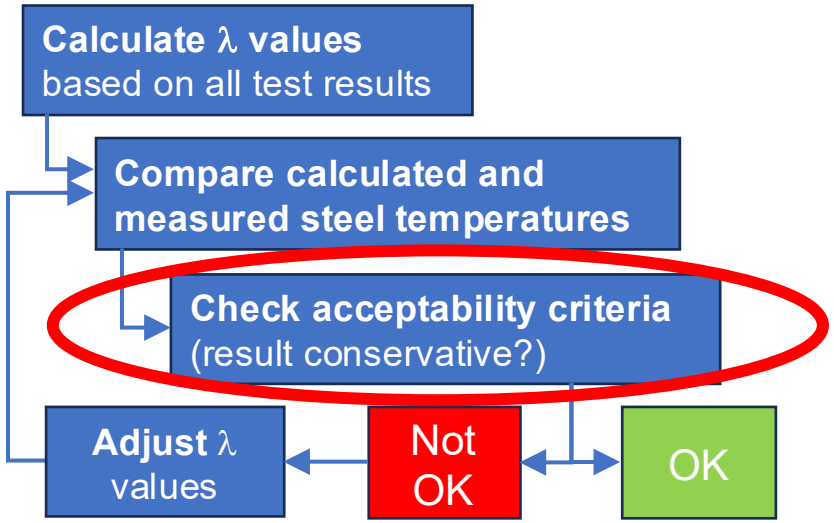
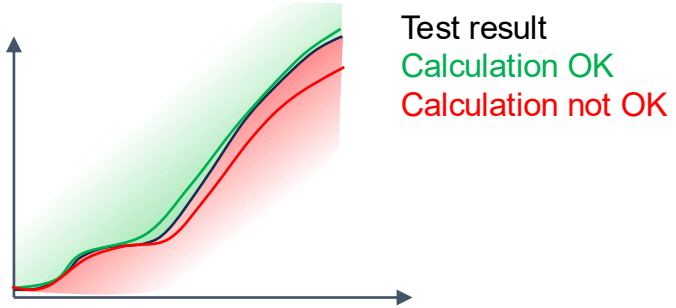
USING THE VARIABLE λ METHOD WITH NATURAL FIRE CURVES

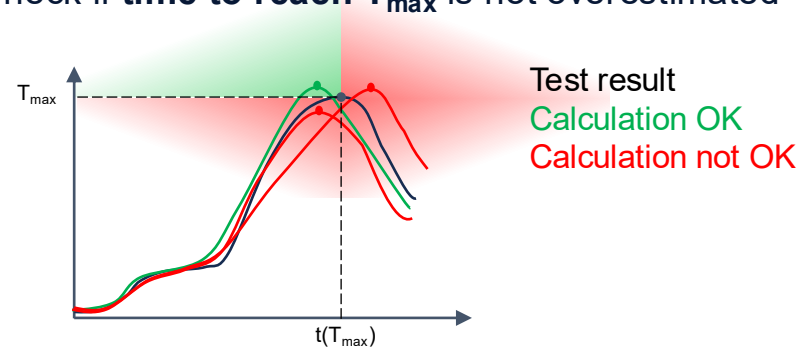
- Due to scatter in test results, the **calculation will never match 100%**
- To make sure the calculation is conservative, EN 13381-4 prescribes **acceptability criteria**
- **Iterative adjustment** of λ values until all criteria are fulfilled:



- **Acceptability criteria EN 13381-4 are suitable for standard fire curve (no cooling down):**
  - Check if **time to reach a given critical steel temperature** is not overestimated



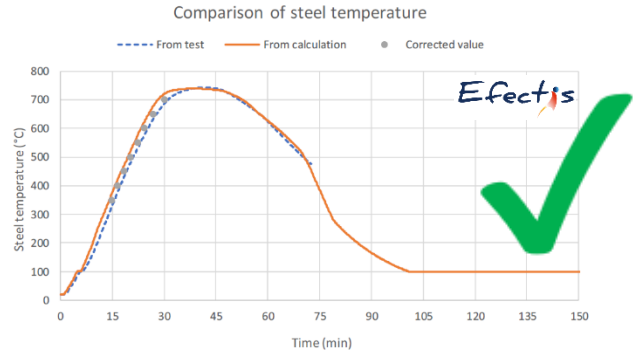
- **Additional acceptability criteria for fire curves with a cooling down phase:**
  - Check if the **maximum steel temperature** is not underestimated
  - Check if **time to reach T_{max}** is not overestimated



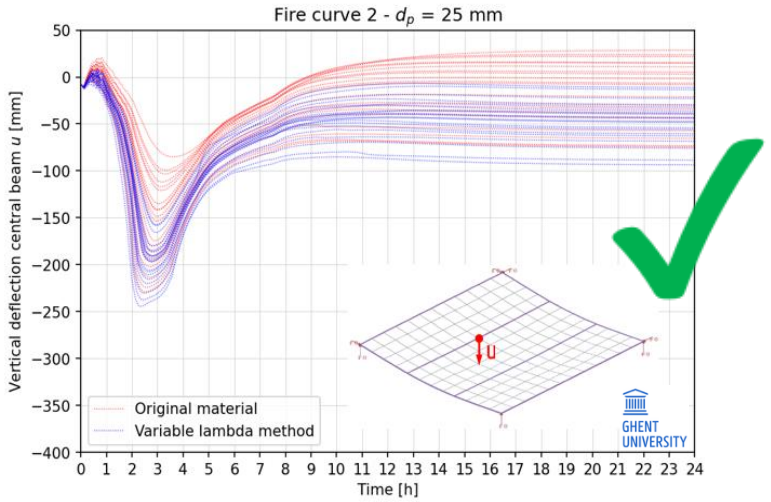
Note: to facilitate the calibration, EN 13381-4 allows incidental "unsafe" values but never more than 15% off the target. This same approach was adopted for the additional criteria for natural fire curves.

RELIABILITY OF THE VARIABLE λ METHOD WITH NATURAL FIRE CURVES

- All parametric fire test results were assessed using the "**variable lambda method**".
  - The method describes the natural fire curve test results very well.



- **Probabilistic analysis by University of Ghent**
  - Thermal and mechanical (framework) analysis in FEM
  - Stochastic input for passive fire protection performance
  - Comparing deformations for two cases:
    - Stochastic PFP (red lines)
    - Stochastic PFP after a virtual fire test and variable lambda assessment (blue lines)
- **Conclusion:** the use of the variable lambda method with natural fire curves is **conservative and reliable**.



PARAMETRIC FIRE CURVE TESTS DONE WITH CALCIUM SILICATE BOARDS

PROMATECT®-H calcium silicate boards

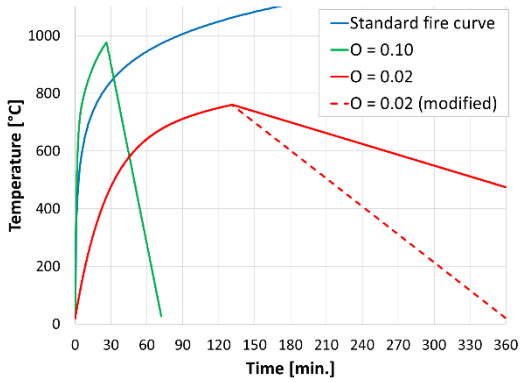
- Relatively inert and stable material
  - Also during cooling down

Fire tests:

- Gas-fired testing furnace
- Single layer board protection system
- **Loaded beams and reference beams** to evaluate stickability when exposed to parametric fire
- **21 short columns** exposed to parametric fire curves

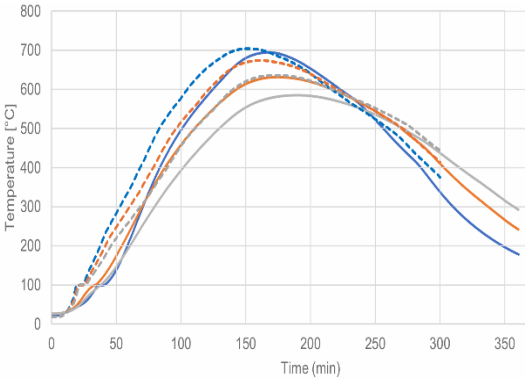
Assessment:

- Variable lambda method
- Use all the available data:
  - New parametric fire curve test data
  - Existing standard fire curve test data



Unloaded short sections	Thickness 12 mm	Thickness 15 mm	Thickness 20 mm	Thickness 25 mm
A/V min	ISO Short Long	ISO Long	ISO	
A/V 0,2-0,5	ISO Short Long	 Short Long	ISO Long	ISO Long
A/V 0,5-0,8	ISO Short Long	ISO Long*	ISO Short Long	ISO Long
A/V max	 Short Long	ISO Long*	ISO Short Long	ISO Long

Short columns after cooling down (protection intact)



Measured (lines) and calculated (dotted) steel temperatures for three tested columns

AS A VALIDATION, A FIRE TEST WITH A REAL (WOODEN CRIBS) FIRE

Steel elements were prepared in accordance with EN 13381-4:

- Loaded beam, reference beam
- Unloaded short columns

The elements were tested in a special test chamber, where

- The fire is created by burning wood cribs
- The beam is mechanically loaded (in bending) in accordance with EN 13381-4

Hydraulic loading on the steel beam

Mechanical load on beam

Protected steel sections

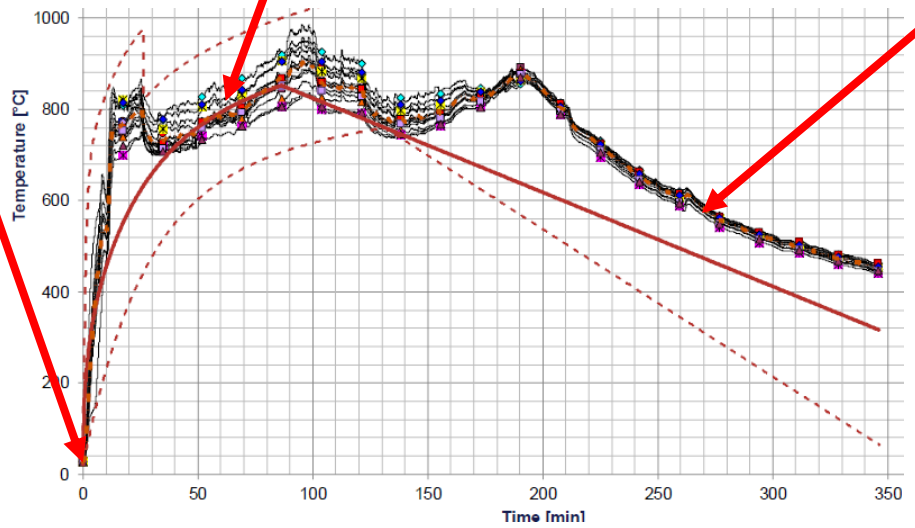
Ventilation openings

Fire load: wooden cribs

Wooden cribs and protected steel elements before the test

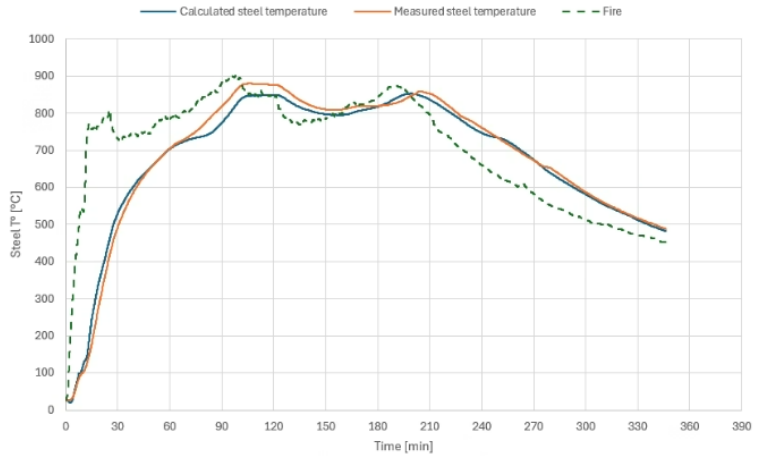
THE WOODEN CRIB TEST VALIDATED THE PERFORMANCE

- The fire developed very fast
- Temperatures reached over 900ºC
- The wood cribs kept the fire burning for 190 minutes



- The performance of the boards matched the calculations

λ values met the acceptability criteria without further adjustment



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SCOPE AND PRACTICAL USE OF THE λ VALUES

- Outcome of the assessment: a set of temperature-dependent λ values for each board thickness of the tested product

- Fire safety engineers can use these λ values in their design with natural fire curves, according to EN 1993-1-2 par. 4.2.5.2

- Scope and limitations of use:
  - Natural and parametric fire curves within the tested range (envelope)
  - Protection of steel beams and columns
  - Fire exposure, dimensions, thicknesses as per EN 13381-4
  - Suitable for FEM in combination with structural framework analysis

- Embedding in regulations
  - Publicly available Efectis Guidance document https://efectis.com/app/uploads/2026/04/Guidance-for-insulated-steel-sections-exposed-to-natural-fires-Performance-evaluation.pdf
  - Input for standard committees (e.g. CEN, ISO)

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Thank you for your attention

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