FIRE RESISTANCE TESTING

Virtual furnace

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Structural fire design

Metods to define fire resistance of structures

1. Experiments
2. Tables
3. Simple models
4. Advanced models

Structural fire design

Metods to define fire resistance of structures

1. Experiments
2. Tables
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Experiments

- Material testing at elevated temperature
- Testing of structures
  - Standard fire testing = fire resistance testing
  - Small-scale testing of structures
  - Full-scale testing of structures

Fire resistance

Fire resistance of a structure, part of the structure or a member is an ability to fullfil required function (bearing and/or other)

- At specified level of mechanical load;
- At specified influence of fire;
- For required time.

- It is defined by time for which the structure is able to fulfill the required function/resist to influence of a fire and keep its characteristic properties.

Fire resistance

Fire resistance is generally influenced by:

- Severity of fire;
- Material of the structural member;
- Geometry of the structure/member;
- Boundary conditions (supports);
- Mechanical load.

Fire resistance testing

Fire resistance is based on fire scenarios:

- For classification during standard fire, see EN 1991-1-2: 3.2, EN 13501-2: 4, EN 1363-1, -2.
- For individual evaluation of structures for parametrical fire, see EN 1991-1-2, Příloha A.

Fire resistance testing

Tested element is exposed to specified heating, during the heating a behaviour of the element is monitored based on criterios which are given in EN 1363-1:

- Resistance (R)
- Integrity (E)
- Insulation (I)

Fire resistance testing

Legislation

For standard fire testing we use standards:

- EN 1363 – 1:2013 Fire resistance tests – Part 1: General requirements
- EN 1363 – 2:2000 Fire resistance tests – Part 2: Alternative and additional procedures
- EN 1363 – 3:1999 Fire resistance tests – Part 3: Verification of furnace performance

Fire resistance testing

Legislation

- **EN 1363 – 1:2013 Fire resistance tests – Part 1: General requirements**
  - Requirements on temperature, pressure in the furnace
  - Requirements on measuring devices
  - Boundary conditions incl. loading of a structures
  - Limiting criteria for deformation and integrity

Fire resistance testing

Furnaces for standard fire testing

Horizontal

- For horizontal members – floors , beams

Vertical

- For vertical members – walls, columns

Fire resistance testing

Furnaces for standard fire testing

Wall furnace

- Testing of cladding systems, glass filling, etc.

Fire resistance testing

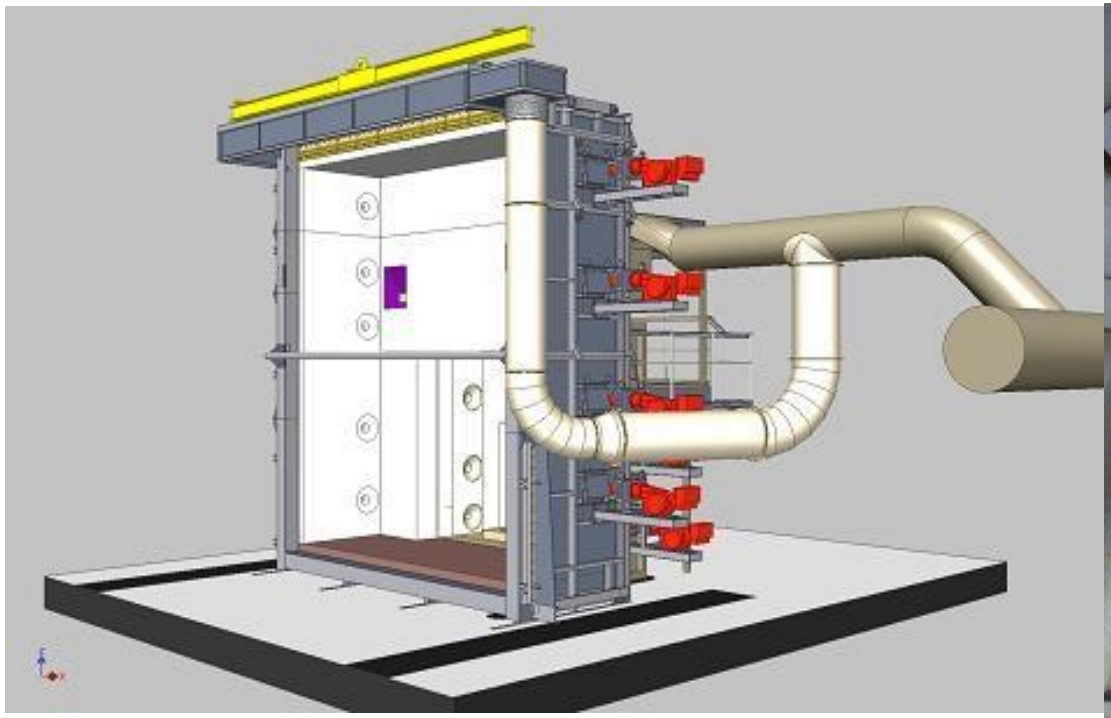
- Horizontal furnace, Pavus a.s.

Fire resistance testing

- Horizontal furnace, Efectis

Fire resistance testing

- Vertical furnace, Pavus a.s.



Fire resistance testing

- Vertical furnace, Pavus a.s.

Fire resistance testing

Requirement for testing according to EN 1363-1

- Temperature inside the furnace
- Pressure inside the furnace
- Atmosphere (O_2) more than 4% of volume
- Density of lining material lower than 1000 kg/m^3

Fire resistance testing

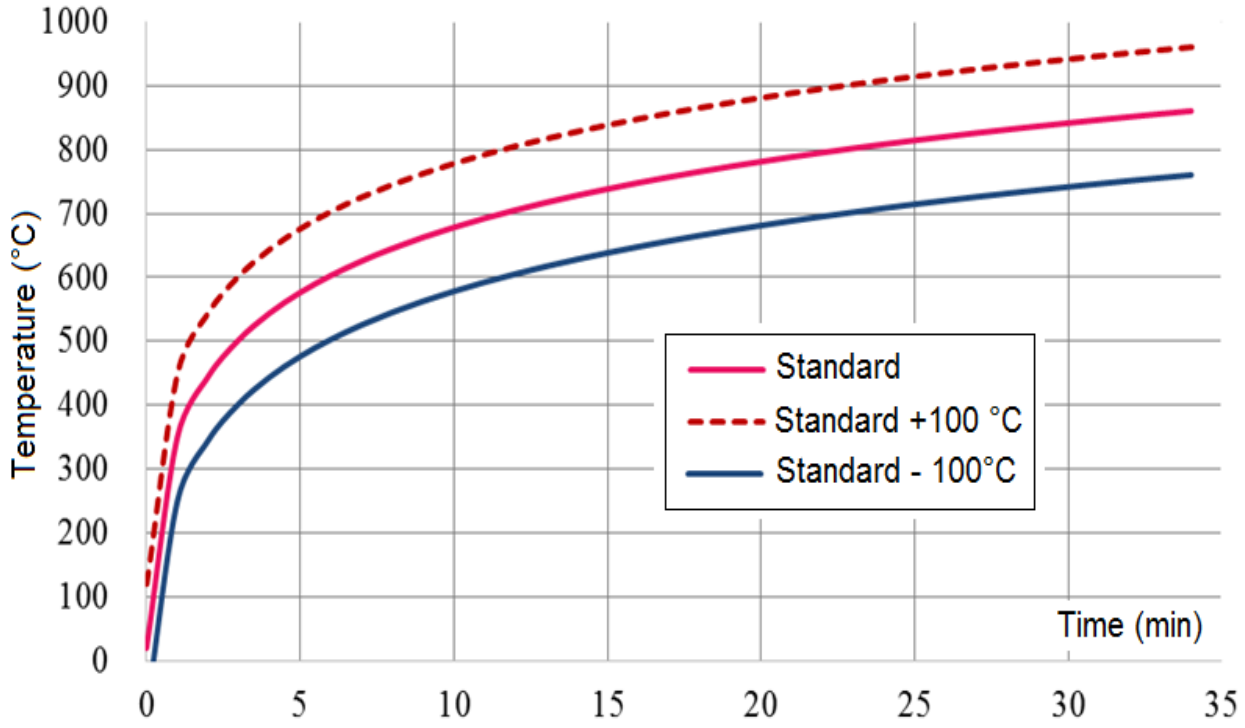
Temperature inside the furnace

- Standard temperature curve (average temp. in furnace)
- Measured by plate thermometers
- In reality gas temperature is not uniform accros the furnace volume
  - Influenced by presence of tested elements

Fire resistance testing

Requriements according to EN 1363-1: 2013

Average temperature according to standard temp. curve

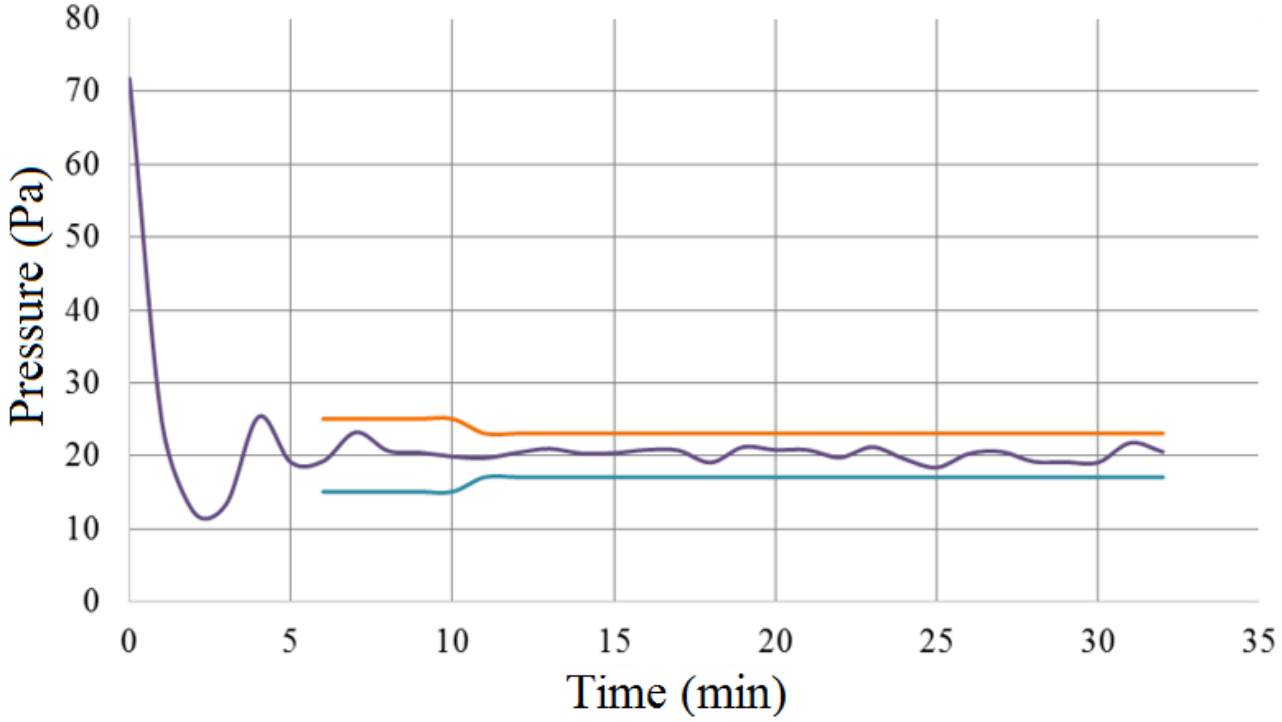


Fire resistance testing

Pressure inside the furnace

Requriements according to EN 1363-1: 2013

Furnace over-pressure should not exceed 20 Pa



Fire test of composite steel-concrete floor

Material

Fibre-reinforced concrete

DE 60/0,8 N (1200 MPa)

DE 60/0,8 M (1550 MPa)

Material test to gain our results

Fire test of composite steel-concrete floor

Preparation – primary and secondary beams, studs

Fire test of composite steel-concrete floor

Trapezoidal sheet

Fire test of composite steel-concrete floor

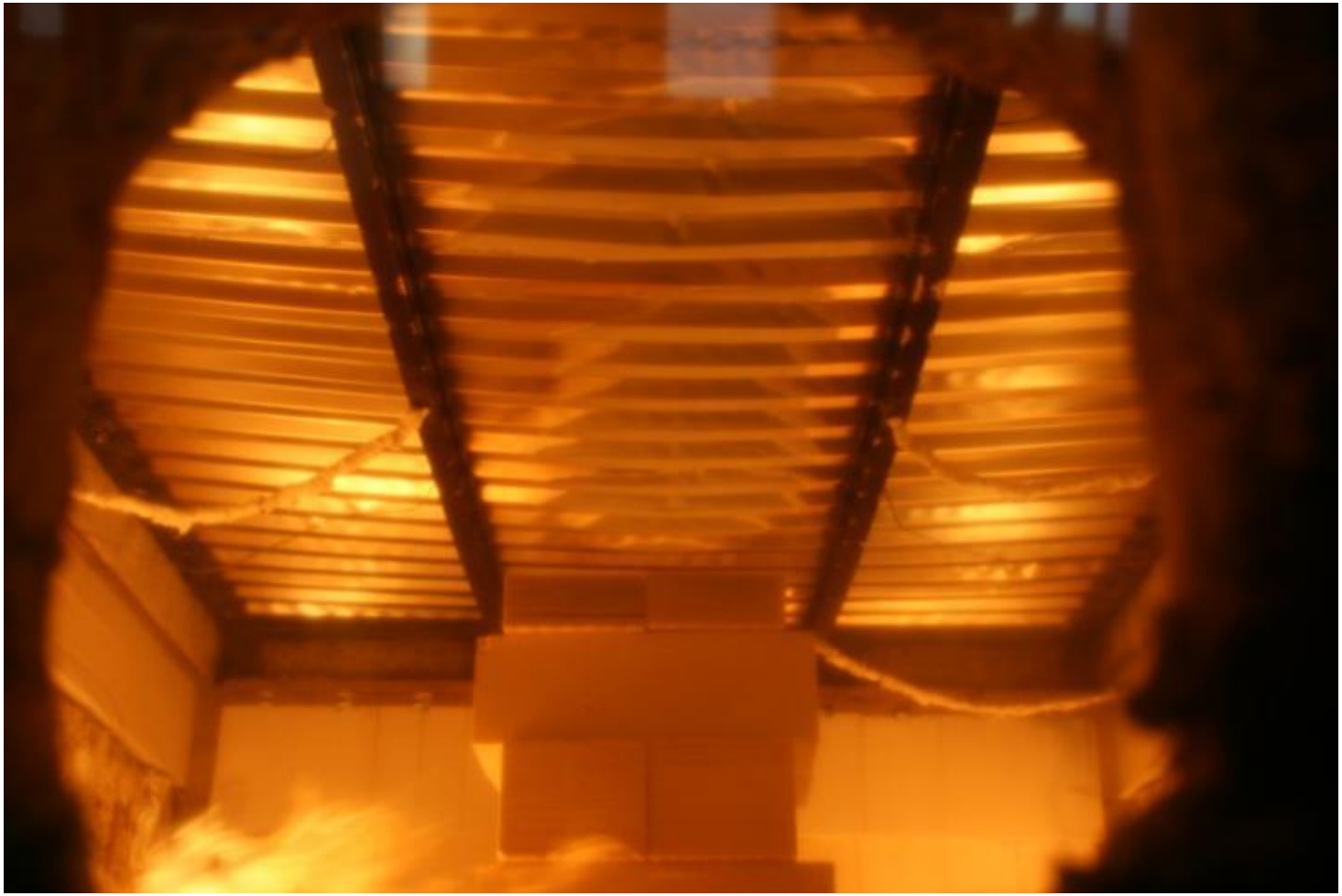
Concreting of the slab

Fire test of composite steel-concrete floor

Slab on the furnace loaded by concrete blocks

Fire test of composite steel-concrete floor

15 min



Fire test of composite steel-concrete floor

60 min

Fire test of composite steel-concrete floor

Failure in 250 min

Fire test of composite steel-concrete floor

Failure in 250 min

Fire test of composite steel-concrete floor

Failure in 250 min

Fire test of composite steel-concrete floor

Failure in 250 min

Fire test of composite steel-concrete floor

Failure in 250 min

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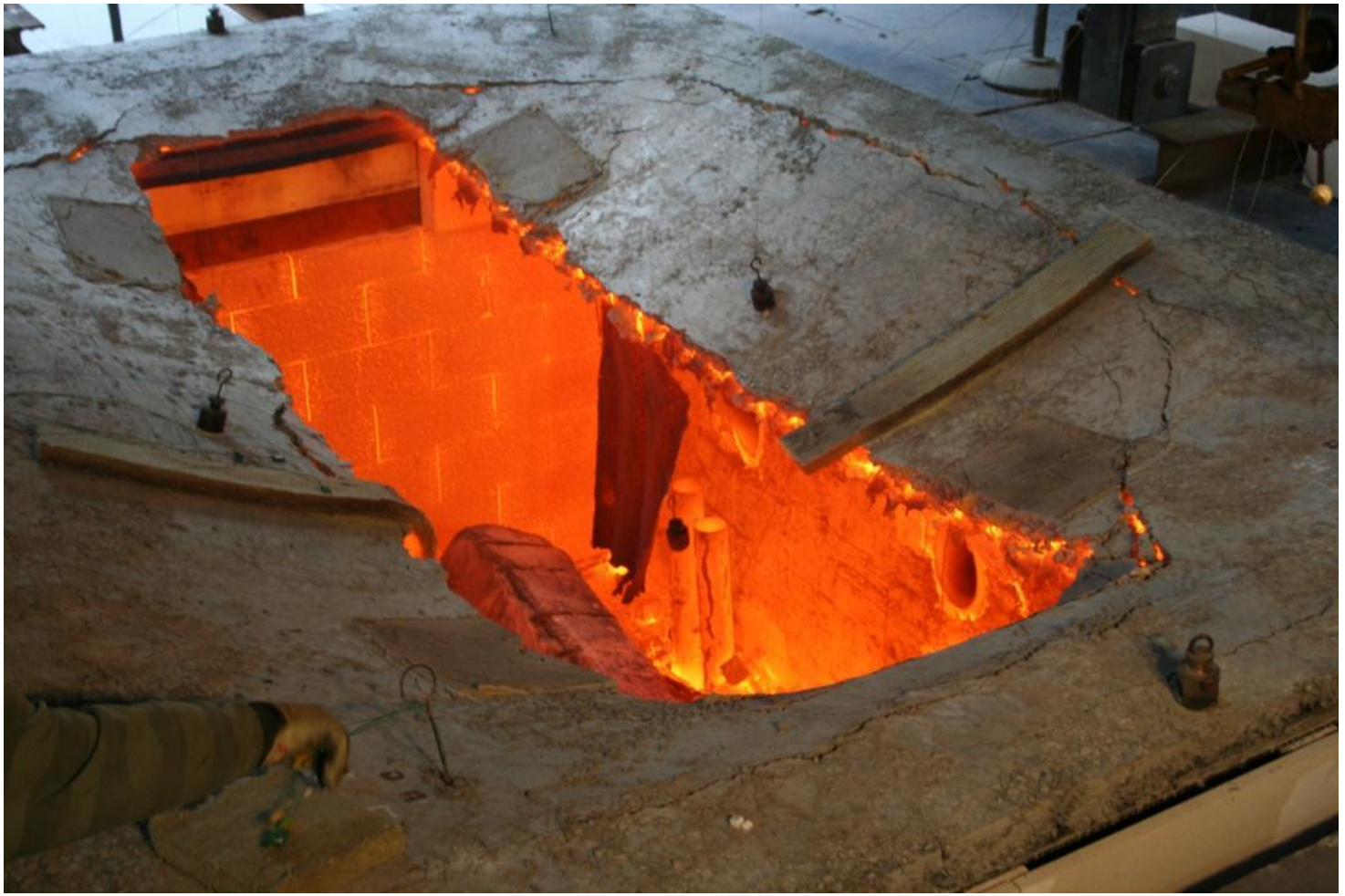
Failure in 250 min

Fire test of composite steel-concrete floor

Failure

Fire test of composite steel-concrete floor

Failure

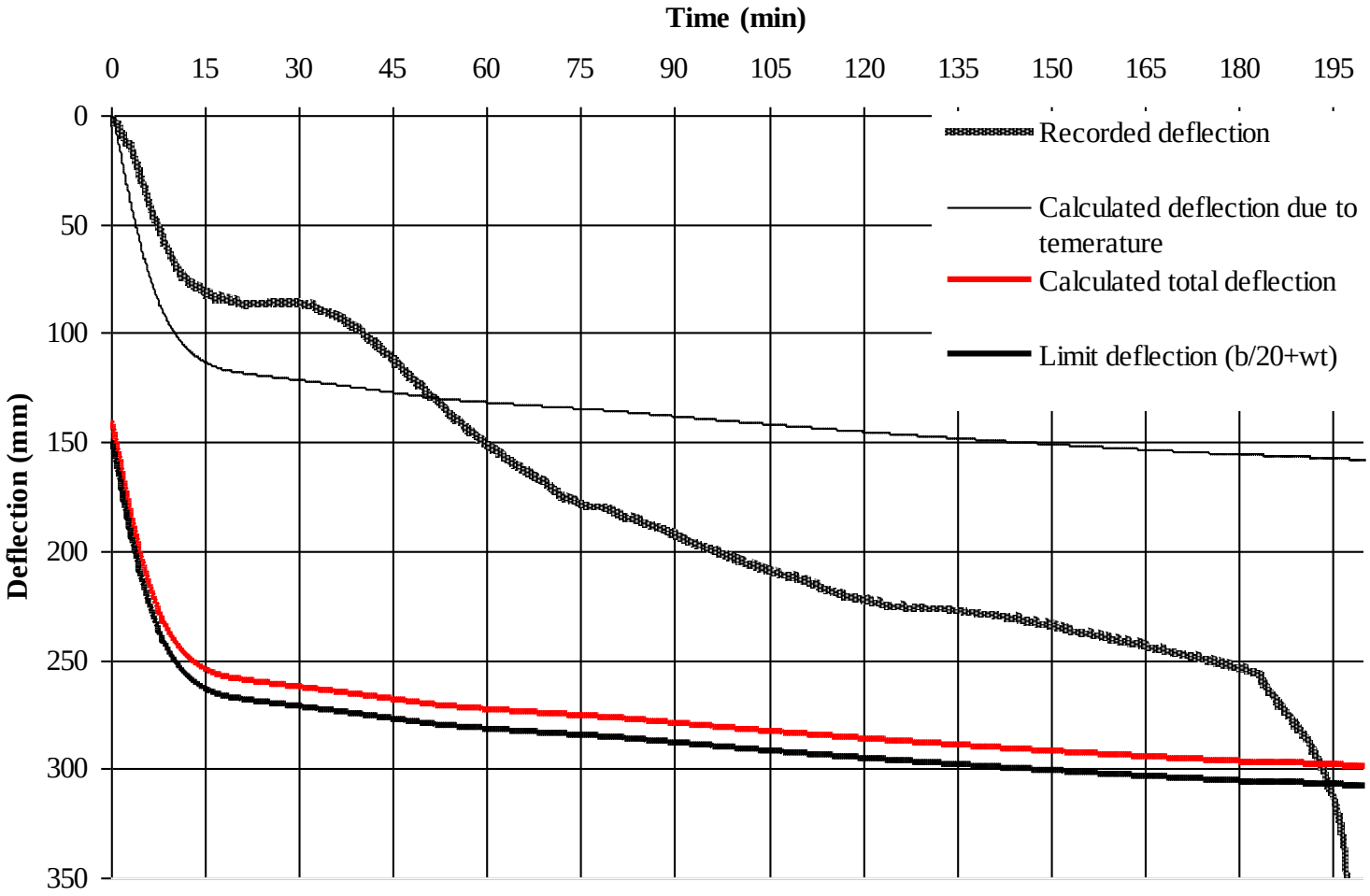


Fire test of composite steel-concrete floor

After cooling

Fire test of composite steel-concrete floor

Slab deflection



Fire test of composite steel-concrete floor

Results of the test

- Fire resistance of 120 min
- Insulation criterion of 65 min
- Slab integrity of 120 min

Virtual furnace

Drawbacks of standard fire testing

- Time consuming (planing, preparation, analysis)
- Expensive

Virtual furnace

- numerical model using CFD (Computational Fluid Dynamics) and FEM (Finite Element Method)
- One-way coupled model

Virtual furnace

- **Coupled CFD-FEM model**

- **Thermal part**
  - FDS (Fire Dynamics Simulator)
  - Temperature environment in the furnace

- **Mechanical part**
  - OOFEM (Object Oriented Finite Element Model)
  - Heat transport and mechanical behaviour

Virtual furnace

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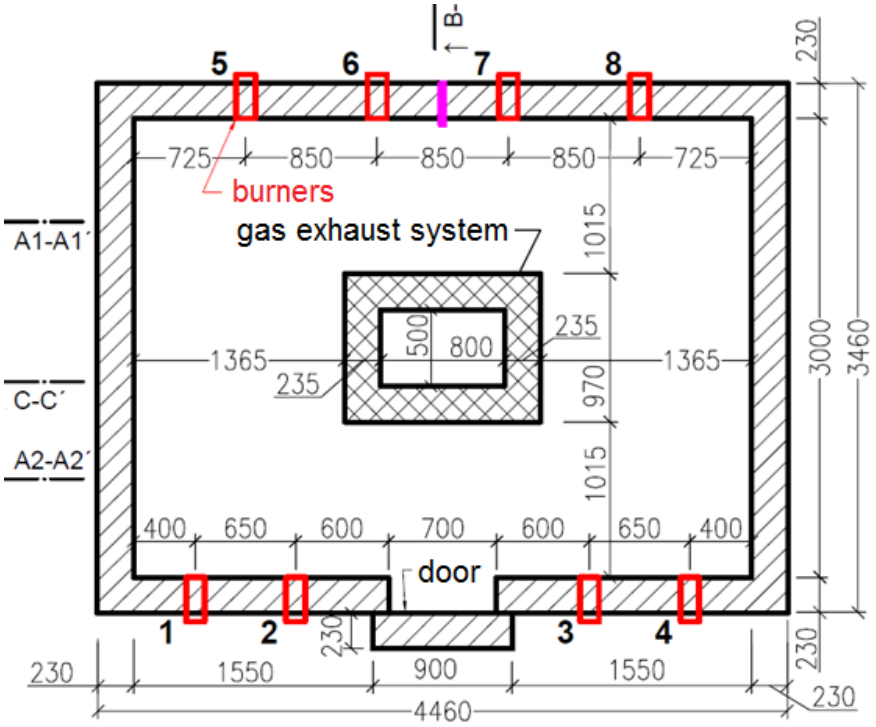
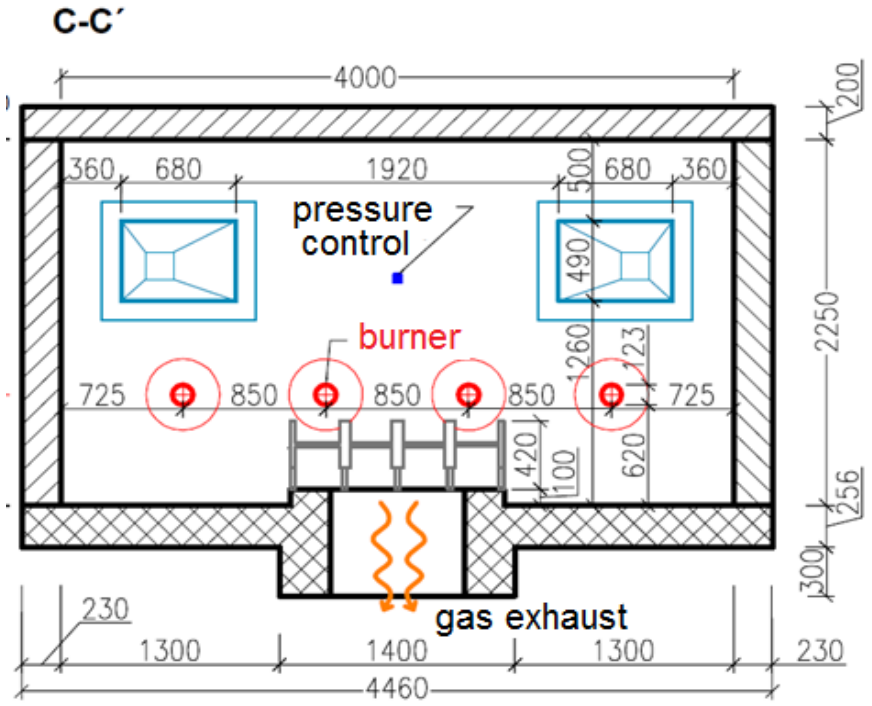
Virtual furnace

- Horizontal furnace
- Fire lab Pavus a.s.

Horizontal furnace in Pavus a.s.



Ground plan

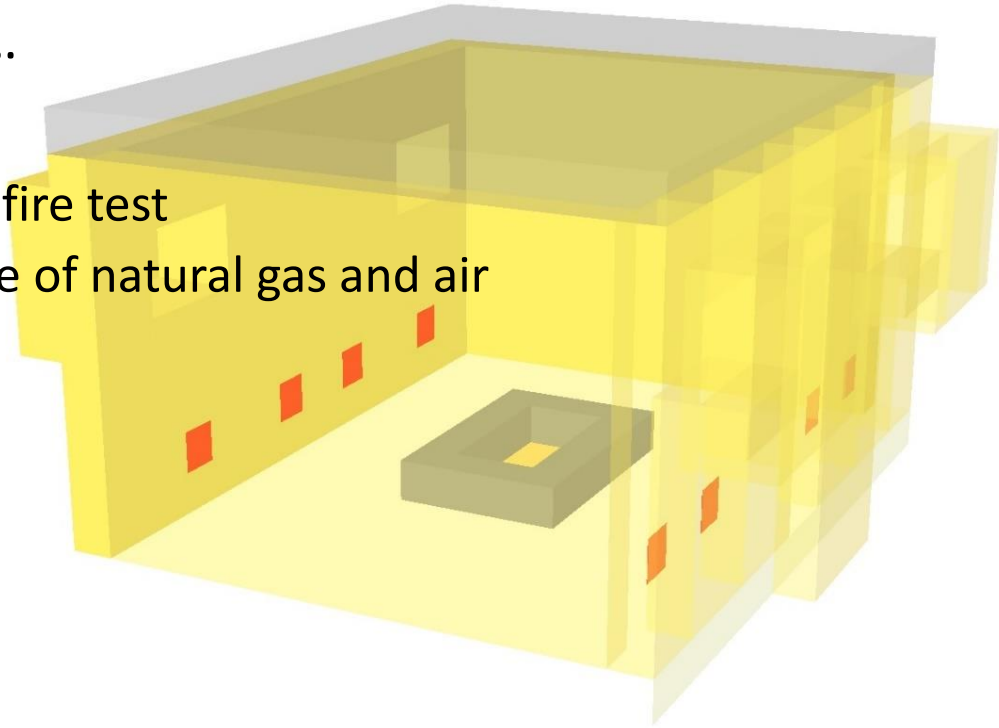


Section C-C‘

Virtual furnace

Numerical model

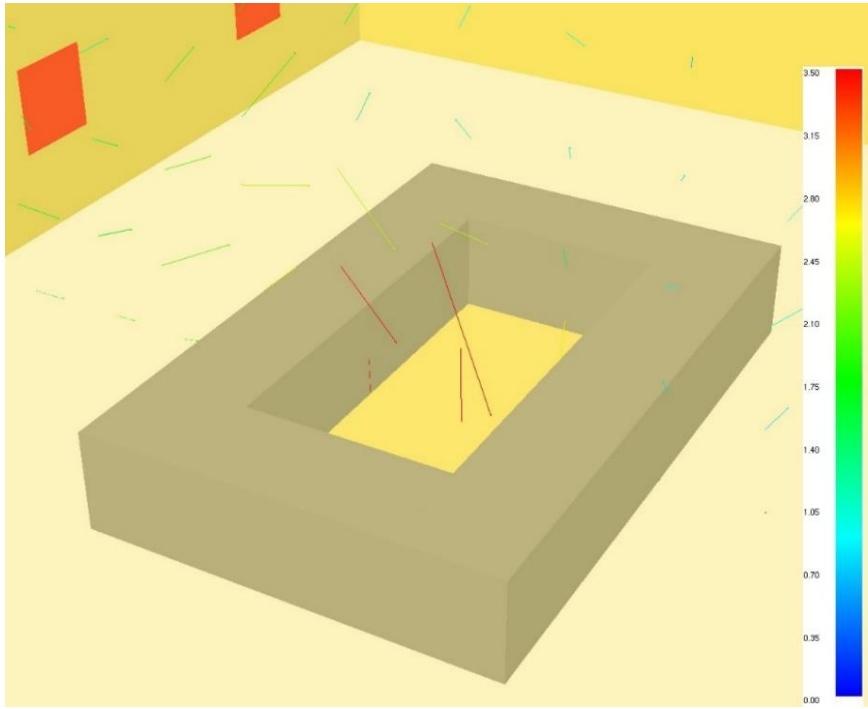
- FDS 6.5.2 (Fire Dynamics Simulator)
- Geometry, material properties, burners = real furnace
- Opening in the floor = real furnace
- Mesh size 250 mm, 100 mm, …
- 8 burners
  - Power measured in the pilot fire test
  - Reaction of burning – mixture of natural gas and air



Virtual furnace

Numerical model

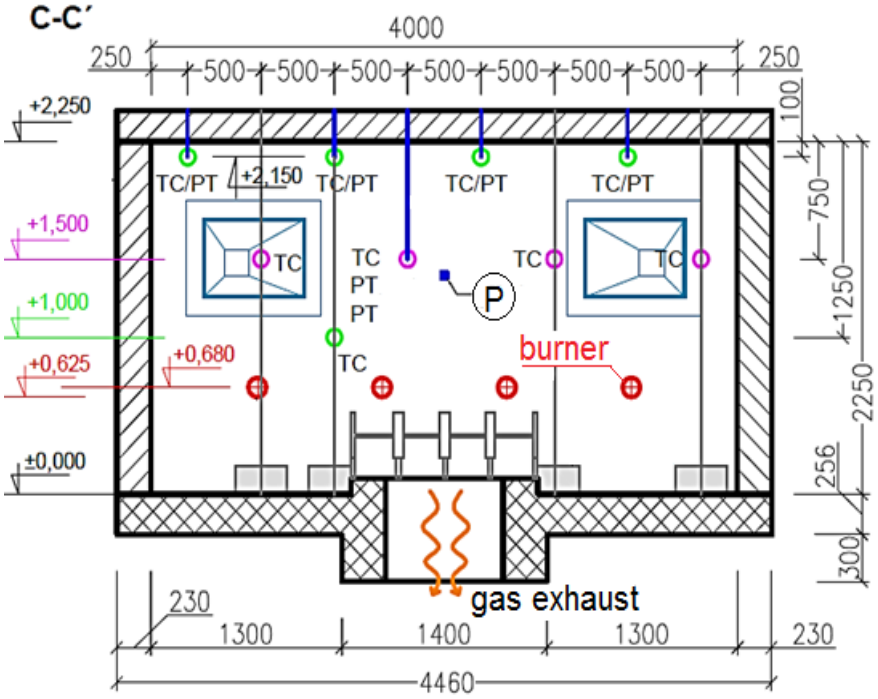
- Ventilation opening
  - Forced ventilation – control function which follows limit of 20 Pa



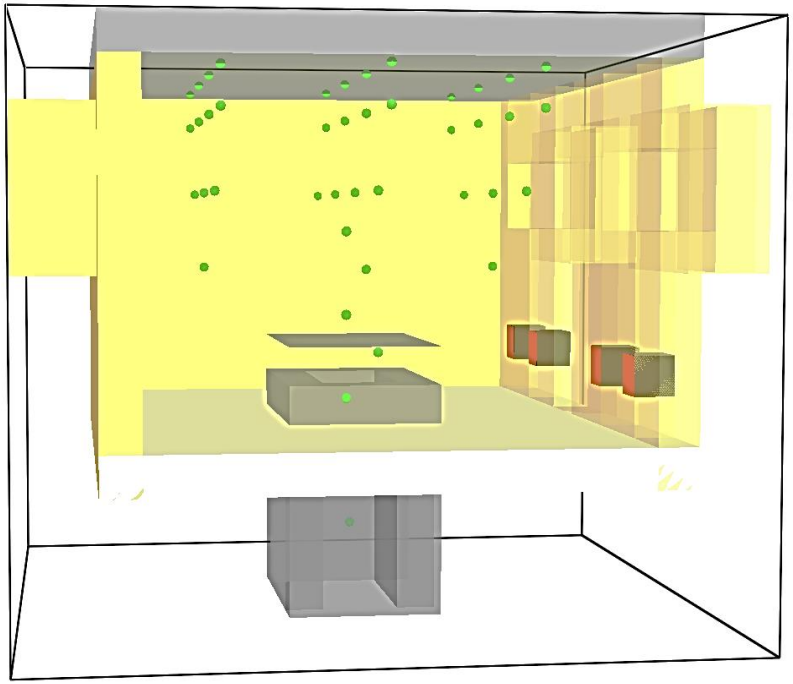
Virtual furnace

Numerical model

- Measurement of gas temperature
- 16 plate thermometers and 25 coated thermocouples



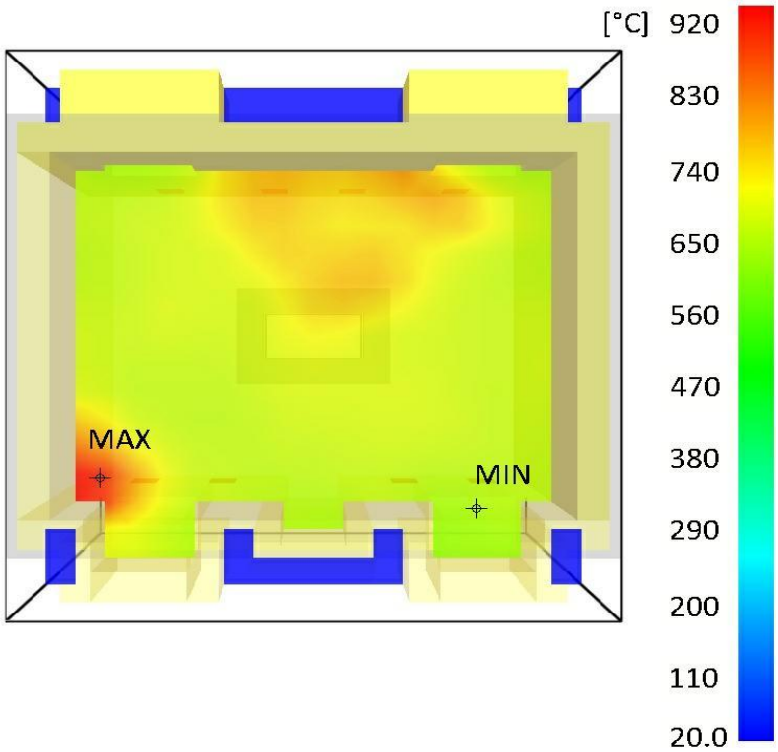
Measurement positions



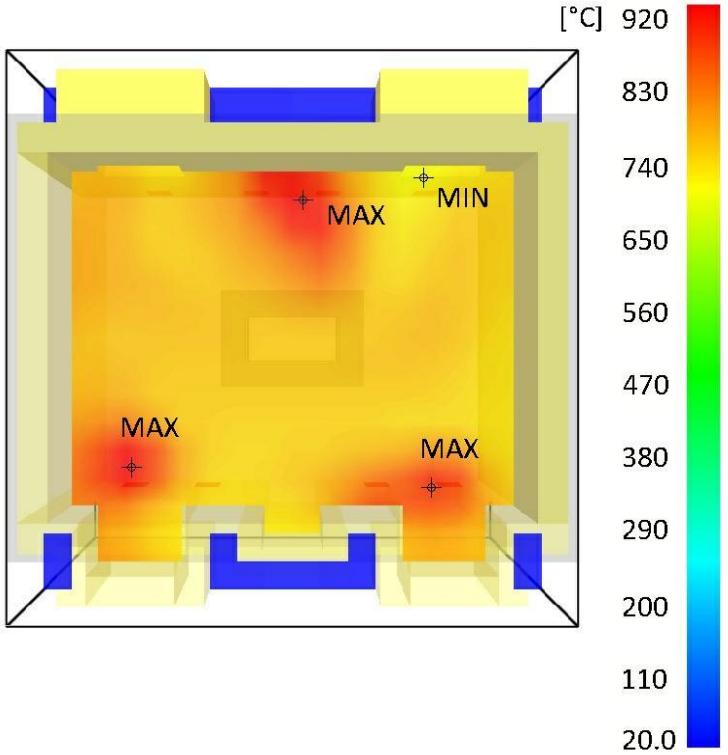
Mesurement sensors in the model

Virtual furnace

Numerical model - results



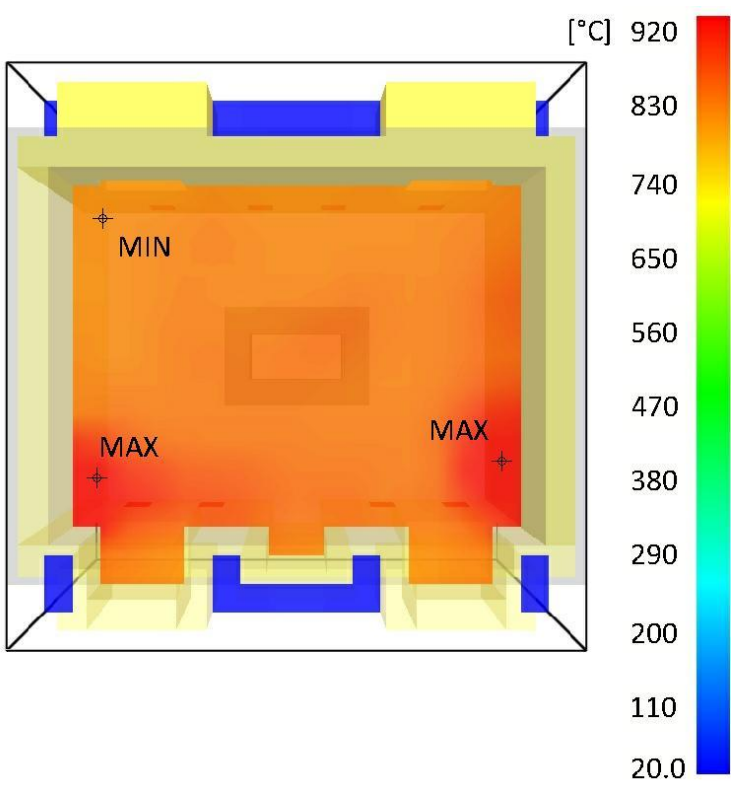
Temperature 100 mm below the ceiling in 5 min



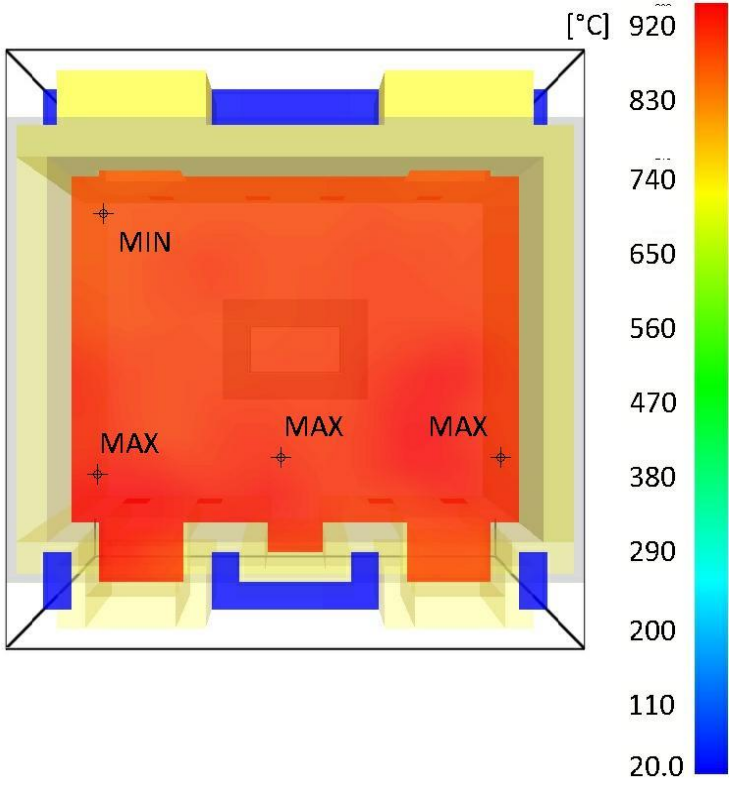
Temperature 100 mm below ceiling in 10 min

Virtual furnace

Numerical model - results



Temperature 100 mm below the ceiling in 20 min



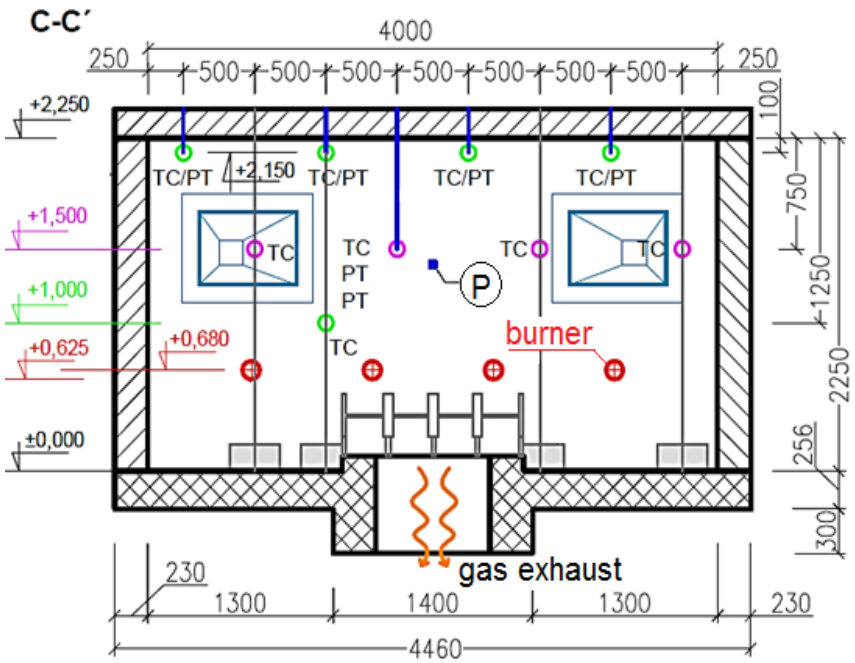
Temperature 100 mm below ceiling in 30 min

Virtual furnace

Validation of FDS model

- Fire test in empty horizontal furnace
- Measurement of gas temperature (TC), AST (PT) and pressure

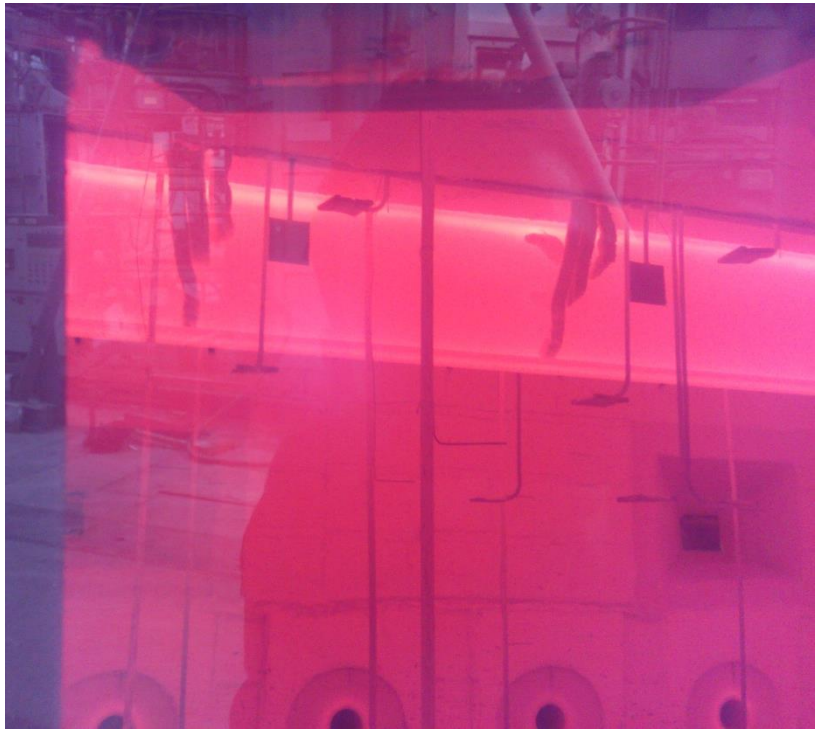
Fire test in the empty furnace



Measurement positions

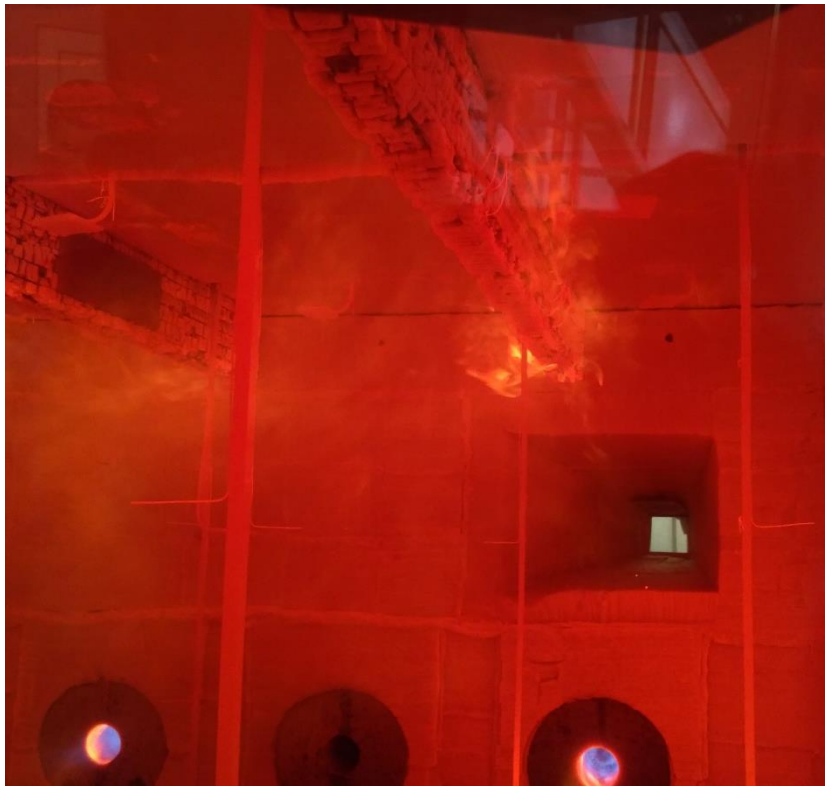
Virtual furnace

Validation of FDS model – fire test of a steel beam



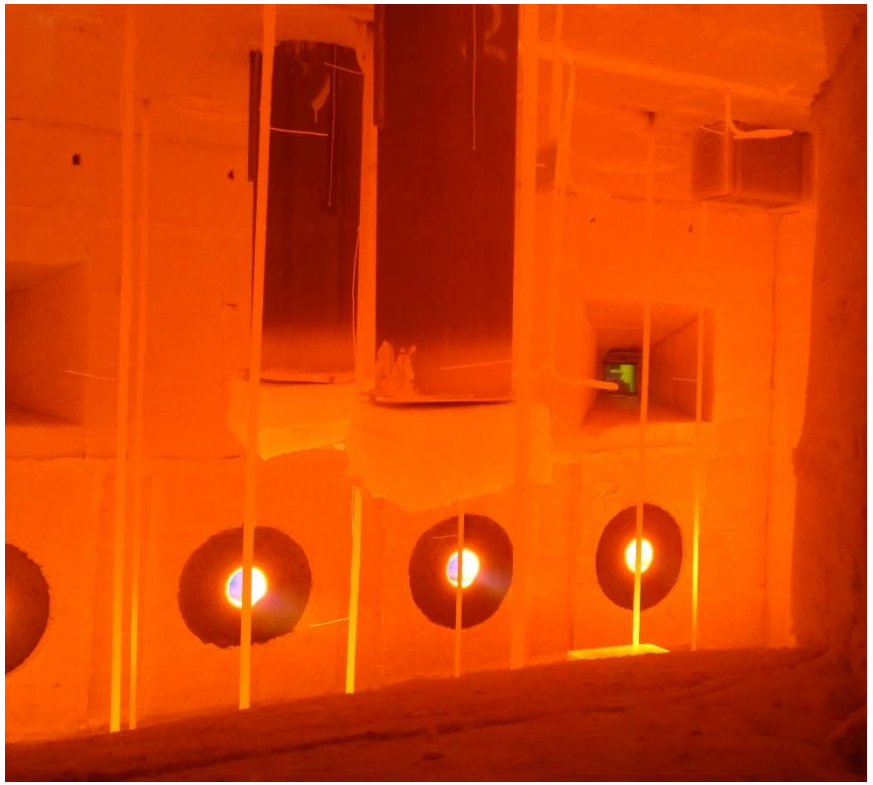
Virtual furnace

Validation of FDS model – fire test of 3 timber beams



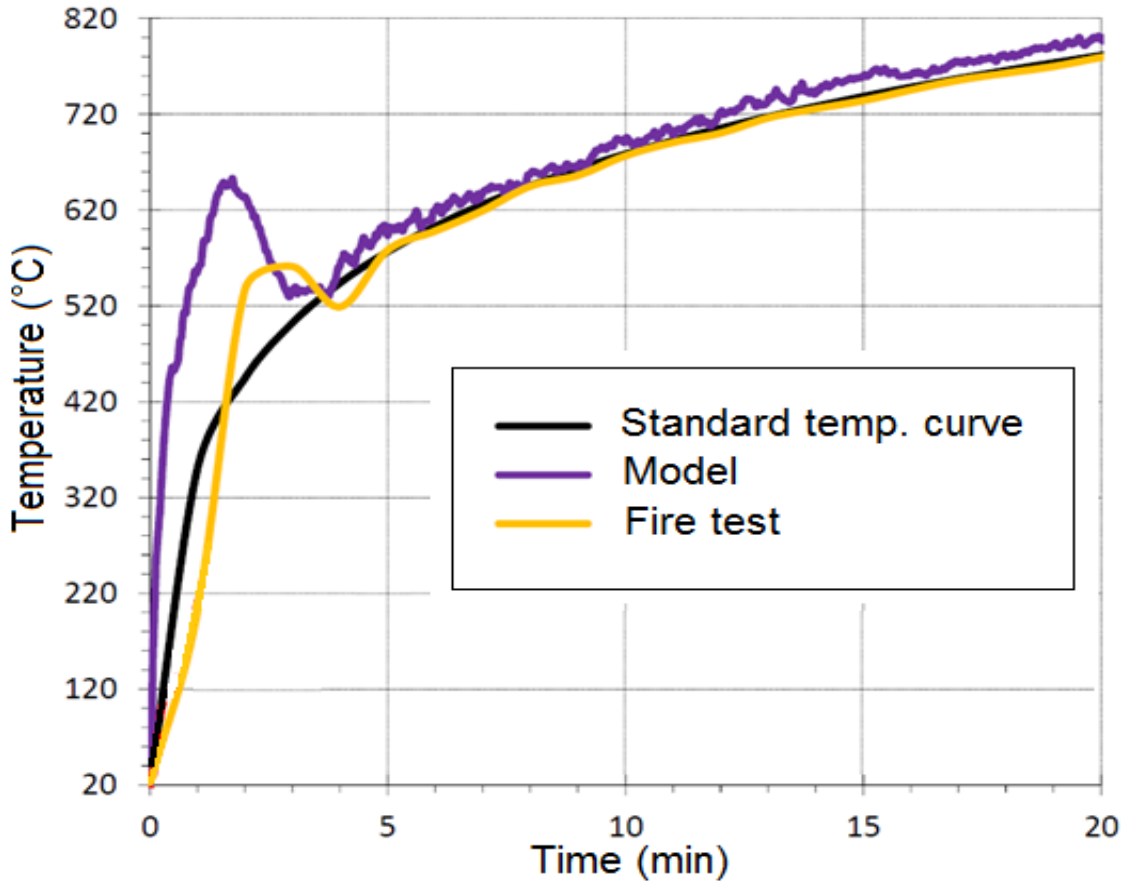
Virtual furnace

Validation of FDS model – fire test of concrete „dolls“



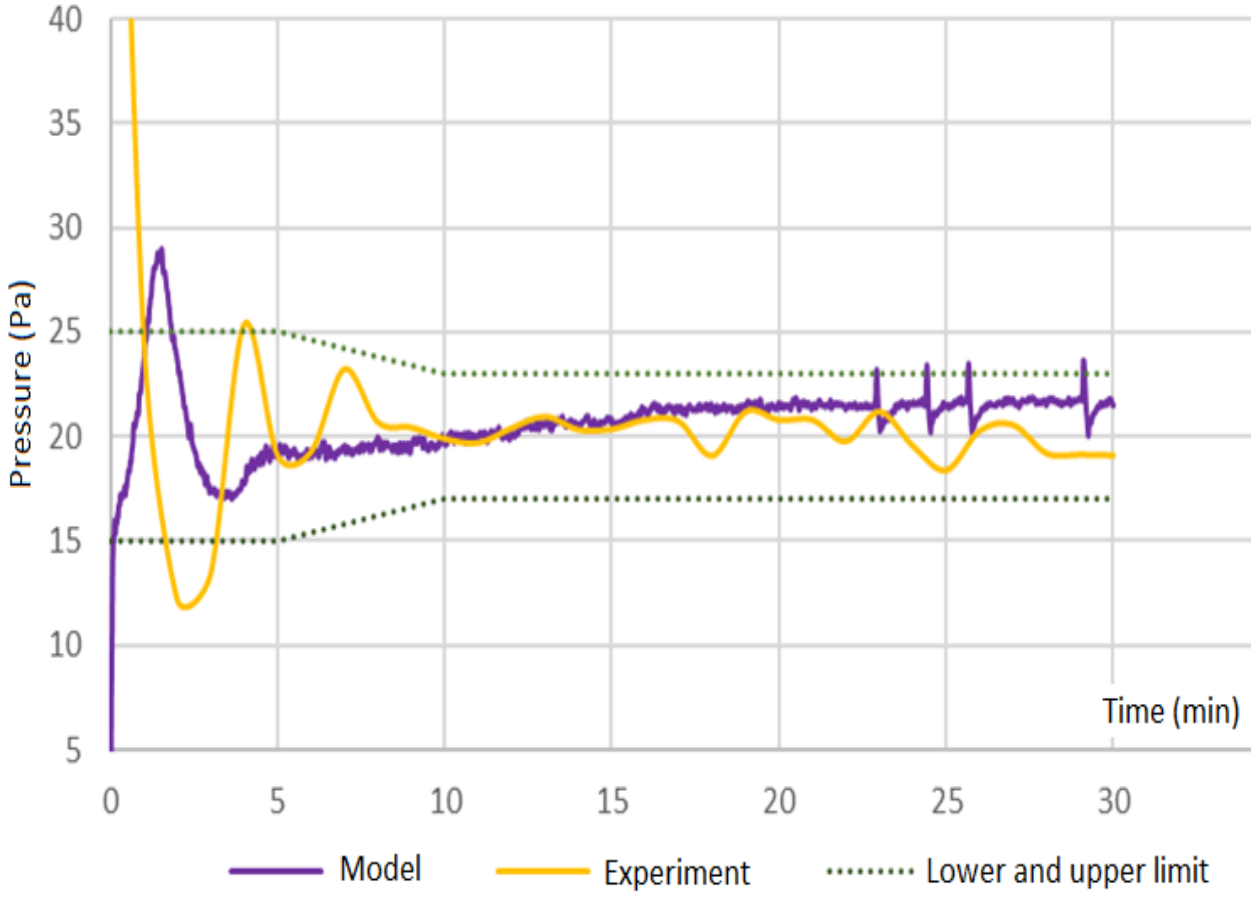
Virtual furnace

Validation of FDS model



Virtual furnace

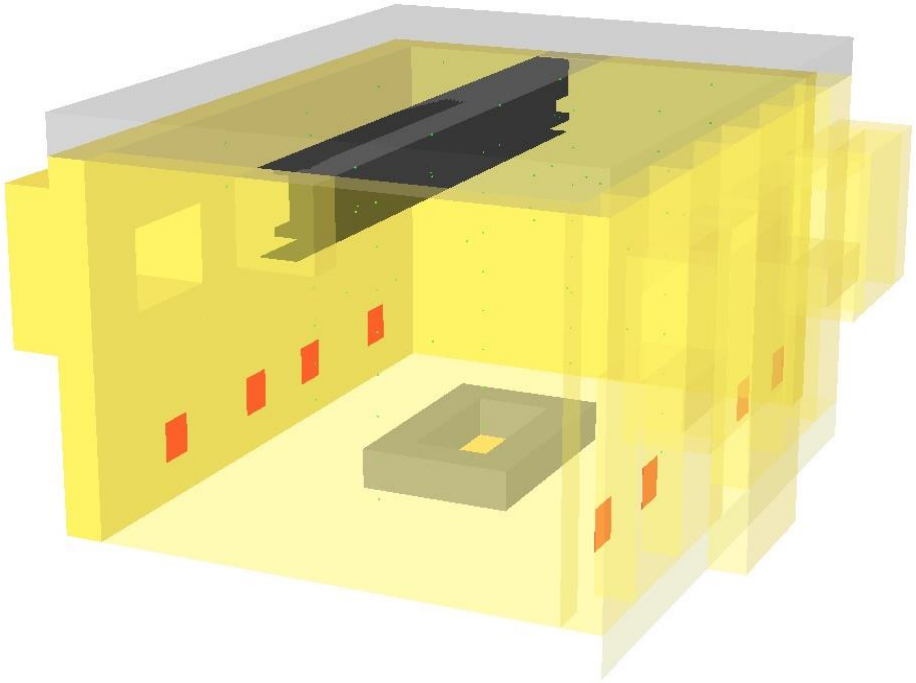
Validation of FDS model



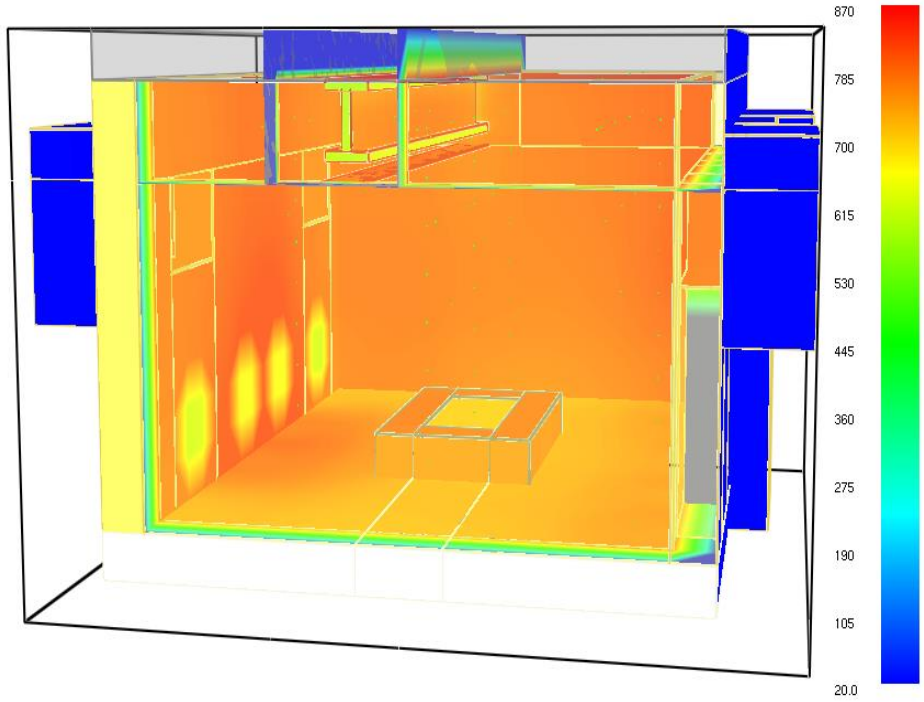
Virtual furnace

Virtual test of a steel beam

- IPE 400
- Heating according to standard temperature curve



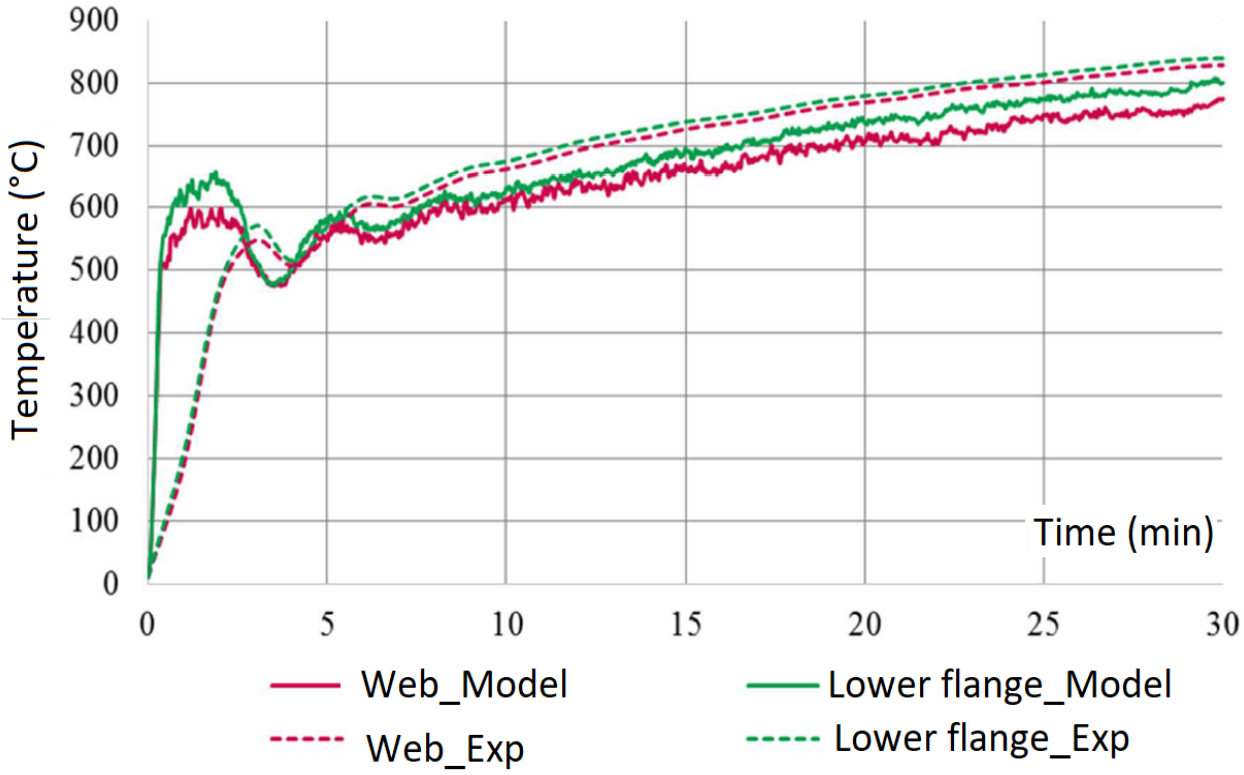
FDS model of furnace with the steel beam



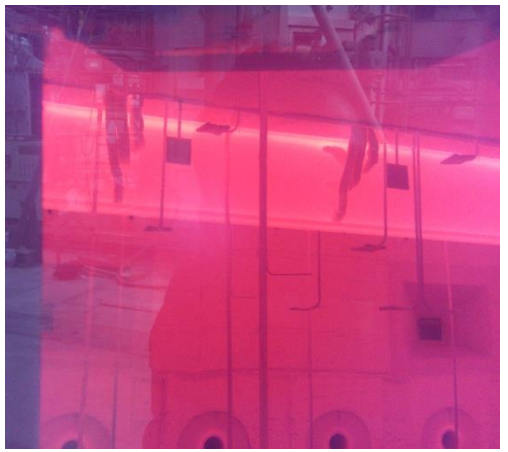
Surface temperatures in 10 min

Virtual furnace

Virtual test of a steel beam – thermal part

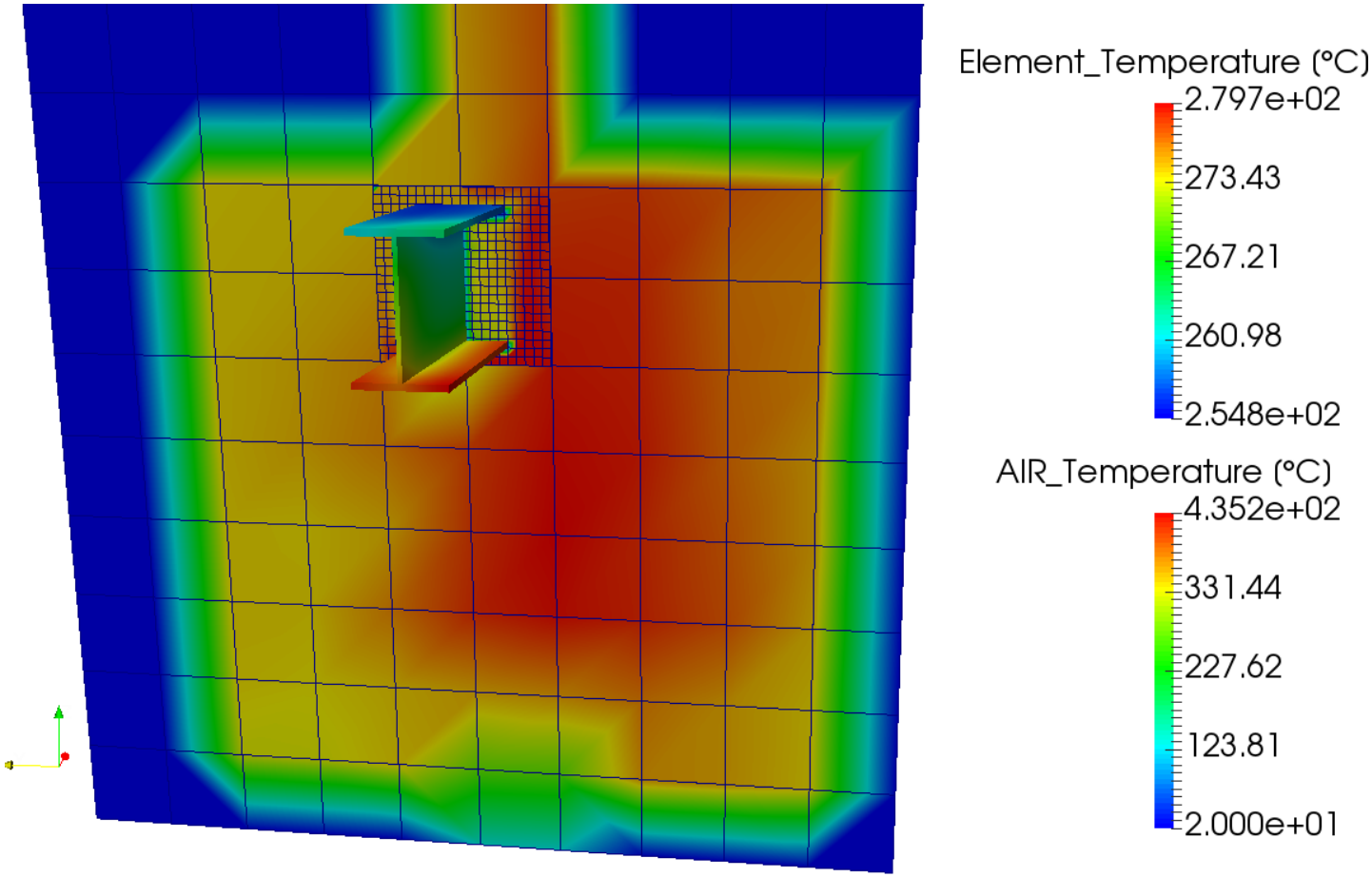


Comparison of adiabatic surface temperature



Virtual furnace

Virtual test of a steel beam – mechanical part



Coupled FDS-OOFEM model

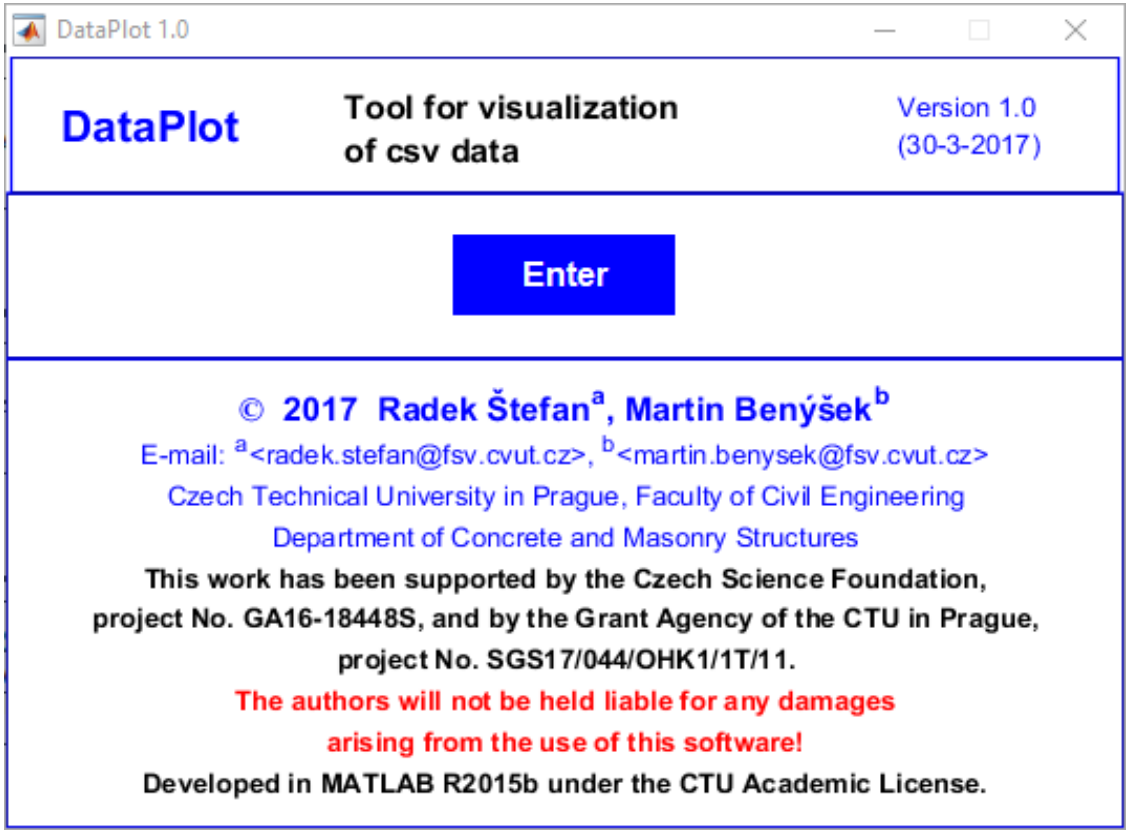
Conclusion

- Fire resistance usually proved by standard fire tests
- Virtual furnace (FDS-OOFEM)
- Validation of FDS model to real fire tests – good agreement
- Further improvement is needed

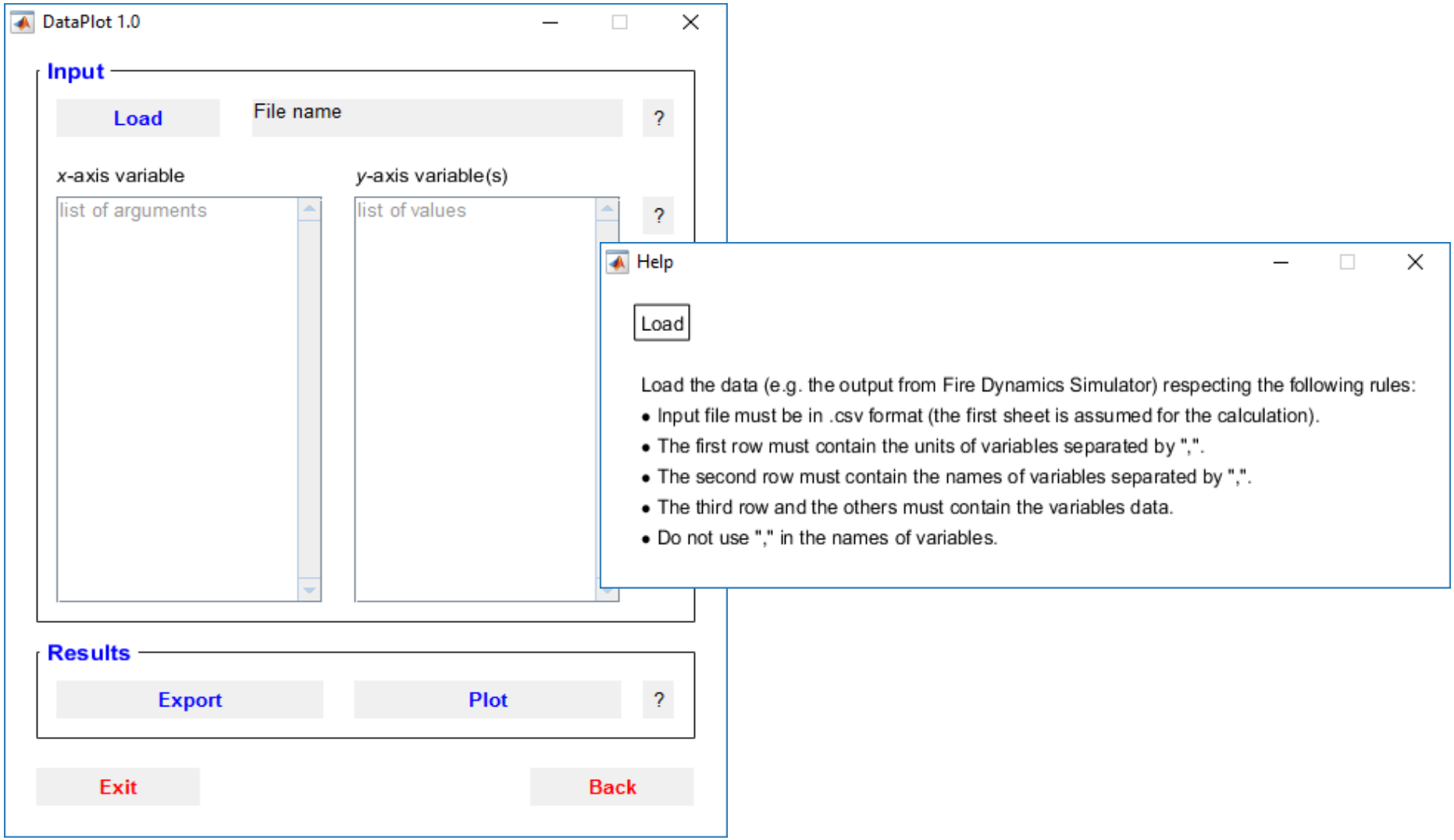
- Coupling of CFD-FEM is a suitable method for modelling of standard fire test for fire resistance of structures
  - Reducing of cost
  - Repetition of testing
  - Optimization of settings of real furnace

DataPlot

Simple software to modify data from FDS – freely available



DataPlot


DataPlot 1.0
Input
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File name
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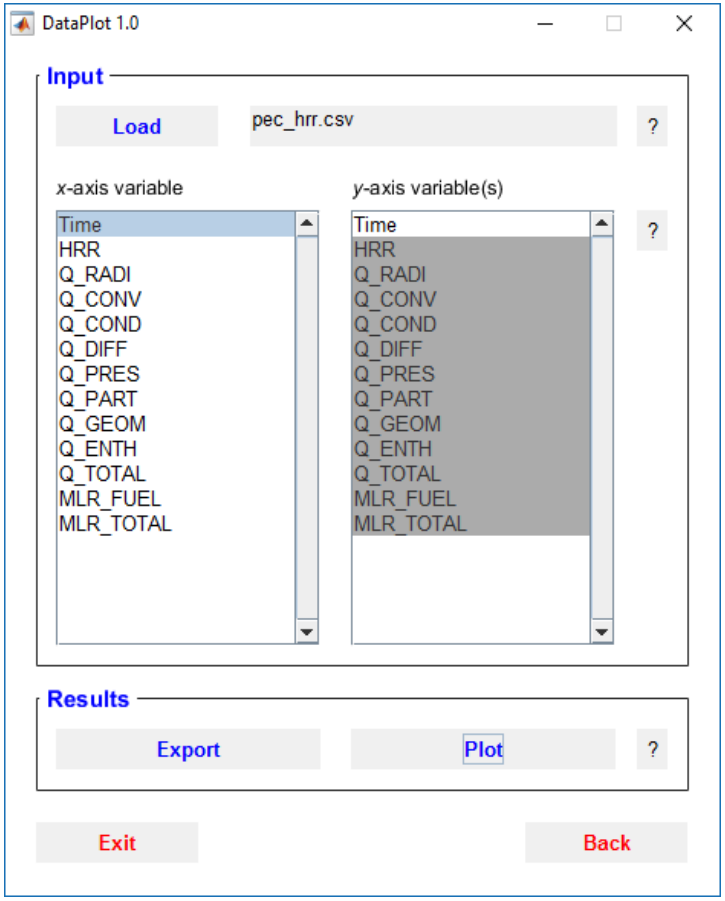
x-axis variable
y-axis variable(s)
list of arguments
list of values
?
Results
Export
Plot
?
Exit
Back
Help
Load
Load the data (e.g. the output from Fire Dynamics Simulator) respecting the following rules:
• Input file must be in .csv format (the first sheet is assumed for the calculation).
• The first row must contain the units of variables separated by ",".
• The second row must contain the names of variables separated by ",".
• The third row and the others must contain the variables data.
• Do not use "," in the names of variables.

DataPlot


DataPlot 1.0
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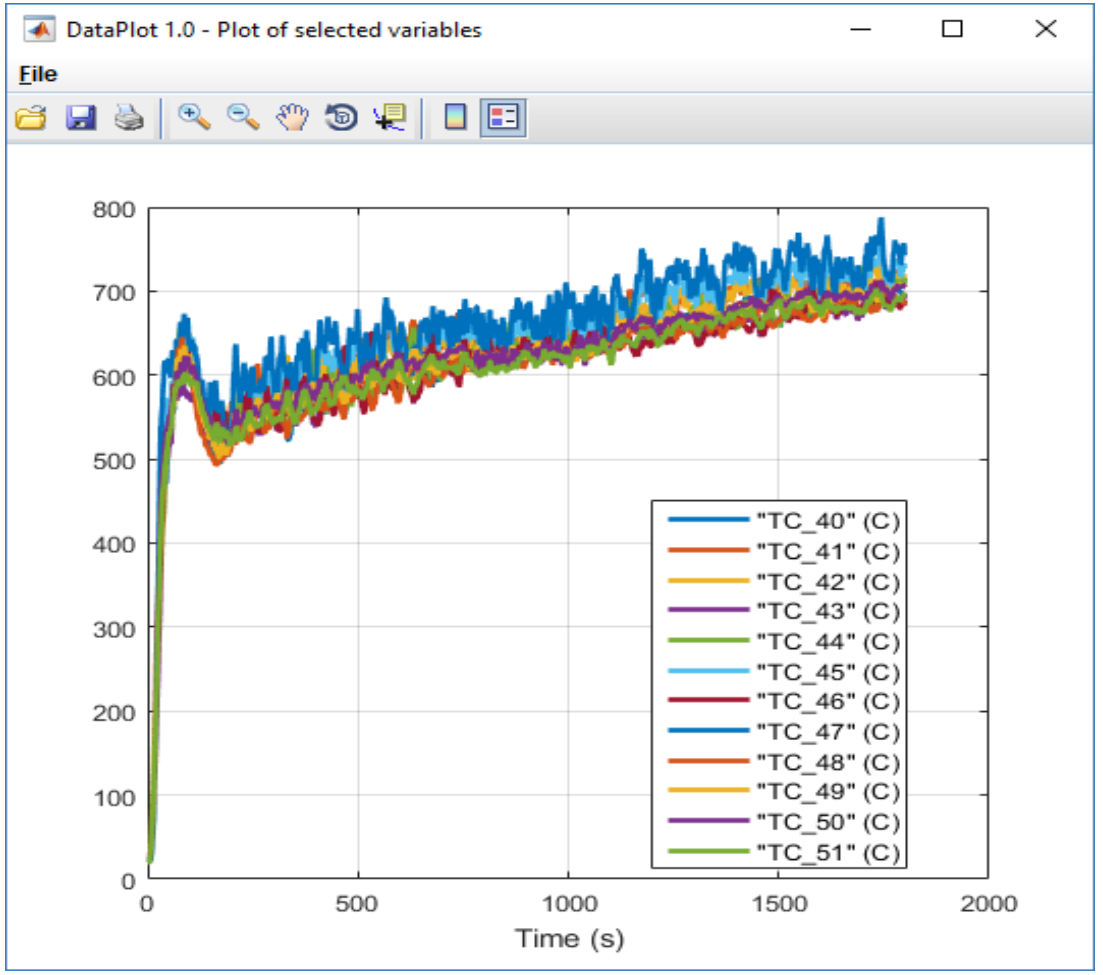
DataPlot 1.0 - Plot of selected variables
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"TC_51" (C)

Thank you for your attention!

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References

CÁBOVÁ, K.; LIŠKOVÁ, N.; ZEMAN, F.; BENÝŠEK, M.; WALD, F. Numerical simulation of fire-resistance test In: Applications of Fire Engineering. Leiden: CRC Press/Balkema, 2017. pp. 171-177. ISBN 978-1-138-09291-4.

CÁBOVÁ, K.; LIŠKOVÁ, N.; ZEMAN, F.; BENÝŠEK, M.; WALD, F. Numerical simulation of fire-resistance test of steel beam In: Eurosteel 2017. Berlin: Ernst & Sohn, 2017. ISSN 2509-7075.

CÁBOVÁ, K.; LIŠKOVÁ, N.; NOVOTNÁ, P.; BENÝŠEK, M.; ZEMAN, F.; WALD, F. Modelling of standard fire test In: Engineering Mechanics 2017 - Book of full texts. Brno: Brno University of Technology, 2017. pp. 226-229. ISSN 1805-8248. ISBN 978-80-214-5497-2.

WELCH, S. a RUBINI, P.A. Three-dimensional Simulation of Fire-Resistance Furnance. Melbourne, Australia : Proccedings of 5th International Symposium on Fire Science, 1997.

PILOTO, P.A.G., MESQUITA, L.M.R. a PEREIRA, Alexandre Augusto. Thermal analysis in fire-resistance Furnace. Santander, Spain : Proceedings of the International Workshop on Fire Protection and Life Safety in Buildings and Transportation Systems, 2009.

CAYLA, F., LEBORGNE, H. A JOYEUX, D. Application of a virtual resistance furnance :fire resistance test simulation of a plasterbiaord membrane. ASFE Conference. Prague, 2011.

LIŠKOVÁ, N. Adiabatická teplota povrchu ve vodorovné peci. Praha 2017. Diplomová práce (Ing.). České vysoké učení technické v Praze, Fakulta stavební, Katedra ocelových a dřevěných konstrukcí, 2017-02-07.

NOVOTNÁ, P. Modelování požární zkoušky v peci. Praha 2017. Diplomová práce (Ing.). České vysoké učení technické v Praze, Fakulta stavební, Katedra ocelových a dřevěných konstrukcí, 2017-02-07.

References

ČSN EN 1363-1. Zkoušení požární odolnosti - Část 1 : Základní požadavky. Praha : ÚNMZ, 2013.

ČSN EN 1363 – 2:2000 Zkoušení požární odolnosti – Část 2: Alternativní a doplňkové postupy

ČSN EN 1363 – 3:1999 Zkoušení požární odolnosti – Část 3: Ověřování charakteristik pec

ČSN EN 13501 – 2:2017 Požární klasifikace stav. výrobků a konstrukcí staveb

ŠTEFAN, R., BENÝŠEK, M.: DataPlot – Tool for visualization of csv data. [Software splňující podmínky RIV (dřív Autorizovaný]. 2017