MEASUREMENT OF TEMPERATURE

Thermocouples
Plate thermometers
Theory of AST

Ing. Kamila Cábová, Ph.D.

Temperature sensors

EN 1363

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

Defines what temperature sensors to use in what cases

chap. 4.5.1.1 Thermoelectric sensors in furnace (plate thermometers, PT)

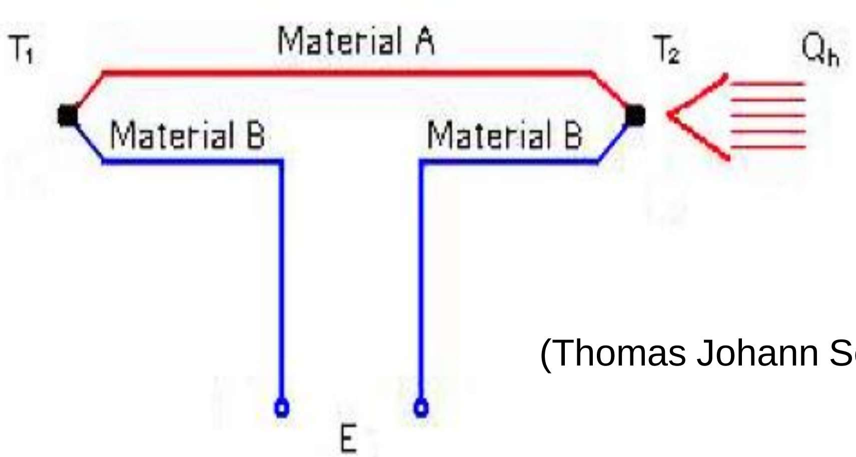
chap. 4.5.1.5 Thermoelectric sensors for environment temperautre (thermocouples, TC)

Thermocouples

➢ thermoelectric device based on physical phenomenon (described in 19. cent.)

The occurrence of voltage in a circuit composed of two different conductors whose ends have a different temperature (voltage in microvolts/°C)

so called Seebeck´s thermoelectric phenomenon

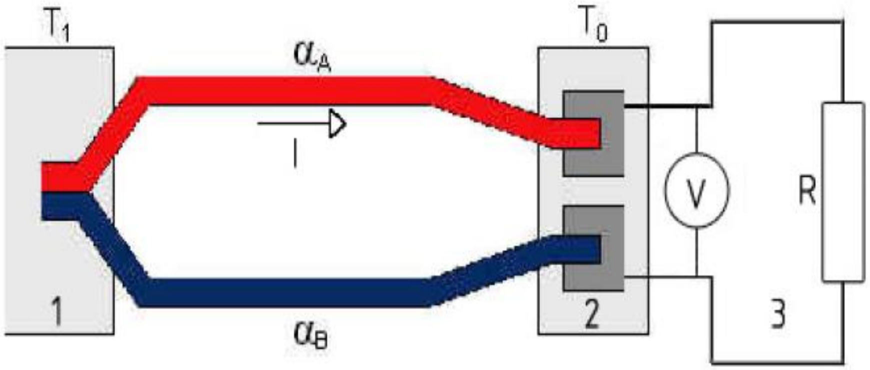


(Thomas Johann Seebeck, 1821)

Thermocouples

Construction of the thermocouple

➢ two wires of different materials, connected at the end of the conductor

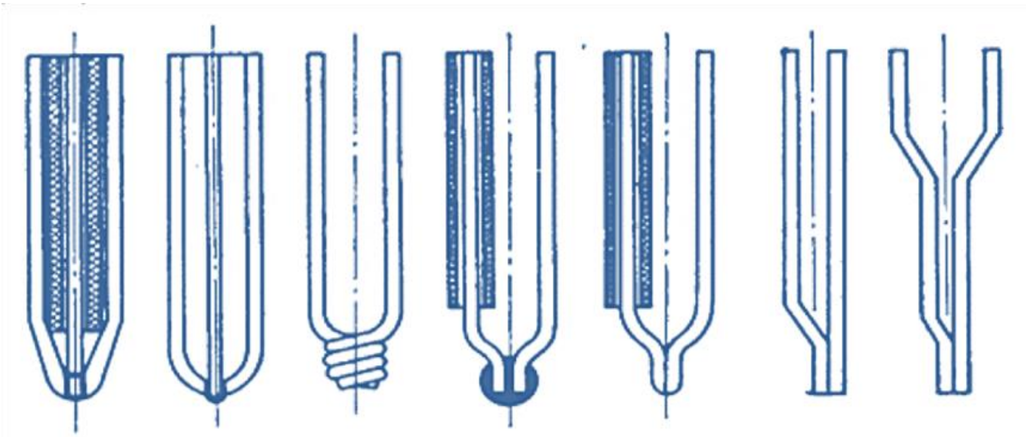


1 – measuring end, 2 –connection to compensation circuit, 3 – compensation circuit, αA, αB – two conductors of different materials

Thermocouples

Construction of the thermocouple

- ➢ measuring end – mechanically connected by brazing, welding



- ➢ end can be protected or unprotected (coated or wired TC)

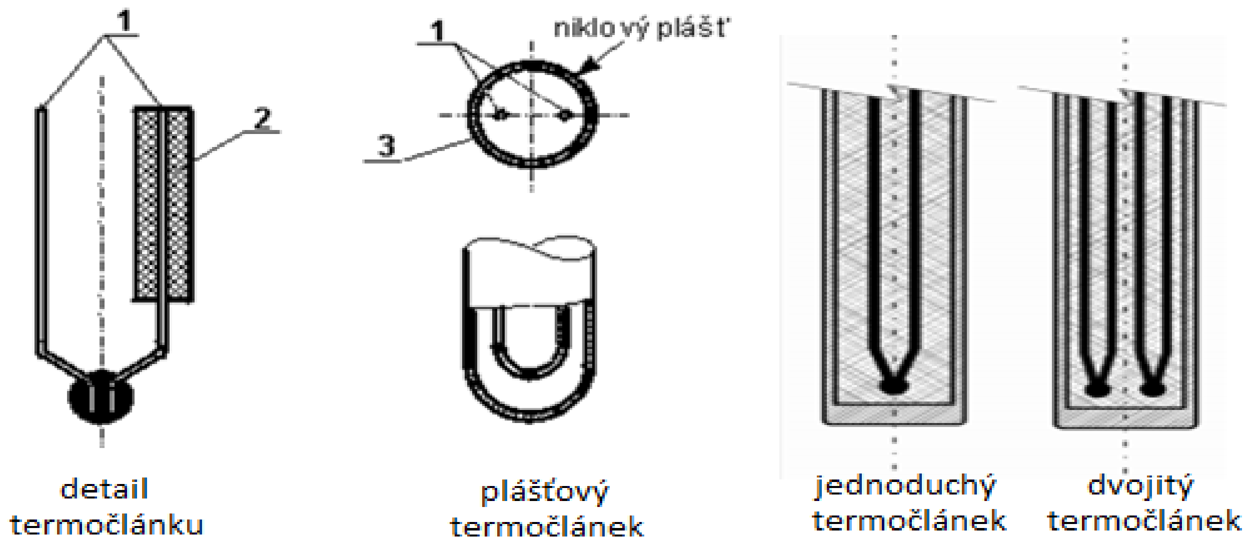
Types of thermocouples

- according to EN 60 584-1 capital letters

Označení	*Původní značení dle složení*	*Doporučený teplotní rozsah použití [°C]*	*Barevné označení*			
			Kladný pól		*Záporný pól*	
T	*Cu-CuNi*	*+200 až +350*	*hnědá*			*bílá*
J	*Fe-CuNi*	*+400 až +750*	*černá*			*bílá*
E	*NiCr-CuNi*	*+440 až +800*	*fialová*			*bílá*
K	*NiCr-NiAl*	*+750 až +1200*	*zelená*			*bílá*
N	*NiCrSi-NiSi*	*+850 až +1250*	*lila*			*bílá*
S	*Pt10Rh-Pt*	*+1400 až +1600*	*oranžová*			*bílá*
R	*Pt13Rh-Pt*	*+1400 až +1600*	*oranžová*			*bílá*
B	*Pt30Rh-Pt6Rh*	*+1500 až +1700*	*bez údaje*	/		*bílá*

Coated thermocouples

- two conducters in a nickel tube filled with powder of oxids (MgO or Al_2O_3)
- tube from stainless stell or inconel

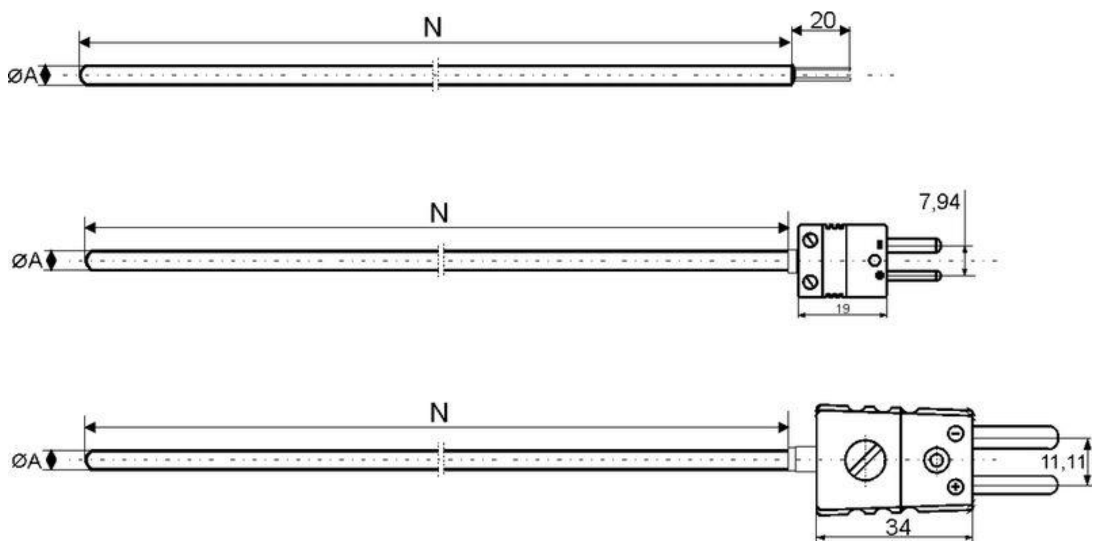


1 ... termočlánkové dráty, 2 ... keramická izolace
3 ... keramický prášek

Coated thermocouples

For testing of fire resistance of structures in furnaces can be used:

Thermoelectric sensor of type K, diameter 3 mm



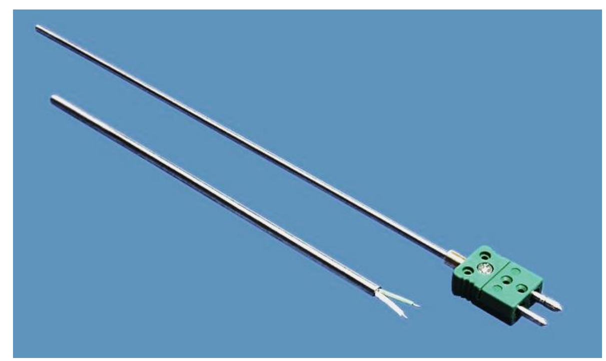
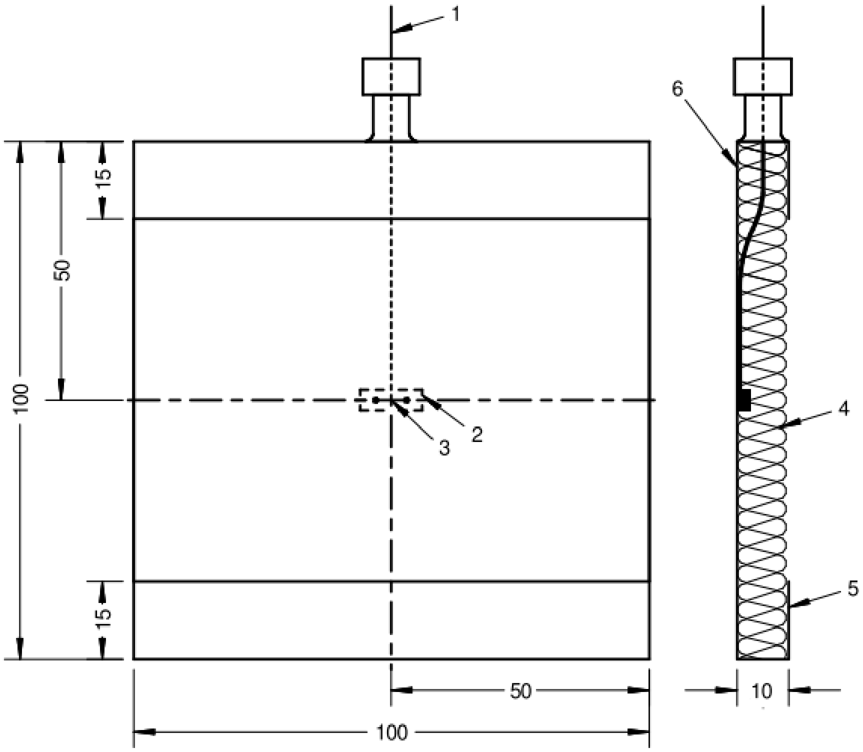


Plate thermometers

Plate thermometer

- often called as PT
- construction and material defined in EN 1363-1: 2013 chapter 4.5.1.1



1 plášťový termoelektrický článek typu K – NiCr-NiAl s izolovaným měřicím spojem, průměr 1 – 3 mm

2 bodově přivařený (18x6 mm) nebo přišroubovaný ocelový pásek (25x6 mm), šroub musí mít průměr 2 mm

3 měřicí spoj termočlánku

4 minerální izolační materiál (97 ±1 mm x 97 ±1 mm x 10 ±1 mm), objem. hmotnost (280 ± 30) kg/m^3

5 pásek slitiny niklu o délce (150 ±1 mm), šířce (100 ±1 mm) a tloušťce (0,7 ±1 mm)

6 strana "A" – přijímající tepelný tok

Plate thermometers

- before the first measurement it must be „aged“ to gain the same emissivity

  = placement into furnace heated to 1000 °C for 1 hour or

  heating in a furnace for 90 min (ISO curve)

- in furnaces it is used for controlling gas burners
- after 50 hours of usage it must be replaced

Plate thermometers

Theory of PT

- thanks to its construction it is able to measure parts of net heat flux ***h_{tot}* *[W/m²]***

$$h_{tot} = h_{tot,c} + h_{tot,r}\ [w/m^2]$$

where $h_{tot,c}$ is a part of net heat flux by convection
$h_{tot,r}$ is a part of net heat flux by radiation

$$h_{tot,r} = \varepsilon.(h_{inc} - \sigma.T_s^4)\ \ [w/m^2]$$

Difference between incident heat flux on a structural surface and emitted heat flux from the structural surface (absorption and emissivity equals)

where
h_{inc} is incident heat flux coming to the surface,
σ is Stephan-Boltzmann constant ($\sigma = 5{,}67\times10^{-8}$ W/m^{2}K^4),
T_s is surface temperature,
ε is emissivity

Plate thermometers

Theory of PT

- incident heat flux equals to

$$h_{inc} = \sum_i \varepsilon_i F_i \sigma . T_s^4 \quad [w/m^2]$$

where
ε_i is emissivity of a surface „i“,
σ is Stefan-Boltzmann constant,
Fi and *Ti* are corresponding view factor and temperature to/on surface „i“

- net heat flux by convection

$$h_{tot,c} = \alpha_c (T_g - T_s) \quad [w/m^2]$$

where
α_c is a convective coefficient
T_g is gas temperature going to the surface

Plate thermometers

Theory of PT

- net heat flux can be written as

$$h_{tot} = \varepsilon(h_{inc} - \sigma T_s^4) + \alpha_c(T_g - T_s) \ \ [w/m^2]$$

or expression of h_{inc} by the aid of radiative temperature

$$h_{tot} = \varepsilon\sigma(T_r^4 - T_s^4) + \alpha_c(T_g - T_s) \ \ [w/m^2]$$

radiative temperature ≠ gas temperature

Often different marking/letters can be found:

h_{tot}, h_{inc} equals to q_{tot}, q_{inc}

α_c equals to h_c

Plate thermometers

Theory of PT

- in the case that a **surface is a perfect insulator**, net heat flux ***h_{tot}*** going into this surface **equals to zero**

$$0 = \varepsilon\sigma(T_r^4 - T_s^4) + \alpha_c(T_g - T_s) \ \ [w/m^2]$$

Surface of PT can be assumed as a perfect insulator (conduction in a thin plate is neglected), therefore above-written equation must be true for PT.

Temperature of an ideal surface, which cannot absorb any heat flux = **ADIABATIC SURFACE TEMPERATURE (AST)**

$$T_{PT} \approx T_{AST}$$

For PT constants should be used (ε_{pt}= 0.9, h_{pt}=10 W/m^{2}K, K_{pt}=8.0 W/m^{2}K)

Plate thermometers

Adiabatic surface temperature

- it can be therefore written

$$0 = \varepsilon\sigma\left(T_r^4 - T_{AST}^4\right) + \alpha_c(T_g - T_{AST}) \ \left[w/m^2\right]$$

T_{AST} differs in position and orientation!

In each point 6 different T_{AST} can be defined. T_g is the only one.

T_{AST} is an weighted average between T_r and T_g

- Is influence by surface emissivity, constant of convective heat. It is not affected by surface temperature.
- T_{AST} lies between T_r and T_g
    - When convective part is dominant – is closed to T_g
    - When radiative part is dominant – is closer to T_r

Plate thermometers

Adiabatic surface temperature

- Difference between the two main formulaes we can get

$$(+)\quad \dot{q}''_{\text{tot}} = \varepsilon\sigma(T_r^4 - T_s^4) + h(T_g - T_s) \qquad \text{(heat transfer)}$$

$$(-)\quad 0 = \varepsilon\sigma(T_r^4 - T_{AST}^4) + h(T_g - T_{AST}) \qquad \text{(def. AST)}$$

$$\dot{q}''_{\text{tot}} = \varepsilon\sigma(T_{AST}^4 - T_s^4) + h(T_{AST} - T_s)$$

- **instead of two different temperatures T_r and T_g, only one temperature T_{AST} can be used for calculation of heat transfer into a structure**

Plate thermometers

Advantages

- thanks to good construction of PT it is possible **to measure AST**

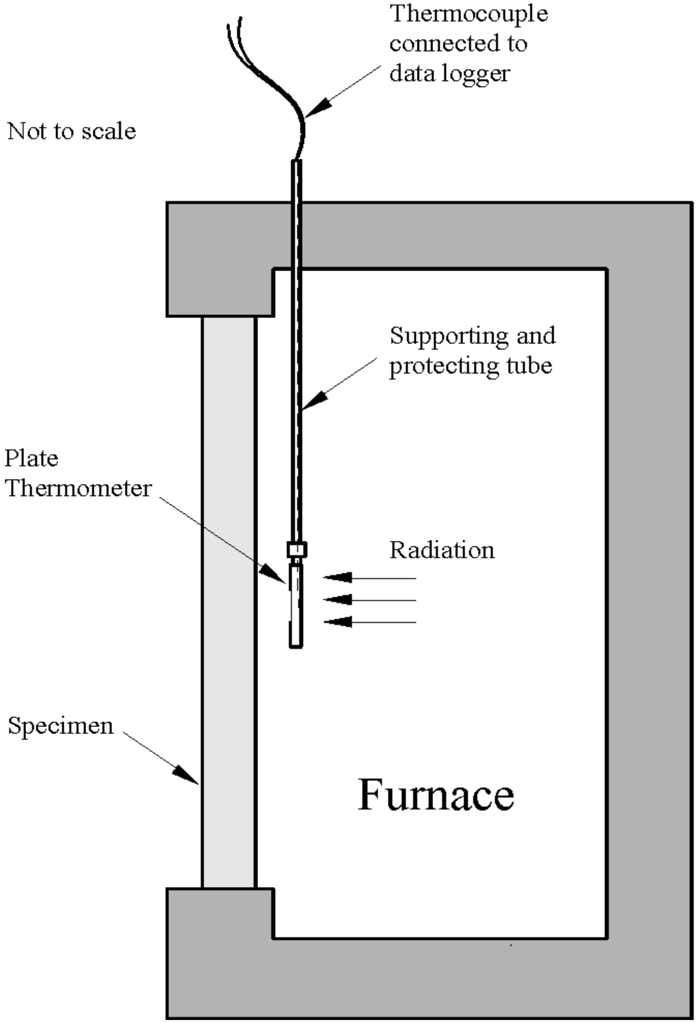
↓

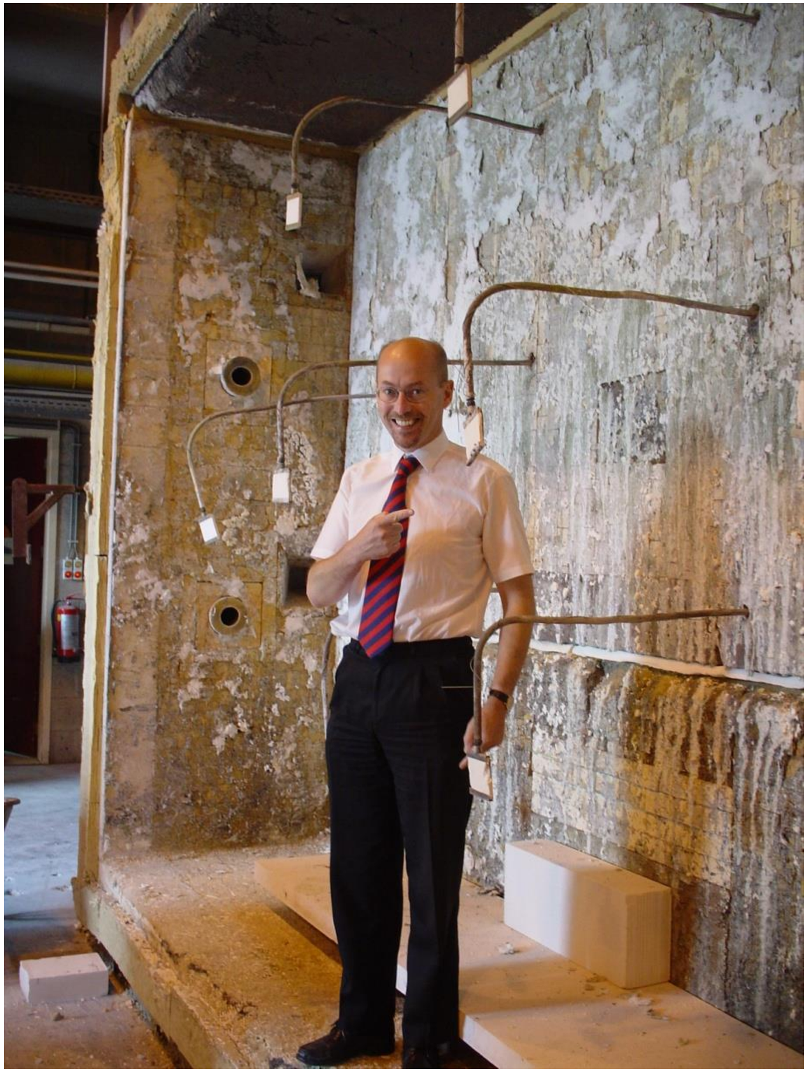
- from above-written formulas **it is possible to calculate parts of the net heat flux**,

meaning how much of heat flux comes by convection and how much by radiation

Plate thermometers

Placement of PT in a furnace





Fotodokumentace prof. Ulf Wickström

Plate thermometers

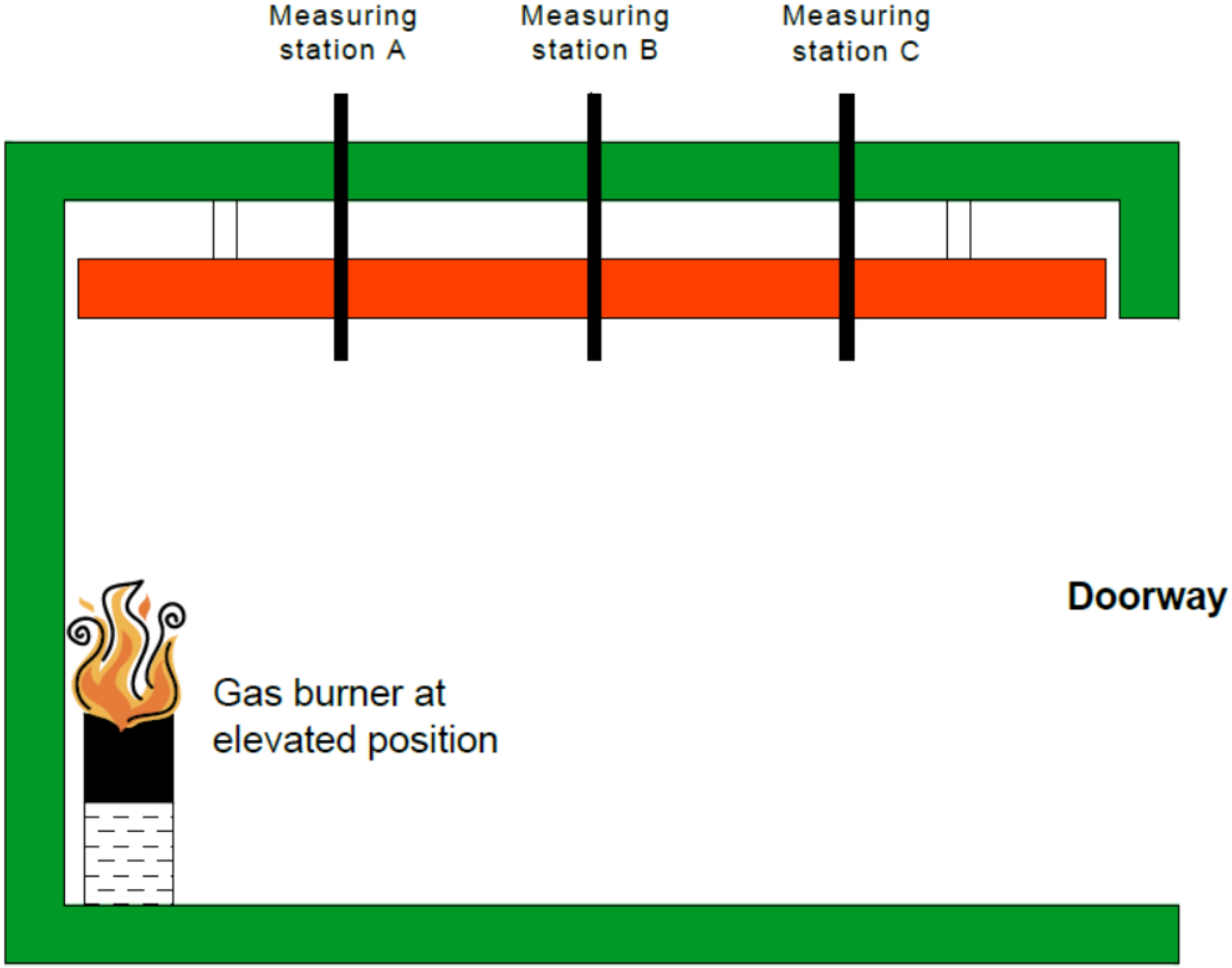
Placement of PT on a structure

Application of PT

Room Corner Test (RCT) with a steel beam (prof. Ulf Wickström)

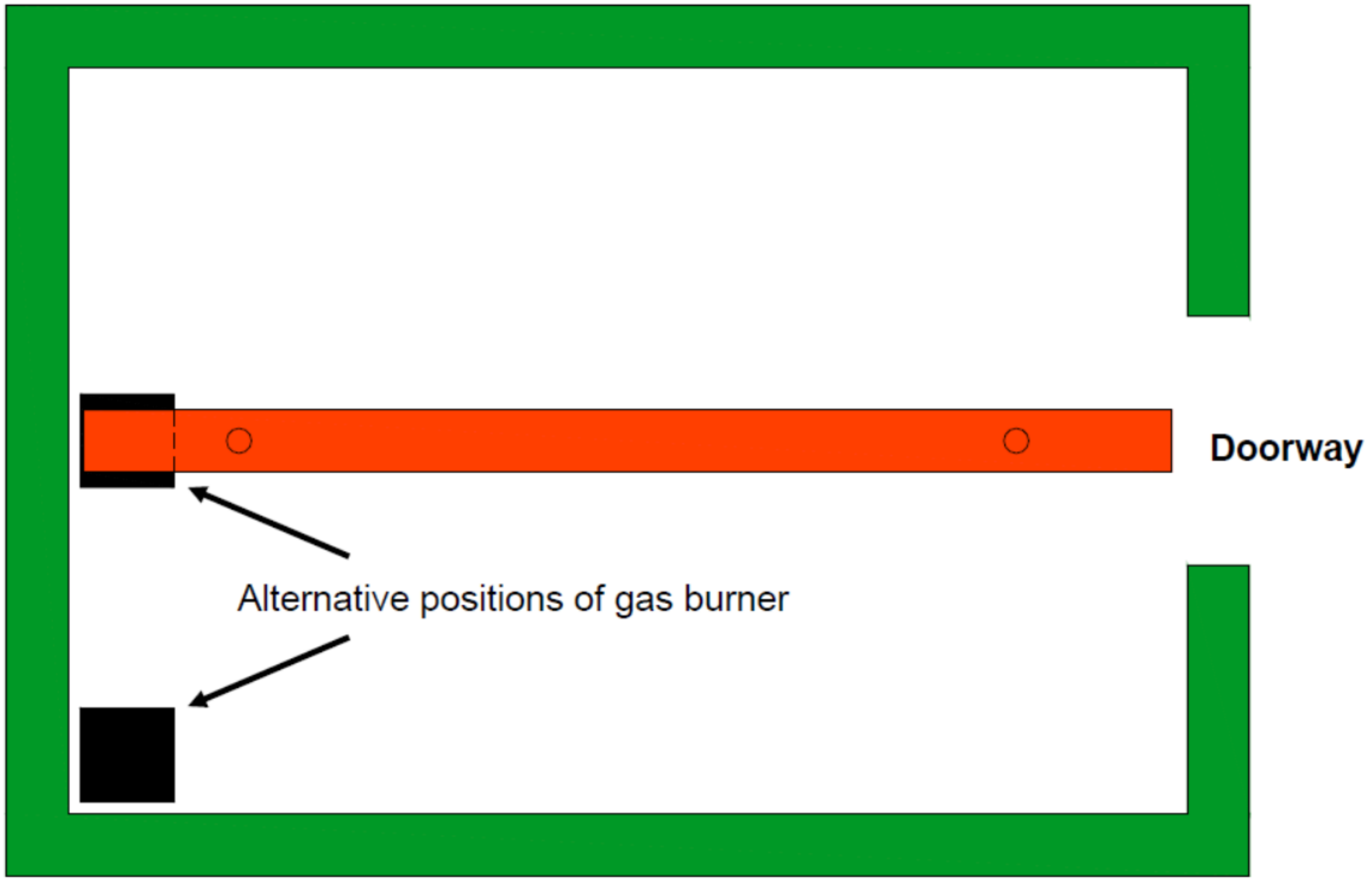
Application of PT

View



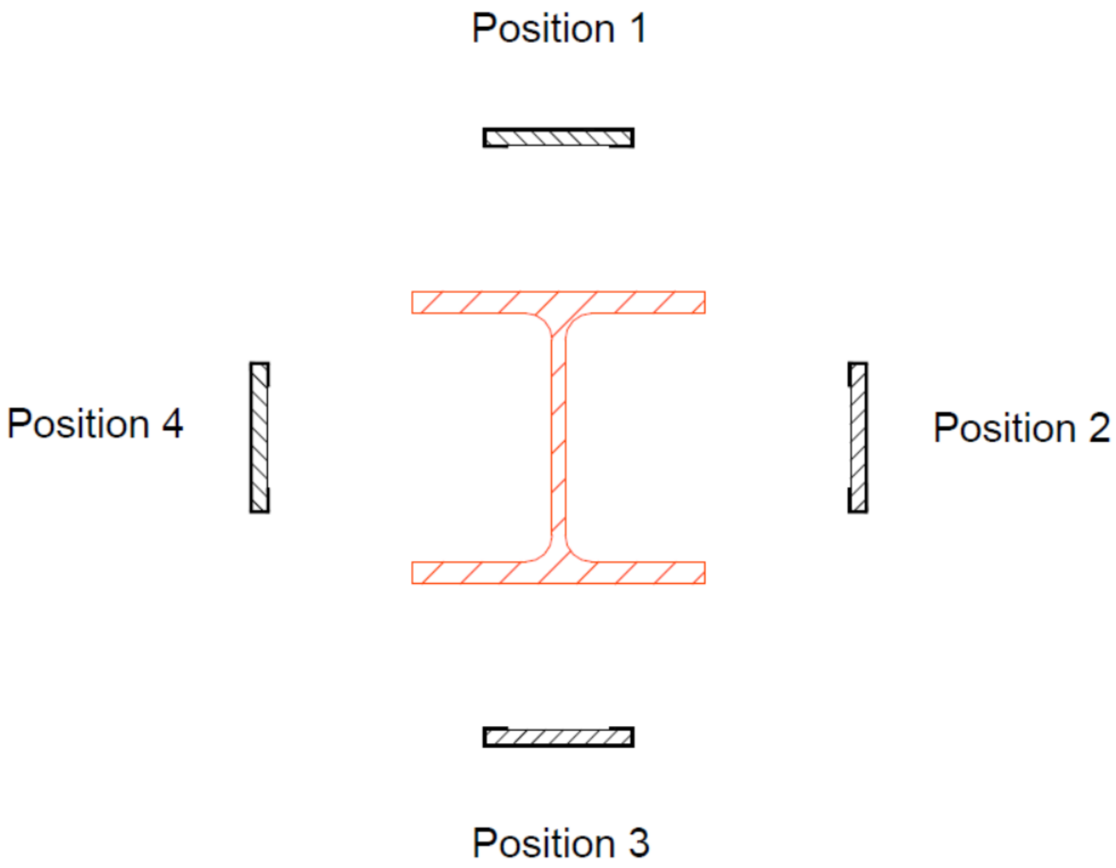
Application of PT

Floor plan



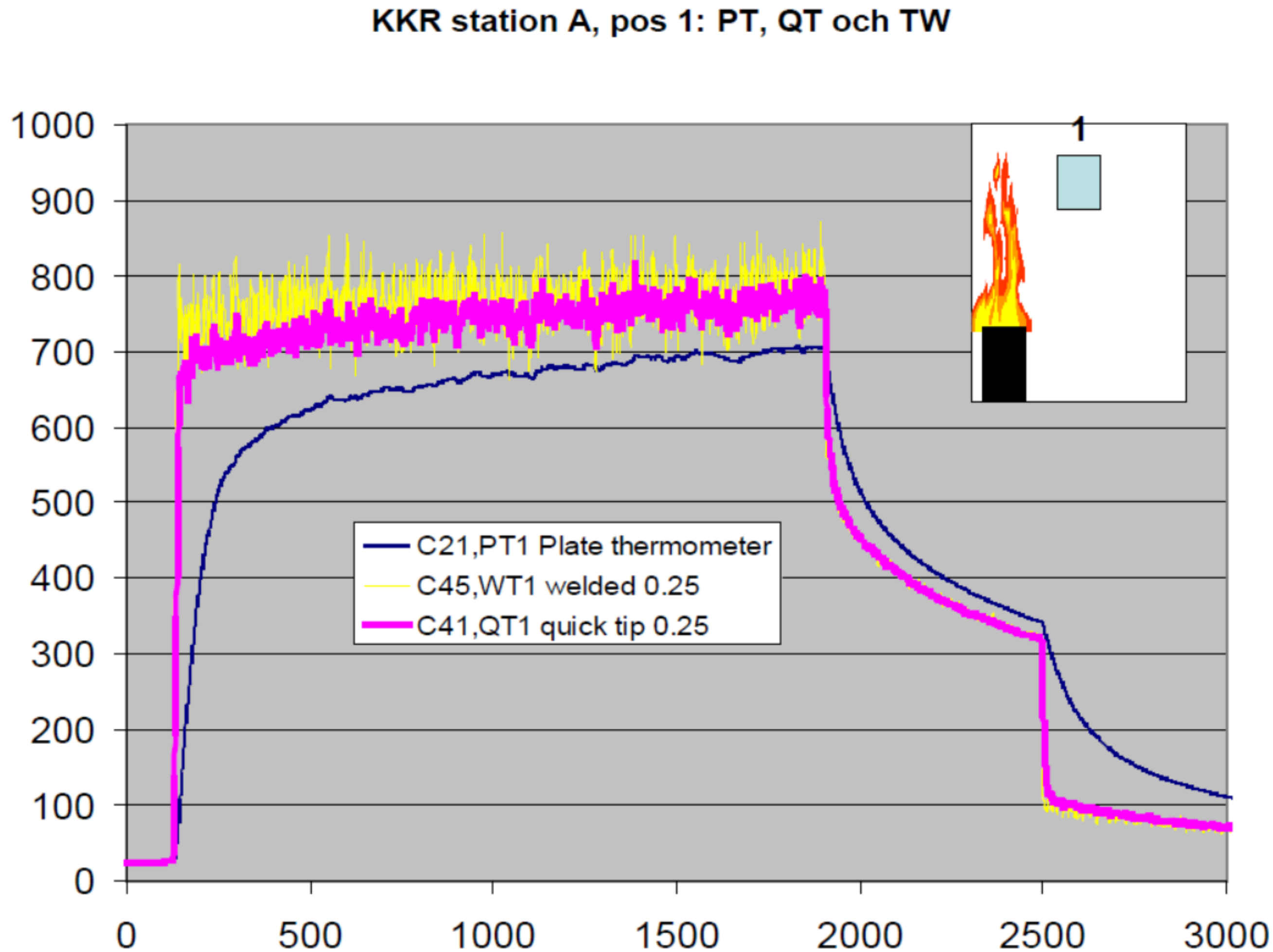
Application of PT

Positions of TP on the steel beam



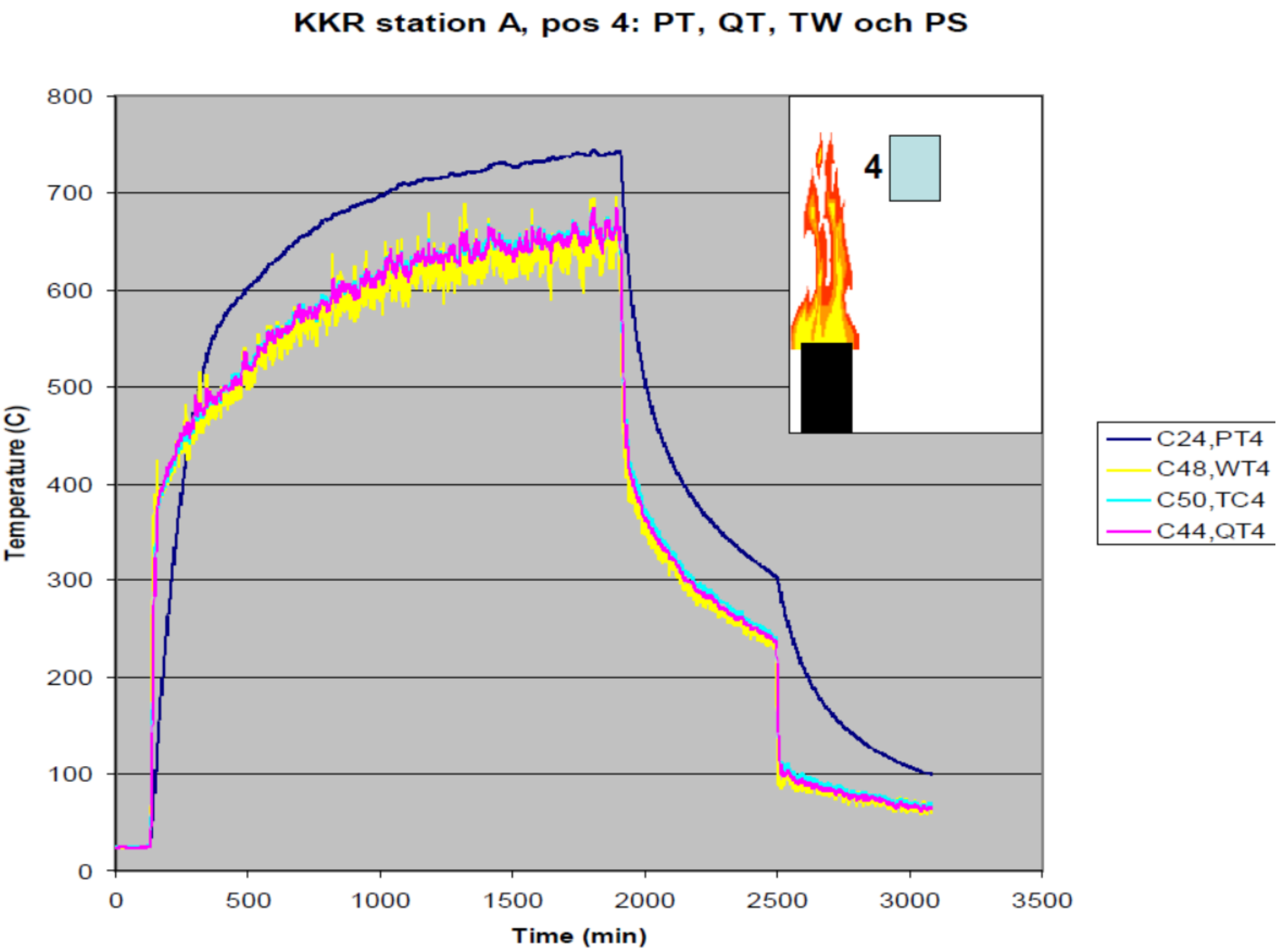
Application of PT

Beam temperature – upper side of the beam



Application of PT

Beam temperature – side exposed to the fire

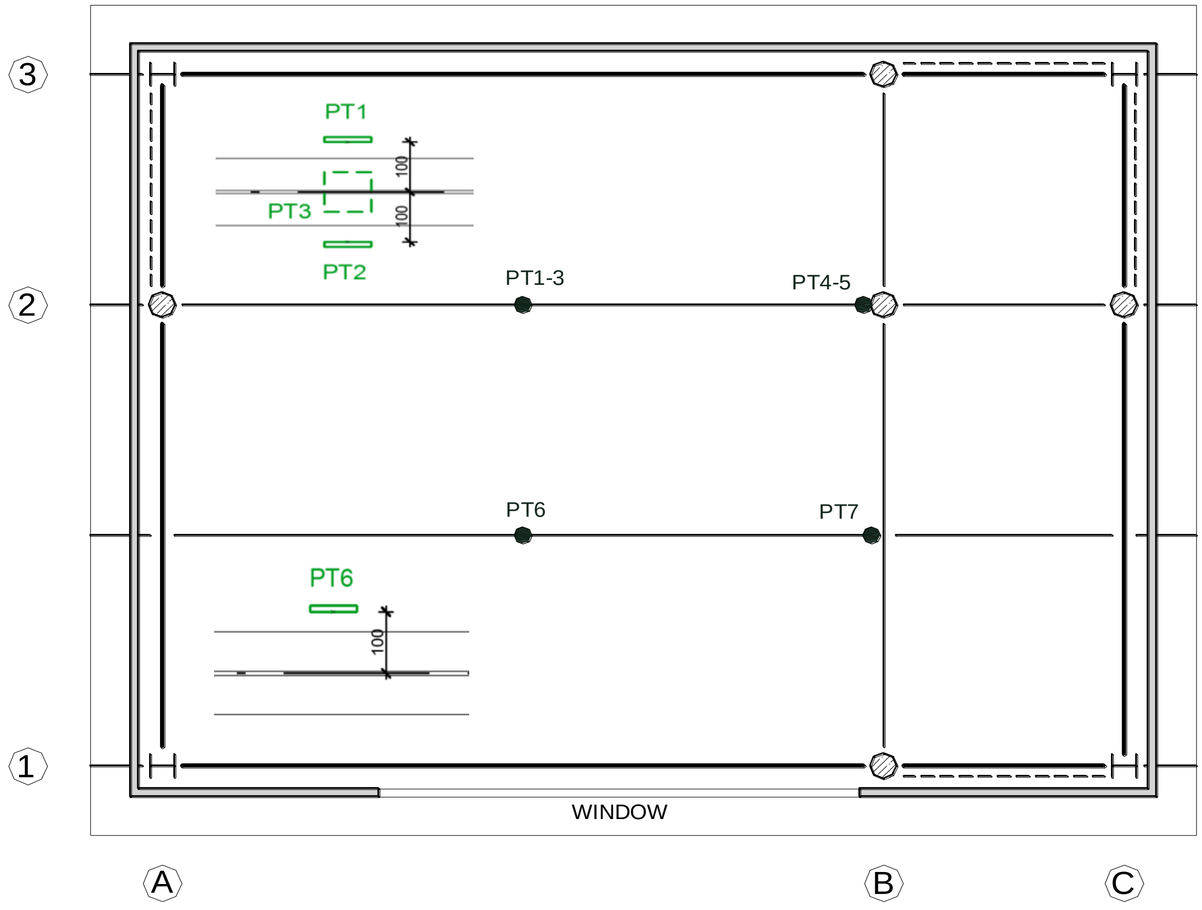


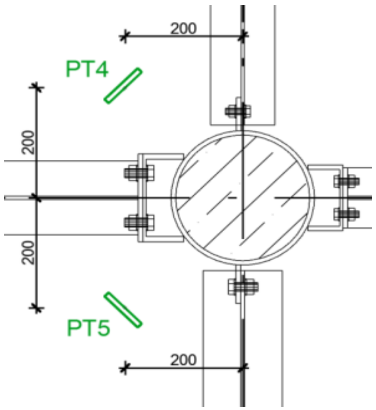
Application of PT

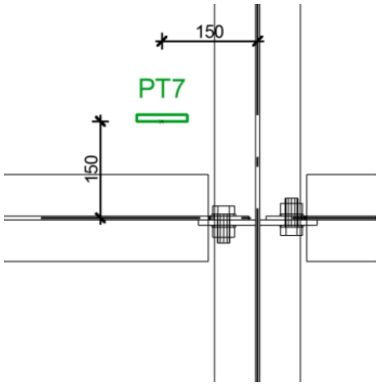
Fire test in Veselí n. L. 6.9.2011

Application of PT

Location of PT

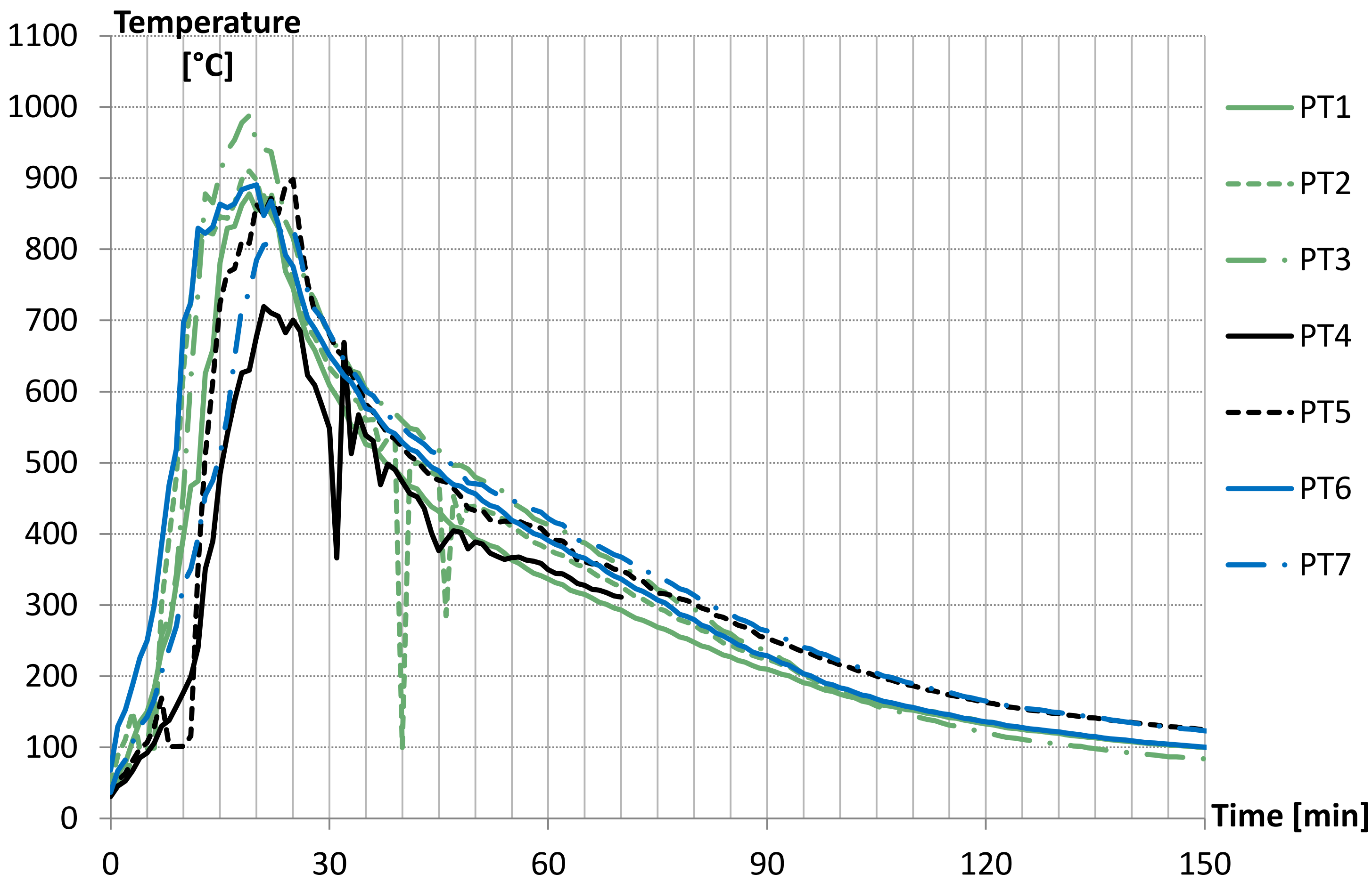






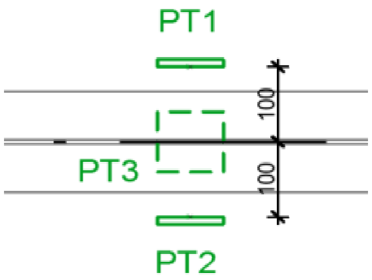
Application of PT

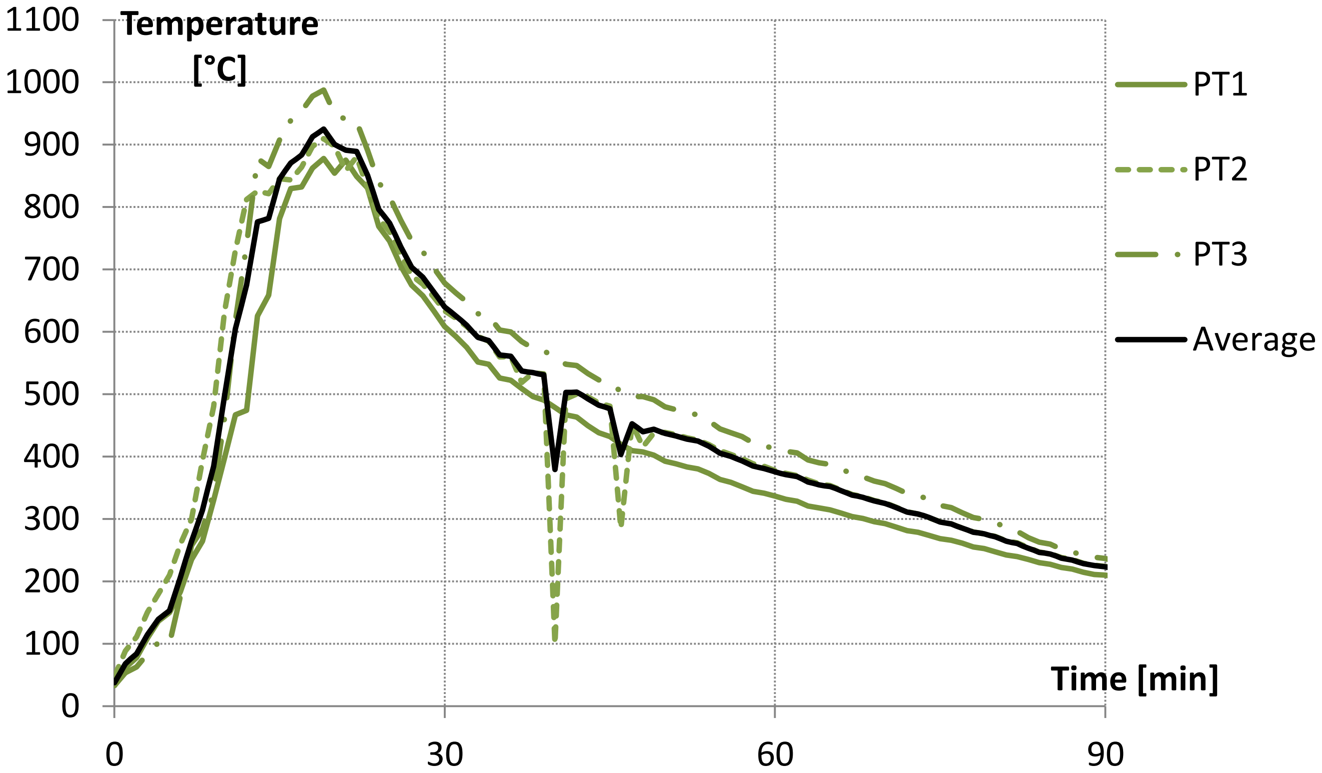
Measured temperature at all PT



Application of PT

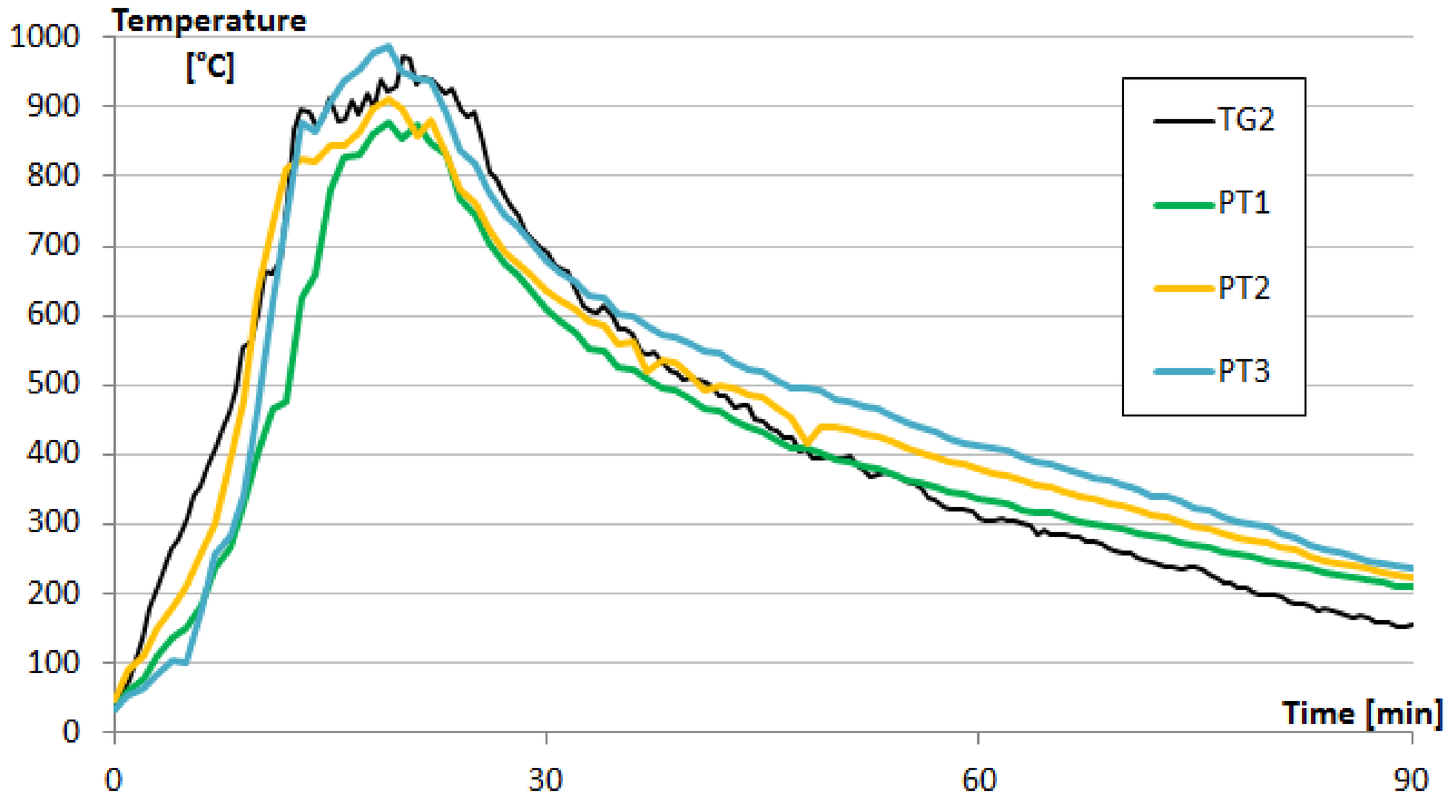
In the middle of the rear beam (farer from the ventilation opening)





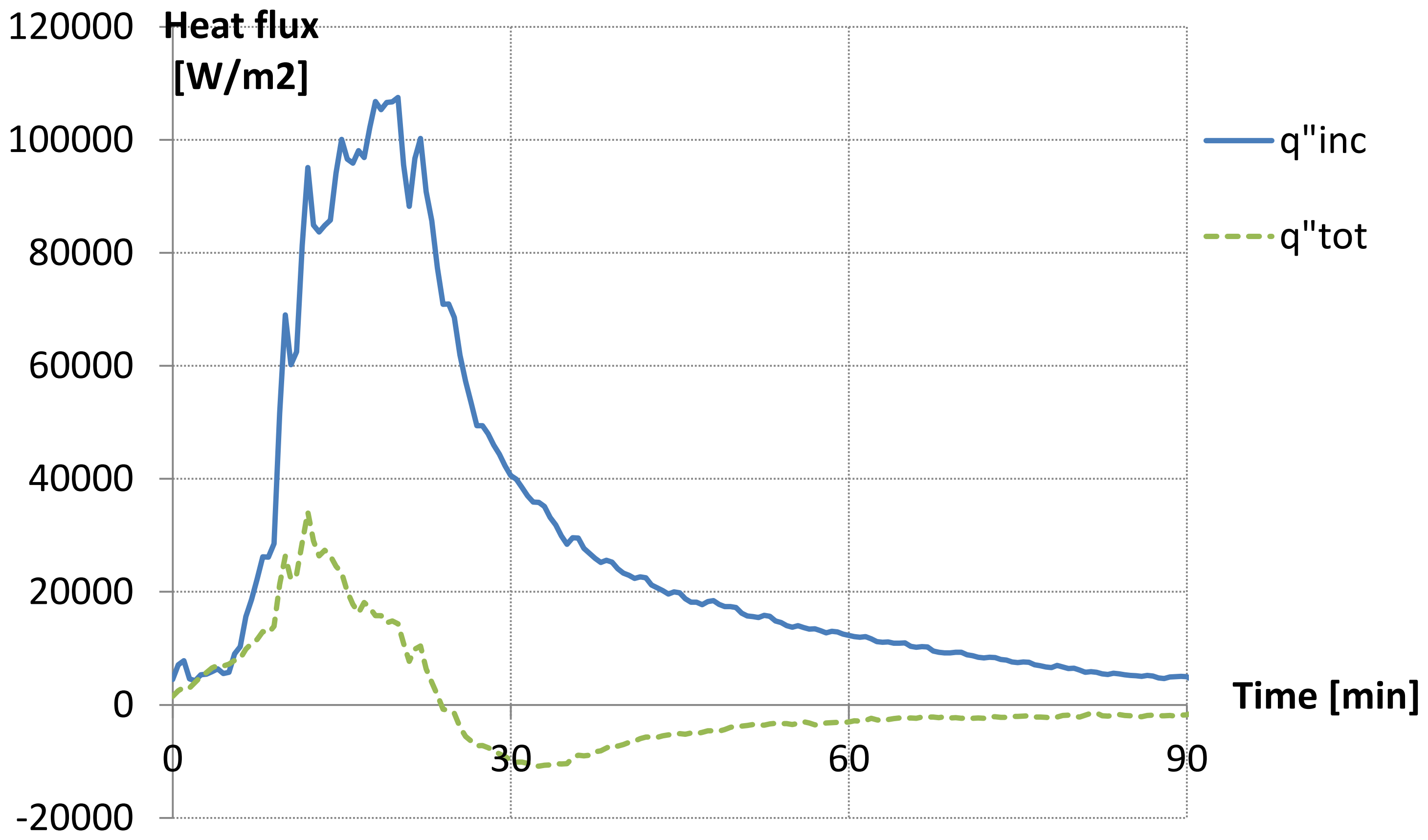
Application of PT

In the middle of the rear beam (farer from the ventilation opening)



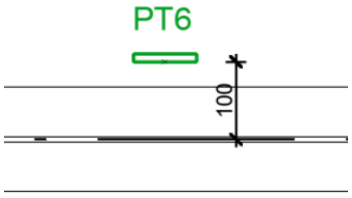
Application of PT

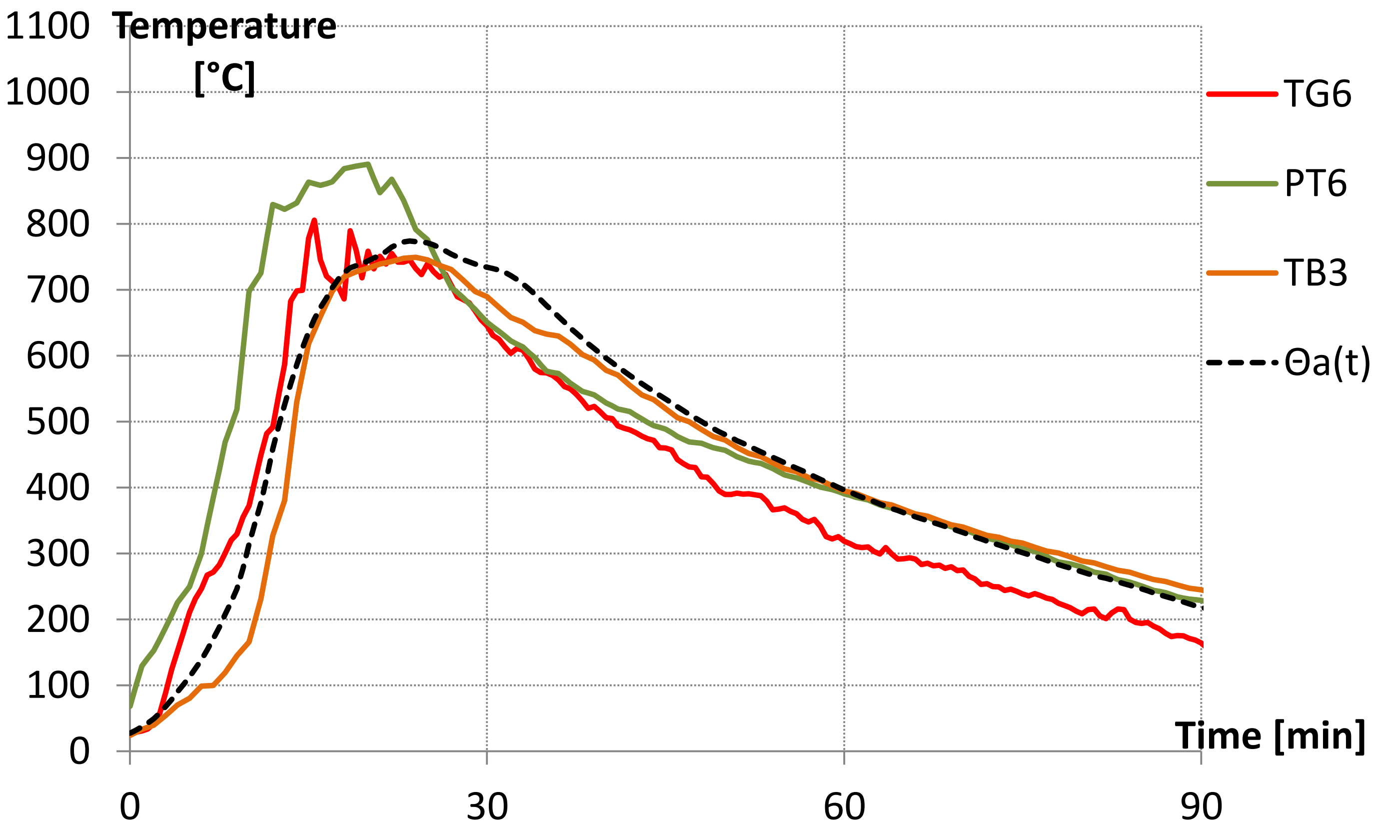
In the middle of the rear beam (farer from the ventilation opening)



Application of PT

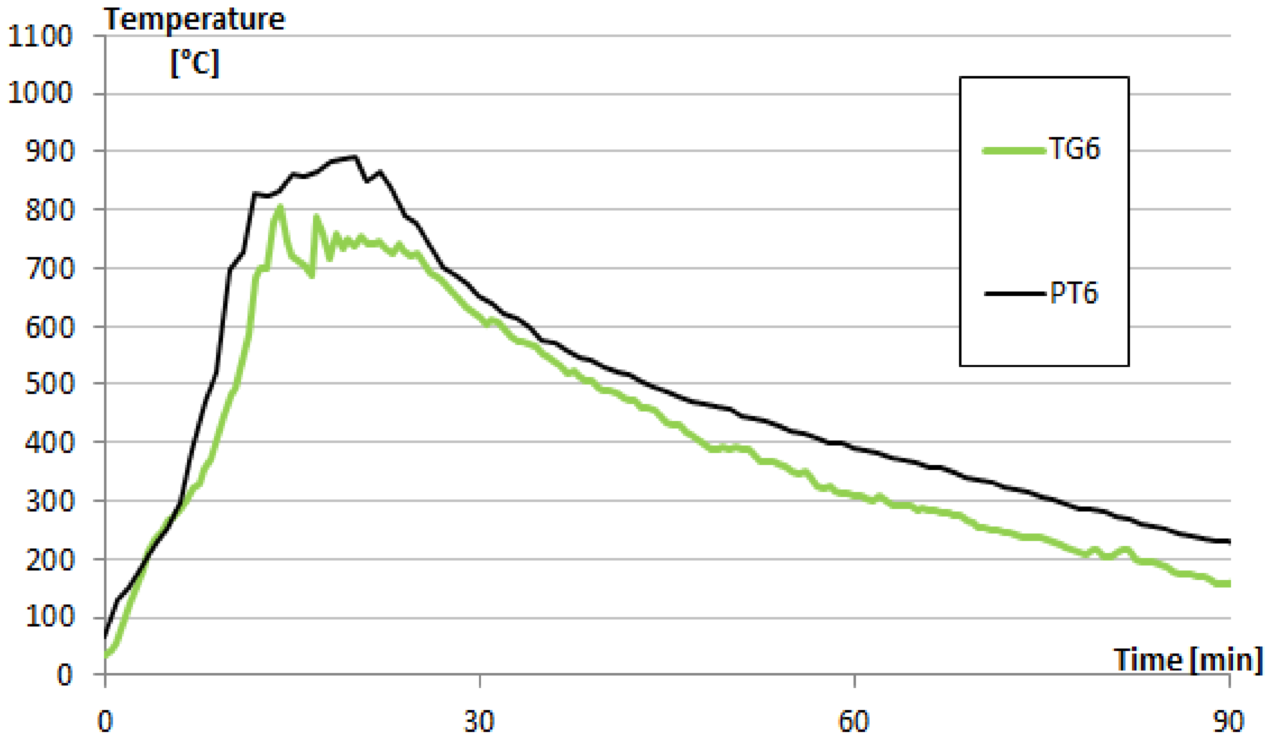
In the middle of the front beam (closer to the ventilation opening)





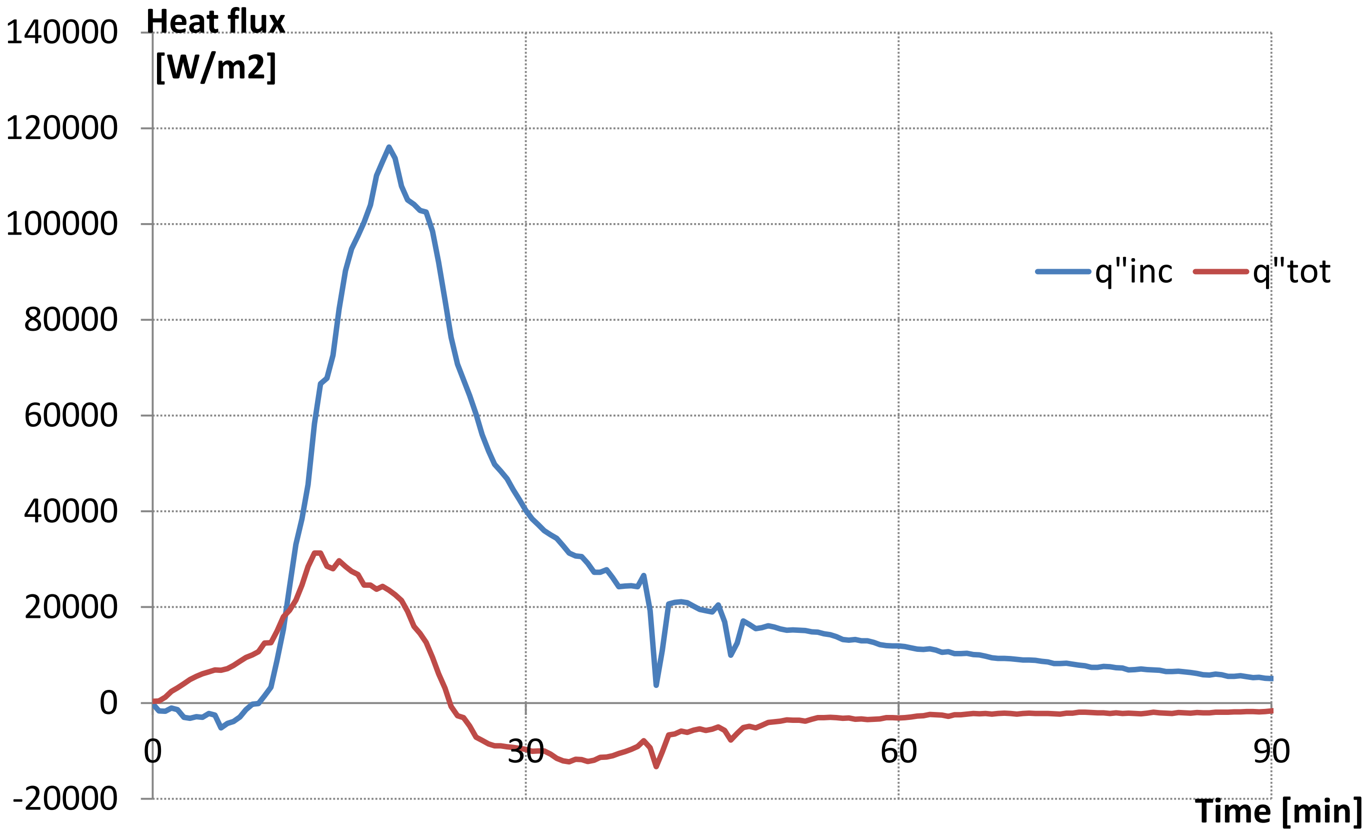
Application of PT

In the middle of the front beam (closer to the ventilation opening)



Application of PT

In the middle of the front beam (closer to the ventilation opening)



Experiment

Measurement of temperature by the aid of different temperature sensors

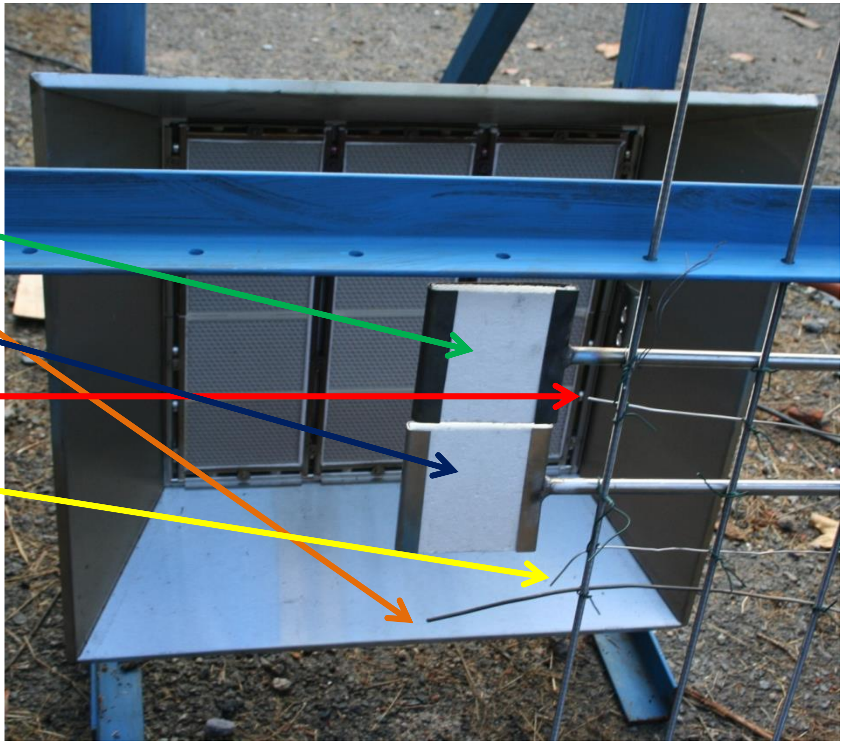
- 5 types of temperature sensors:
  - PT shiny
  - PT „aged“
  - coated TC diameter 3 mm
  - coated TC diameter 2 mm
  - coated TC diameter 1,5 mm

- Heating by radiant panel in outside the building

Experiment

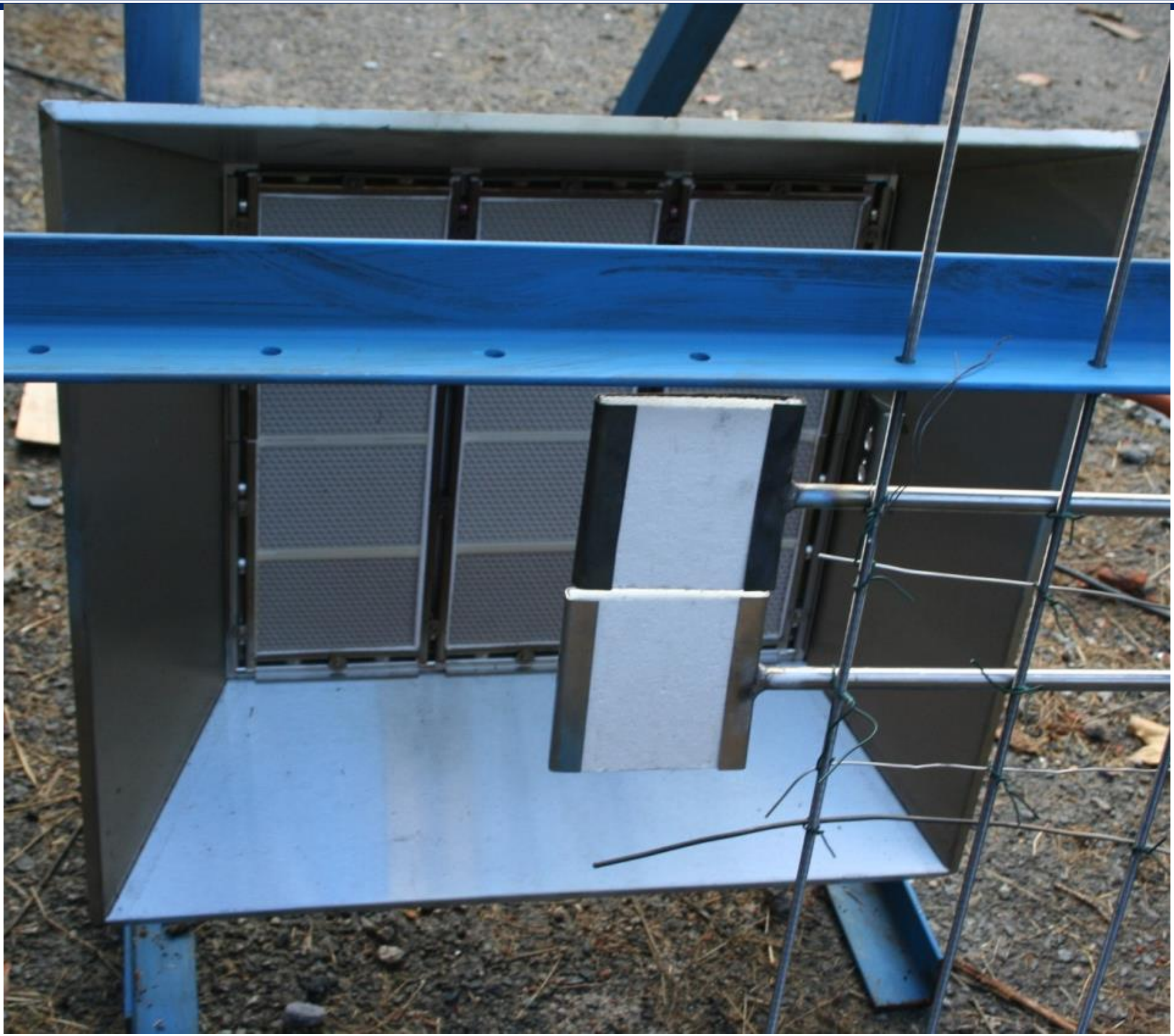
How the temperature development from all sensors will look like?

- PT „aged“
- PT shiny
- coated TC diam 3 mm
- coated TC diam 2 mm
- coated TC diam 1,5 mm

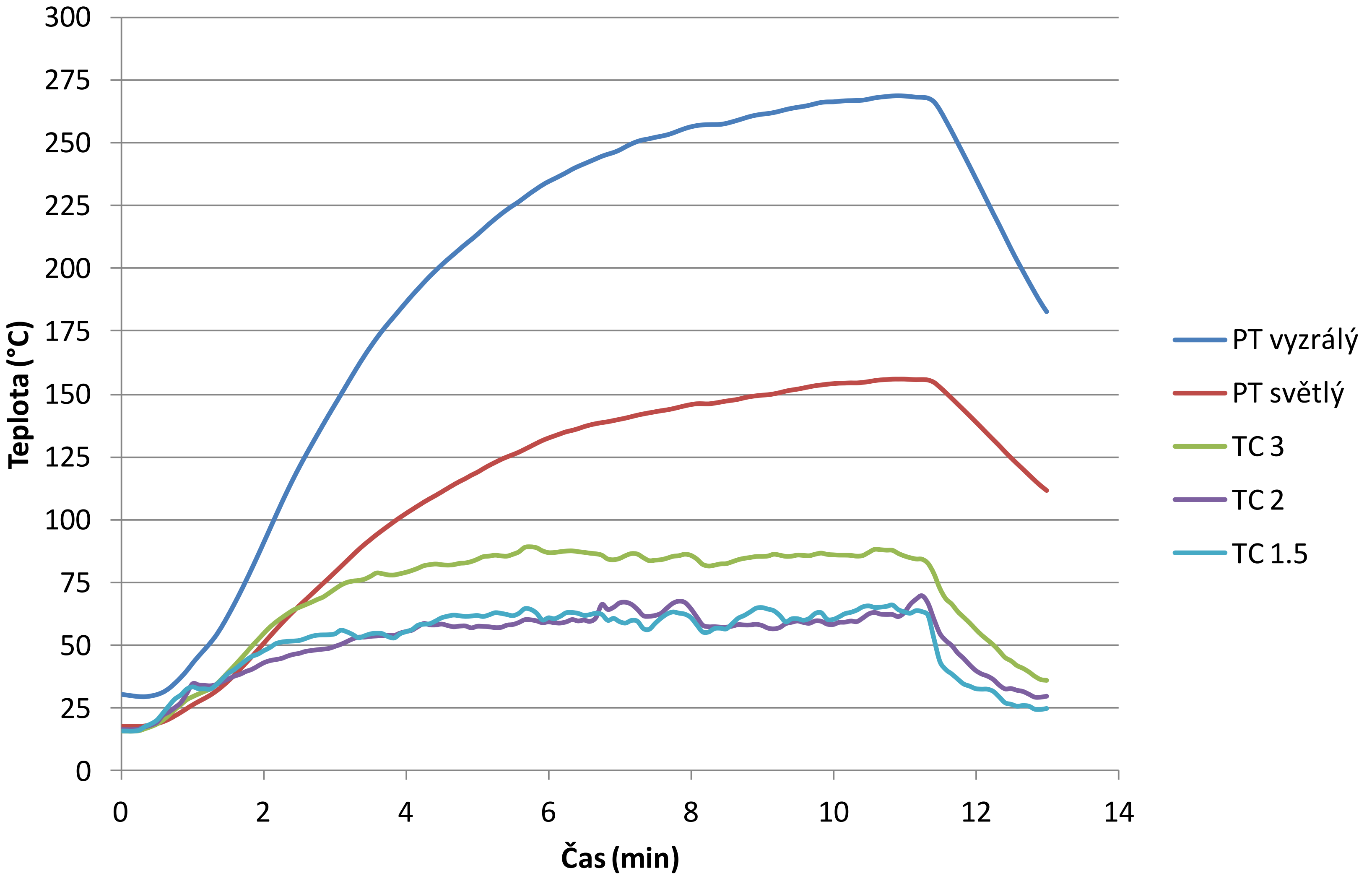


Why?

Experiment



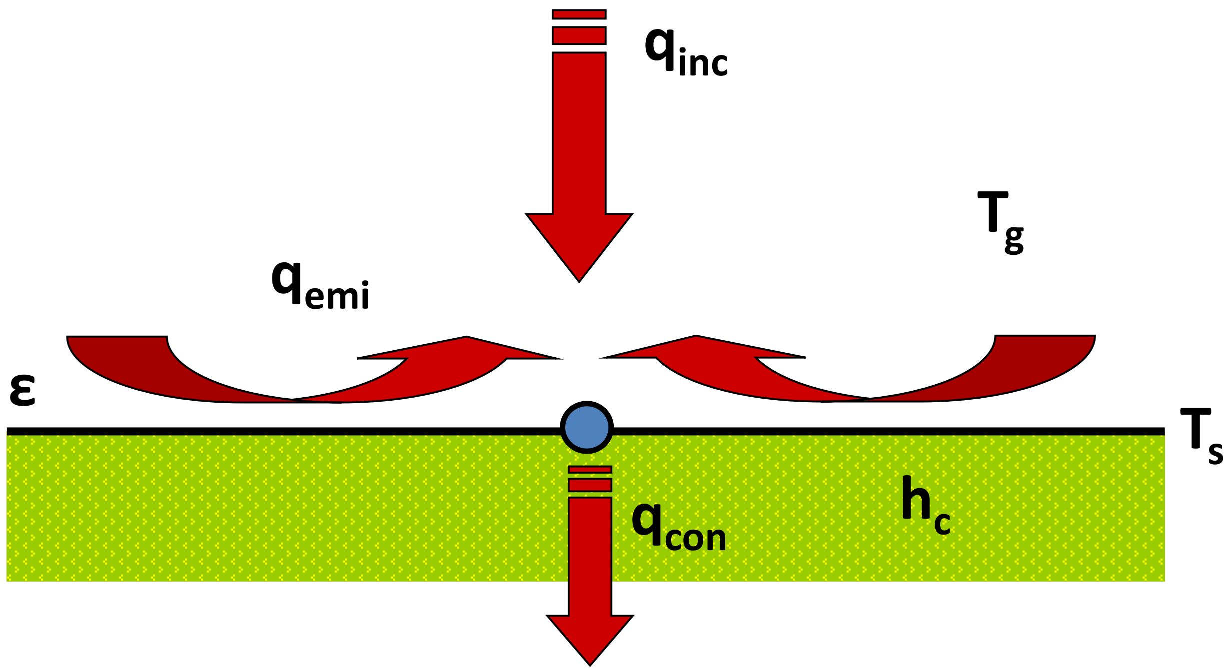
Experiment



Teplota (°C)
300
275
250
225
200
175
150
125
100
75
50
25
0
0
2
4
6
8
10
12
14
Čas (min)
PT vyzrálý
PT světlý
TC 3
TC 2
TC 1.5

How to calculate net heat flux?

Use of PT to measure heat flux



q_{inc}… incident (absolut) heat flux (W/m^2)

q_{emi}… emitted heat flux (W/m^2)

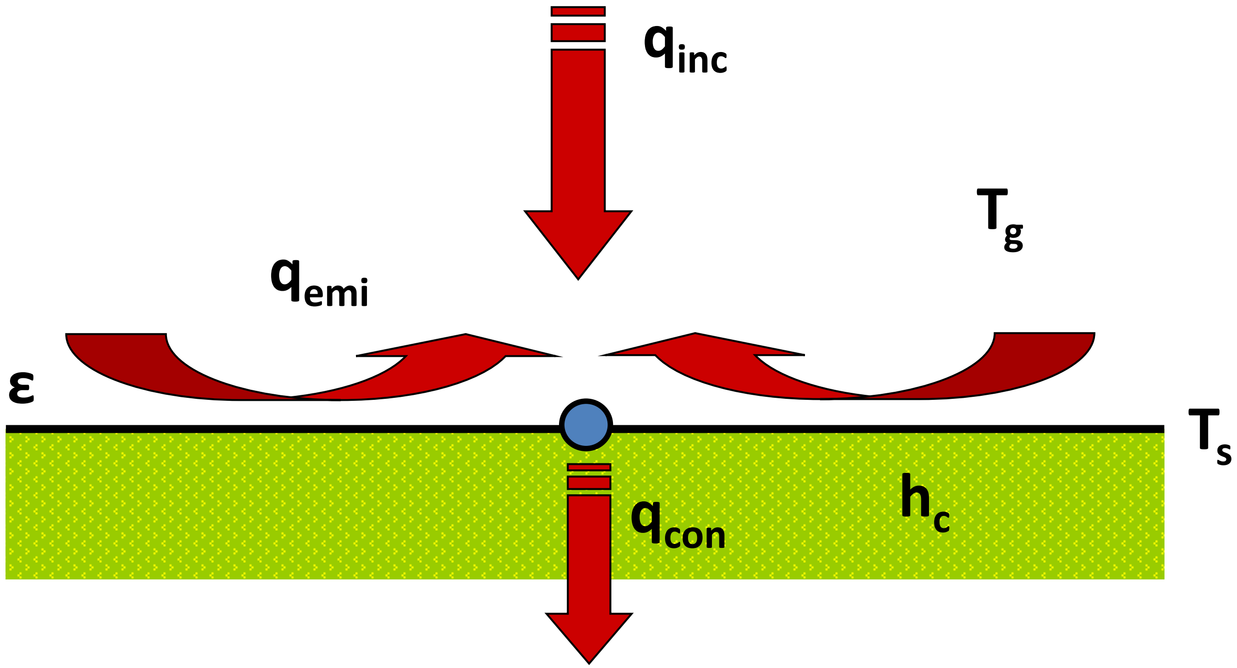
$q_0 = q_{tot}$ … net heat flux (W/m^2)

How to calculate net heat flux?

Use of PT to measure heat flux

Equilibrum on a surface

$$\dot{q}_0'' = \varepsilon\left(\dot{q}_{inc}'' - \sigma T_s^4\right) + h_c\left(T_g - T_s\right)$$



How to calculate net heat flux?

Use of PT to measure heat flux

Equilibrum on a surface:

$$\dot{q}_0'' = \varepsilon\left(\dot{q}_{inc}'' - \sigma T_s^4\right) + h_c\left(T_g - T_s\right)$$

$$\dot{q}_{inc}'' \equiv \sigma\, T_r^4$$

$$\dot{q}_0'' = \varepsilon\sigma\left(T_r^4 - T_s^4\right) + h_c\left(T_g - T_s\right)$$

Equilibrum on surface of PT:

$$\dot{q}_0'' = \varepsilon\dot{q}_{inc}'' - \varepsilon\sigma T_{PT}^4 + h_c\left(T_g - T_{PT}\right)\ \left[w/m^2\right]$$

How to calculate net heat flux?

Use of PT to measure heat flux

Structure of PT is an perfect insulator, it does not absorb any heat flux:

$$\dot{q}_0'' = \varepsilon \dot{q}_{inc}'' - \varepsilon\sigma T_{PT}^4 + h_c\left(T_g - T_{PT}\right) = 0 \quad [w/m^2]$$

Calculate incident heat flux from the formulae

For surface of PT we can use:

ε_{pt}= 0.9 (aged PT)

h_{pt}=10 W/m^{2}K

K_{pt}=8.0 W/m^{2}K

h_c = 18 W/m^{2}K … includes conduction into insulation and thin sheet

How to calculate net heat flux?

Use of PT to measure heat flux

Calculation of net heat flux:

$$\dot{q}_0^{"} = \varepsilon\sigma\left(T_{AST}^4 - T_S^4\right) + \alpha_c(T_{AST} - T_s) \ [w/m^2]$$

For surface of PT we can use:

$$(+) \quad \dot{q}''_{tot} = \varepsilon\sigma(T_r^4 - T_s^4) + h(T_g - T_s) \quad \text{(heat transfer)}$$

$$(-) \quad 0 = \varepsilon\sigma(T_r^4 - T_{AST}^4) + h(T_g - T_{AST}) \quad \text{(def. AST)}$$

$$\dot{q}''_{tot} = \varepsilon\sigma(T_{AST}^4 - T_s^4) + h(T_{AST} - T_s)$$

ε_{pt}= 0.9 (aged PT)

h_{pt}=10 W/m^{2}K

K_{pt}=8.0 W/m^{2}K

h_c = 18 W/m^{2}K … includes conduction into insulation and thin sheet

References

- Ulf, Wickström, Temperature calculation in fire safety engineering, Lulea, Sweden, 2016, ISBN 978-3-319-30172-3.
- Ulf, Wickström, Heat transfer in fire technology, Draft document for the EGOLF course on fire science, 2012.
- ČSN EN 1363-1. Zkoušení požární odolnosti - Část 1: Základní požadavky. Praha : ÚNMZ, Leden 2013.
- ČSN EN 1363-2. Zkoušení požární odolnosti - Část 2: Alternativní a doplňkové postupy. Praha : ÚNMZ, Únor 2000.
- ČSN P ENV 1363-3. Zkoušení požární odolnosti - Část 3: Ověřování charakteristik pecí. Praha : ÚNMZ, Listopad 1999.
- ČSN EN 60 584-1. Termoelektrické články - Část 1: Údaje napětí a tolerance. Praha : ÚNMZ, Květen 2013.

Thank you for your attention!

kamila.cabova@fsv.cvut.cz