FULL-SCALE FIRE TESTING

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Structural fire design

Metods to define fire resistance of structures

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

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Metods to define fire resistance of structures

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Experiments

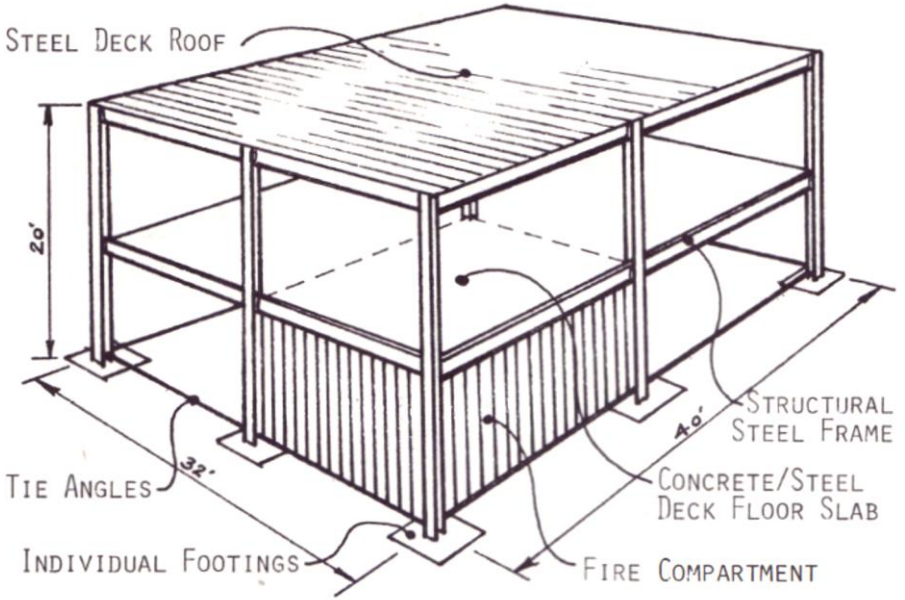
- Material testing at elevated temperature
- Testing of structures
  - Standard fire testing = fire resistance testing
  - Small-scale testing of structures
  - Full-scale testing of structures

Full-scale fire testing

About 1980 a full-scale fire testing begins

1982, NIST, USA

Steel-concrete composite structure



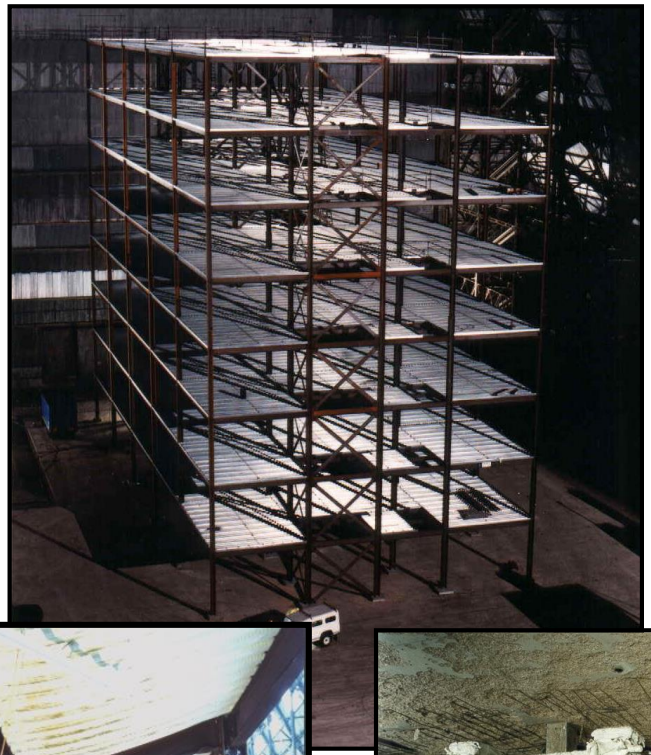
In presence about **25+** full-scale, non-standard fire tests in the literature

- Steel-concrete composite structure (≈ 20)
- Concrete (≈ 5)
- Timber (1?)

Full-scale fire testing

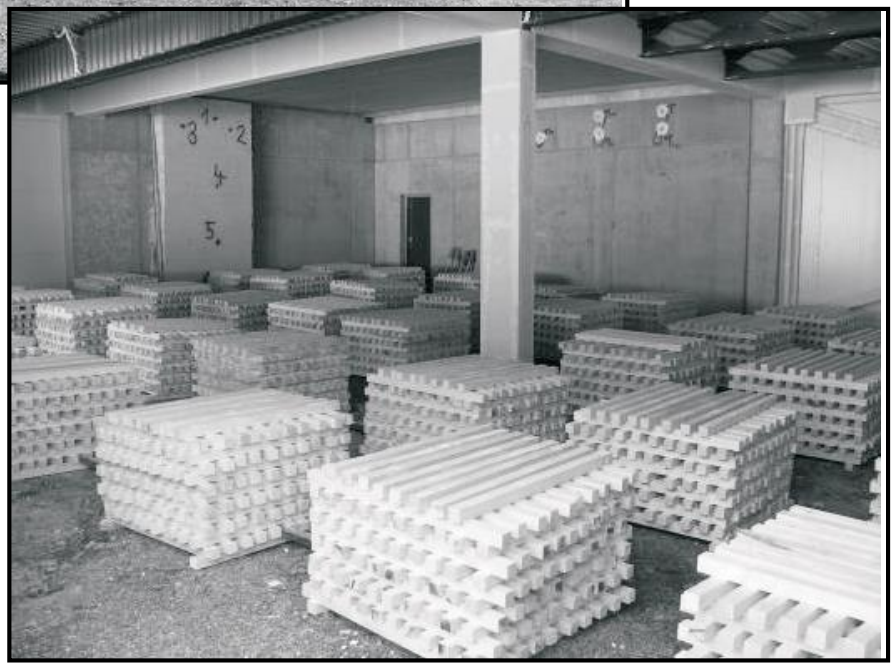
- Cardington

1995-2003



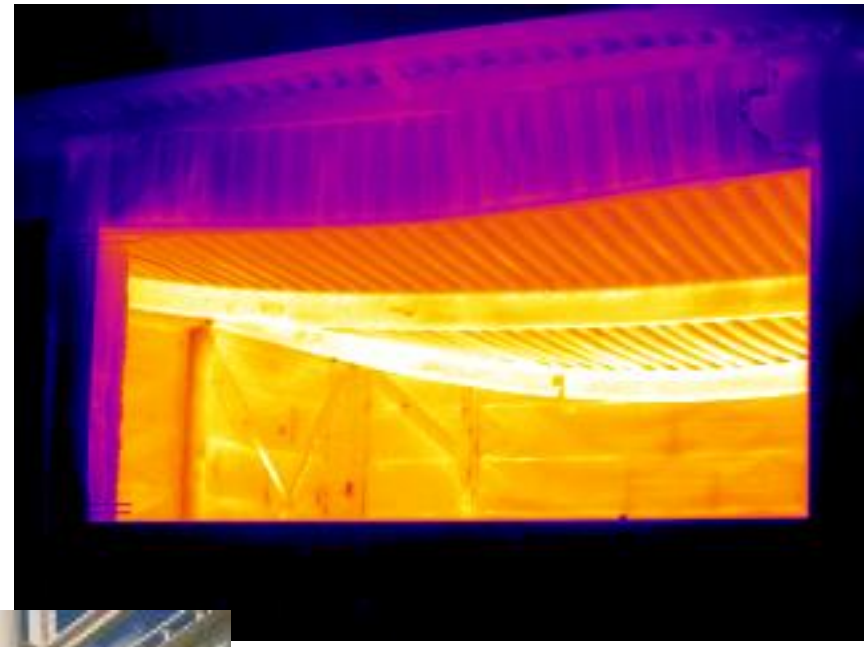
Full-scale fire testing

- Mokrsko, 2008



Full-scale fire testing

- Veselí n. L., 2011



Cardington

- 8-floor composite steel-concrete building
- Fire tests between 1995 – 2003
  - Fire test organized by CTU in 2003

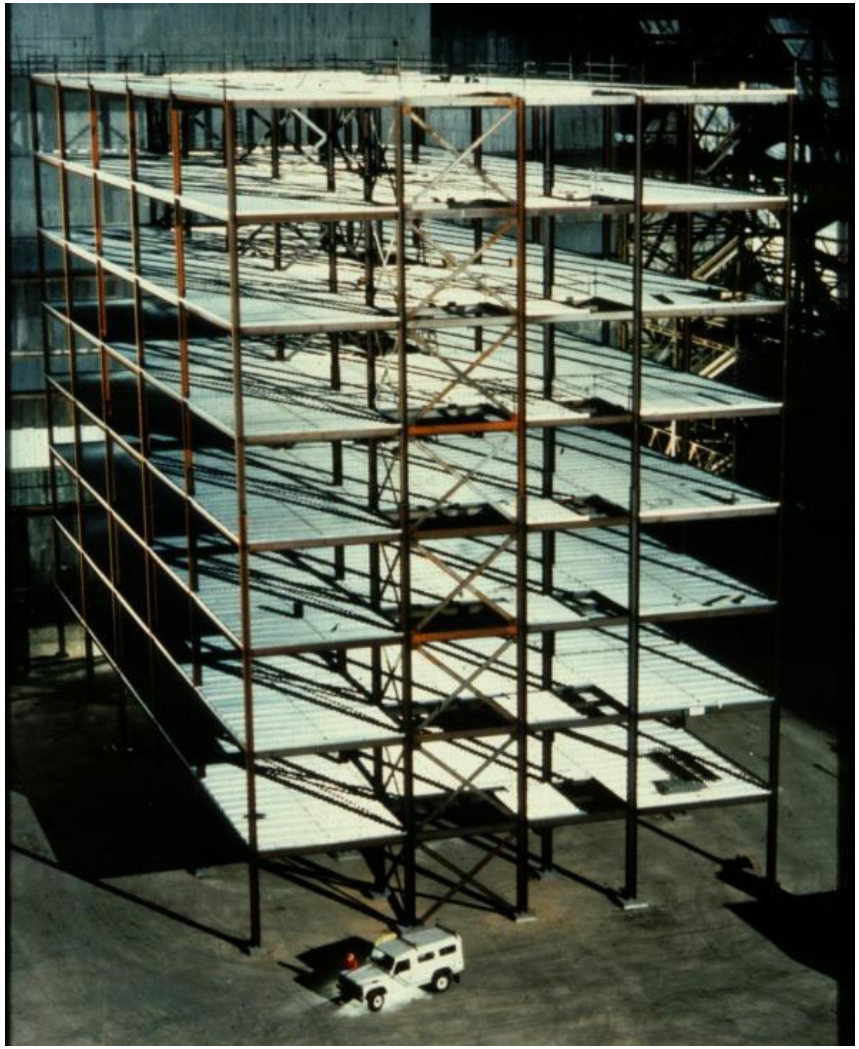
CTU test in Cardington.

Cardington

The main building parameters

- Length - 42 m, 5 spans of 9 m
- Width - 21 m, 3 spans - 6 m, 9 m and 6 m
- Floor hight – 4,2 m
- Cross-sections - imperial beams UB, columns UC
- Steel-concrete composite floor – light concrete of 130 mm in trapezoidal sheet
- Area of reinforcement of the slab of 142 mm^2
- Connections
  - secondary beam to primary beam – thin plate
  - primary/secondary beam to column – end-plate
- Mechanical load – bags with sand

Cardington



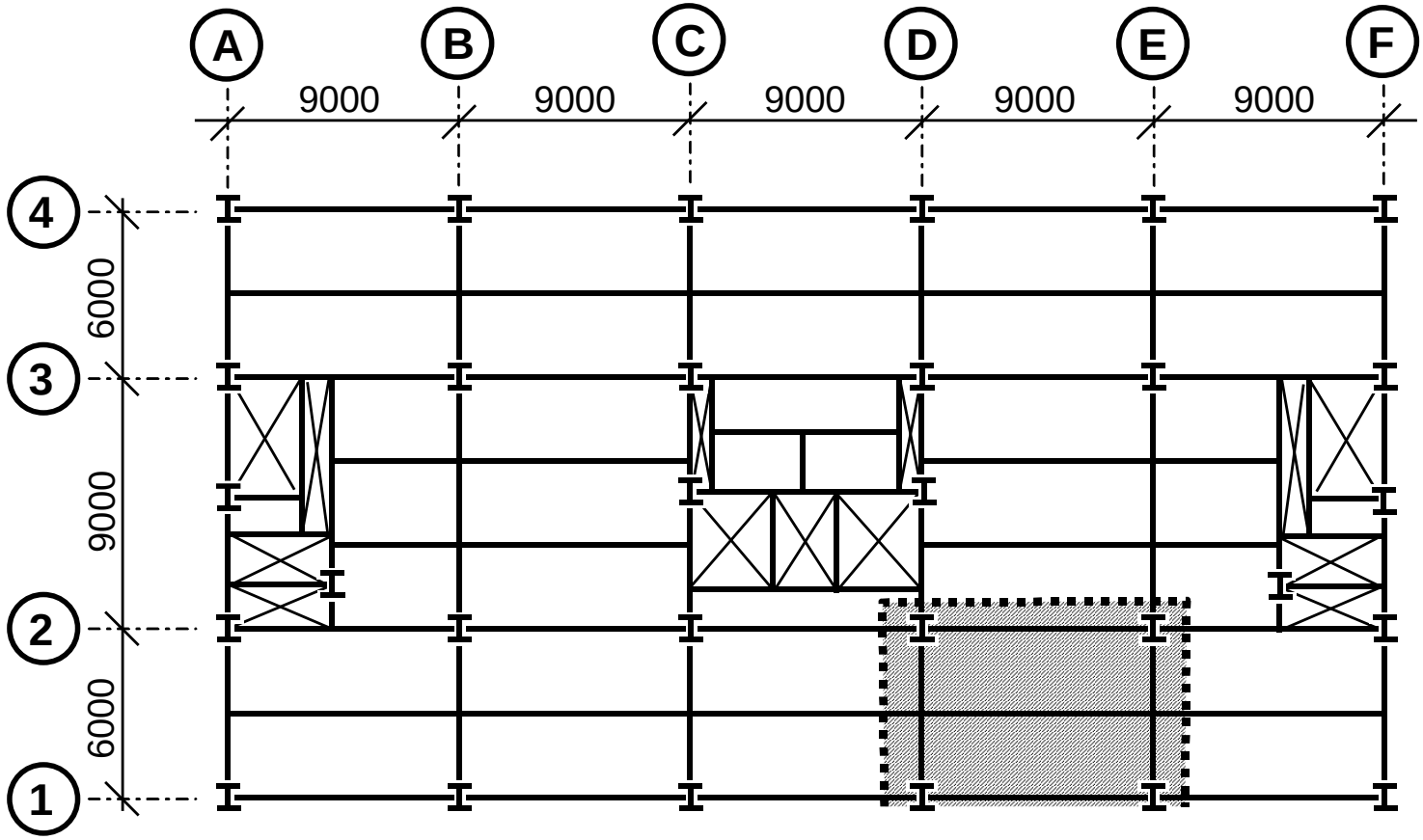
Beam-to-beam connection

Beam-to-column connection

Cardington

Fire test of CTU

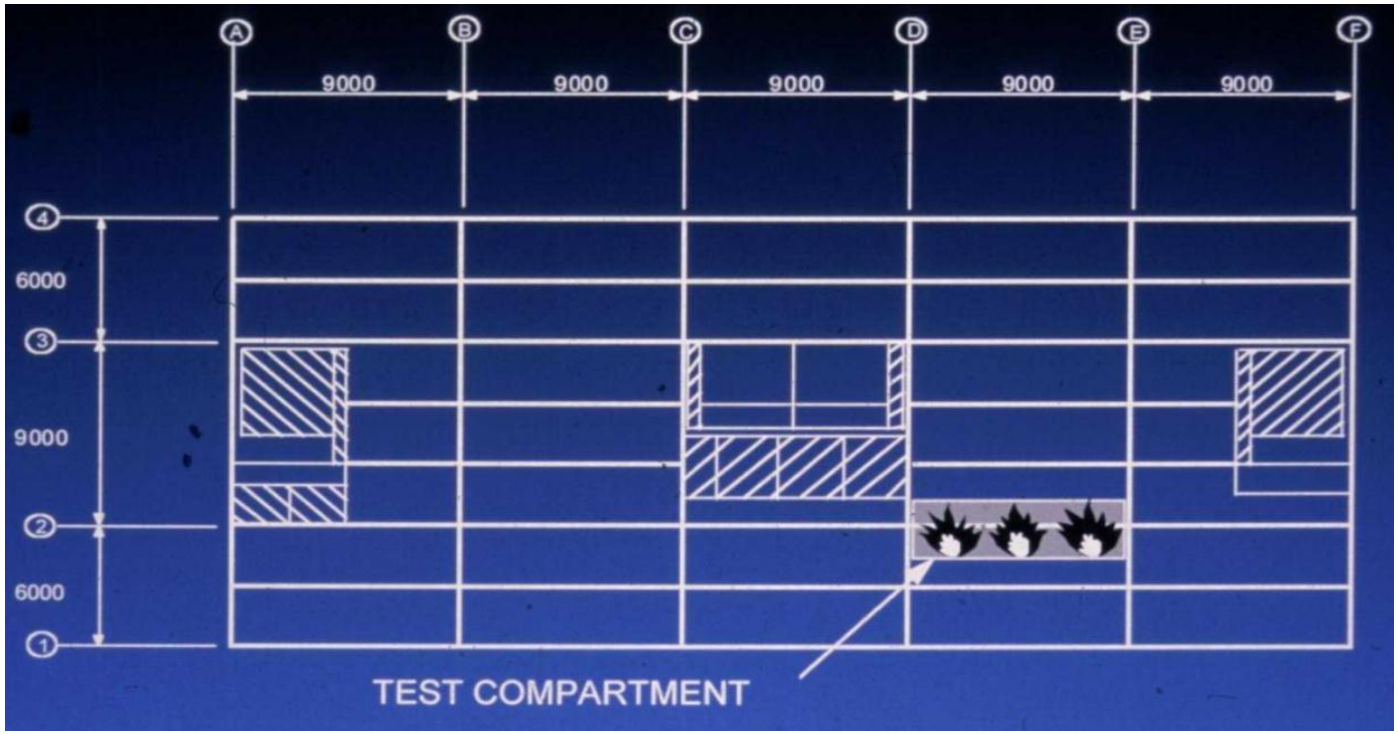
- Fire compartment



Cardington

Beam in the compartment

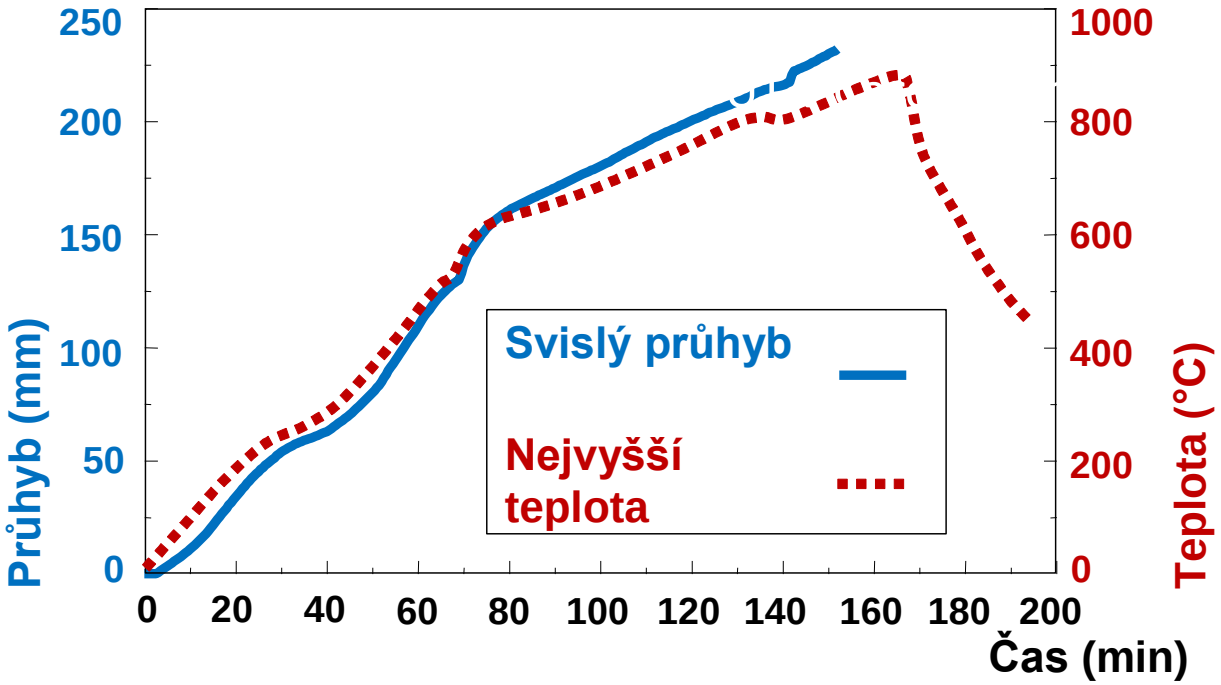
- Length 9,0 m
- Heating by gas burners according to standard temperature time curve



Cardington

Beam in the compartment

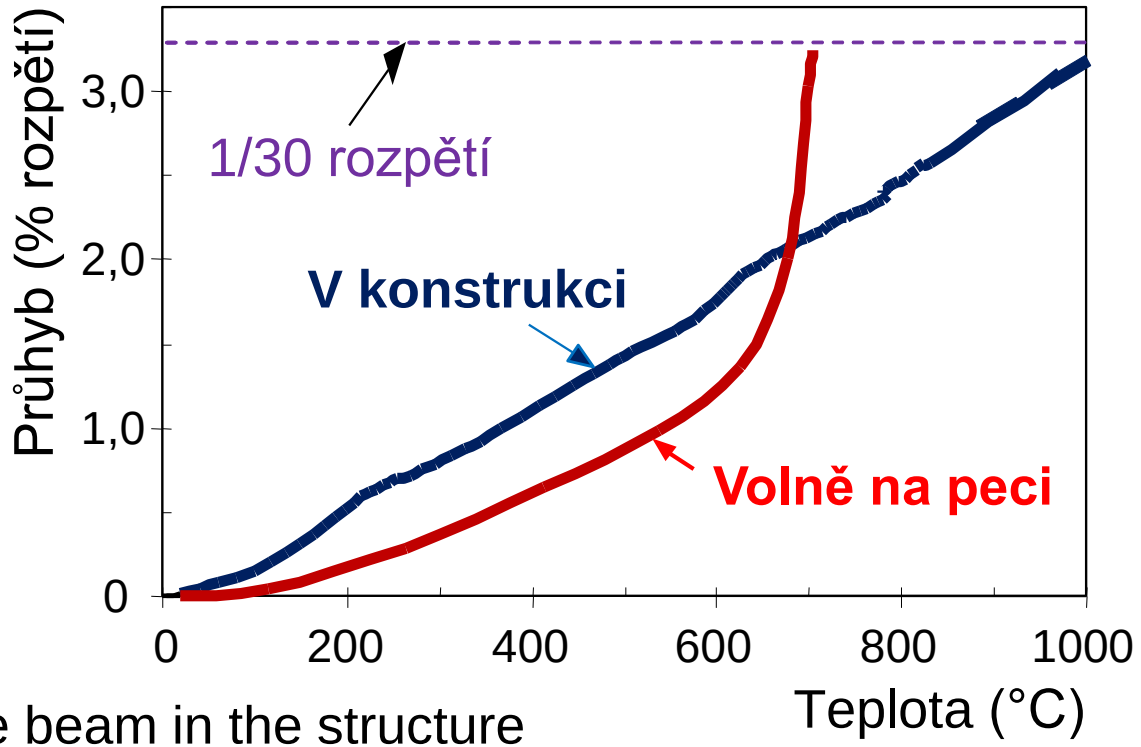
- Results
  - Max. temperature 900 °C
  - Beam deflection < 250 mm



Cardington

Beam in the compartment

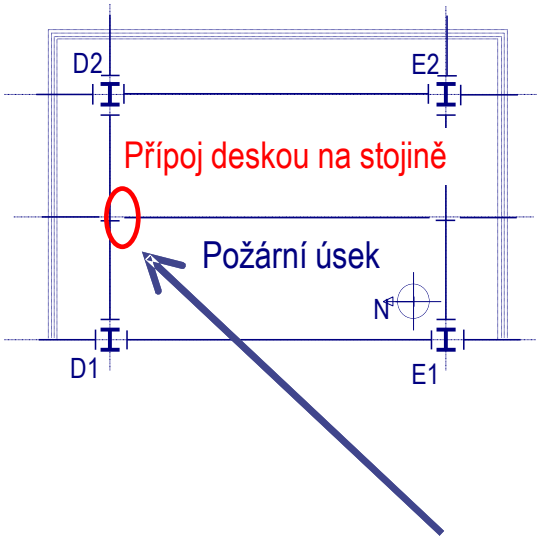
• Comparison of the beam deflection in the structure and deflection of a the beam tested on the horizontal furnace

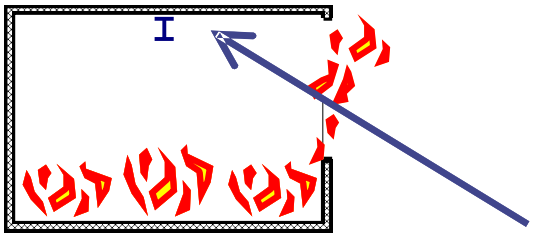


– No failure of the beam in the structure
– Failure of the beam on the furnace at $\theta \approx 650$ °C

Cardington

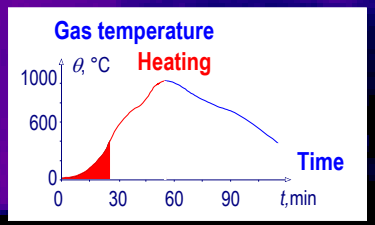
Beam-to-beam connection in the compartment

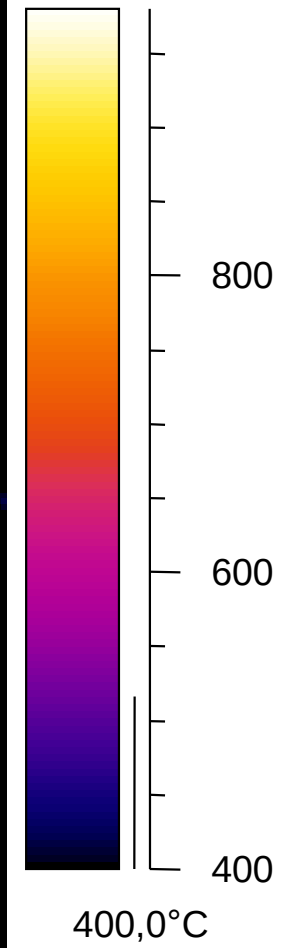




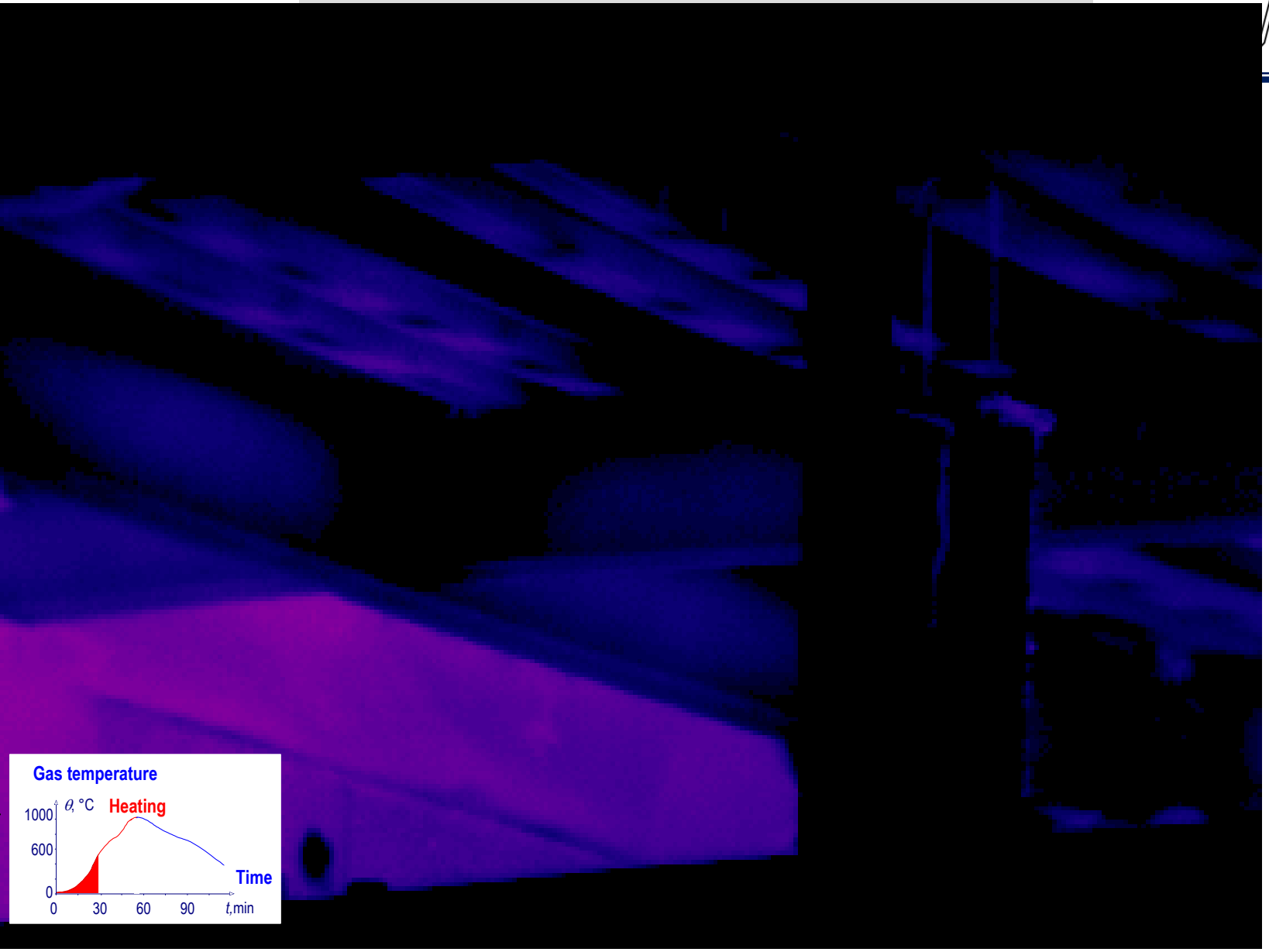
t = 26 min. $\theta_{con,ø}$ = 275 °C

In 26 min of fire temperature of the structure is below 400°C



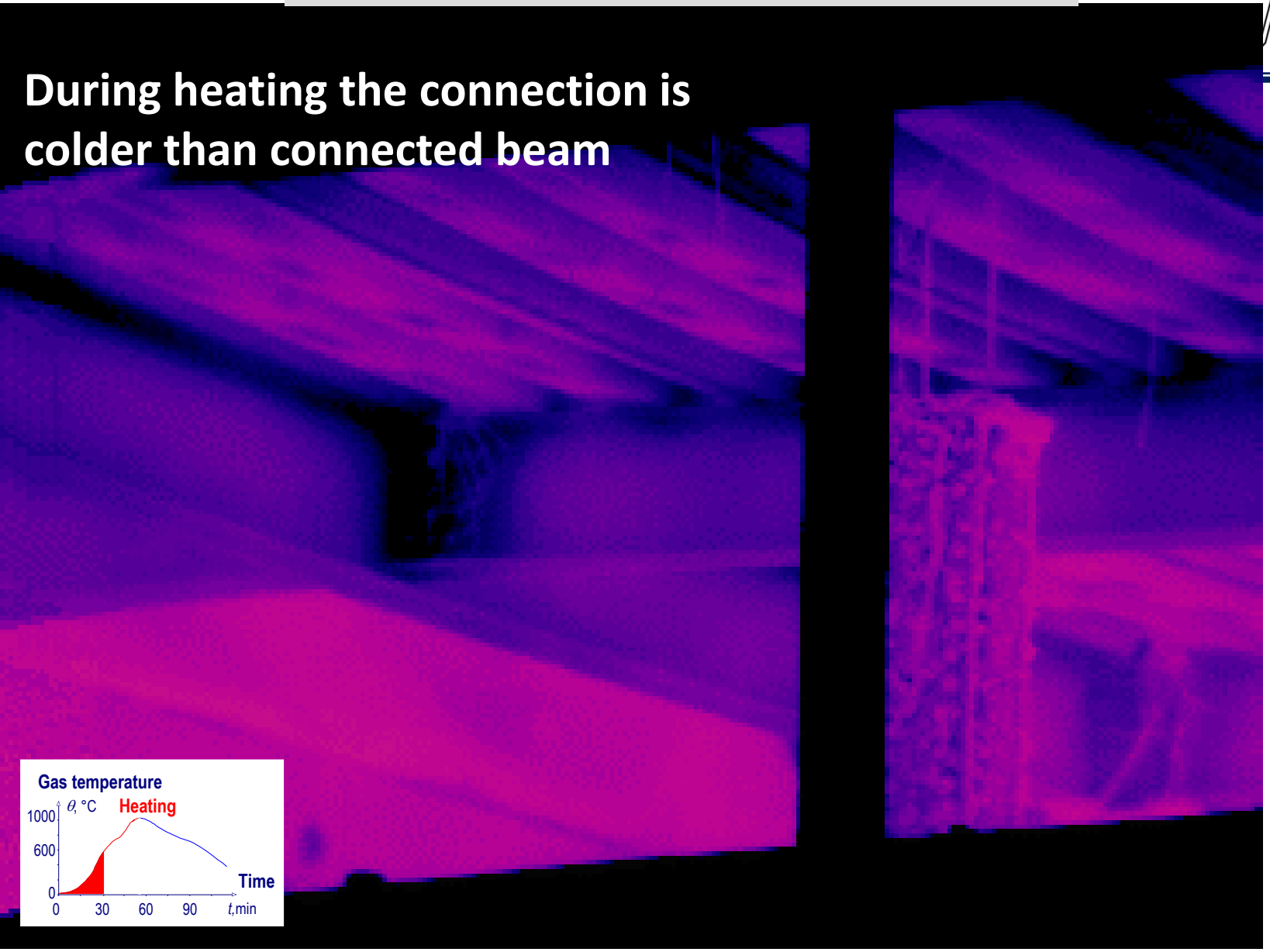


t = 28 min. $\theta_{con,ø}$ = 330 °C

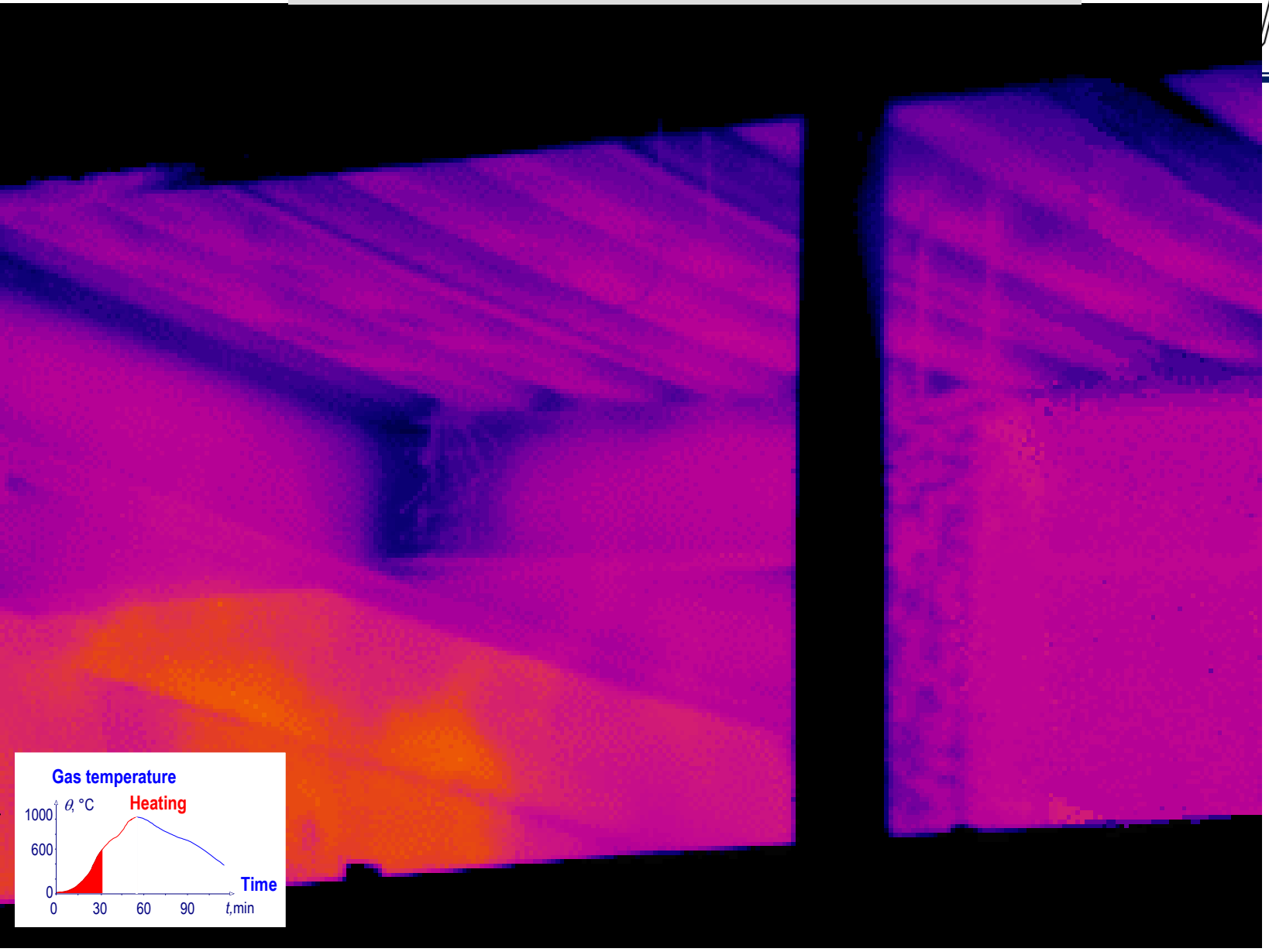


t = 30 min. $\theta_{con,ø}$ = 390 °C

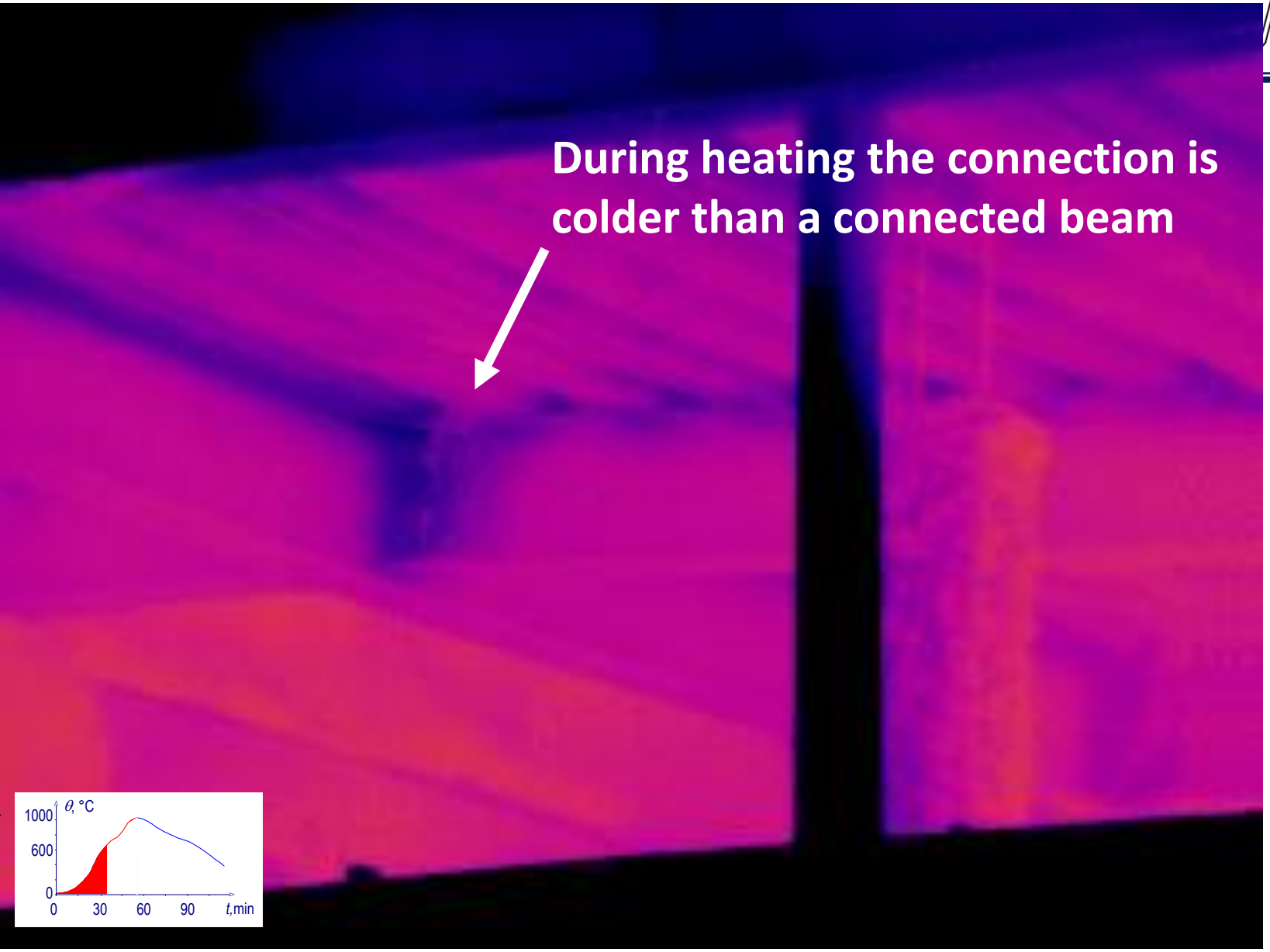
During heating the connection is colder than connected beam



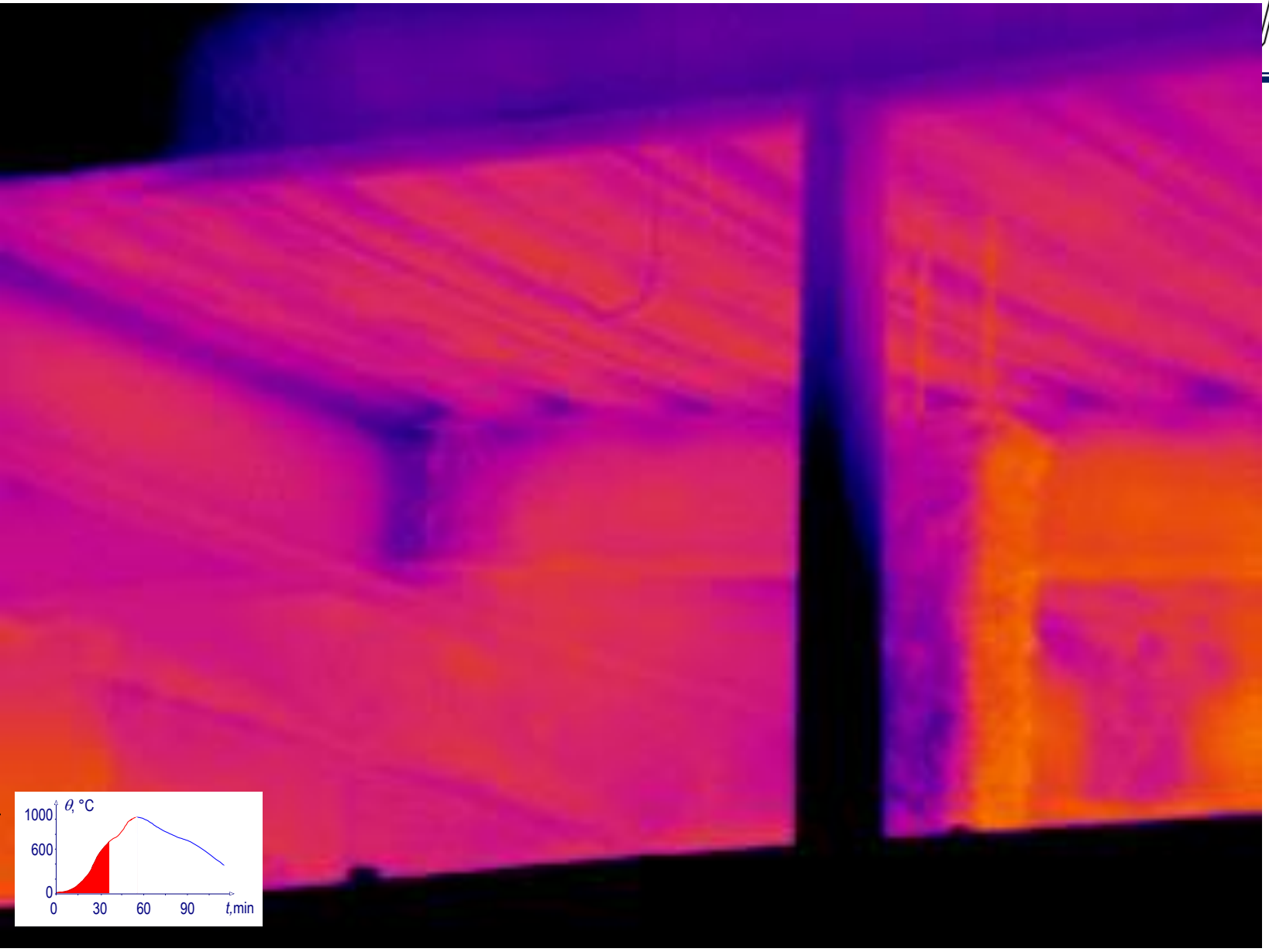
t = 32 min. $\theta_{con,ø}$ = 440 °C



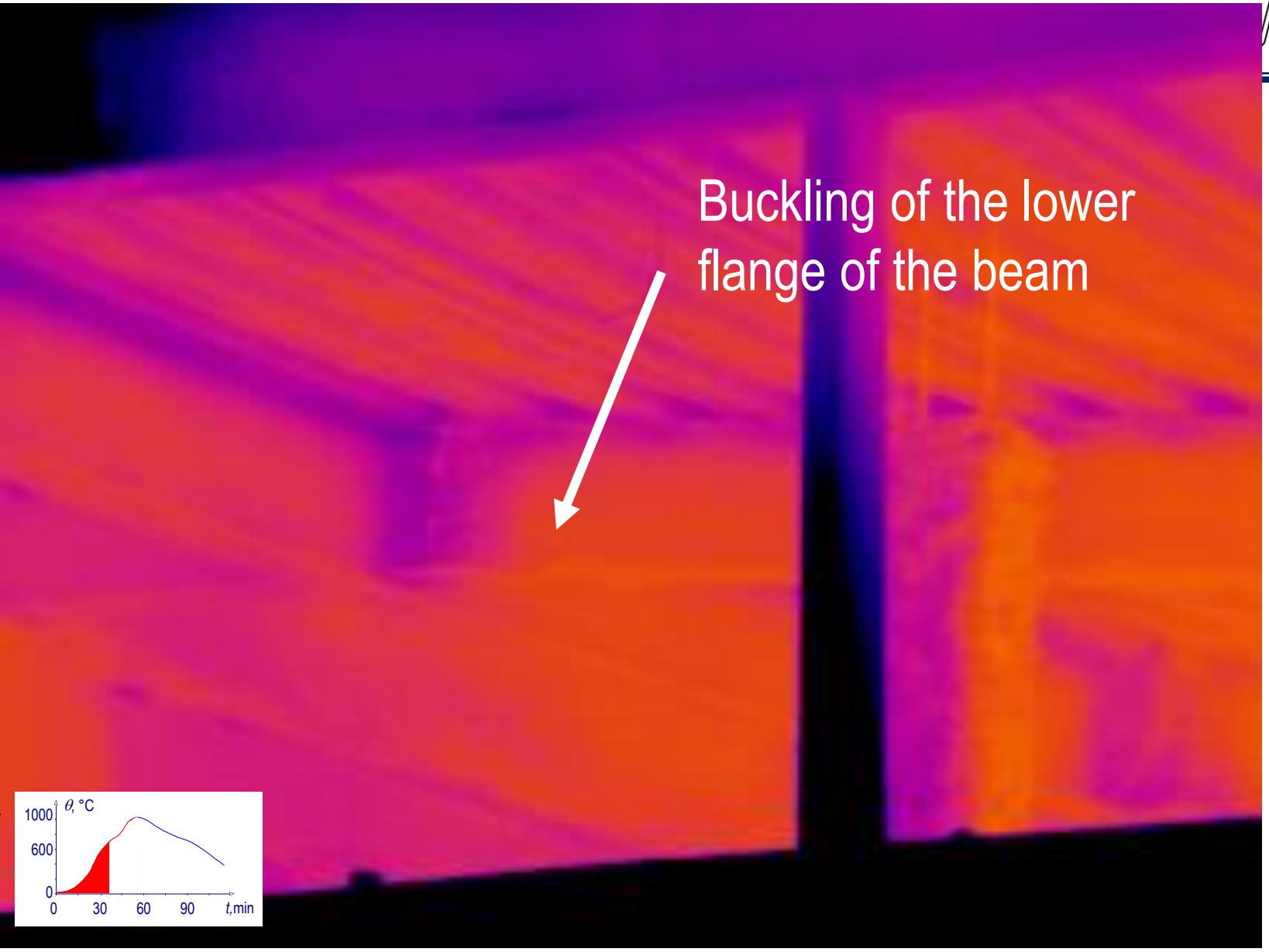
t = 34 min. $\theta_{con,ø}$ = 480 °C



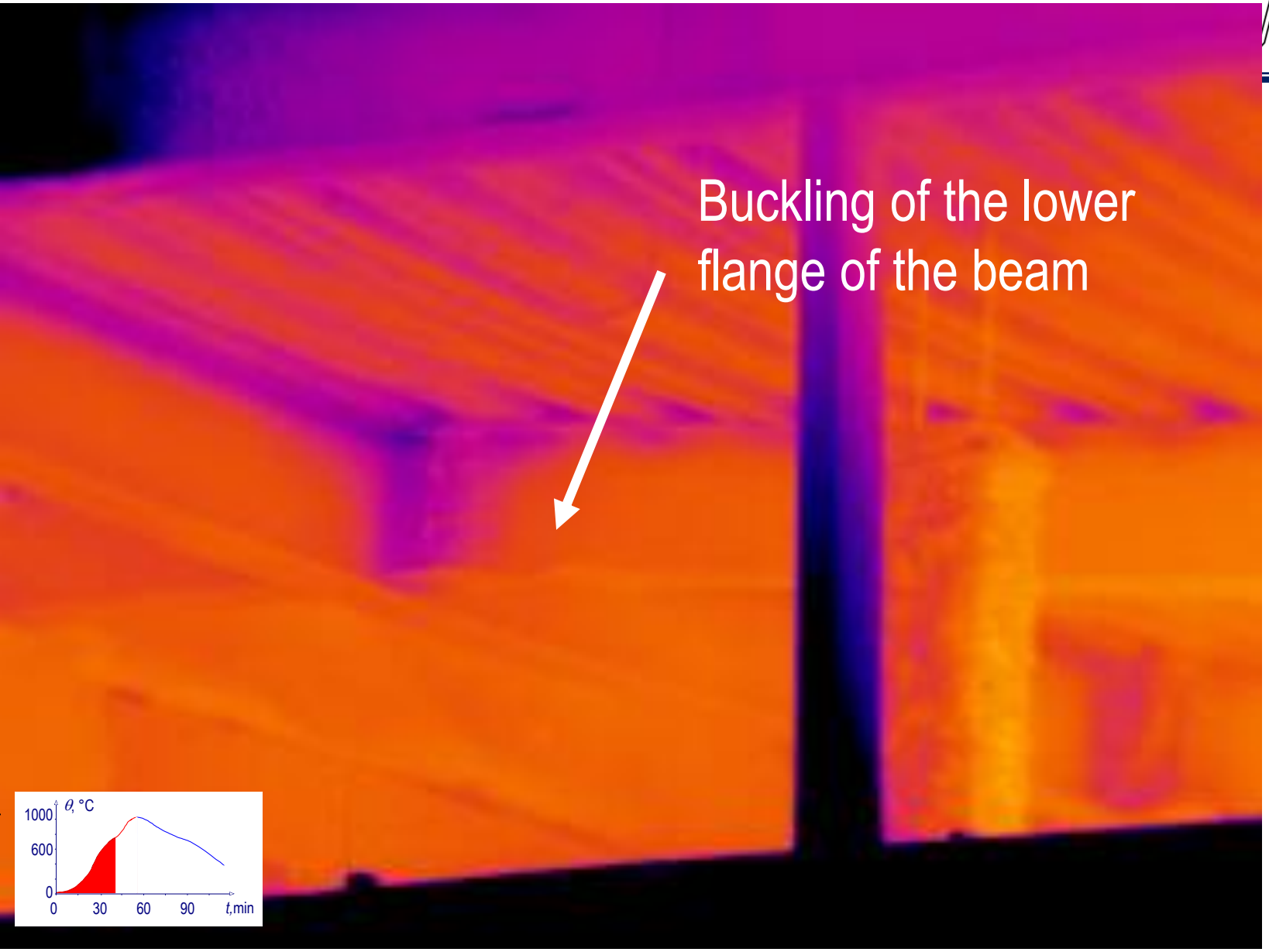
t = 36 min. $\theta_{con,ø}$ = 520 °C



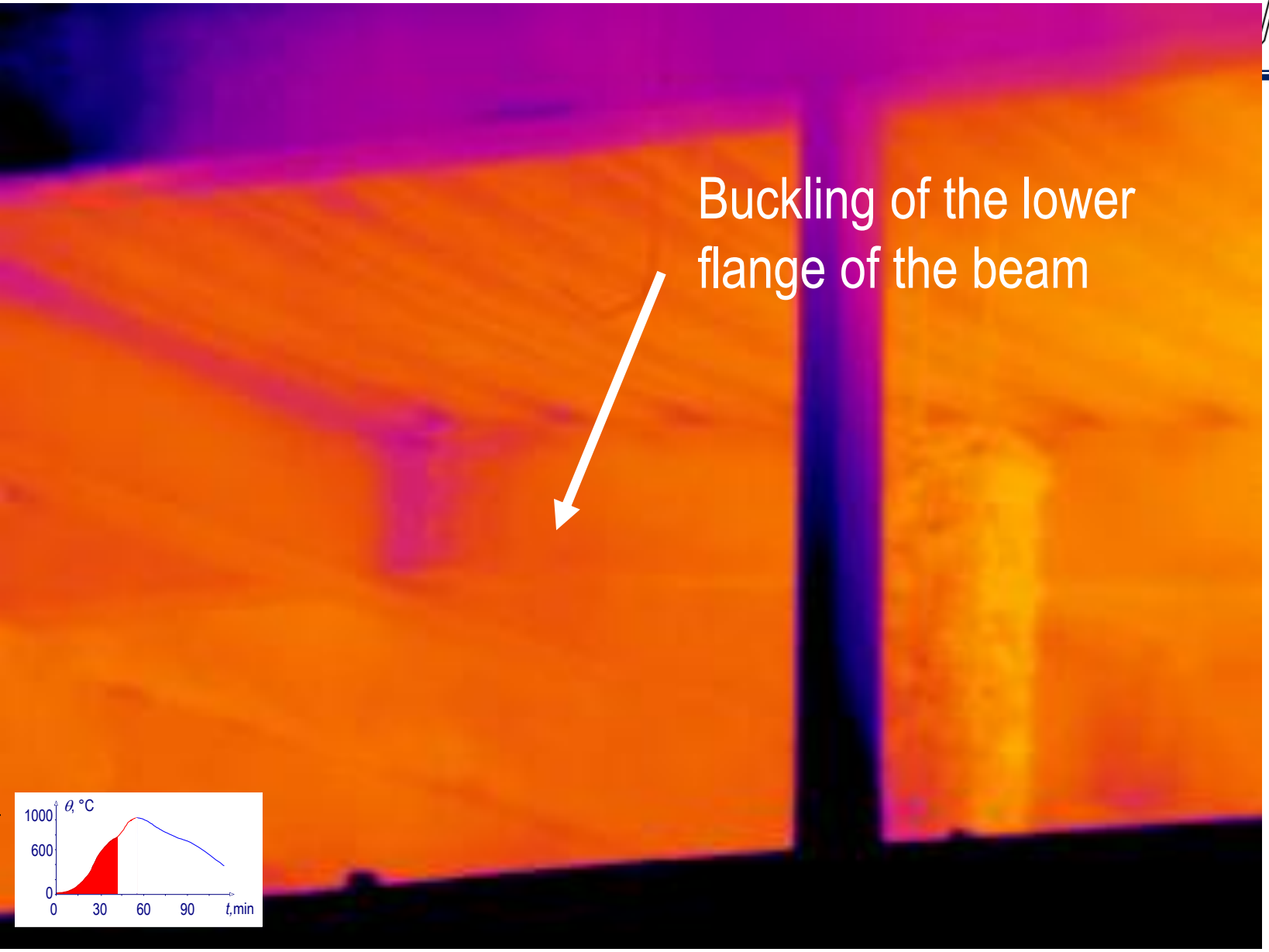
t = 38 min. $\theta_{con,ø}$ = 565 °C



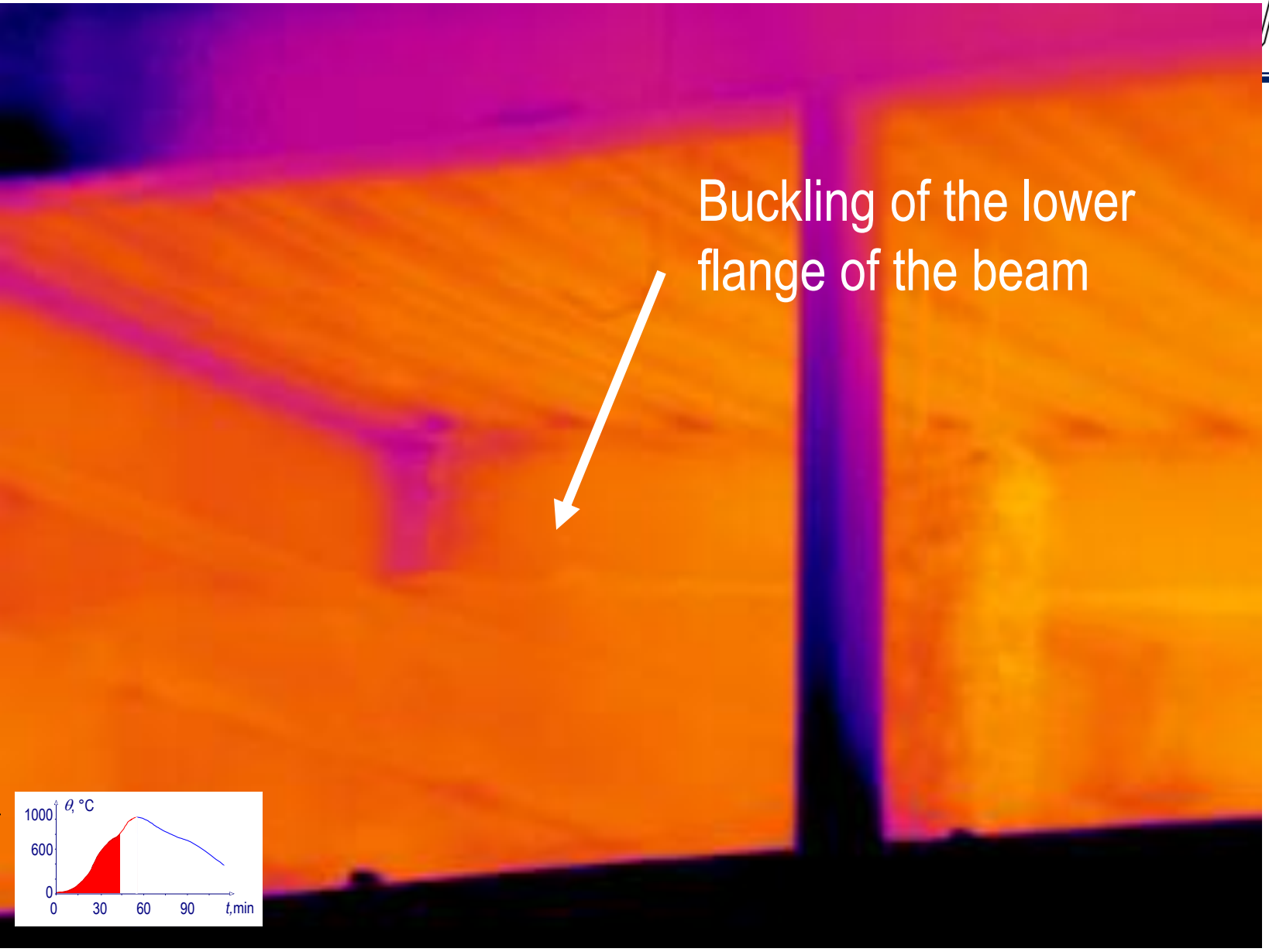
t = 40 min. $\theta_{con,ø}$ = 590 °C



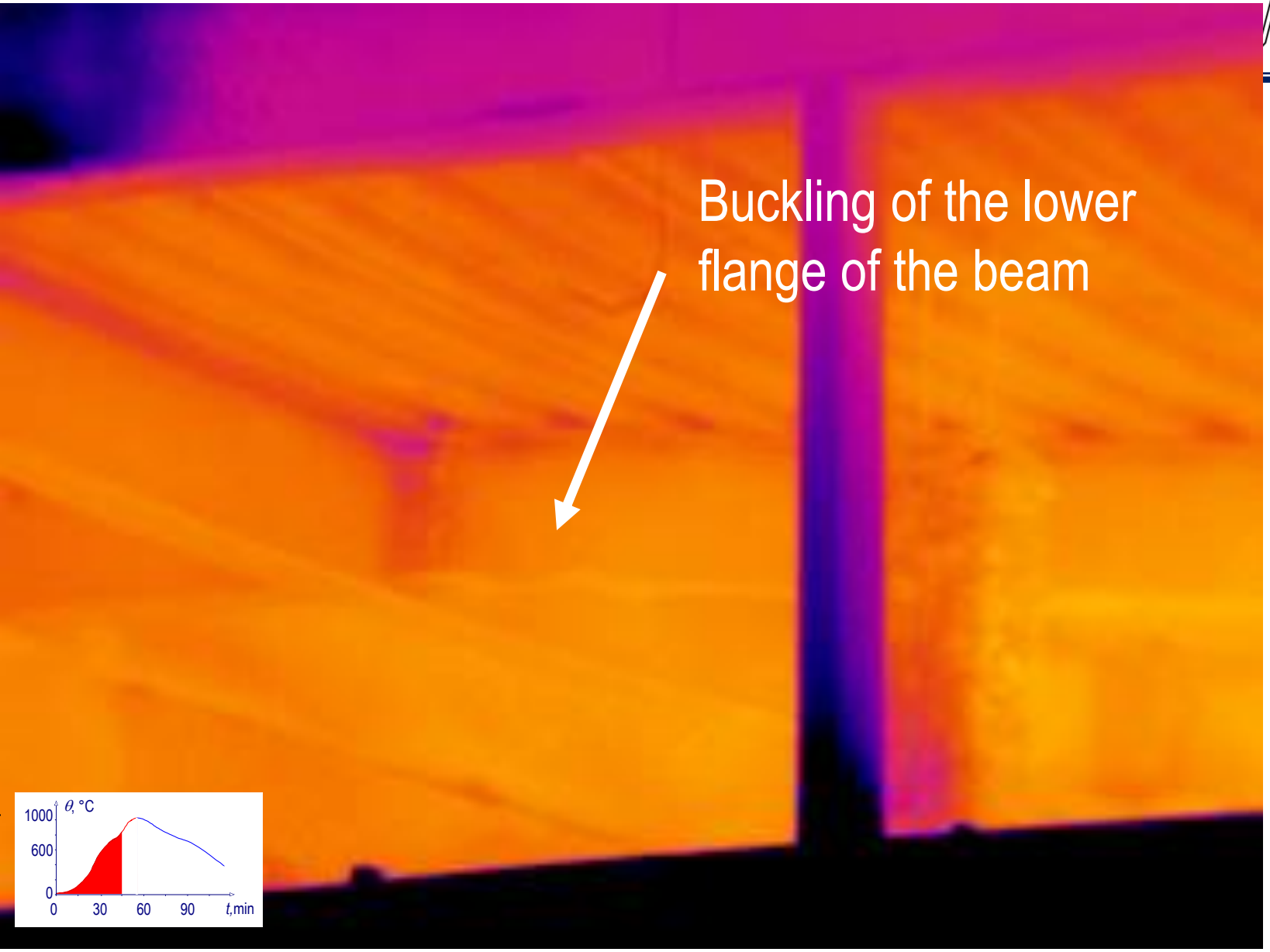
t = 42 min. $\theta_{con,ø}$ = 645 °C



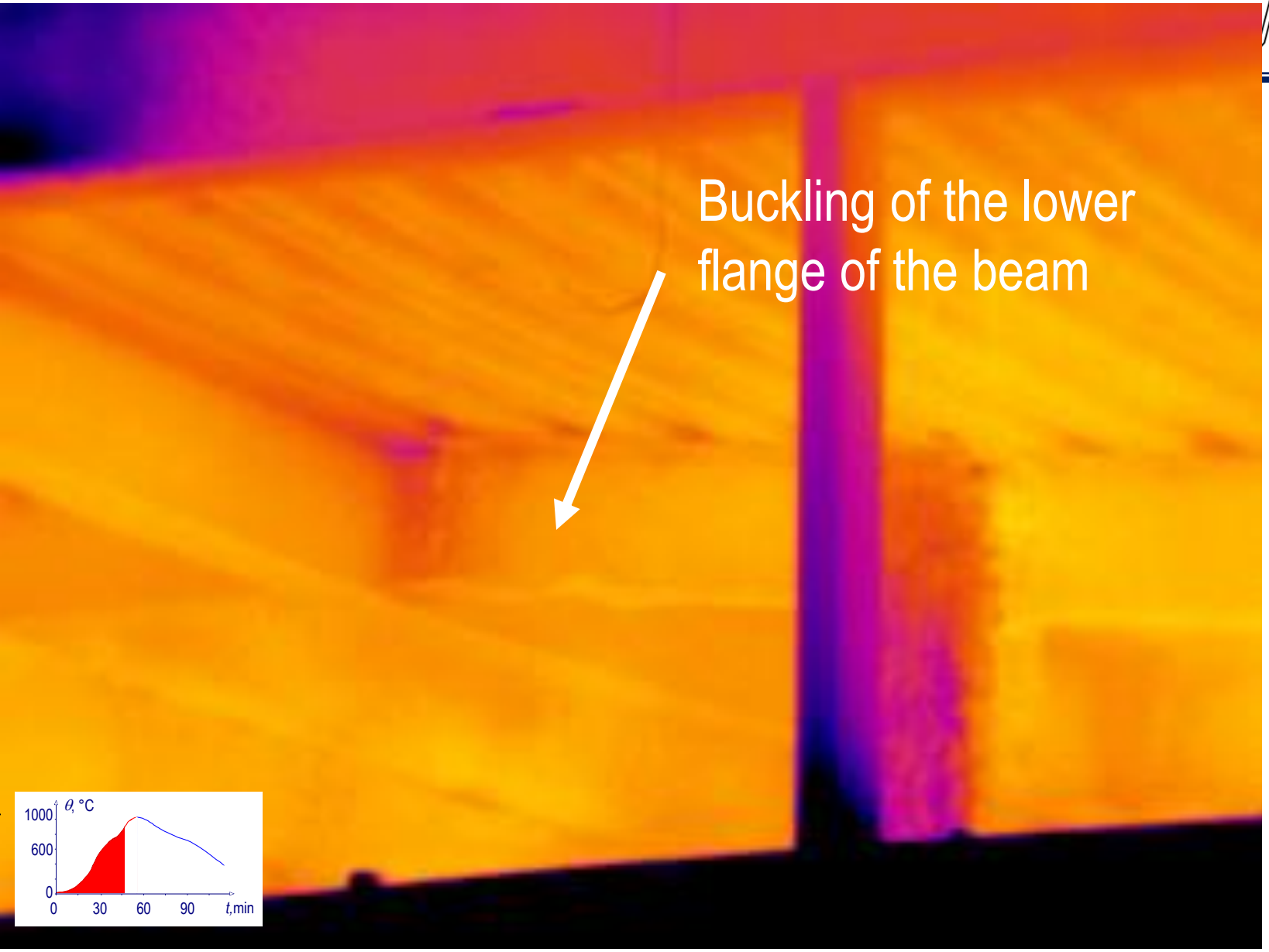
t = 44 min. $\theta_{con,ø}$ = 660 °C



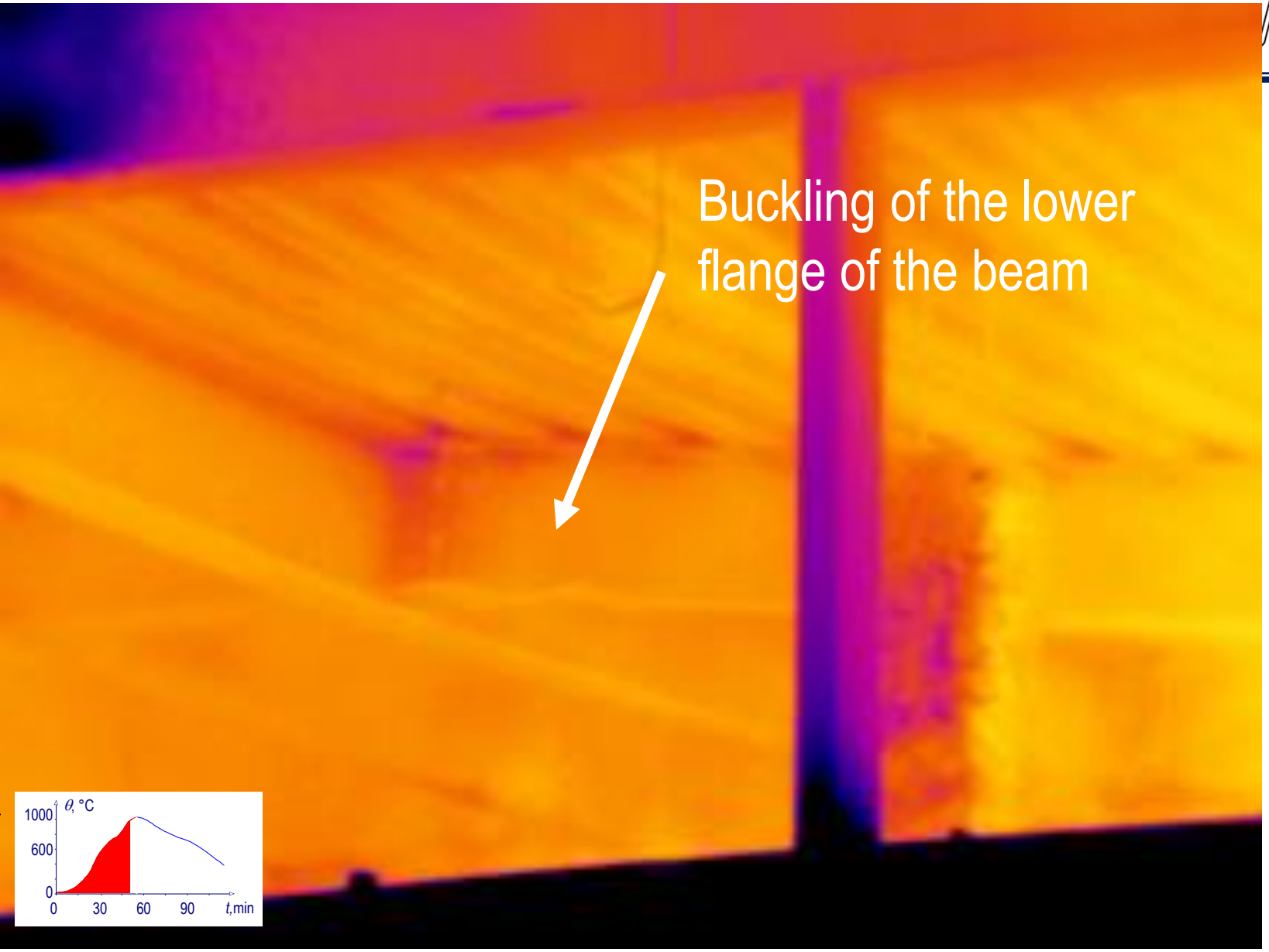
t = 46 min. $\theta_{con,ø}$ = 685 °C



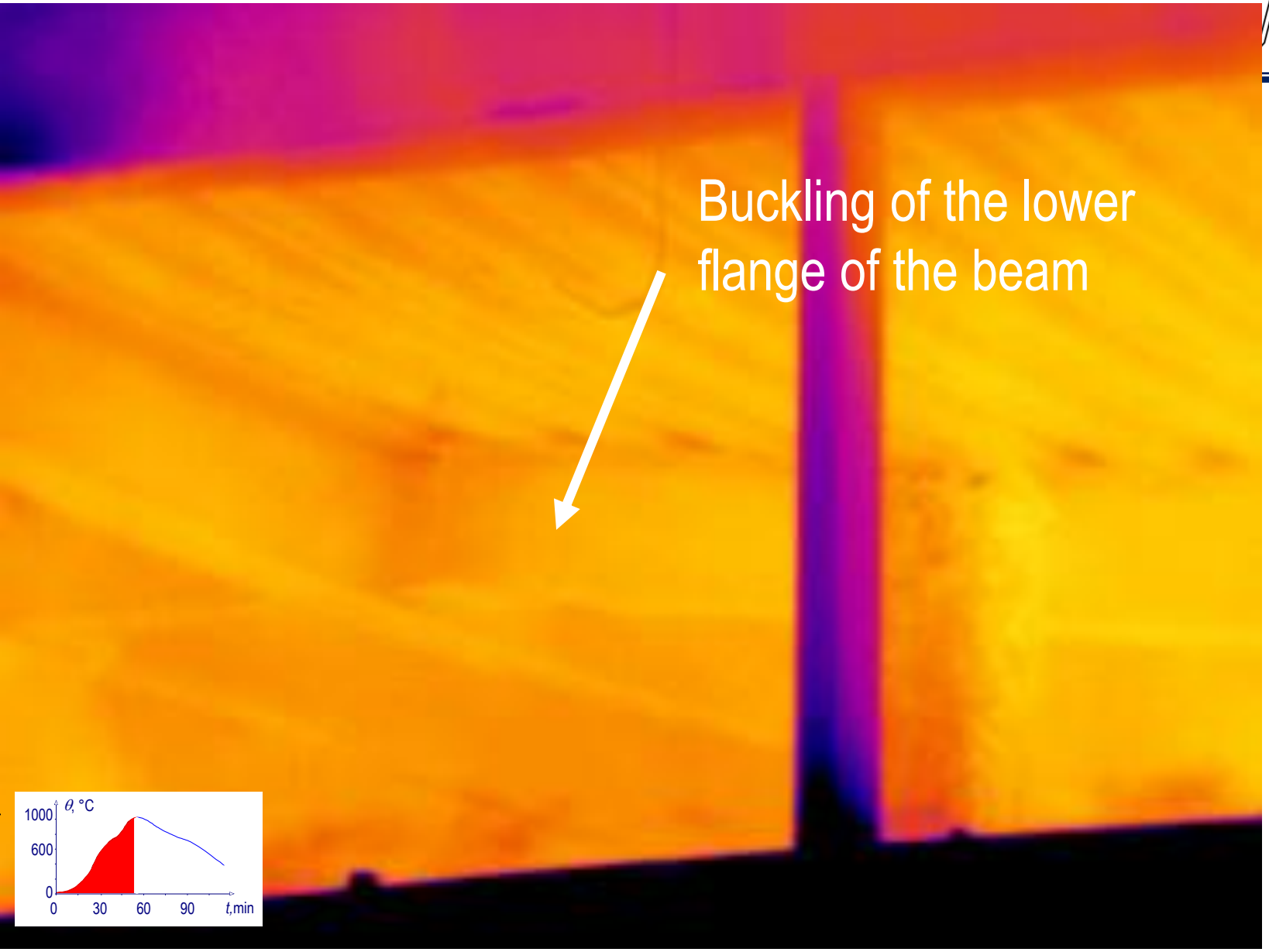
t = 48 min. $\theta_{con,ø}$ = 710 °C



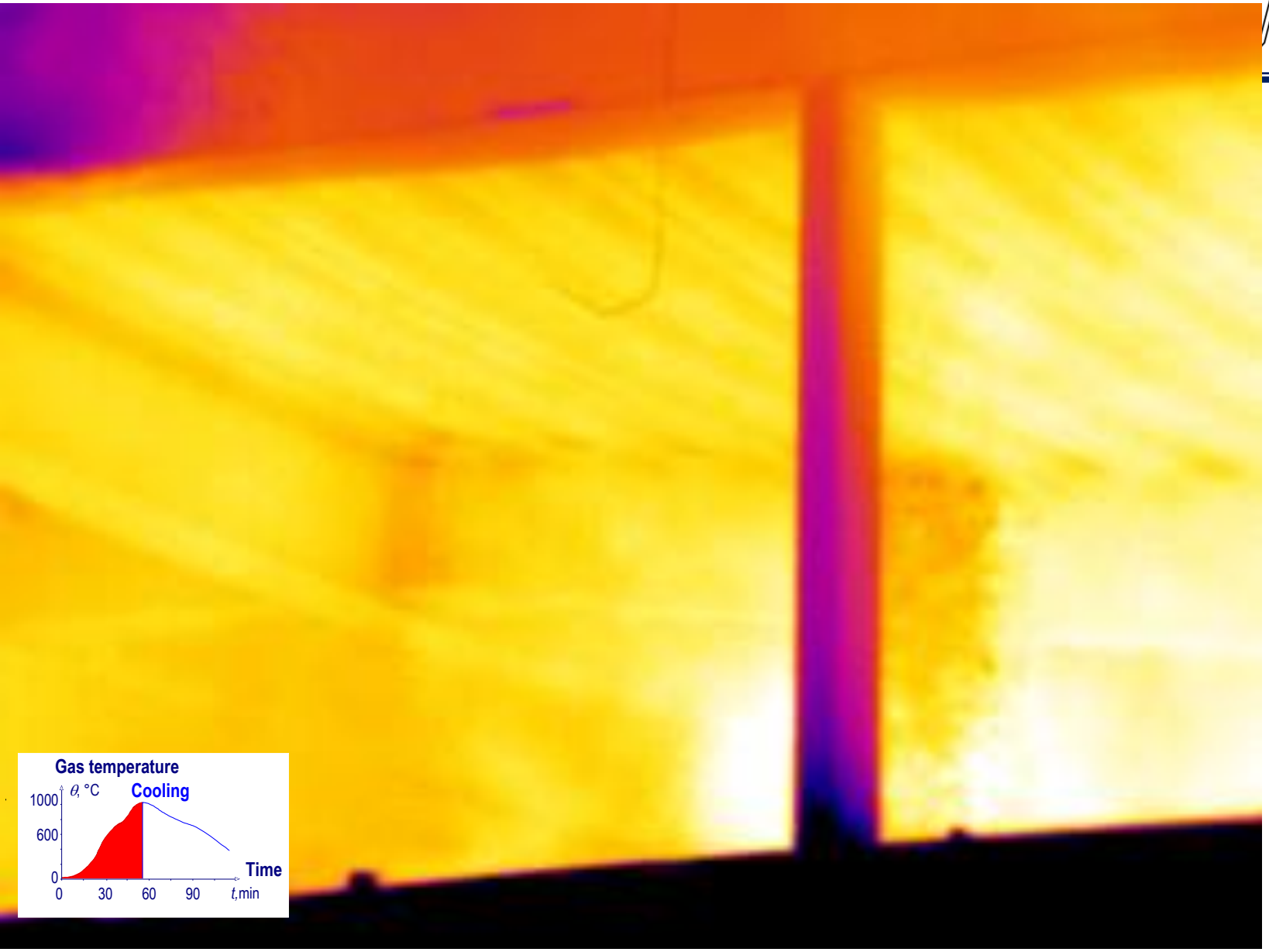
t = 50 min. $\theta_{con,ø}$ = 730 °C



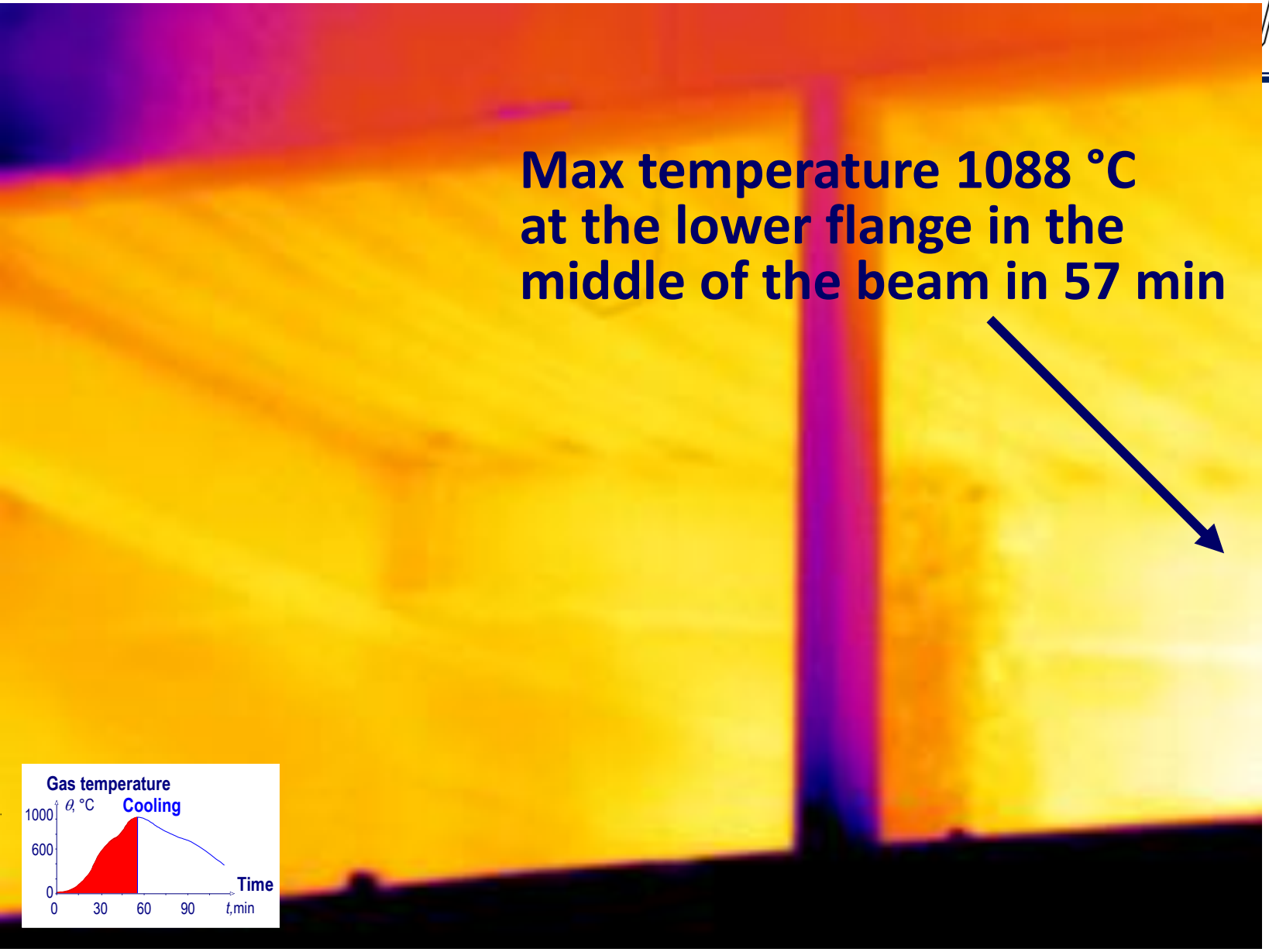
t = 52 min. $\theta_{con,ø}$ = 775 °C



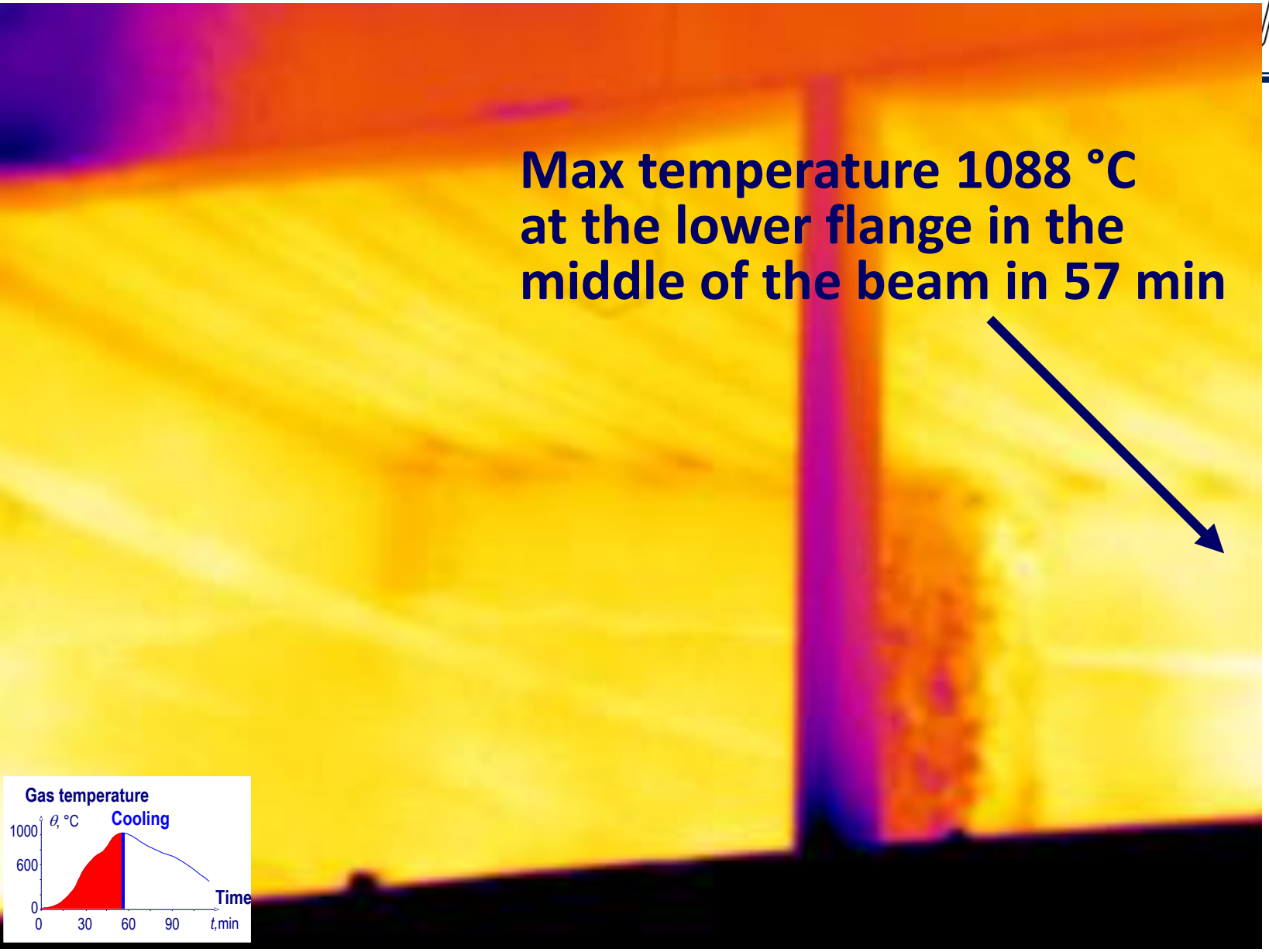
t = 54 min. $\theta_{con,ø}$ = 810 °C



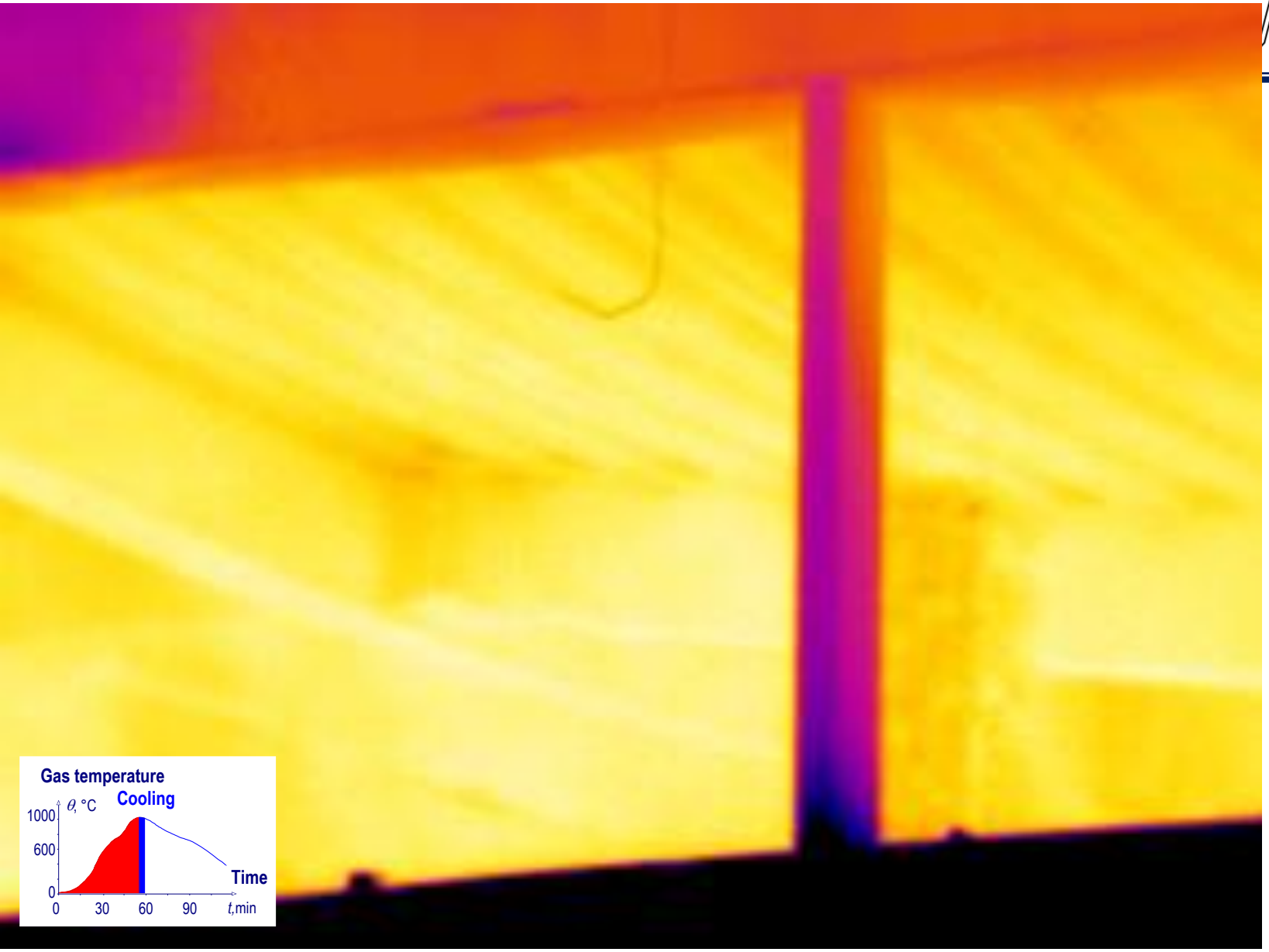
t = 56 min. $\theta_{con,ø}$ = 835 °C



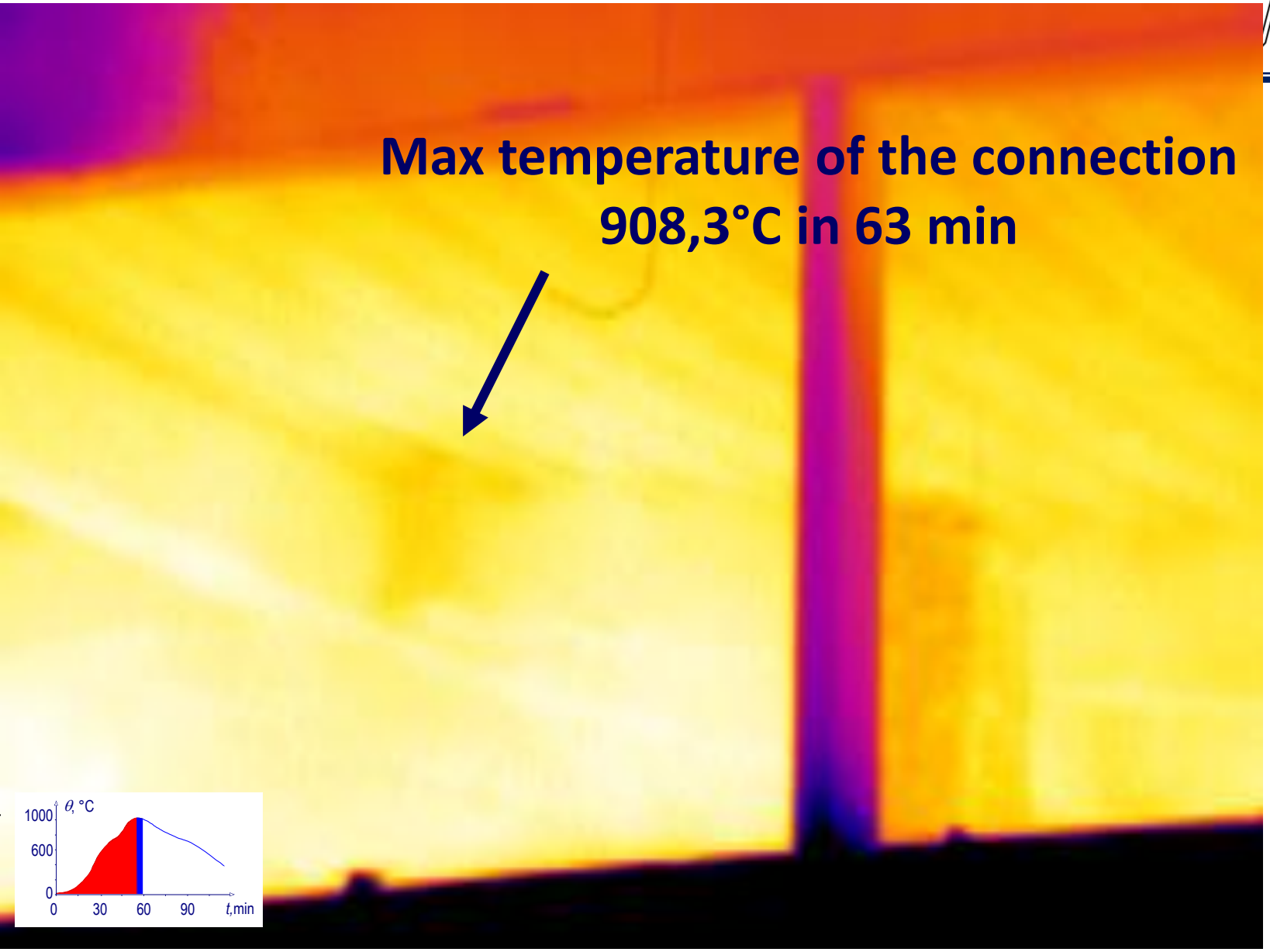
t = 58 min. $\theta_{con,ø}$ = 855 °C



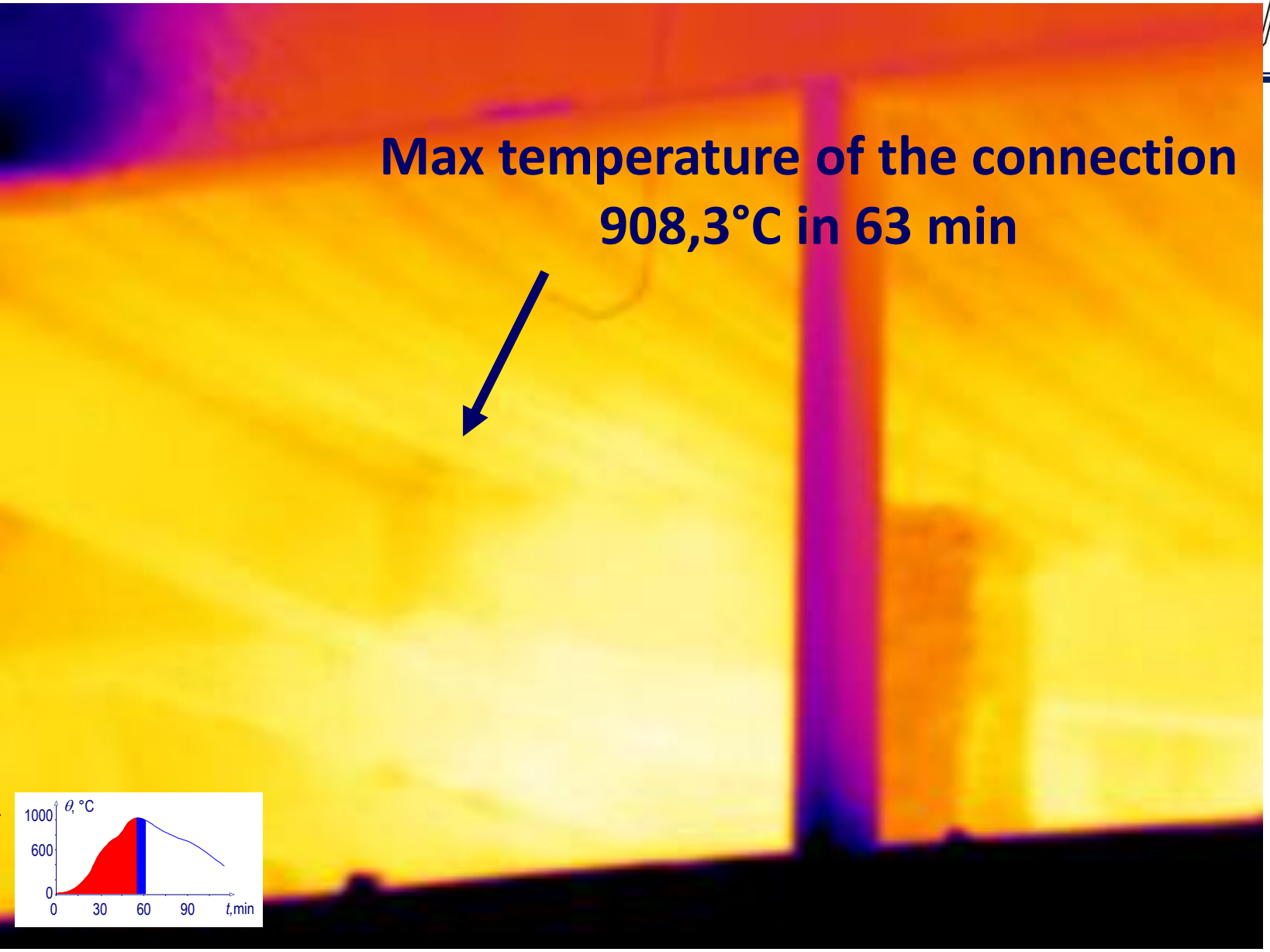
t = 60 min. $\theta_{con,ø}$ = 880 °C



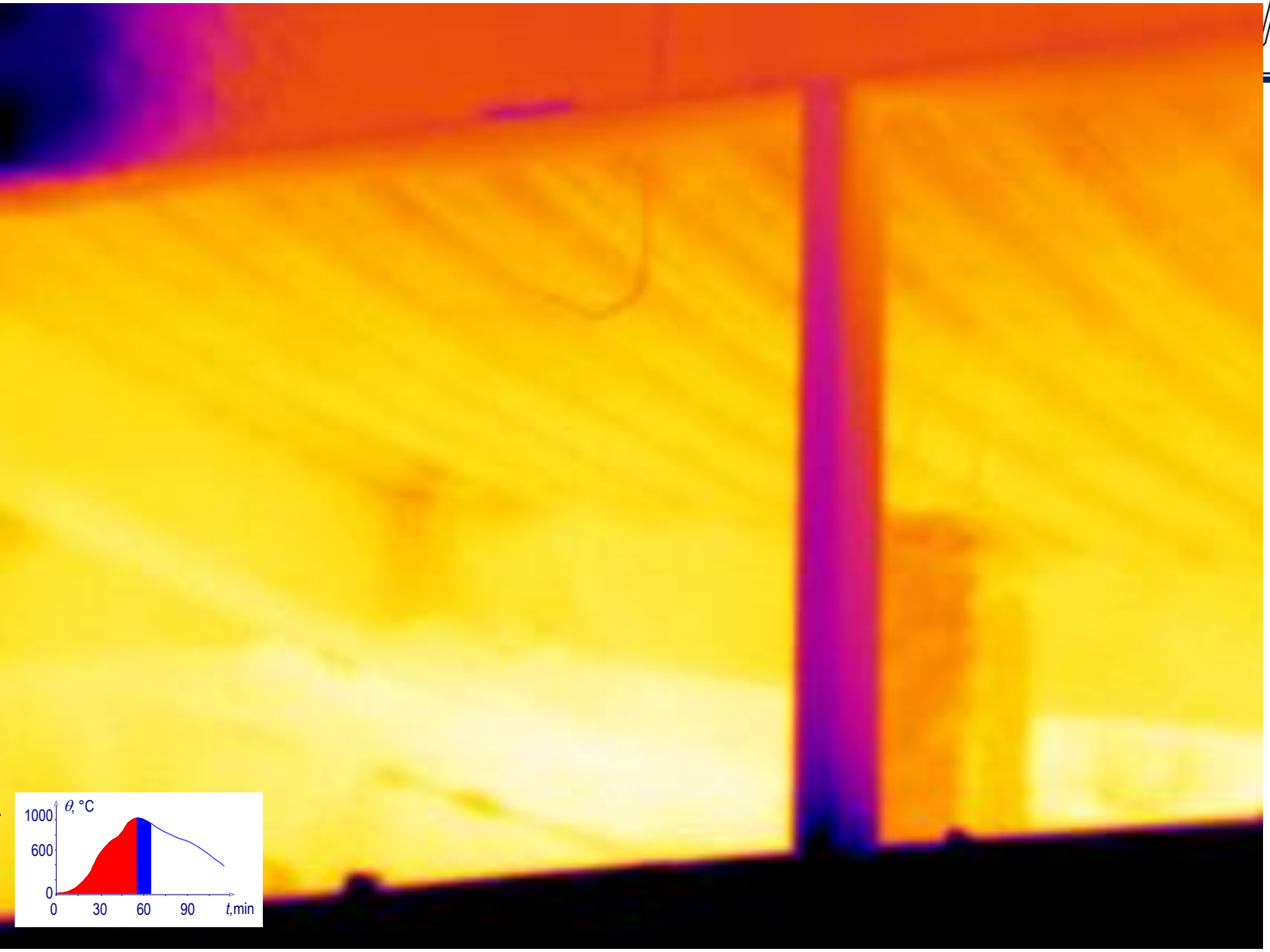
t = 62 min. $\theta_{con,ø}$ = 900 °C



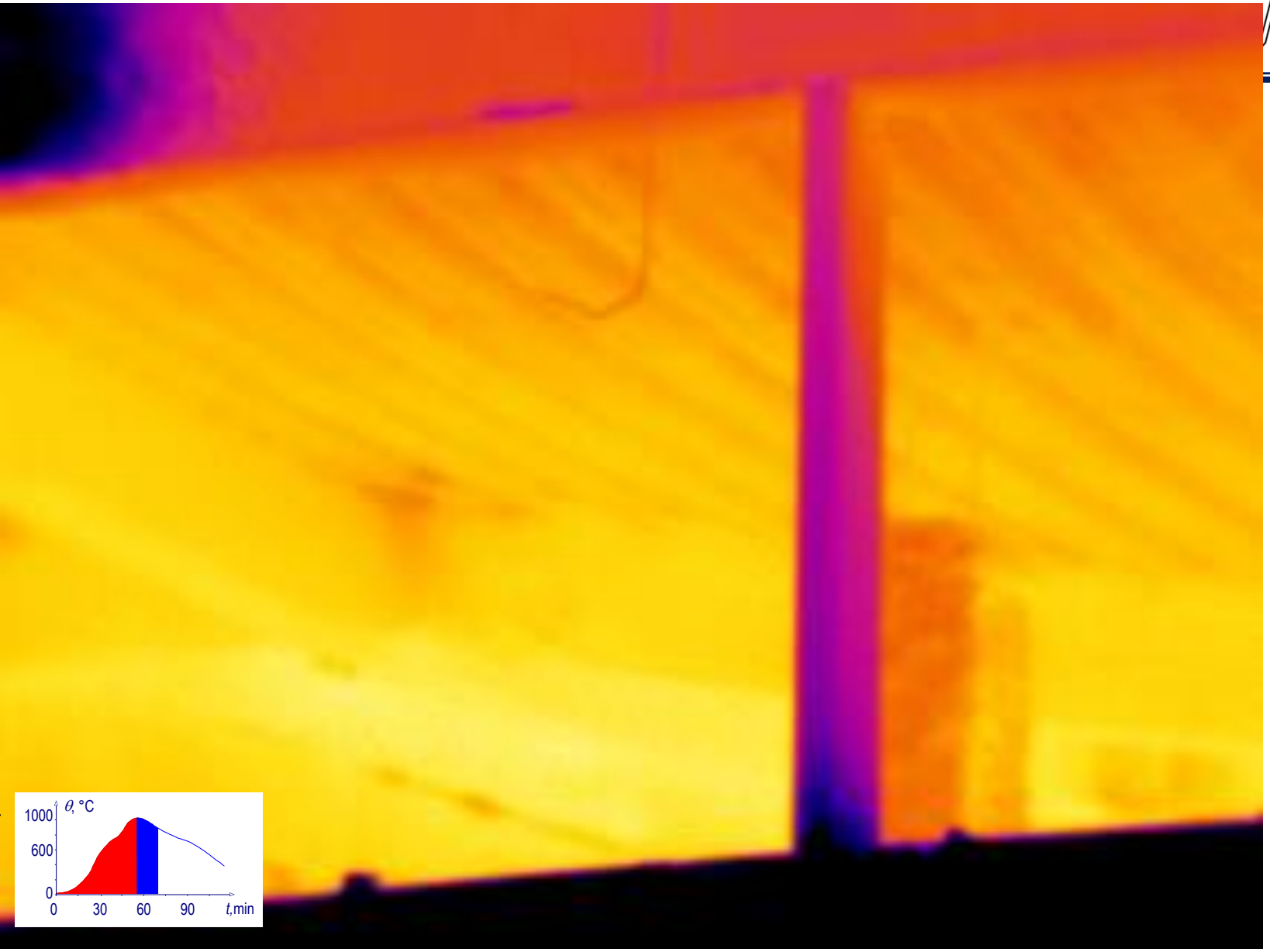
t = 64 min. $\theta_{con,ø}$ = 885 °C



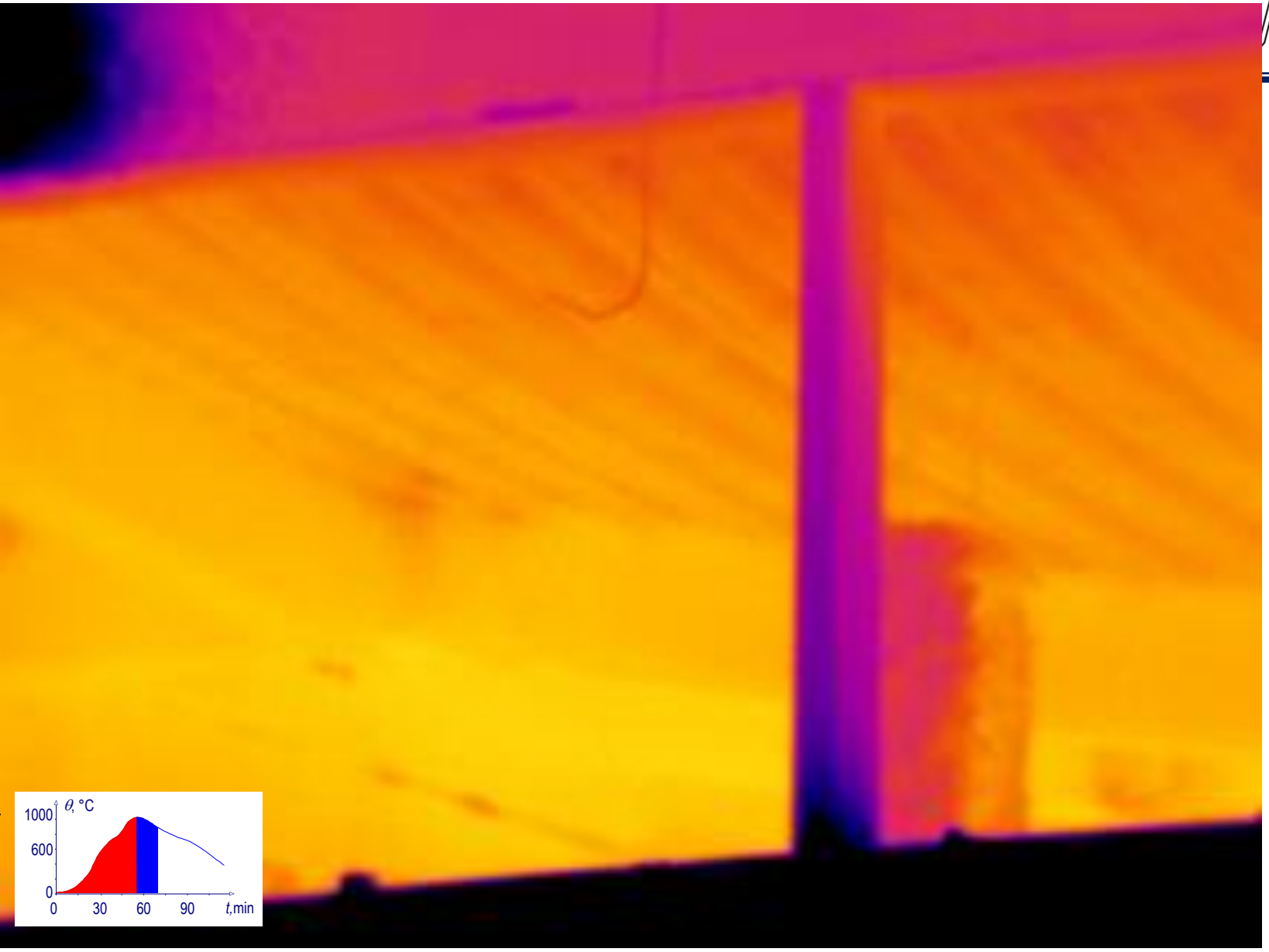
t = 66 min. $\theta_{con,ø}$ = 860 °C



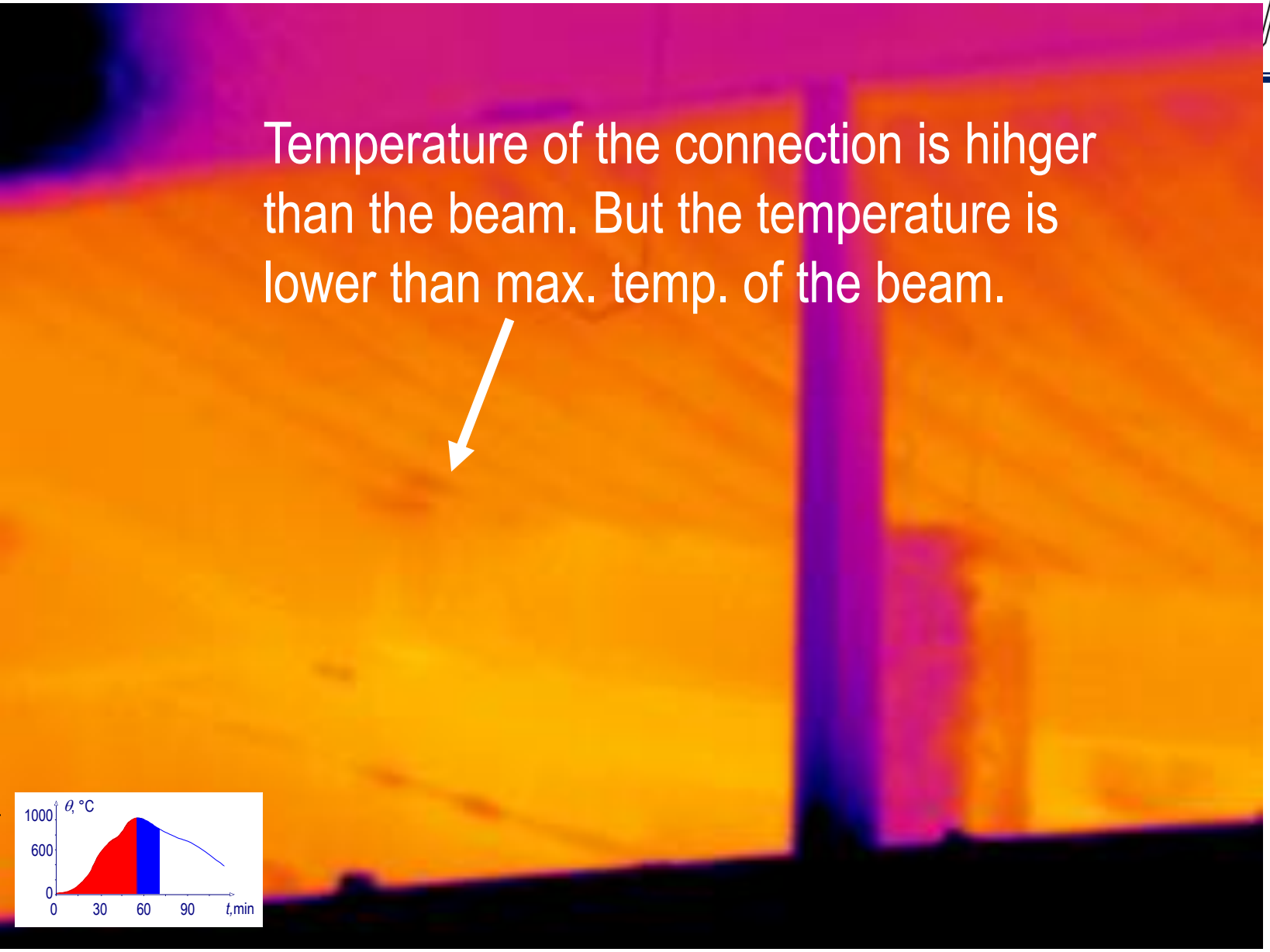
t = 68 min. $\theta_{con,ø}$ = 840 °C



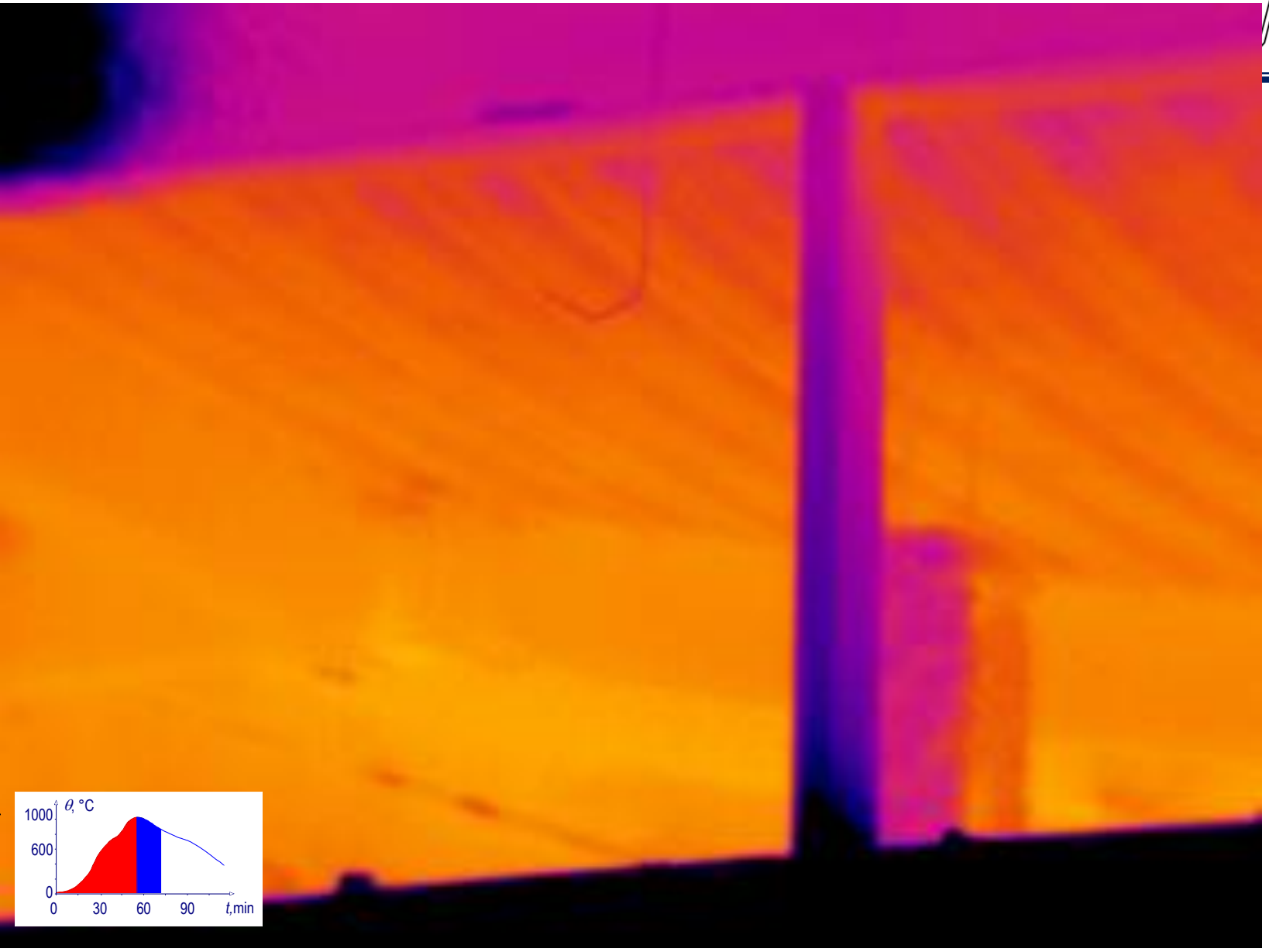
t = 70 min. $\theta_{con,ø}$ = 820 °C



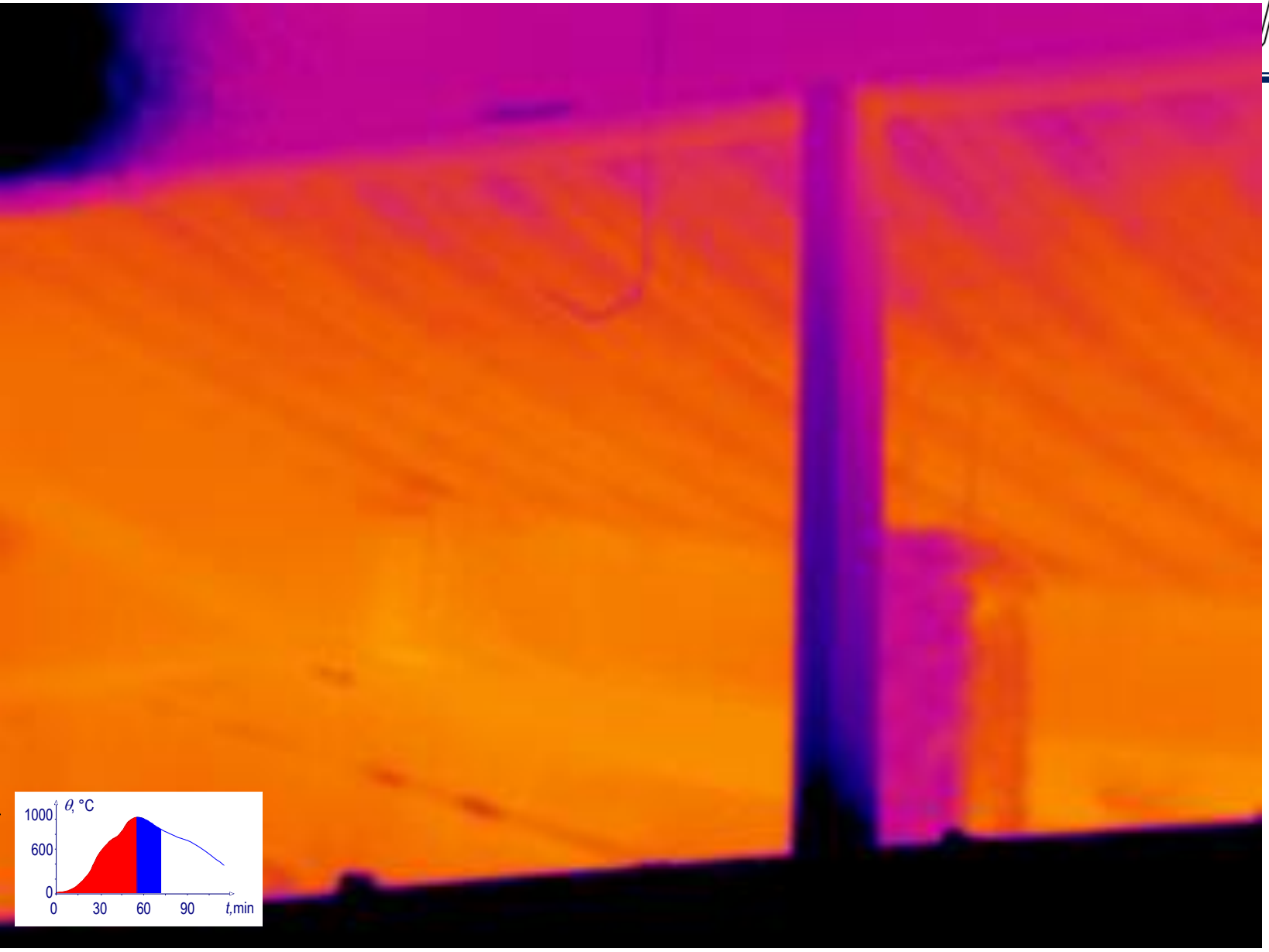
$t = t_0 + 1\ h\ 12'$ $T_{con,ø} = 800\ °C$



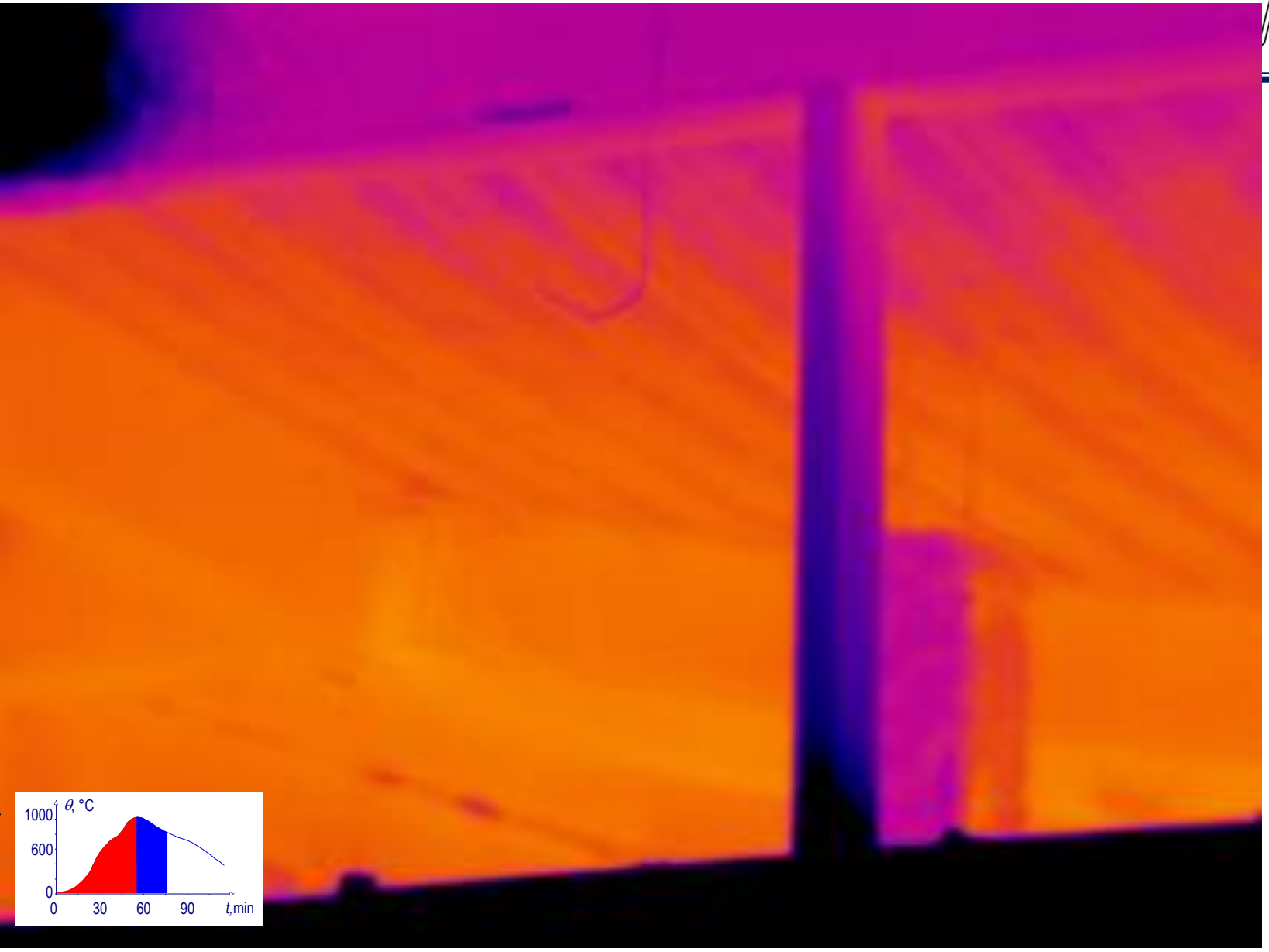
t = 74 min. $\theta_{con,ø}$ = 790 °C



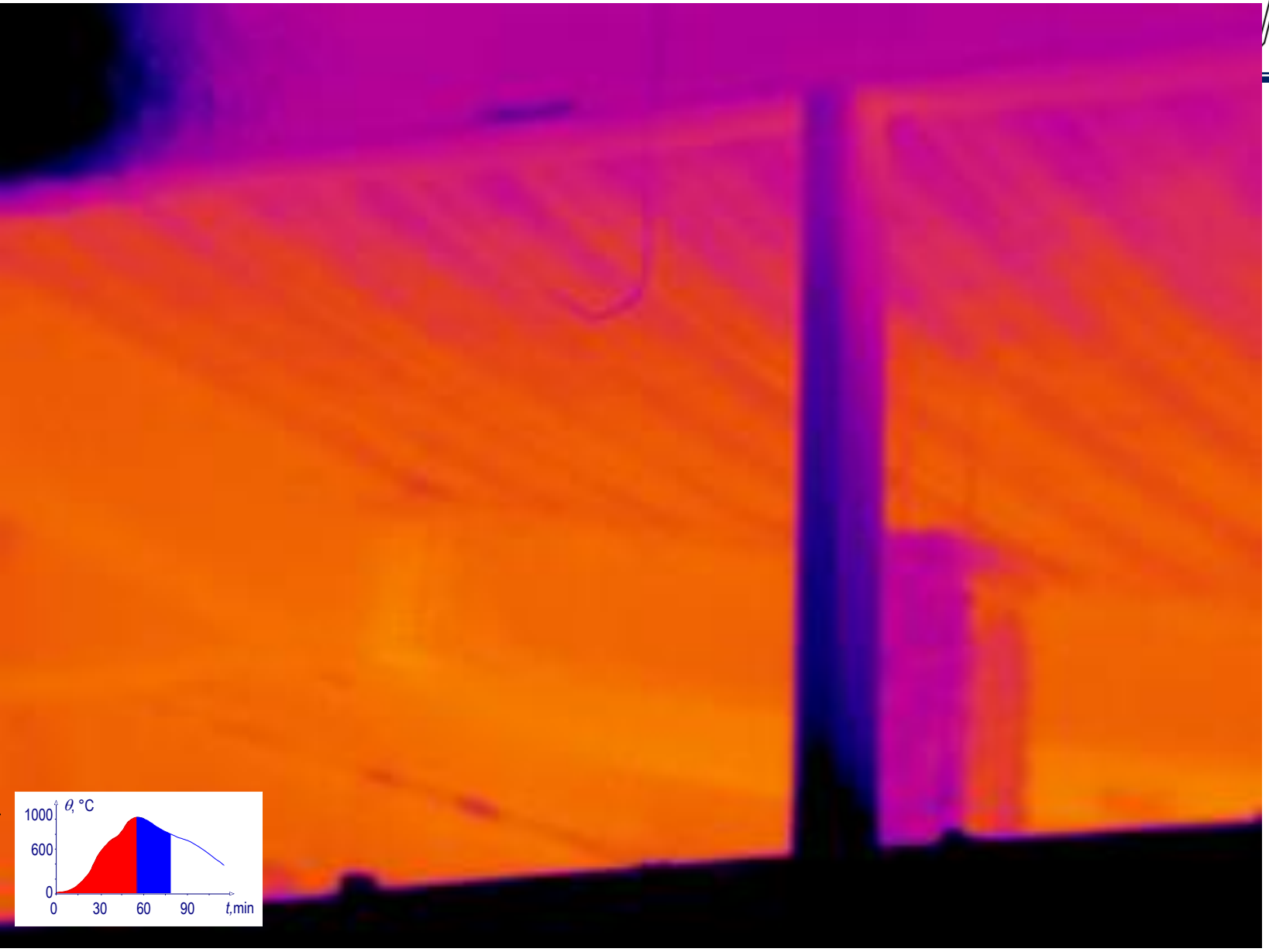
t = 76 min. $\theta_{con,ø}$ = 770 °C



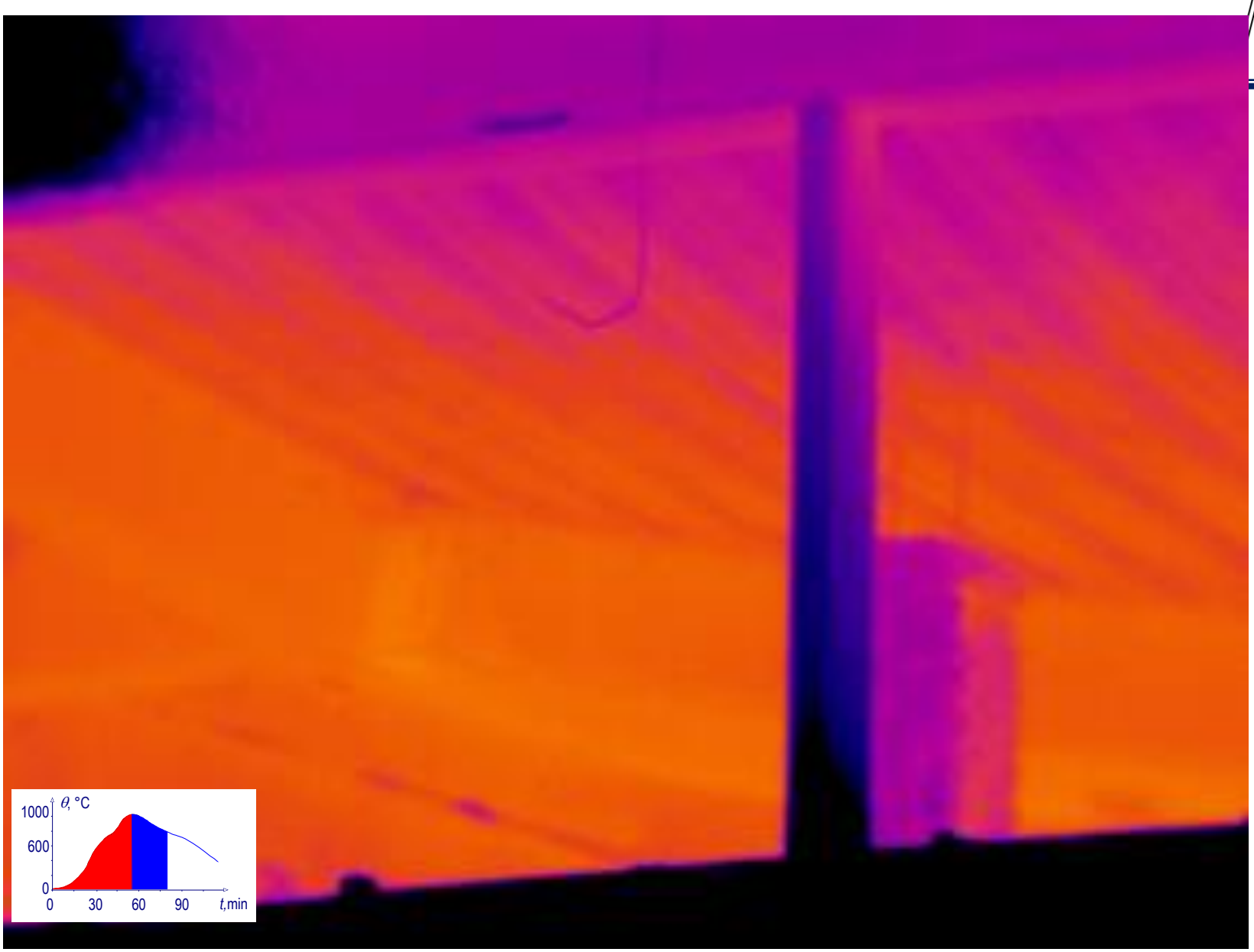
t = 78 min. $\theta_{con,ø}$ = 775 °C



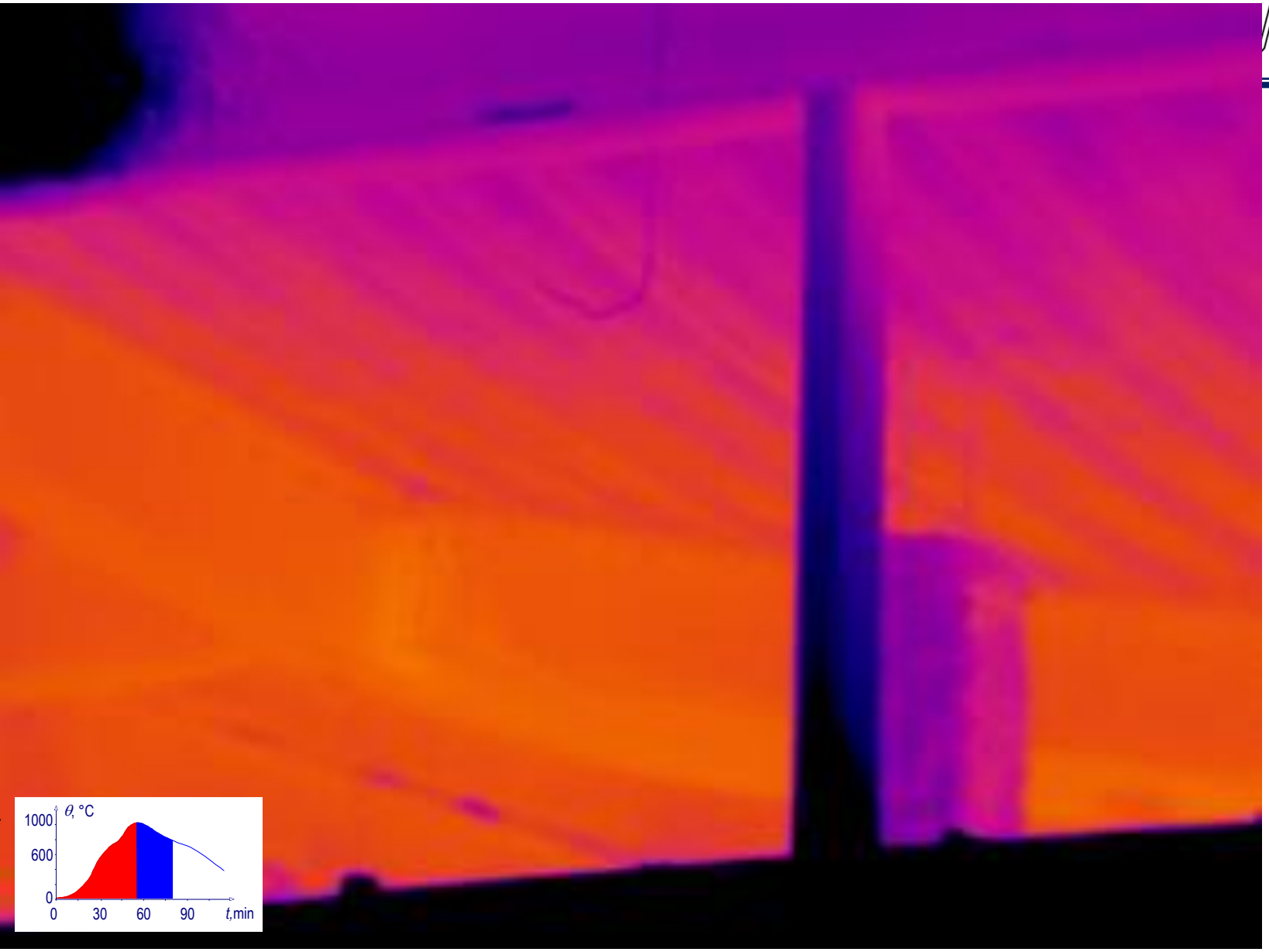
t = 80 min. $\theta_{con,ø}$ = 745 °C



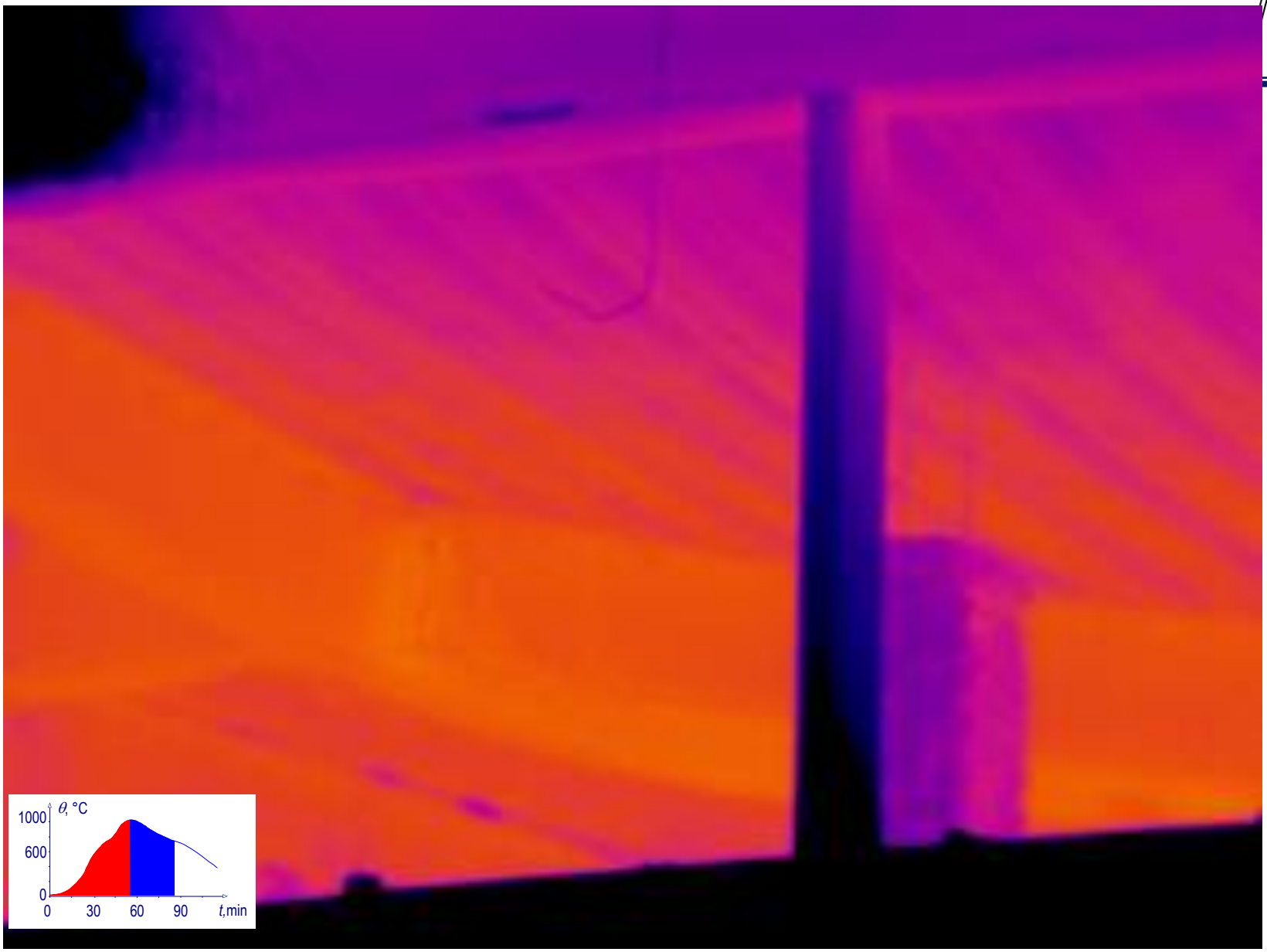
t = 82 min. $\theta_{con,ø}$ = 740 °C



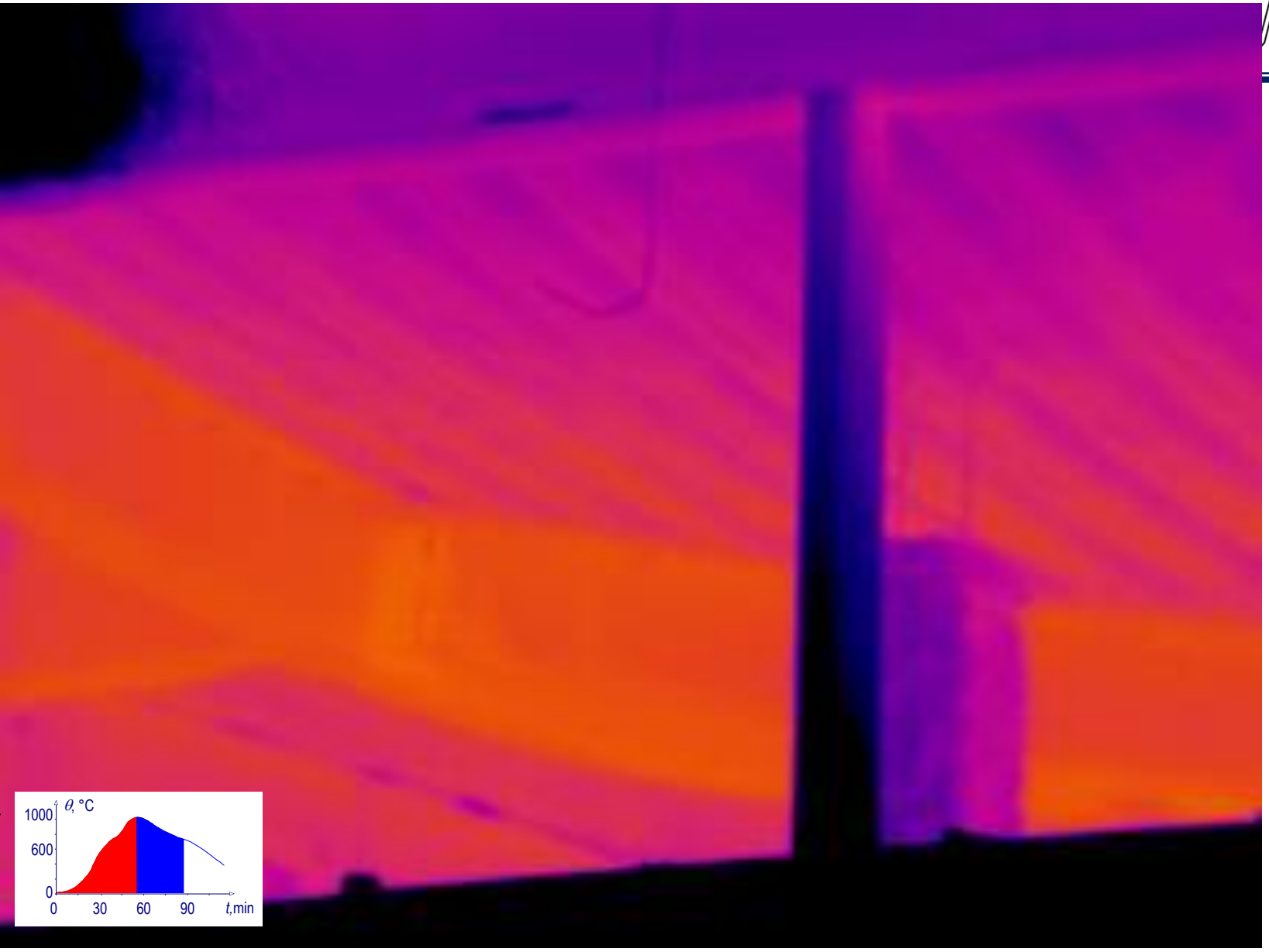
t = 84 min. $\theta_{con,ø}$ = 730 °C



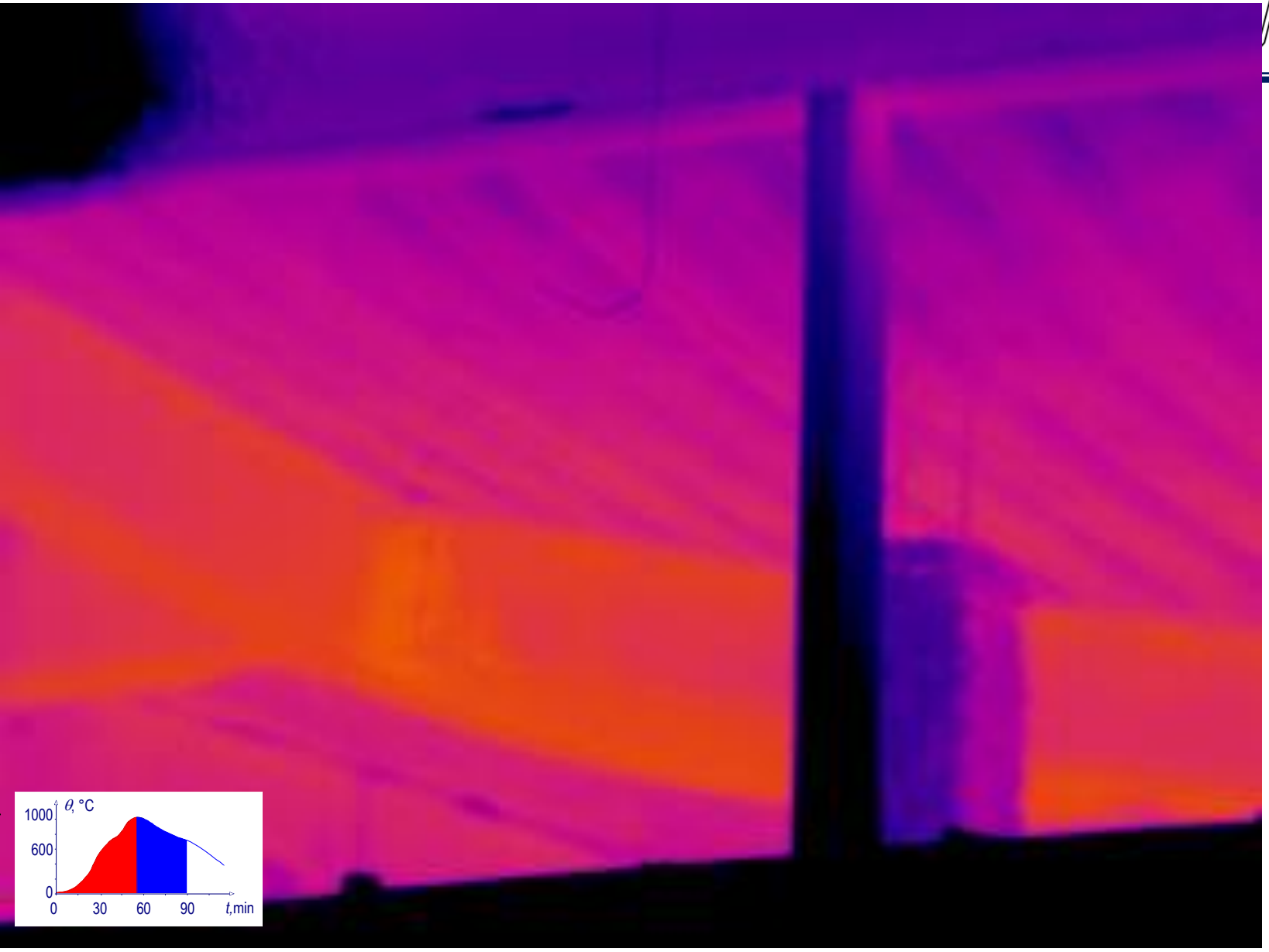
t = 76 min. $\theta_{con,ø}$ = 720 °C



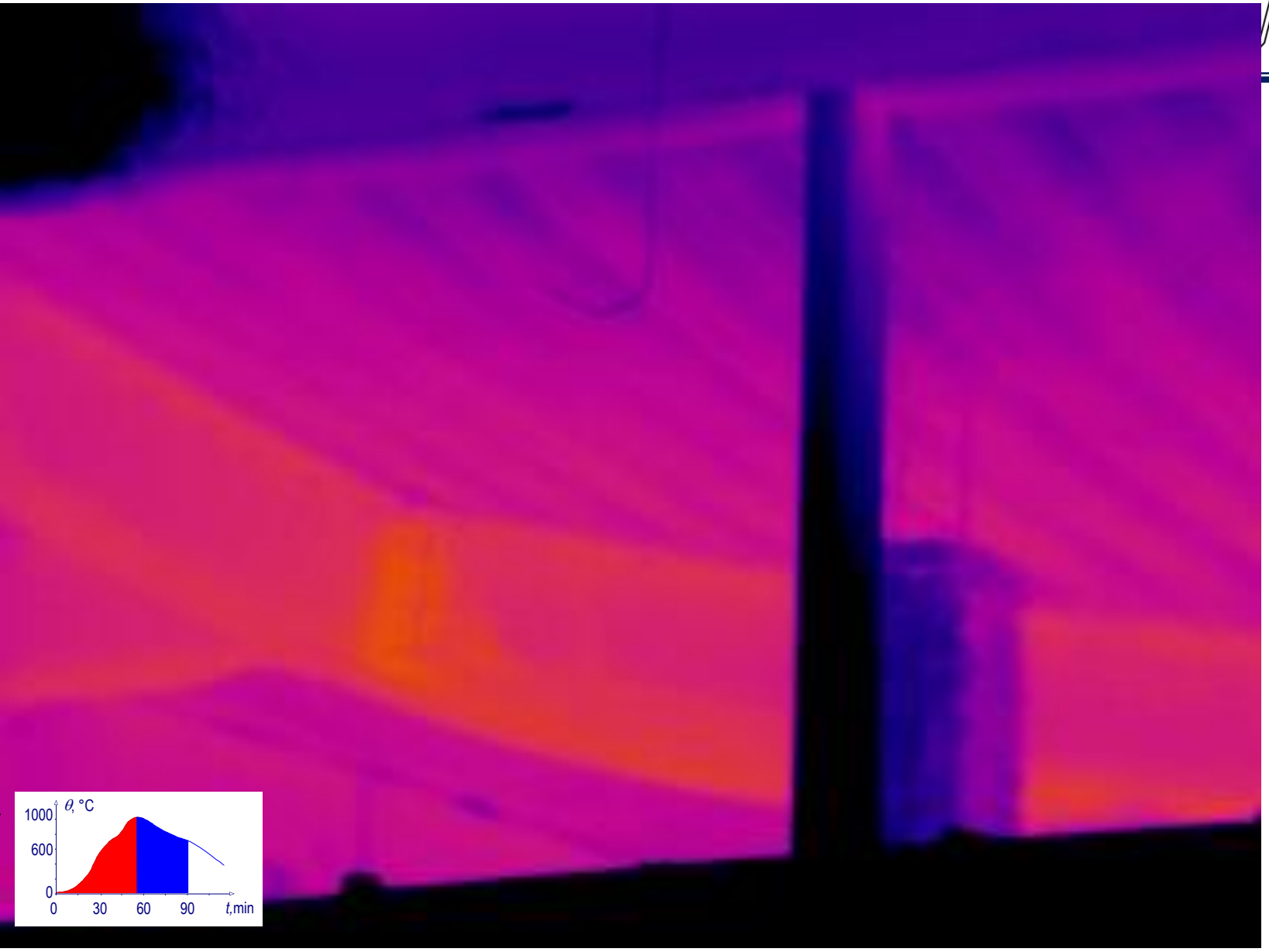
t = 78 min. $\theta_{con,ø}$ = 710 °C



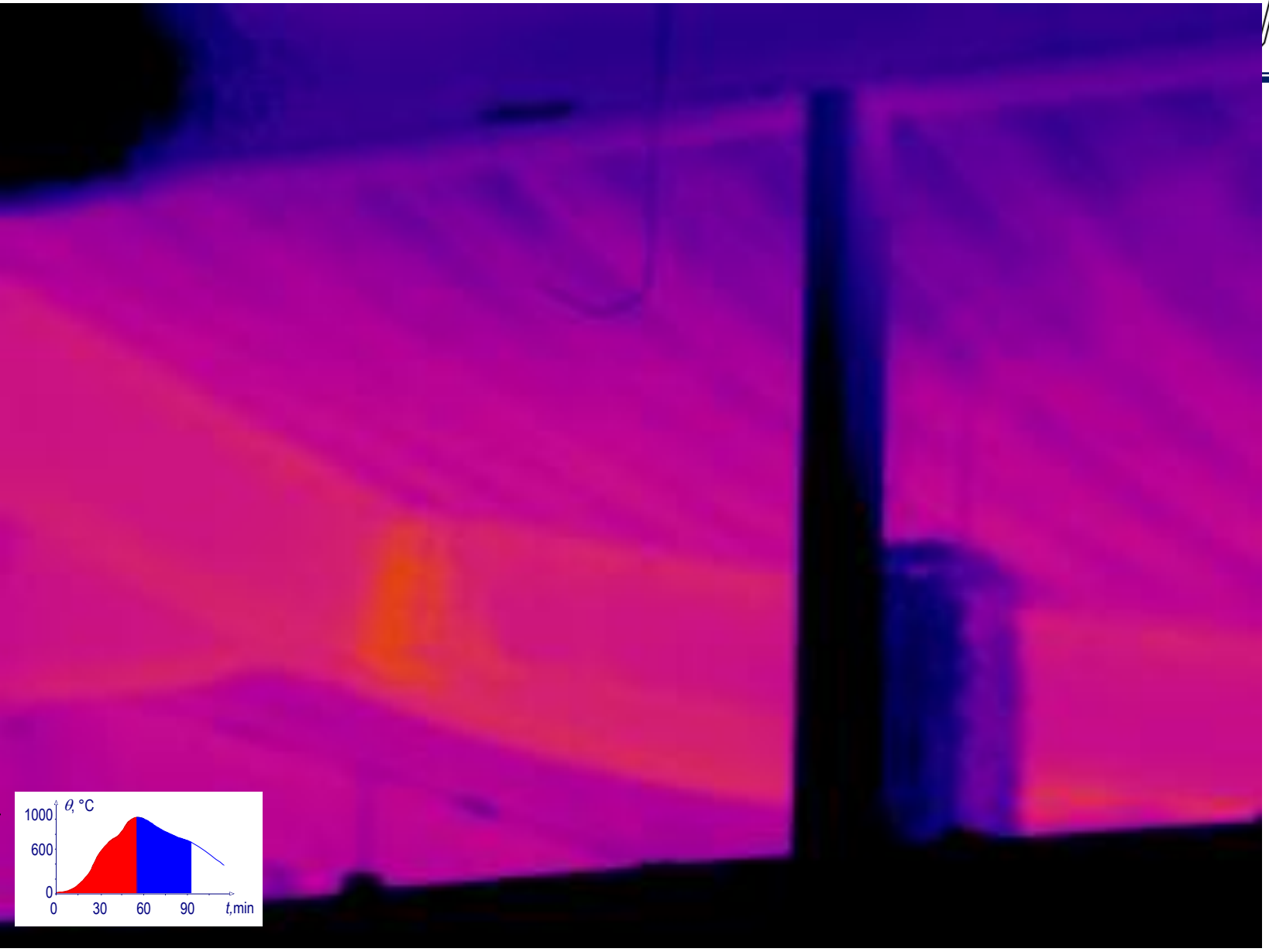
t = 90 min. $\theta_{con,ø}$ = 690 °C



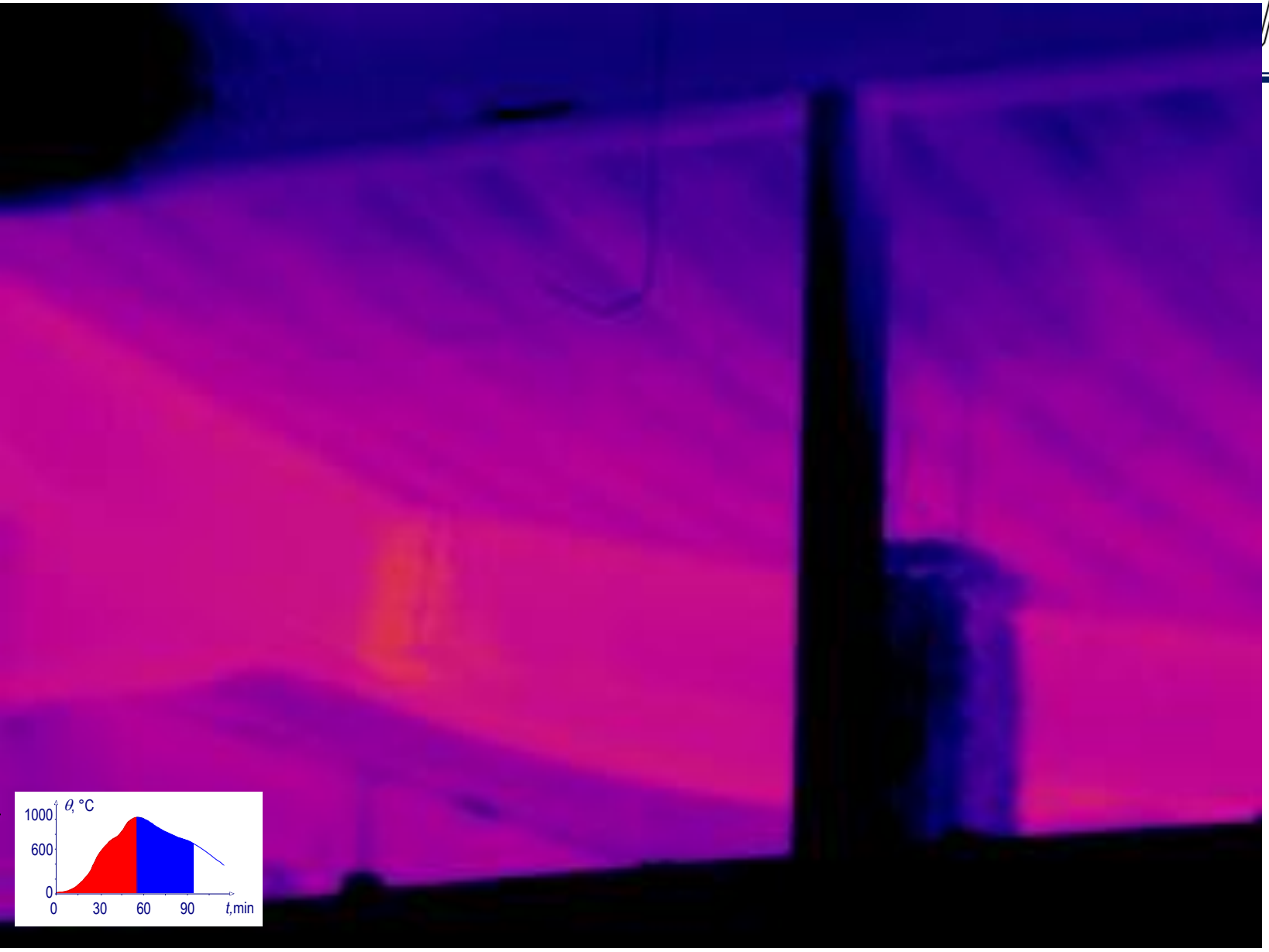
t = 92 min. $\theta_{con,ø}$ = 680 °C



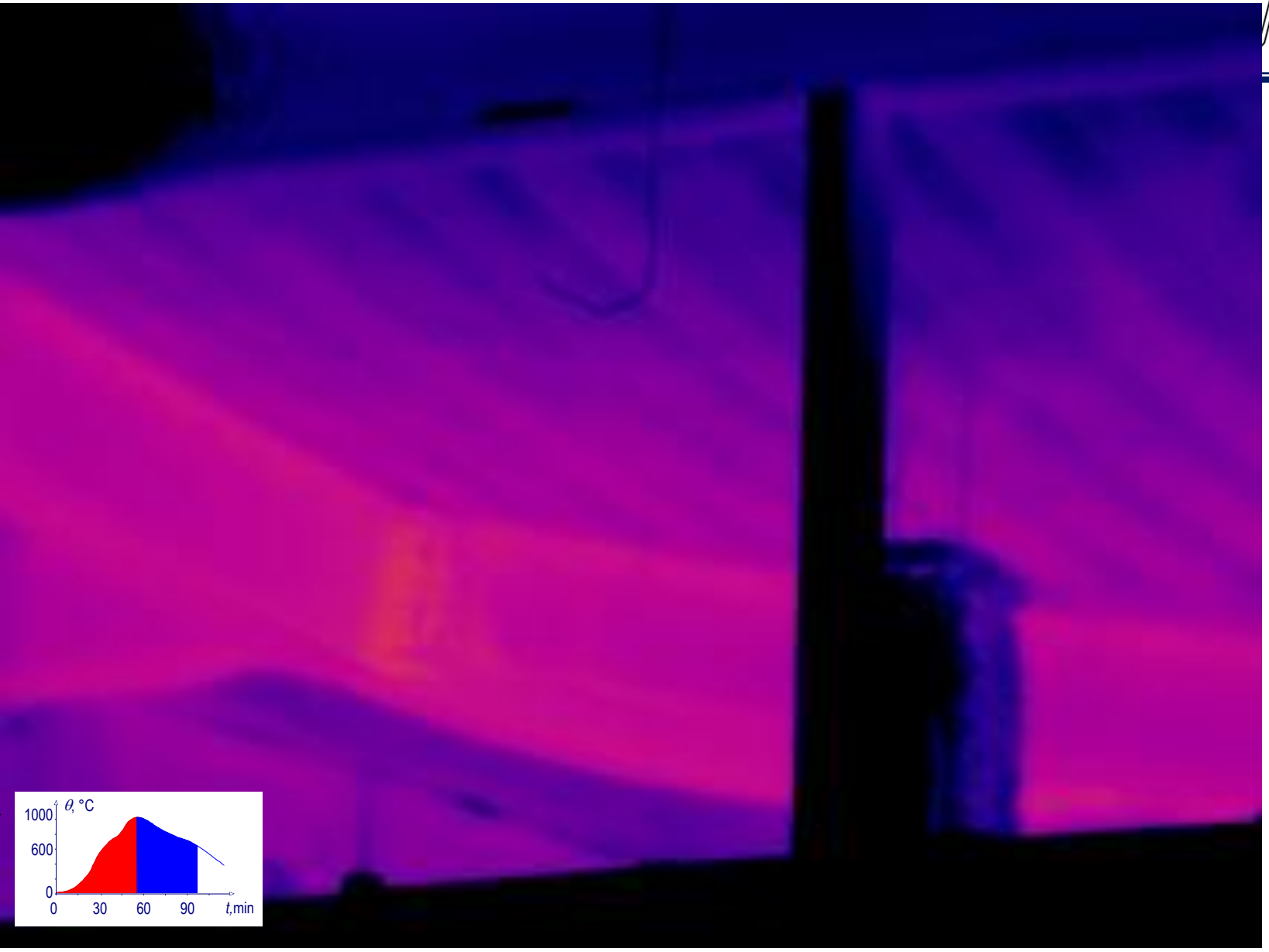
t = 94 min. $\theta_{con,ø}$ = 670 °C



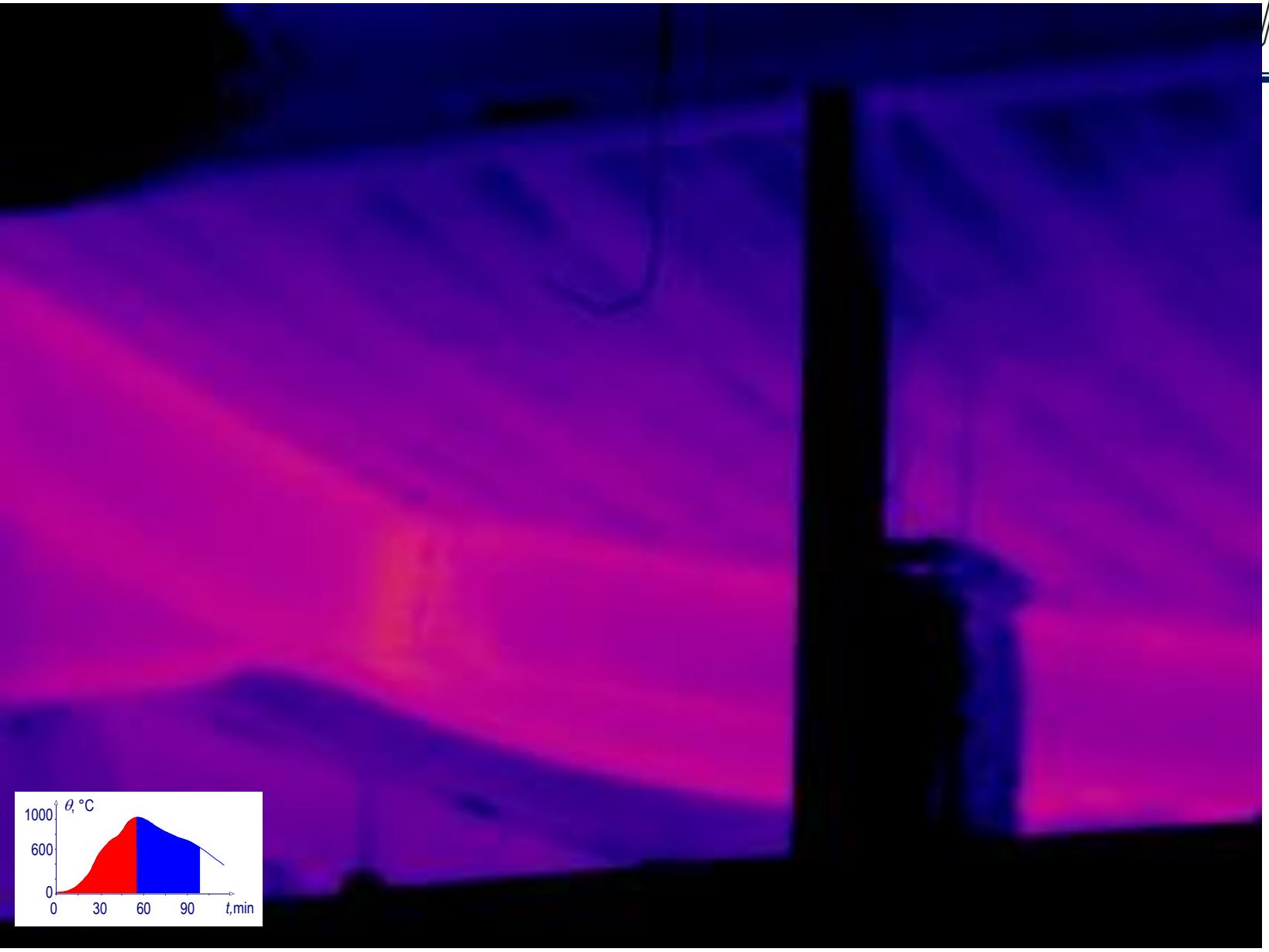
t = 96 min. $\theta_{con,ø}$ = 650 °C



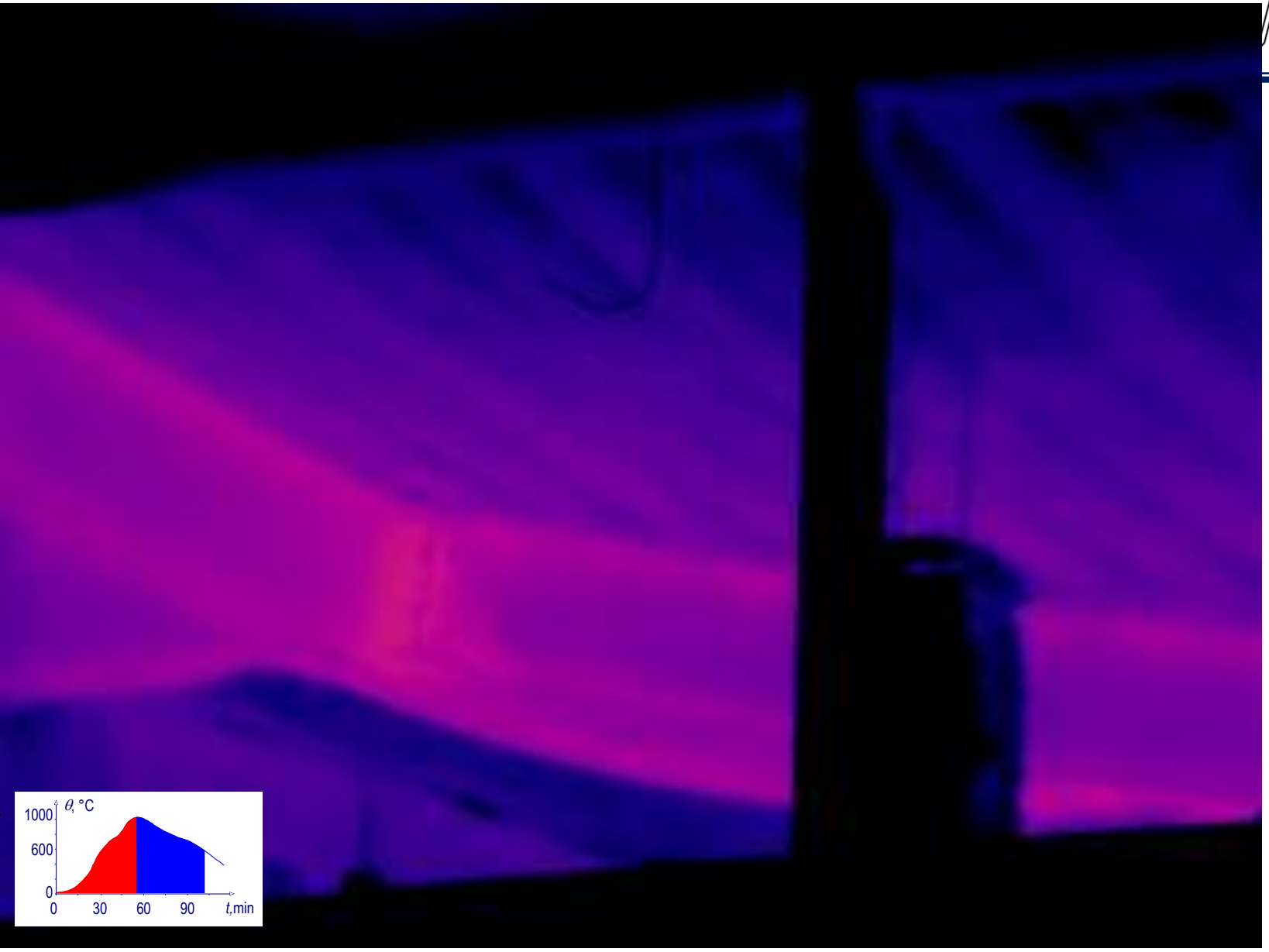
t = 98 min. $\theta_{con,ø}$ = 640 °C



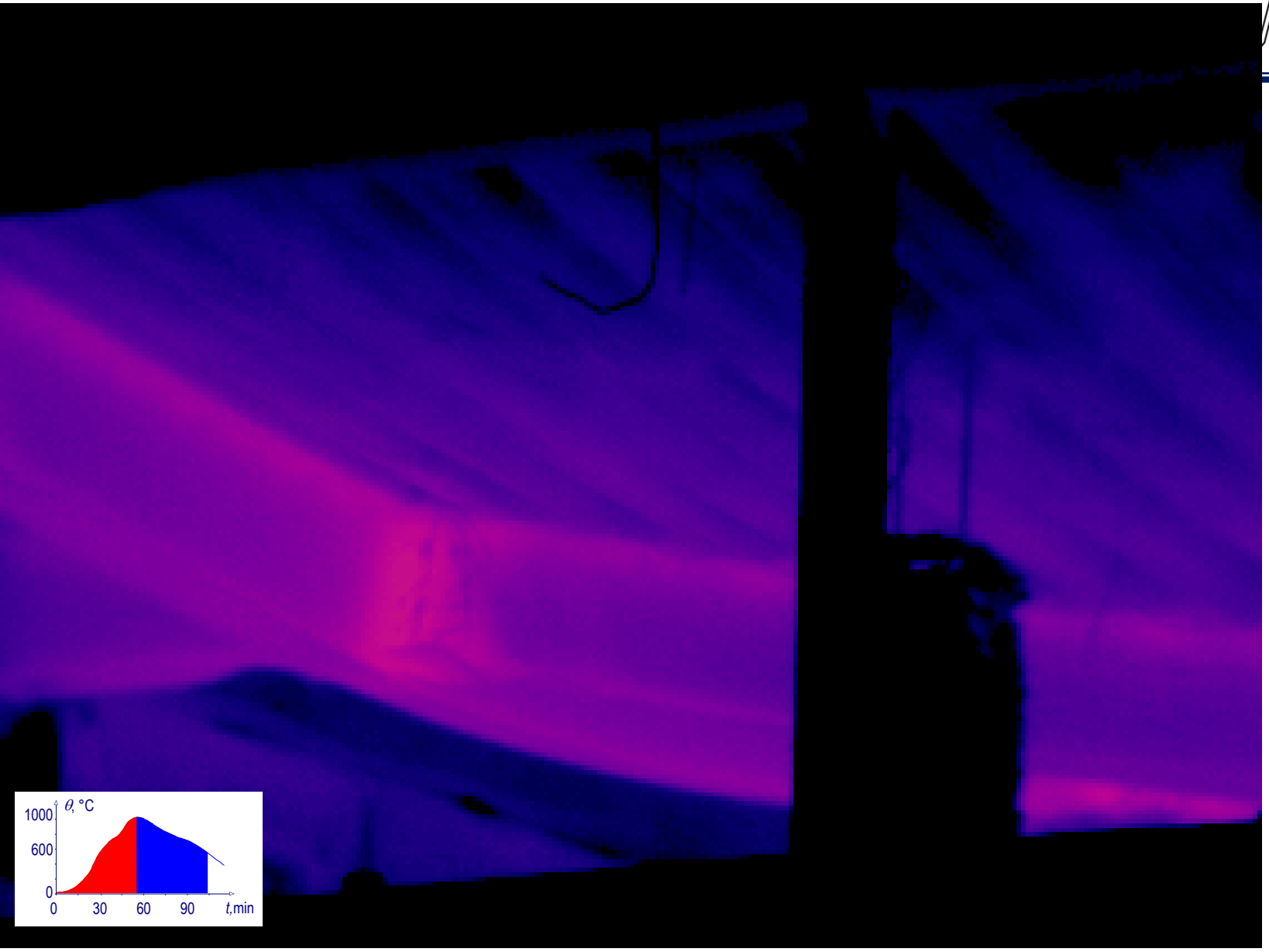
t = 100 min. $\theta_{con,ø}$ = 635 °C



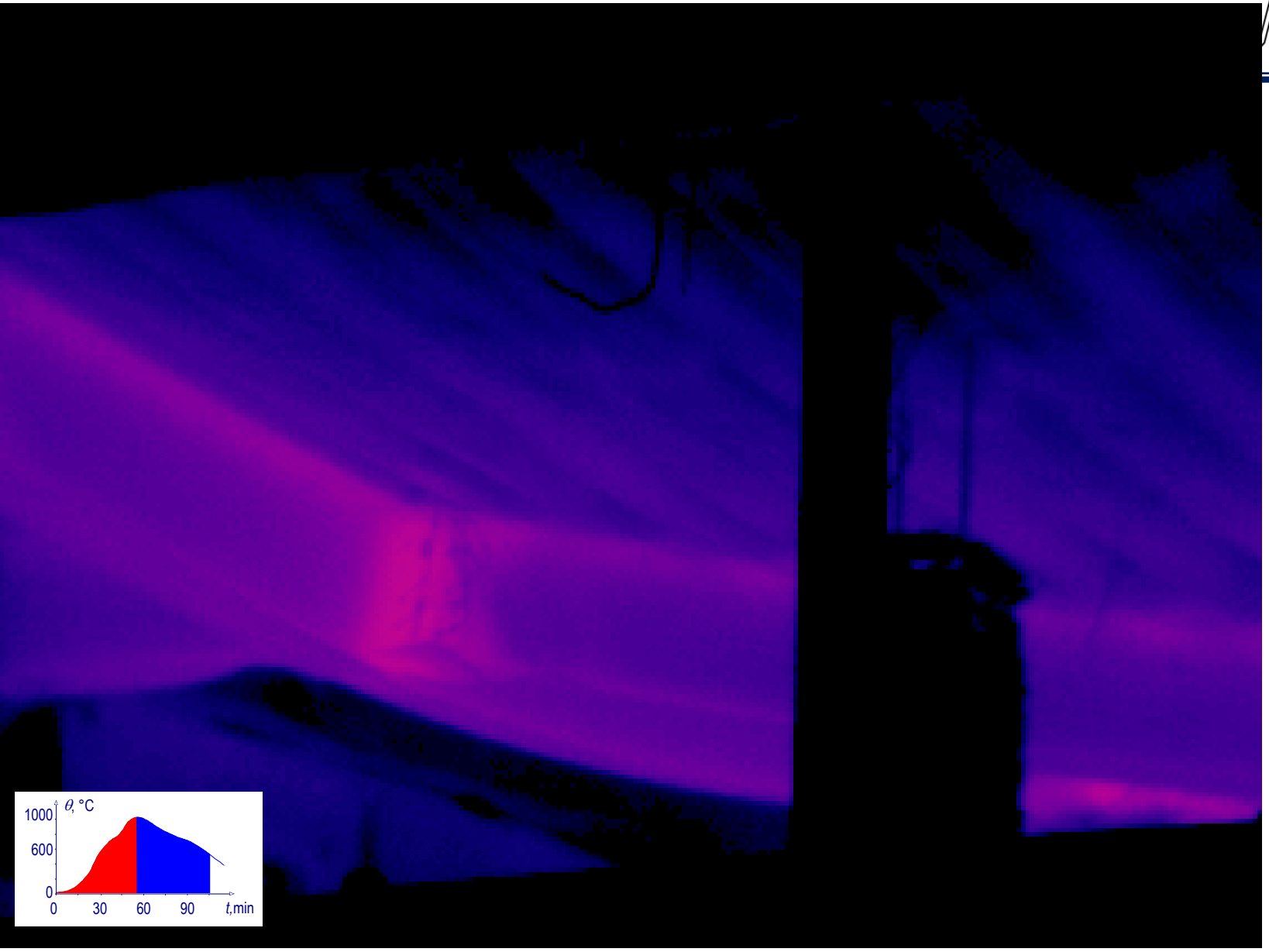
t = 102 min. $\theta_{con,ø}$ = 620 °C



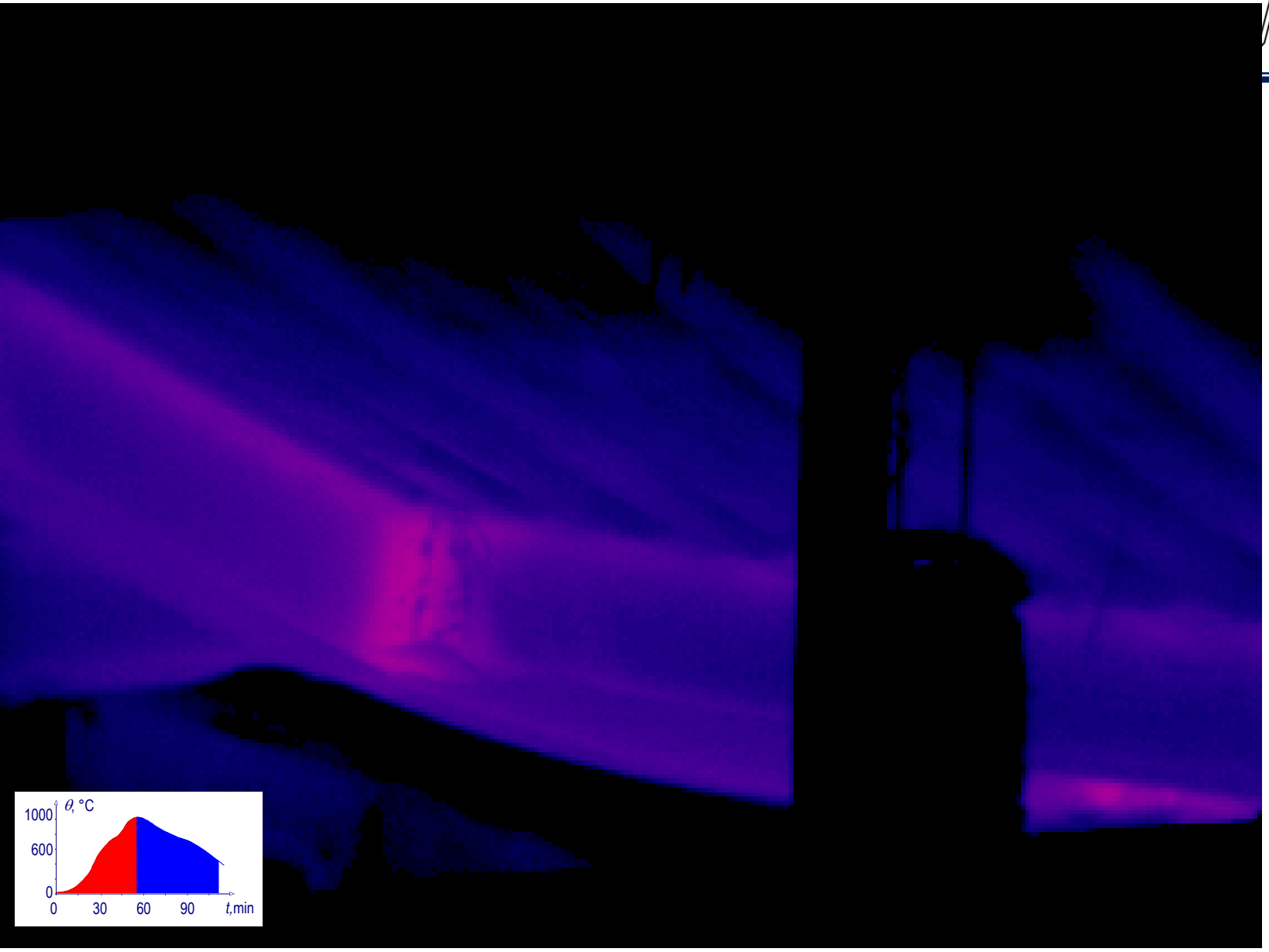
t = 104 min. $\theta_{con,ø}$ = 600 °C



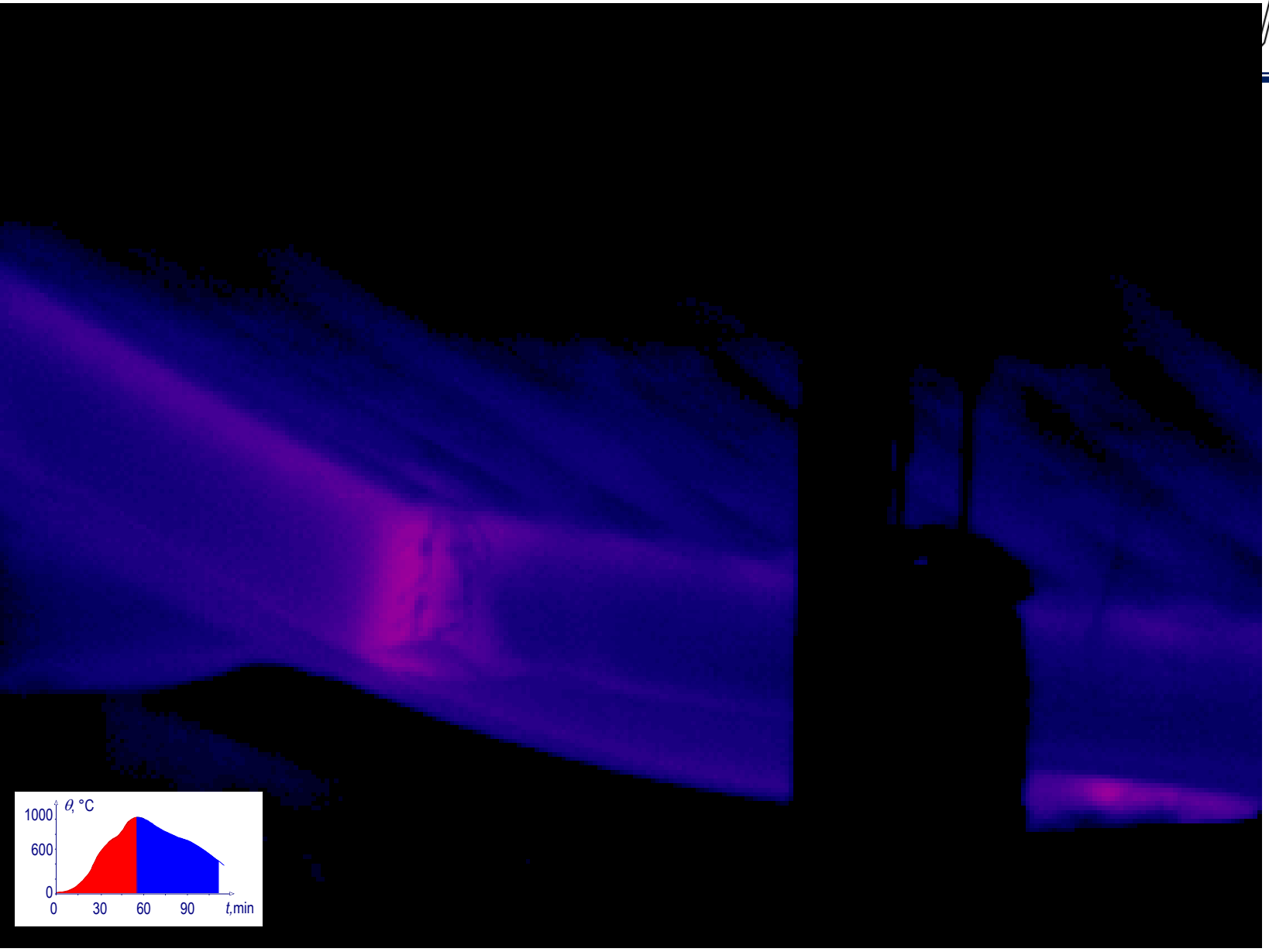
t = 106 min. $\theta_{con,ø}$ = 585 °C



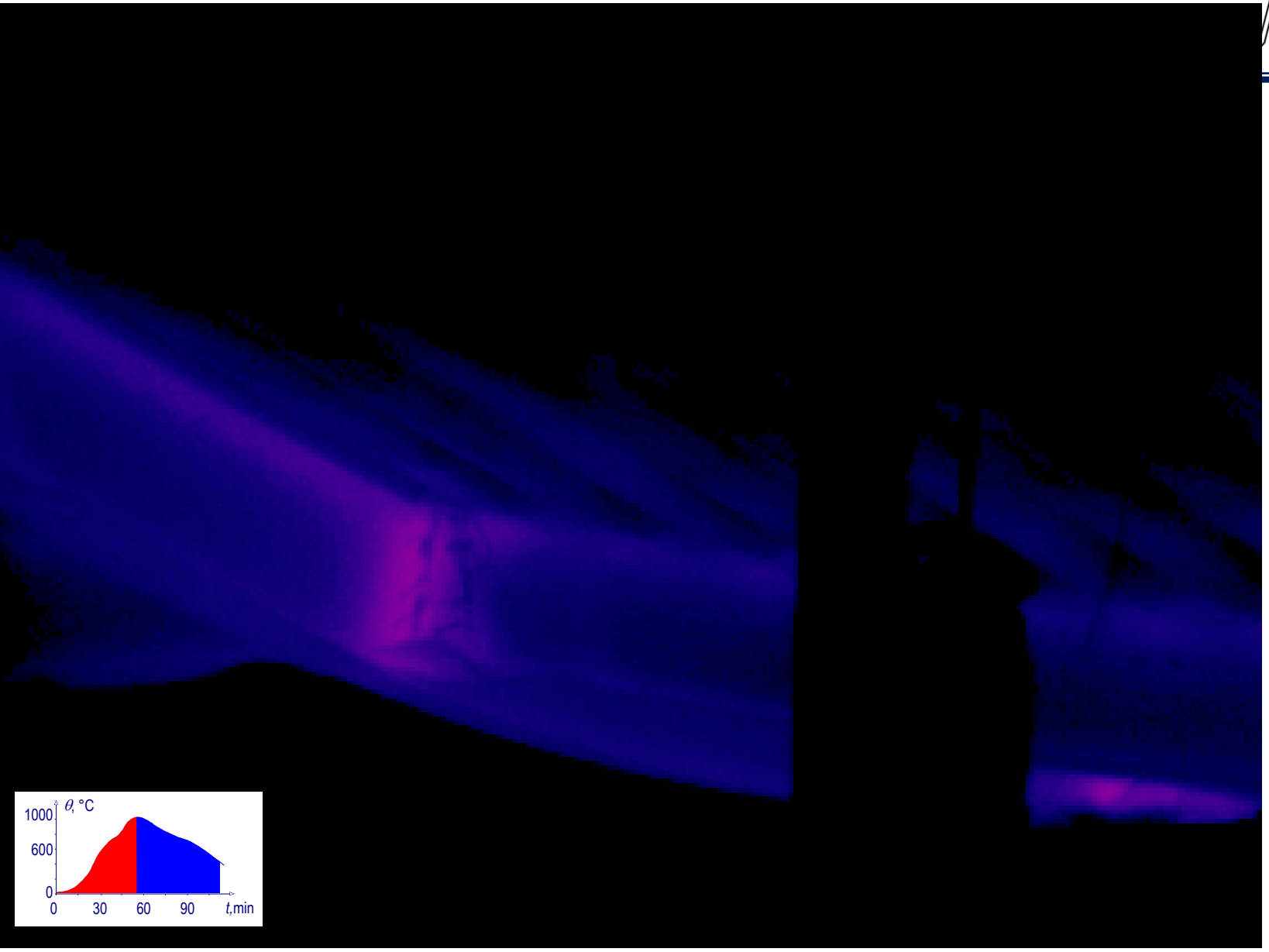
t = 108 min. $\theta_{con,ø}$ = 560 °C



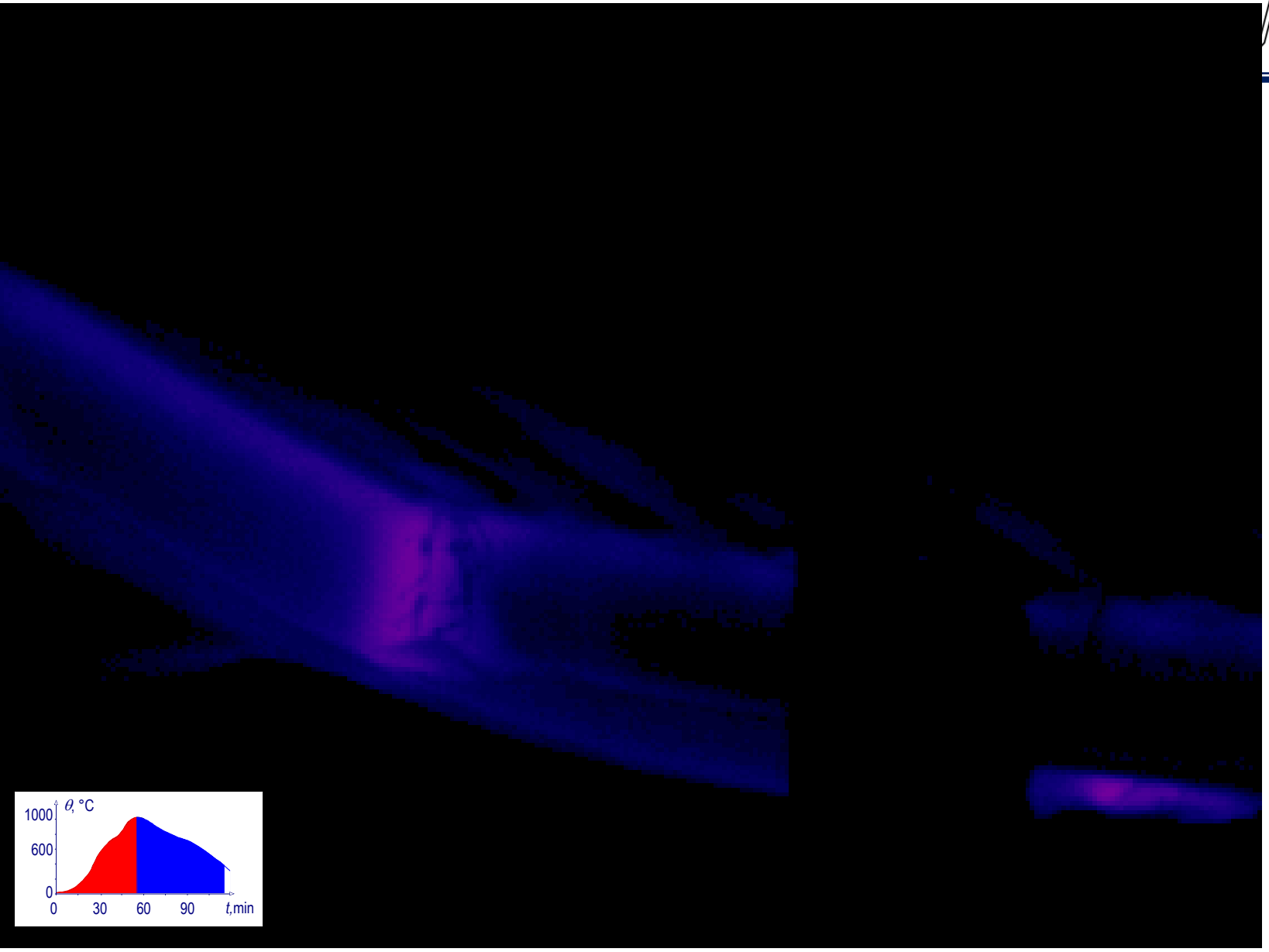
t = 110 min. $\theta_{con,ø}$ = 540 °C



t = 112 min. $\theta_{con,ø}$ = 520 °C

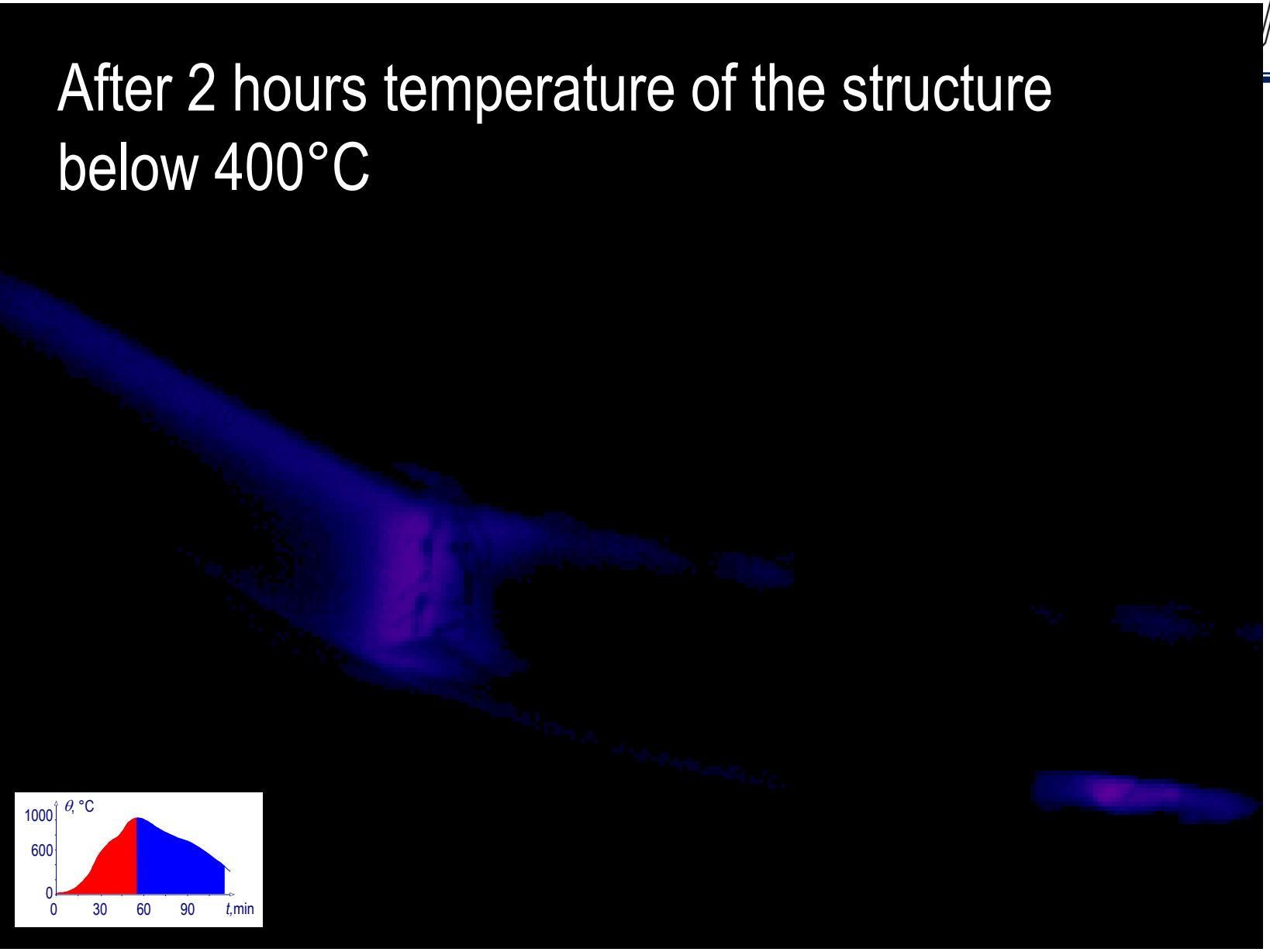


t = 114 min. $\theta_{con,ø}$ = 505 °C

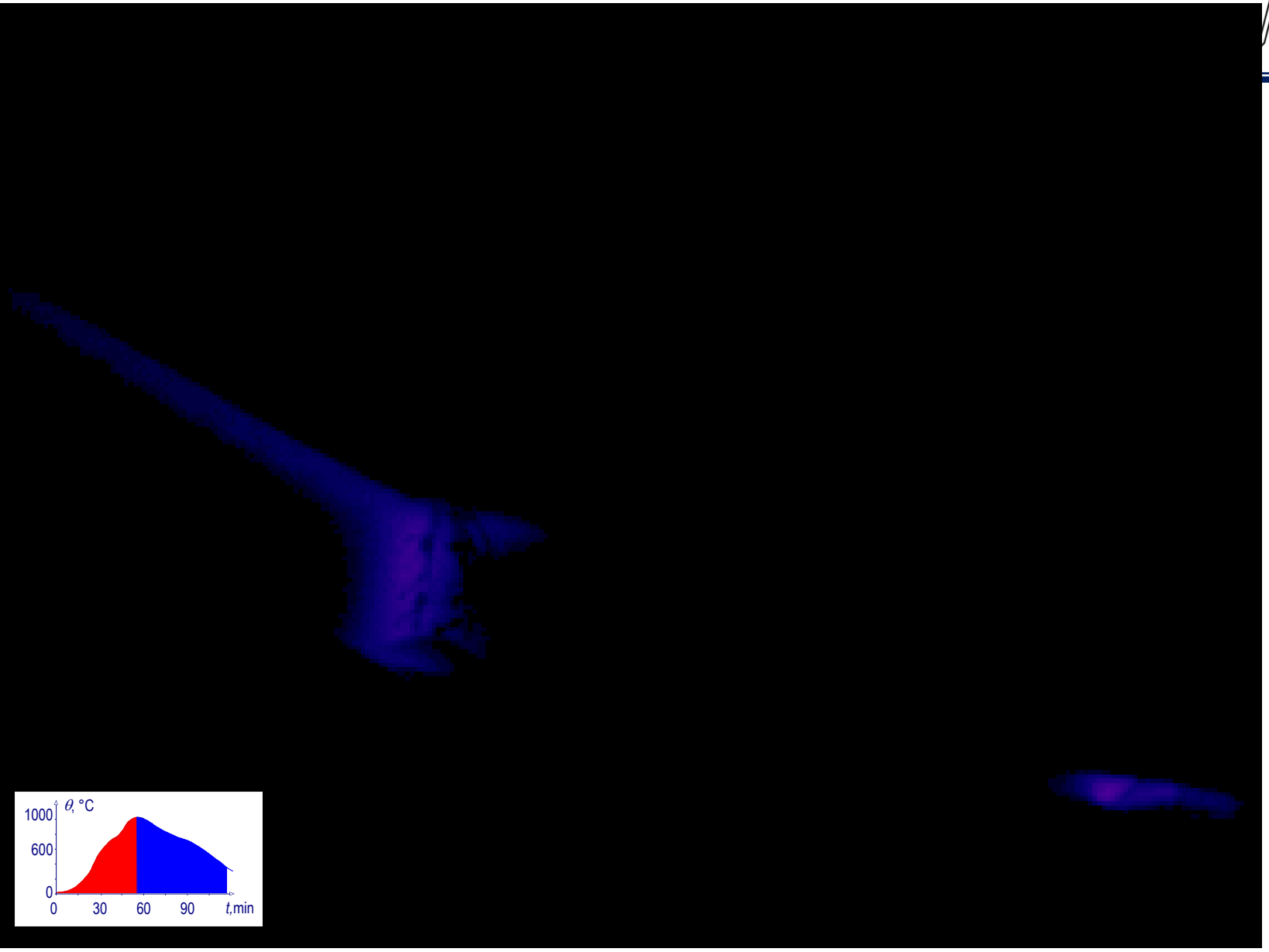


t = 116 min. $\theta_{con,ø}$ = 585 °C

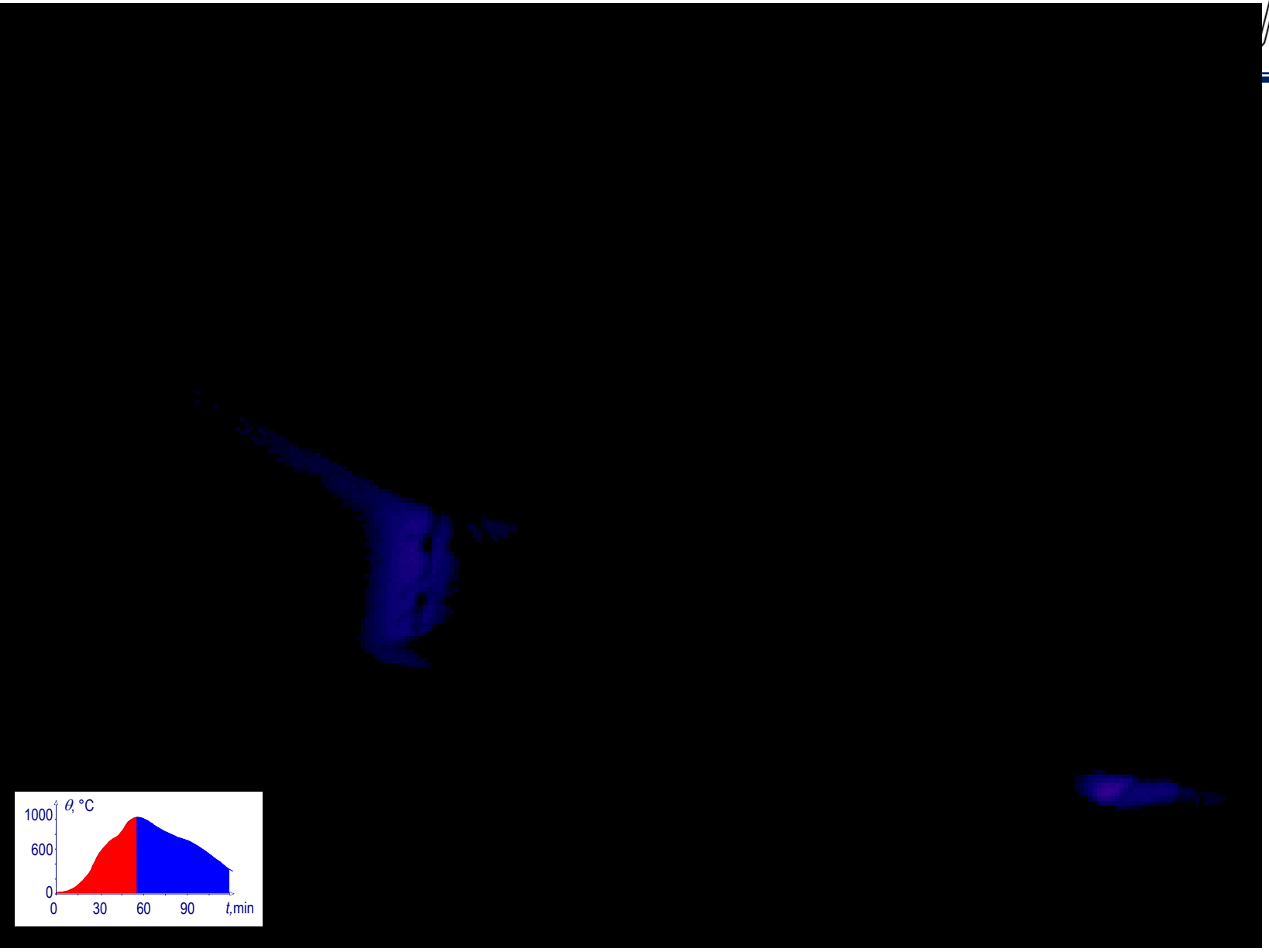
After 2 hours temperature of the structure below 400°C



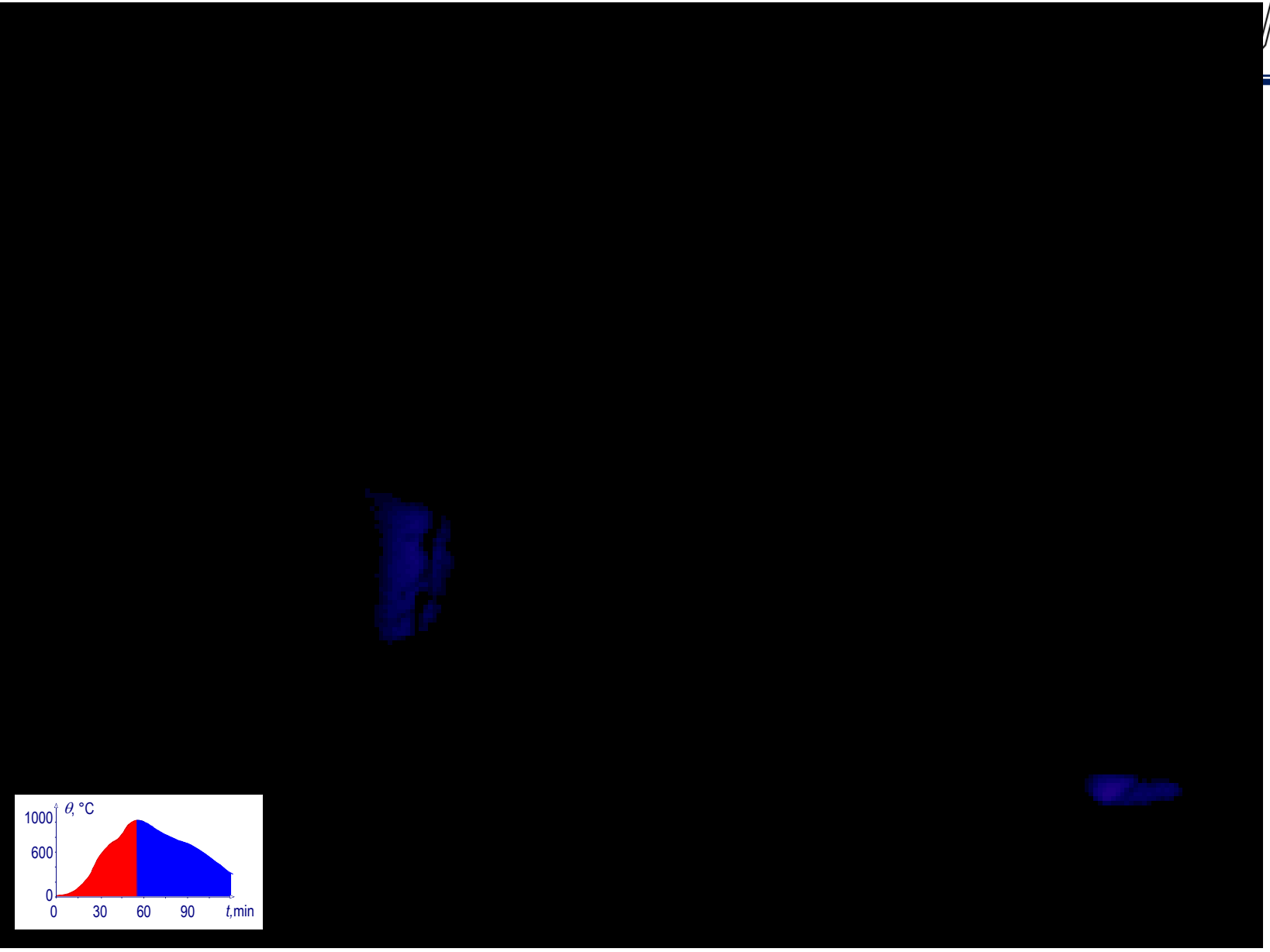
t = 118 min. $\theta_{con,ø}$ = 470 °C

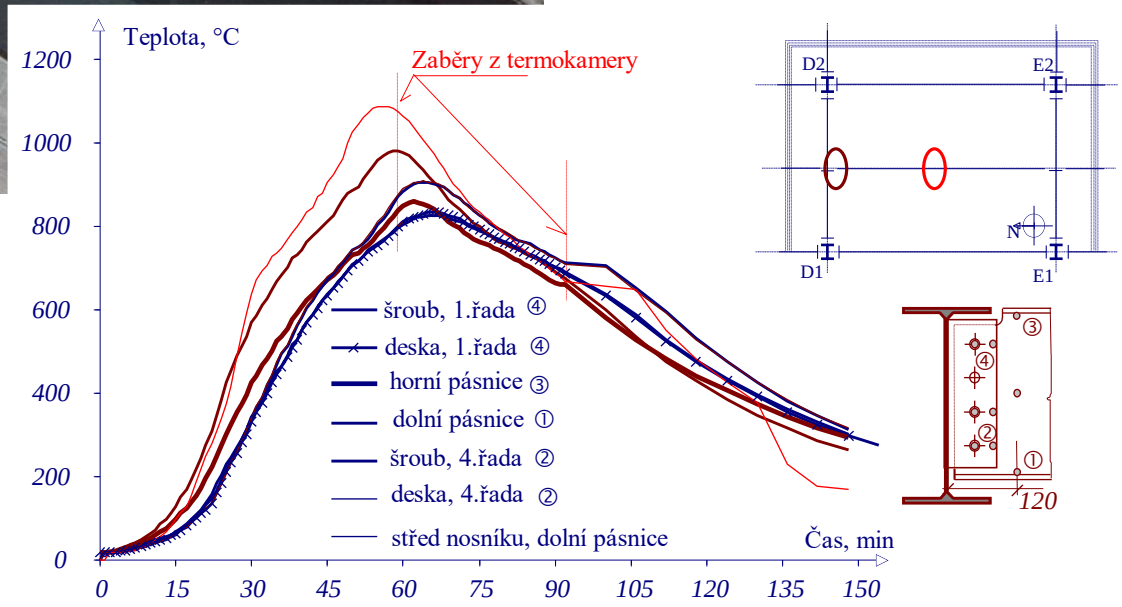


t = 120 min. $\theta_{con,ø}$ = 450 °C



t = 122 min. $\theta_{con,ø}$ = 435 °C



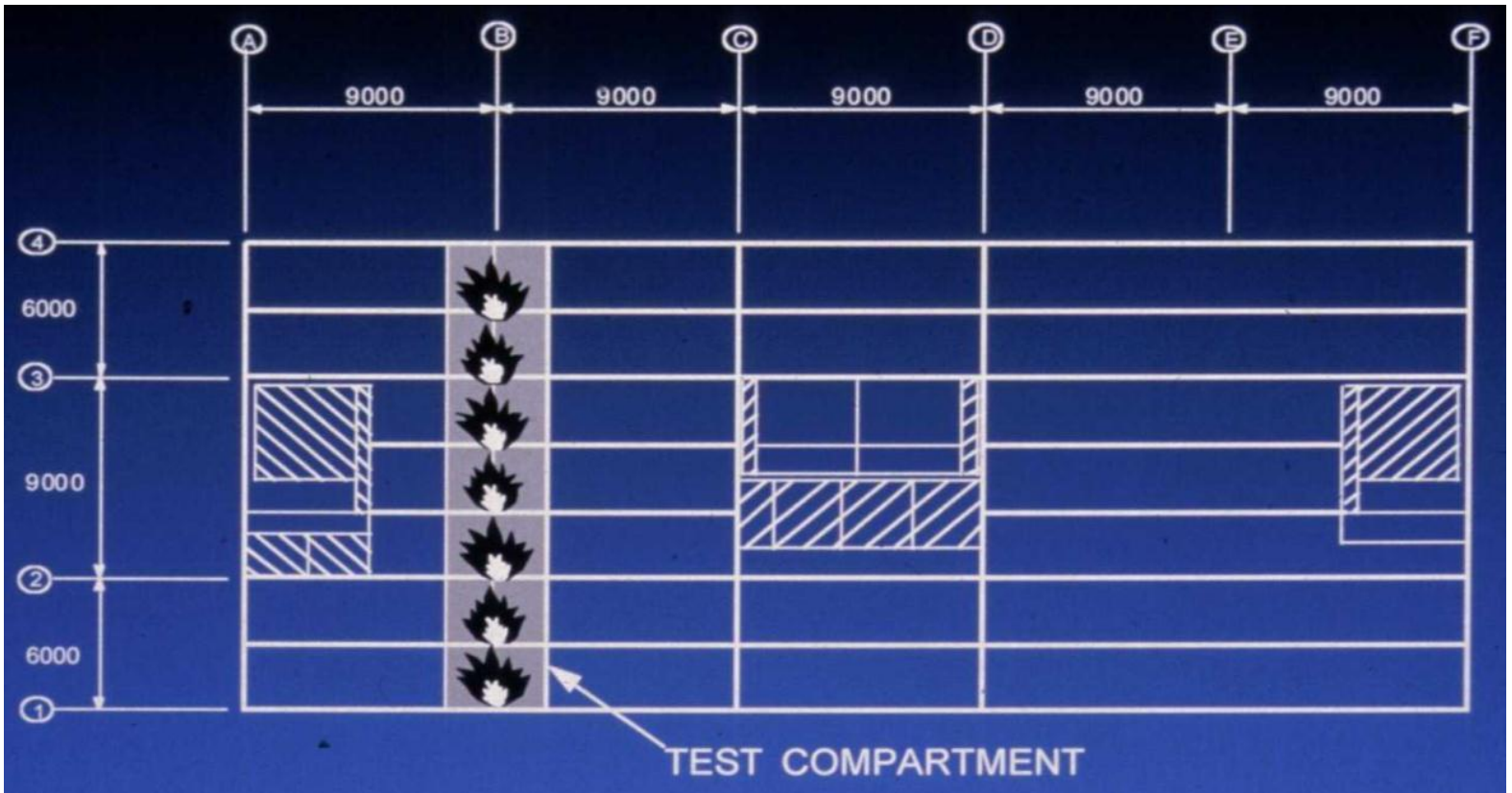


Connection after the test

Cardington

Primary beams along the whole object

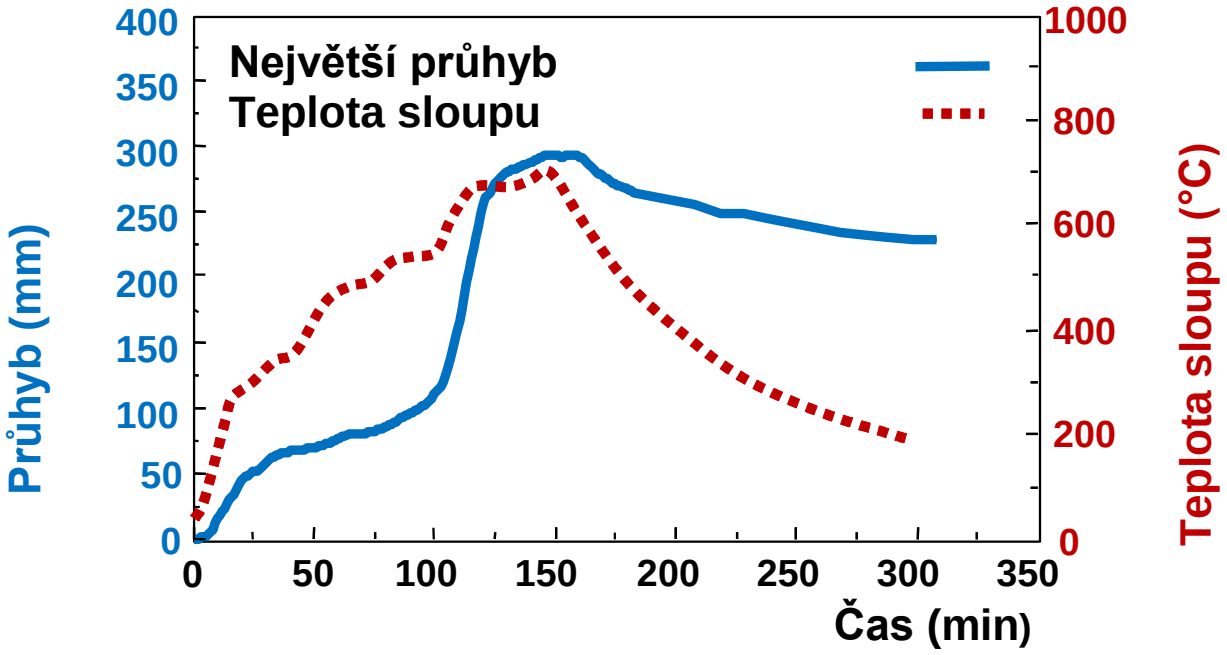
- Heating by gas burners according to standard temperature time curve



Cardington

Primary beams along the whole object

- Results
  - Max. temperature of the beam 750 °C
  - Beam deflection ≈ 300 mm



Cardington

Primary beams along the whole object

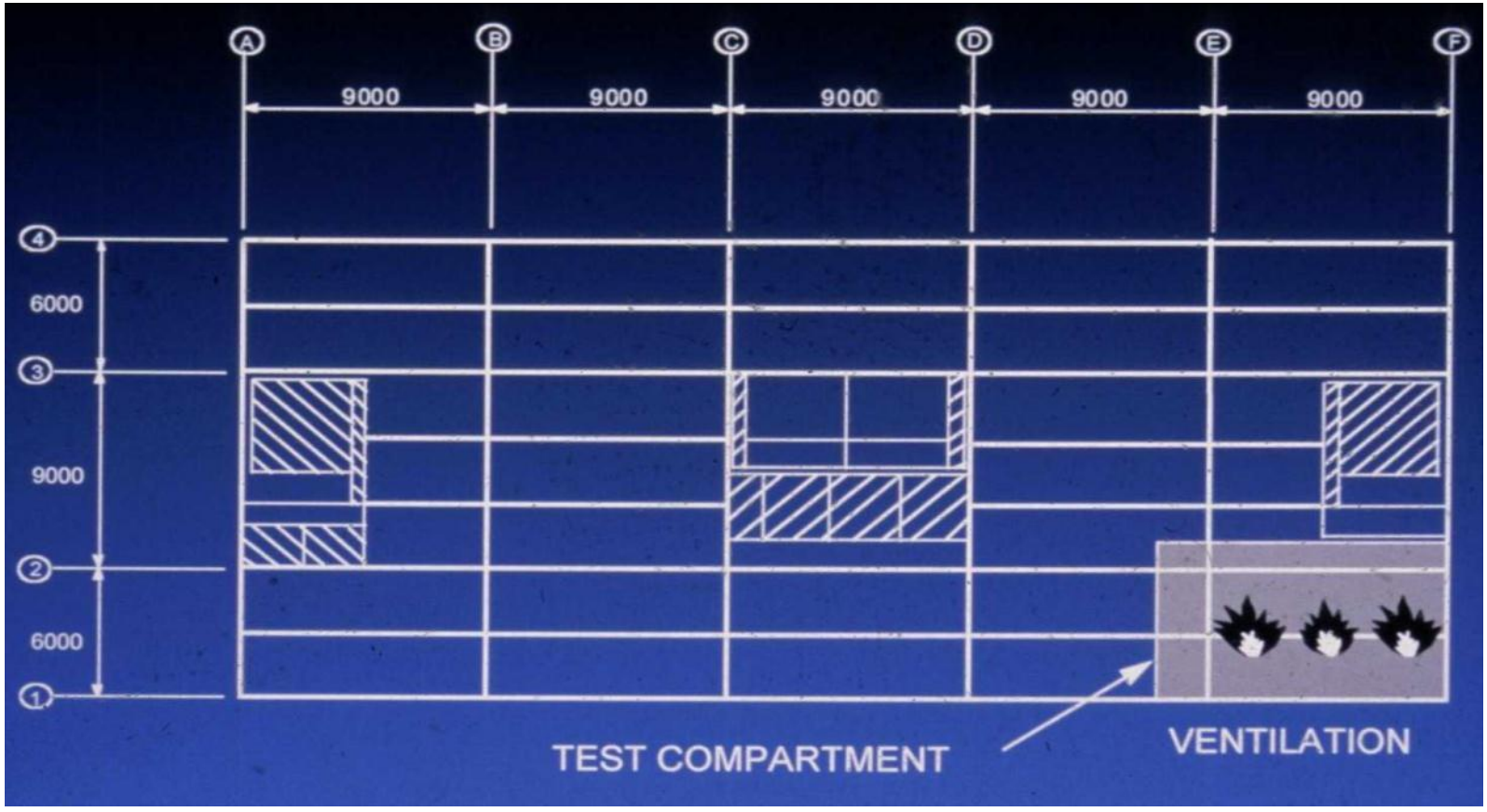
- Beams deflection

- Deformation of the column

Cardington

Fire compartment in the corner of the object

- Fire load – wooden cribs



Cardington

Fire compartment in the corner of the object

- **Before the test**

Walls of the fire compartment

Fire load of 45 kg/m²

Cardington

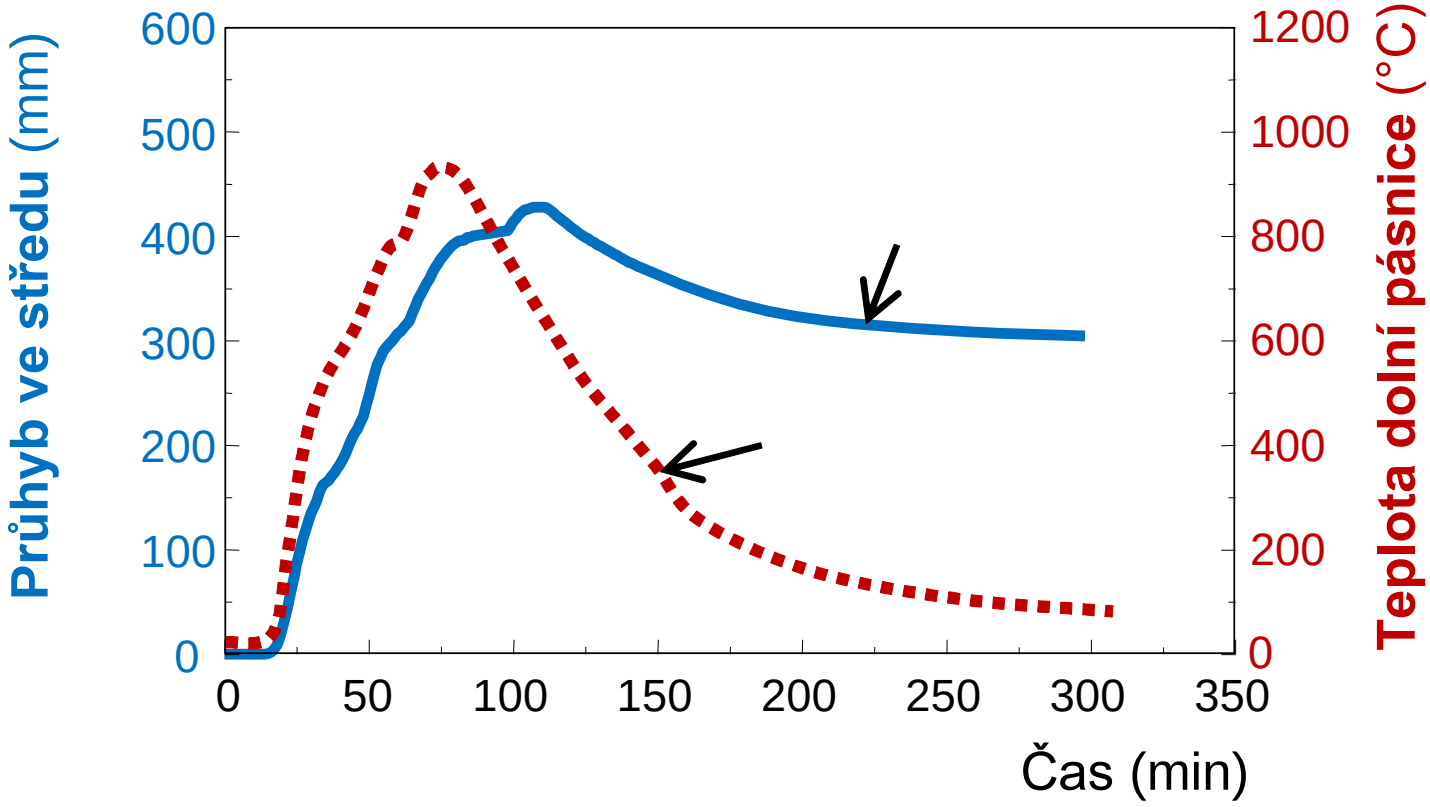
Fire compartment in the corner of the object

During the fire test

Fire load after the test

Cardington

Fire compartment in the corner of the object



- Lower flange beam temperature 1014 °C
- Deflection in the middle of the span over 428 mm

Cardington

Fire compartment in the corner of the object

- **Structure after the fire test**

Deformation of the floor slab

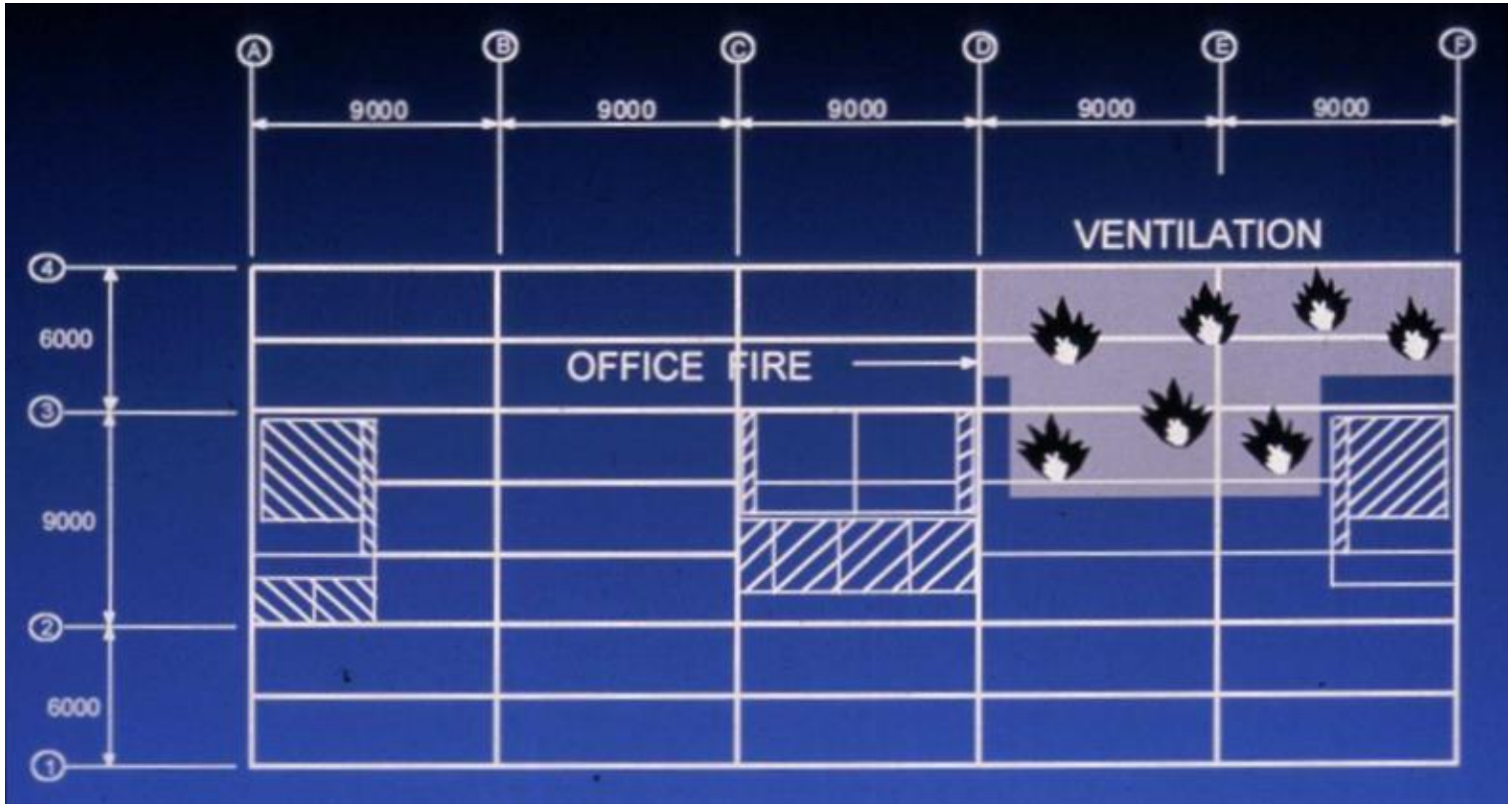
Beams around the fire protected column

- **Conclusions**
  - **Failure of the structure was not observed, only heating and deformation of members**

Cardington

Demonstration fire test

- Floor area of the fire compartment 130 m²
- Fire load – office furniture, computers, papers



Cardington

Demonstration fire test

Fire load

Windows with glass

Cardington

Demonstration fire test

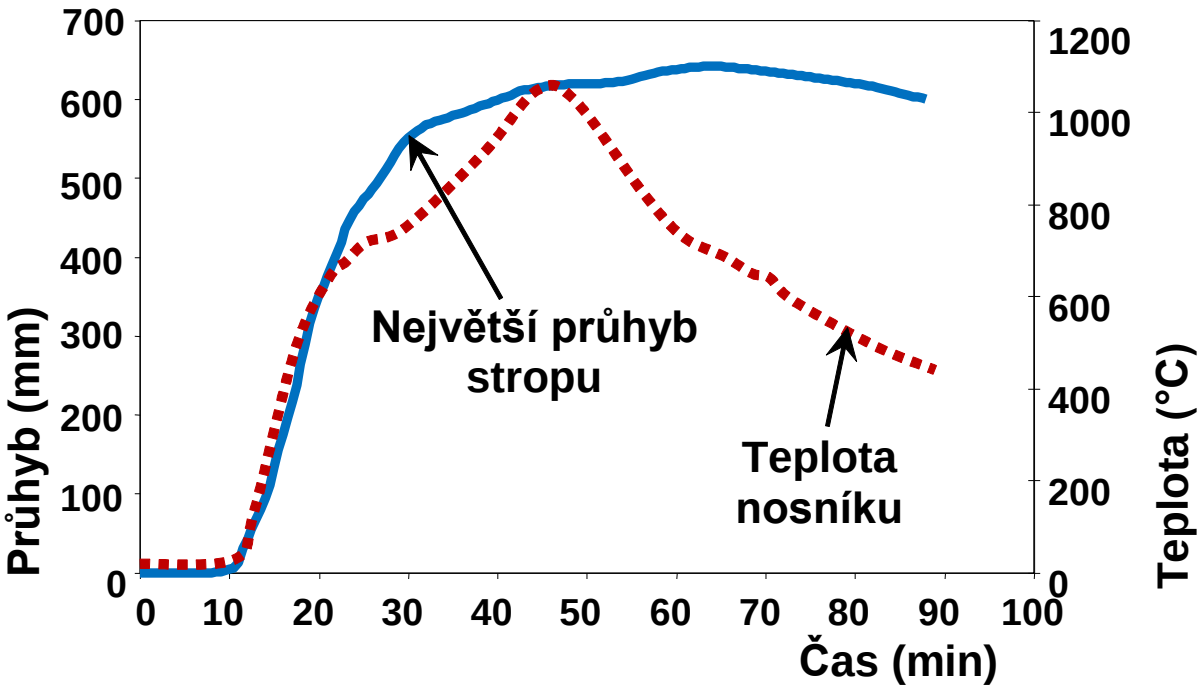
Begining of the fire

Fully-developed fire

Cardington

Demonstration fire test

- **Results**



- **Observation**
  - Floor slab deformation ≈ 640 mm
  - No brekage of integrity

Cardington

Demonstration fire test

- After the fire test
- No loss of integrity of the structure, no failure

Secondary beam deflection
640 mm

Connection to column

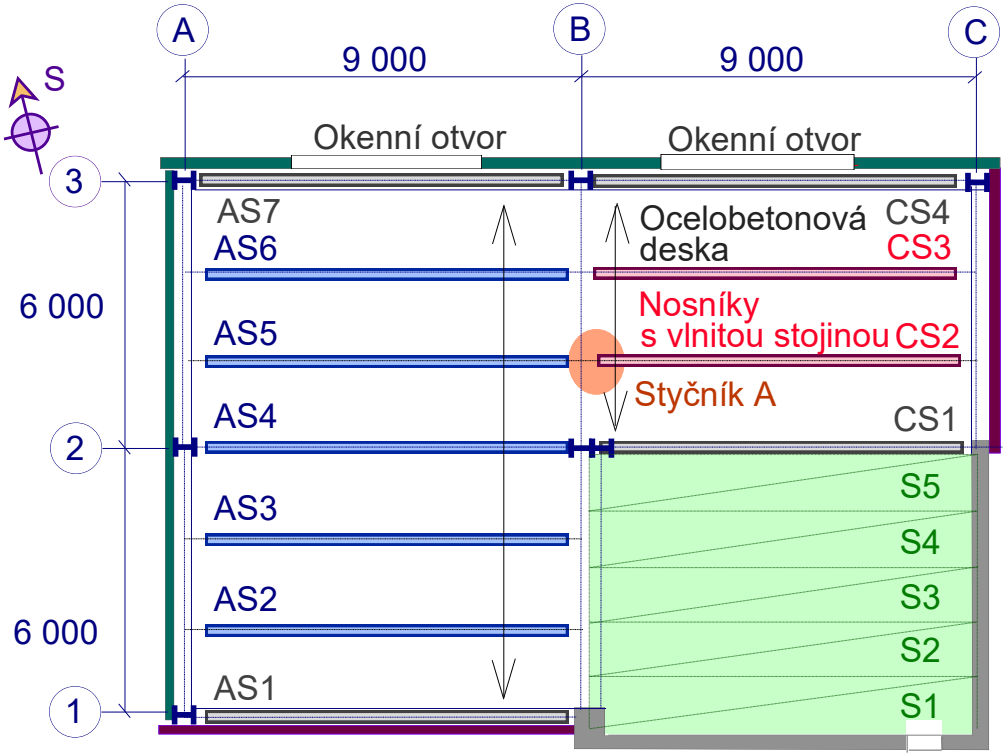
Cardington

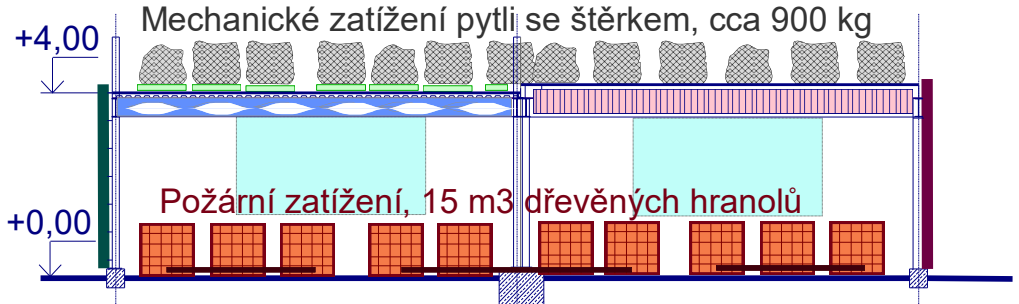
- Findings
  - On the structure of steel-concrete composite building there were 7 full-scale tests – no failure of the structure
  - Behaviour of the structure is better than behaviour of the separated members
  - Floor slab could resist to temperatures over 1000 °C
  - During big deflections a membrane effect was observed
  - Floor slab kept its integrity

Mokrsko

- CTU fire test in 2008

Mokrsko



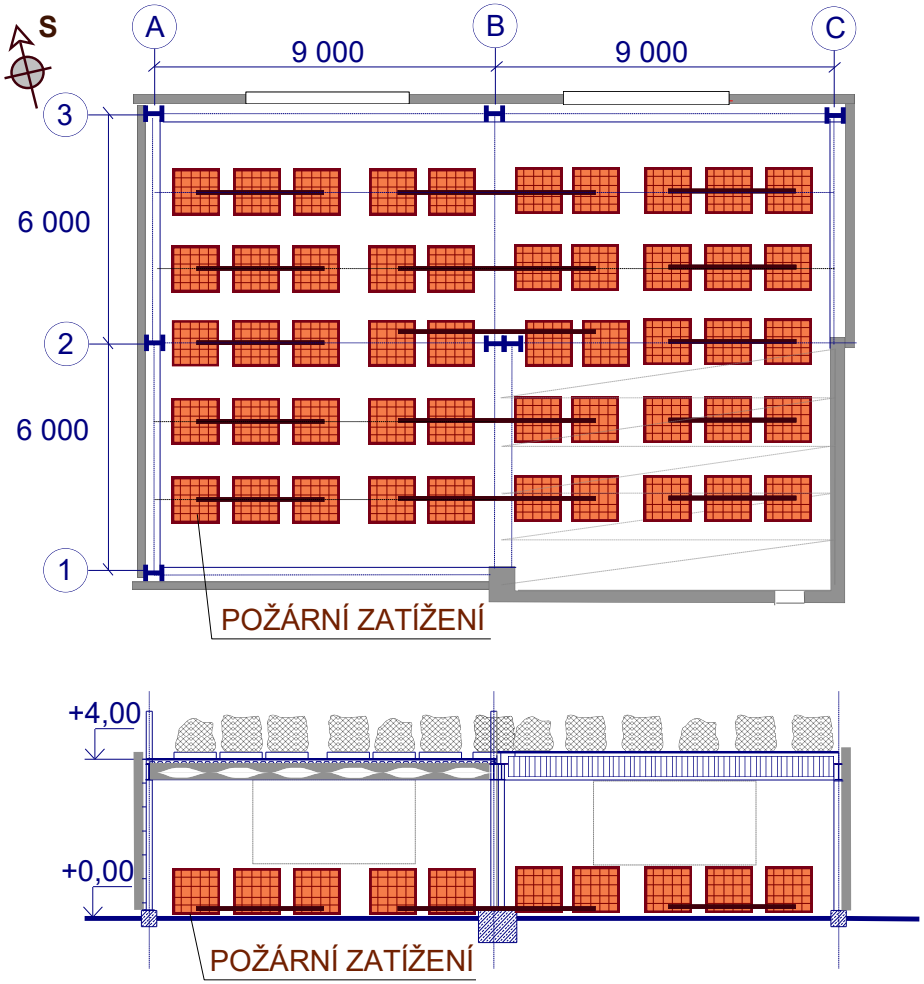


Load:
mechanical
q_k = 3,25 kN/m^2 ,
Dead weight of the slab
g_k = 2,60 kN/m^2

Internal forces at beam CS2 during the fire test:
M = 119,8 kNm,
V = 53,24 kN

Mokrsko

- Fire load – wooden cribs, 35,5 kg/m^2



Mokrsko

- Fire load – wooden piles, 35,5 kg/m^2

Mokrsko

- Bearing structure

- Beams with corrugated web, cellular beams (Angelina)
- Composite steel-concrete floor
- Concrete SPIROL panels

Mokrsko

- Measuring of temperature of the structure

Mokrsko

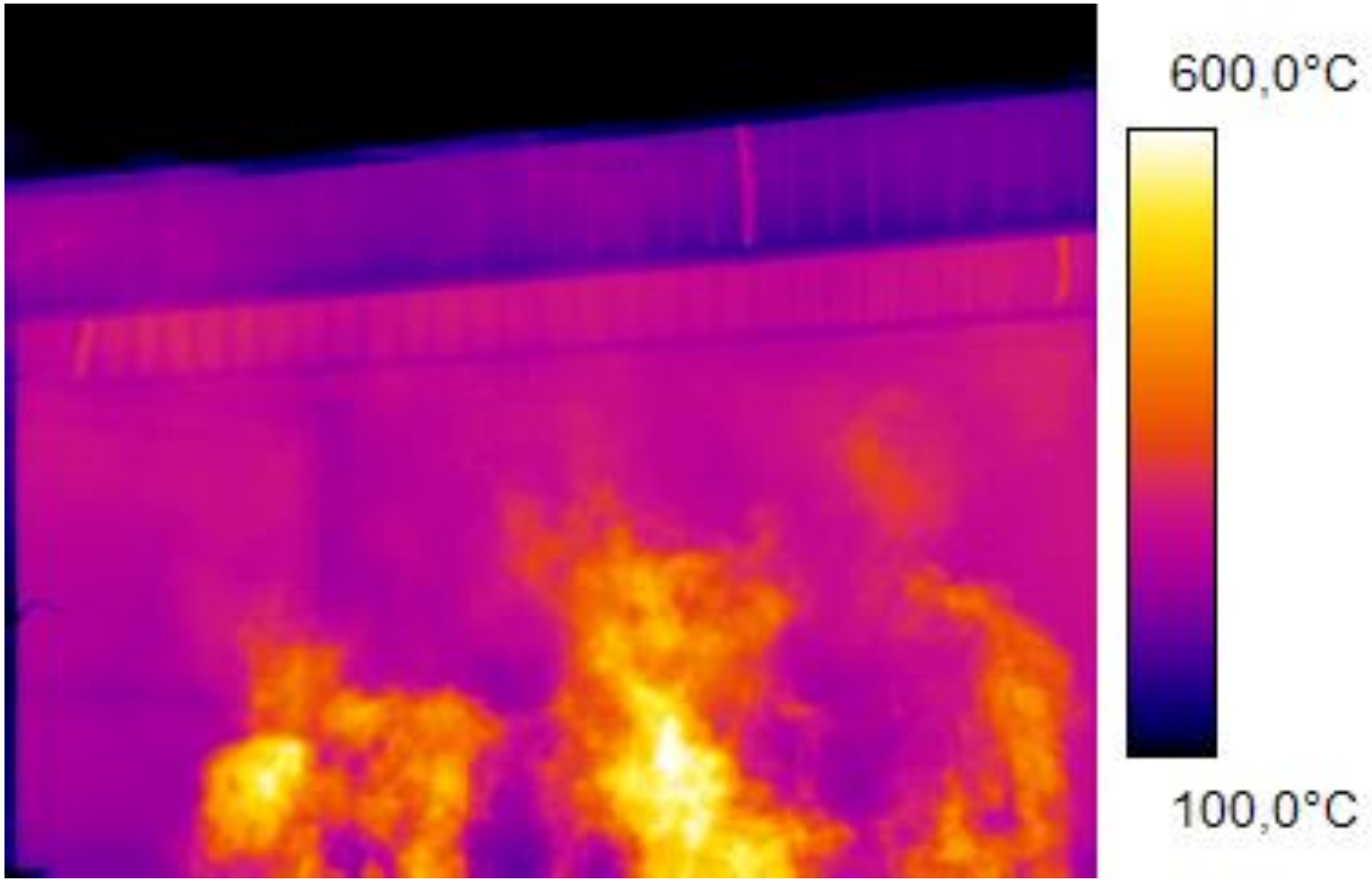
- During the fire test

Mokrsko

- During the fire test

Mokrsko

- Measurement with thermocamera

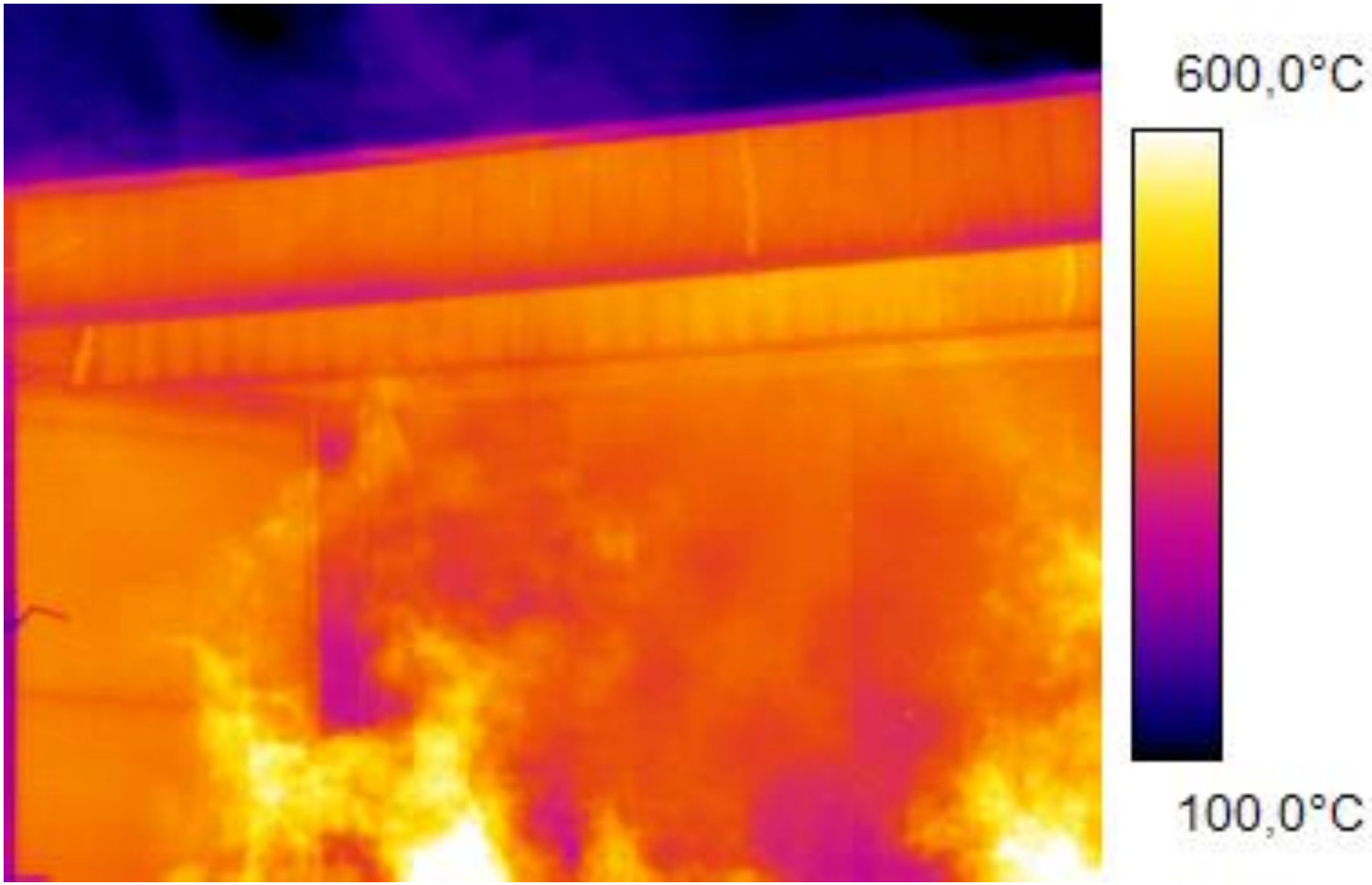


Mokrsko

- Fully-developed fire

Mokrsko

- Measurement with thermocamera

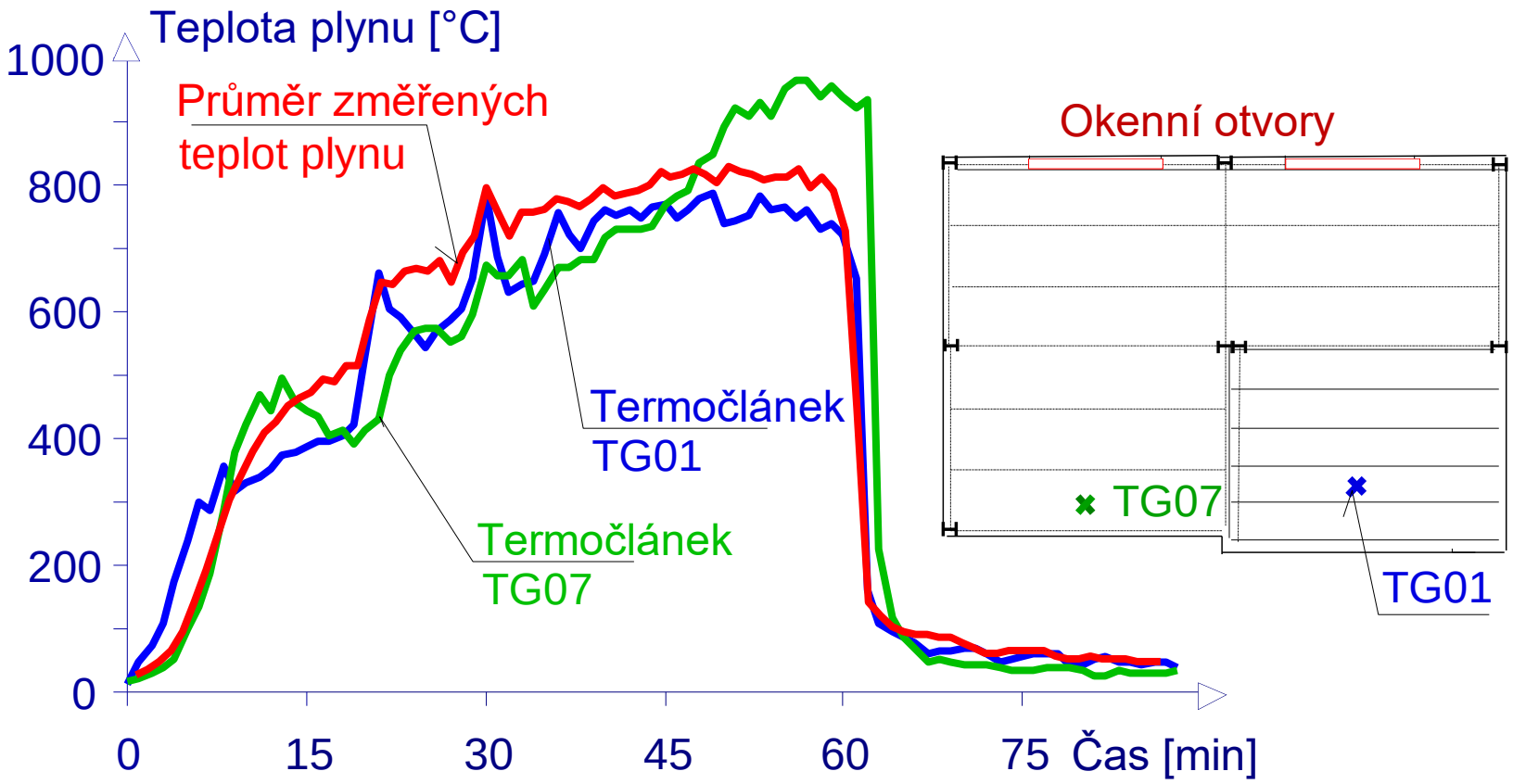


Mokrsko

- During the fire test

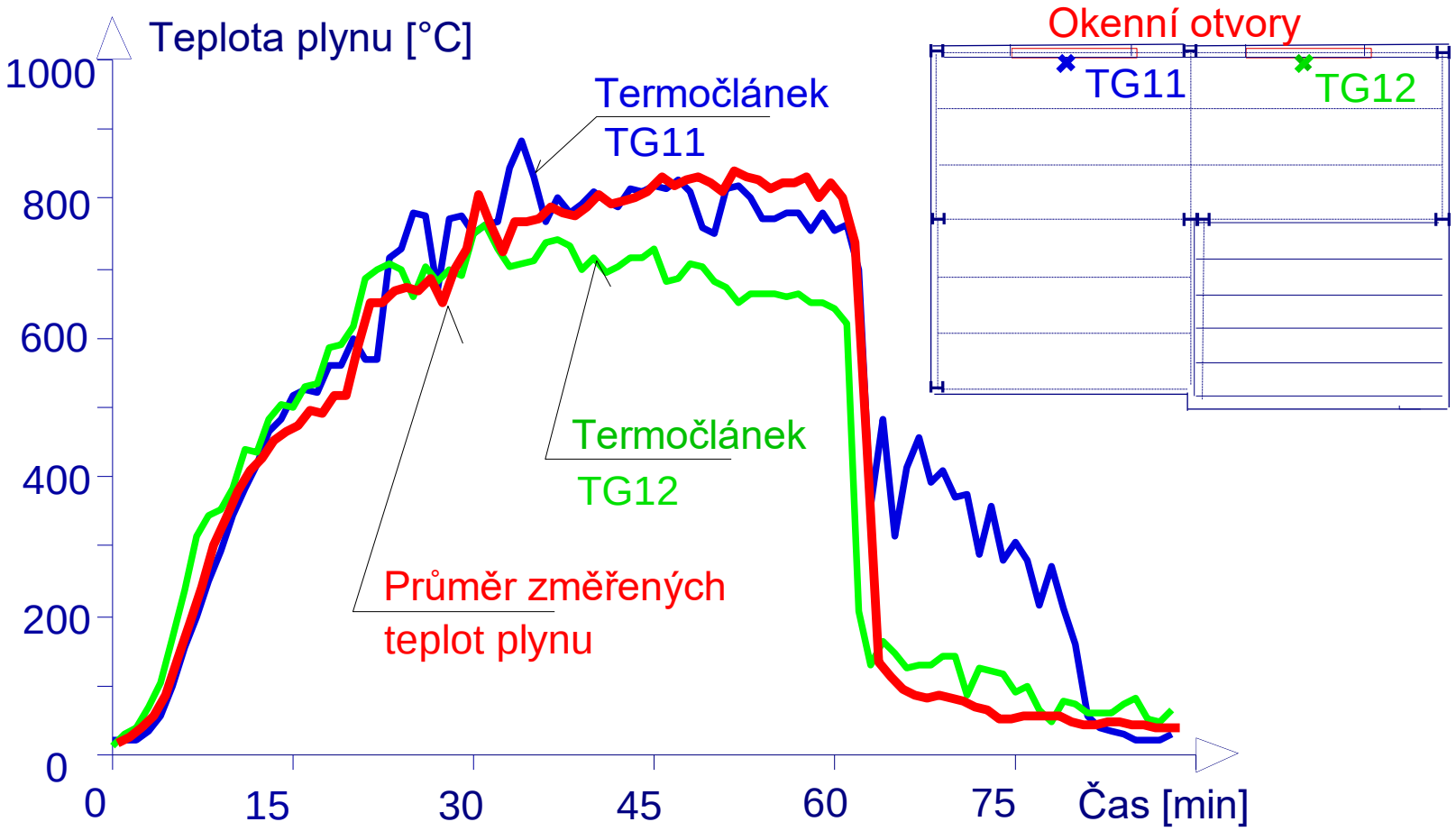
Mokrsko

- Gas temperature



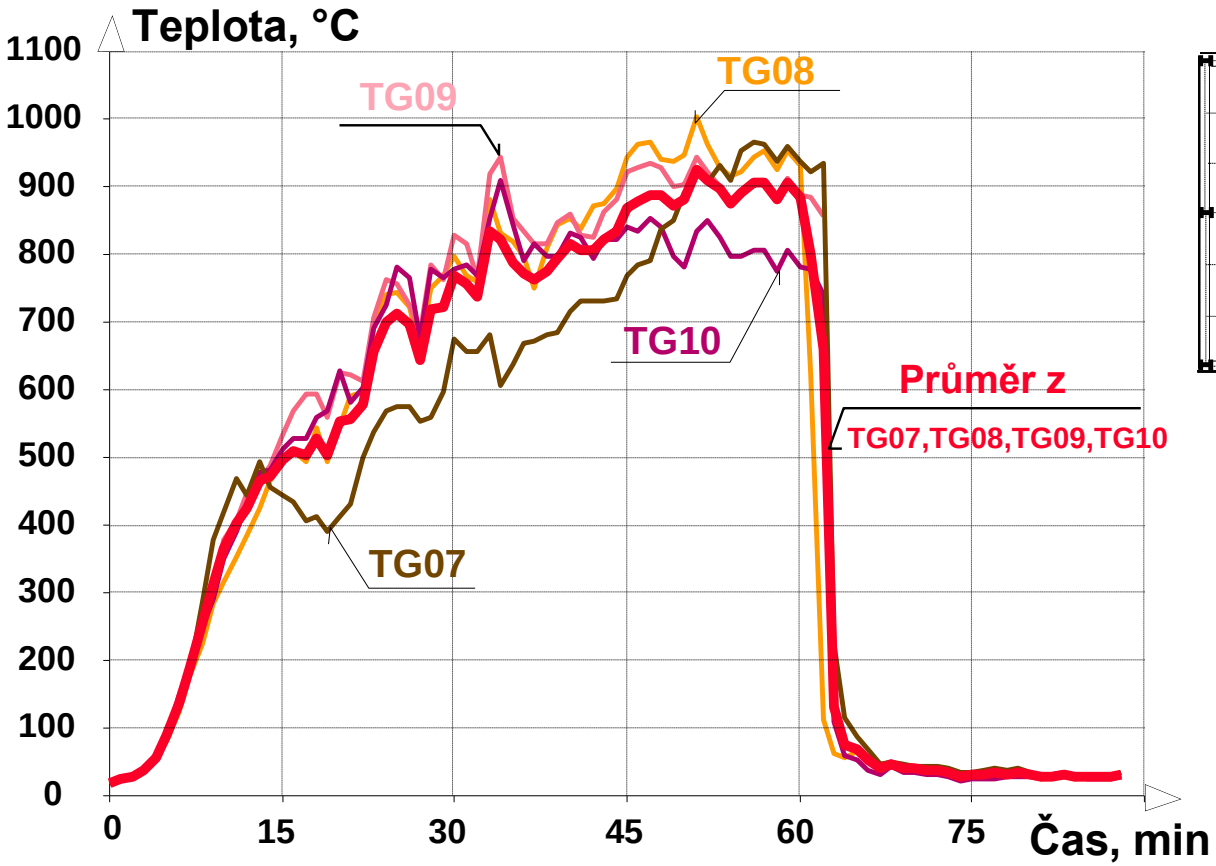
Mokrsko

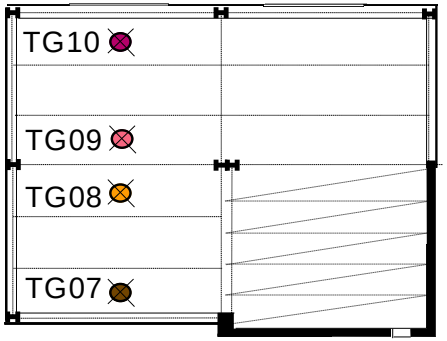
- Gas temperature



Mokrsko

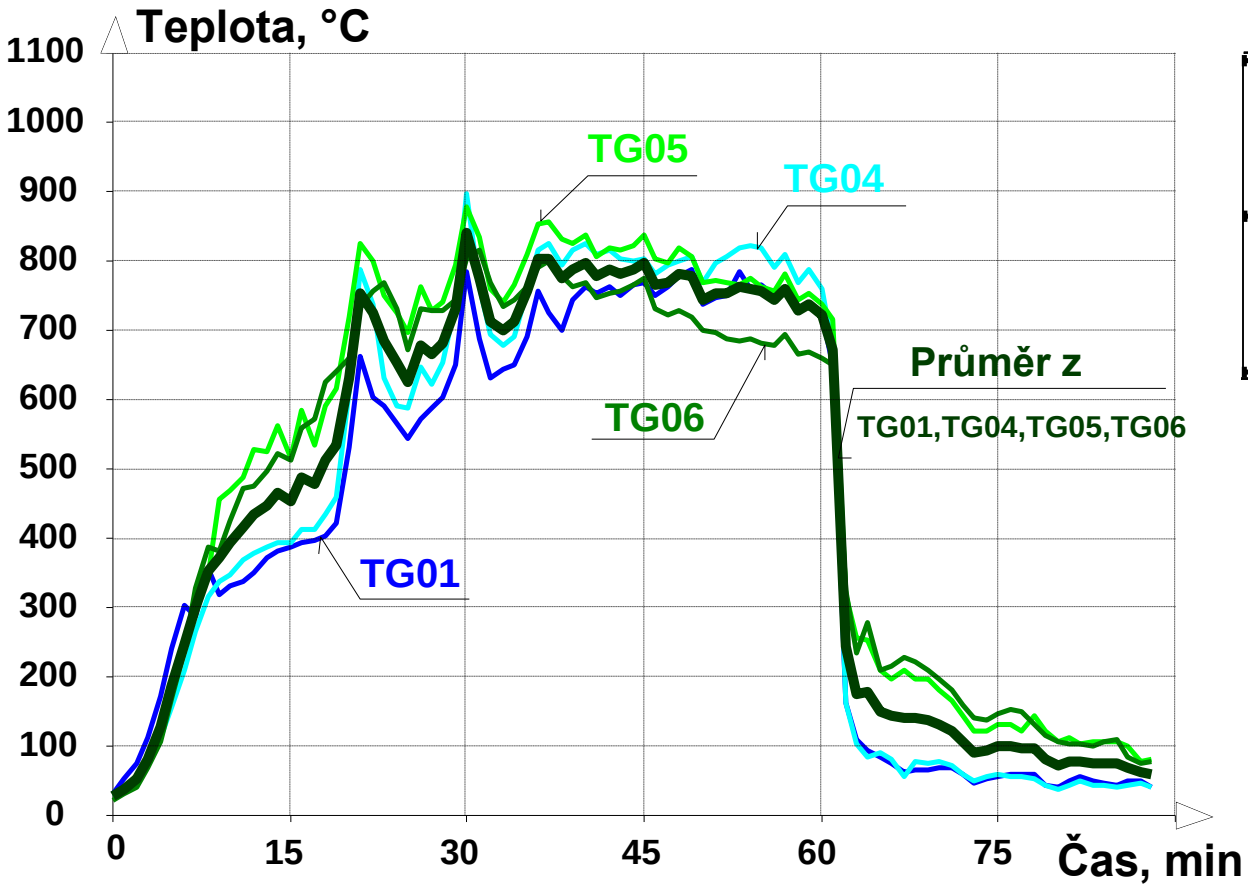
- Gas temperature

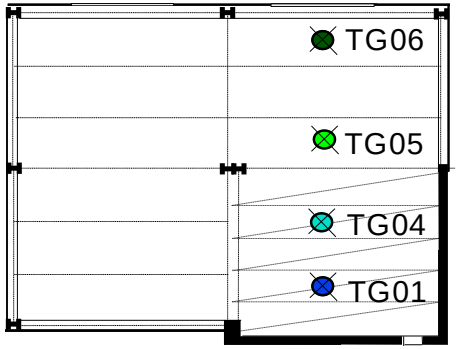




Mokrsko

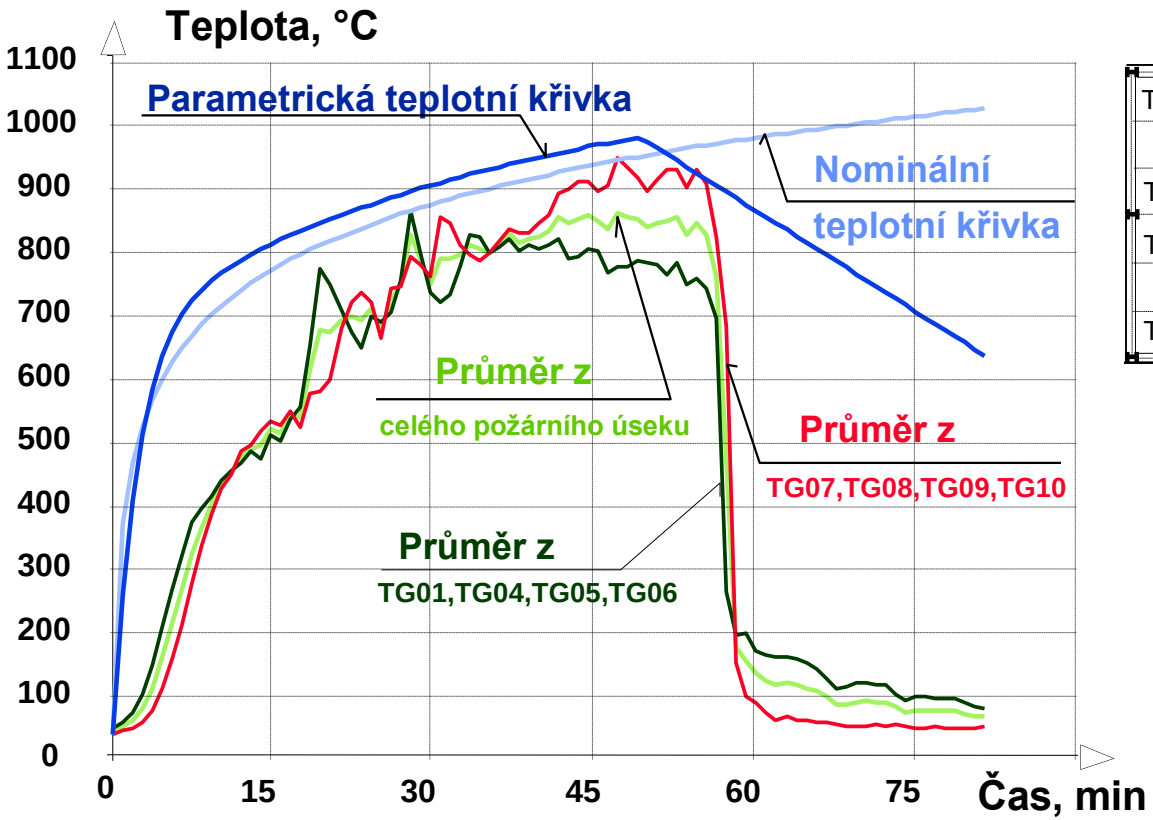
- Gas temperature

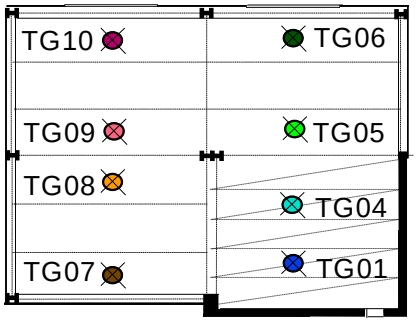




Mokrsko

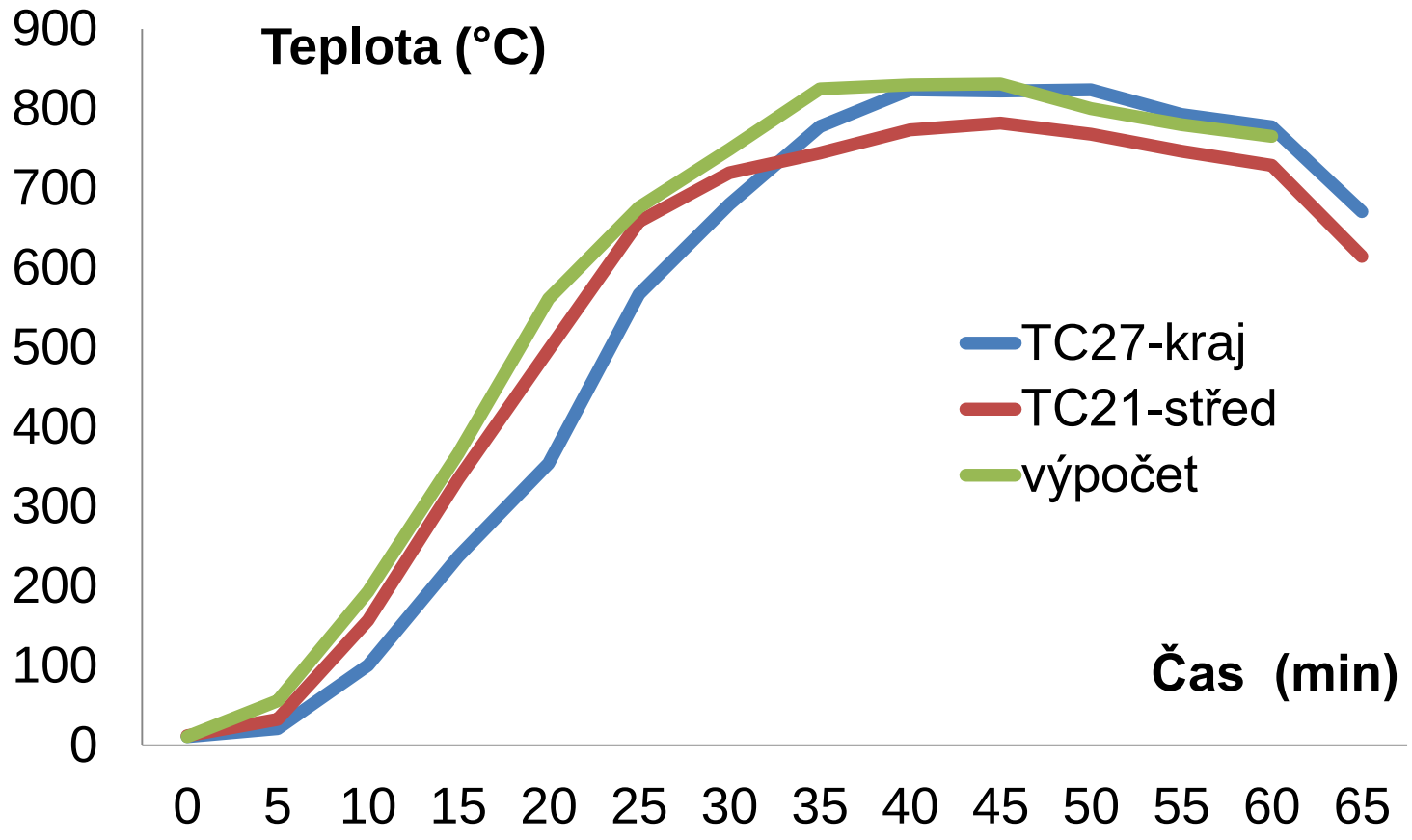
- Gas temperature – comparison to design fire models





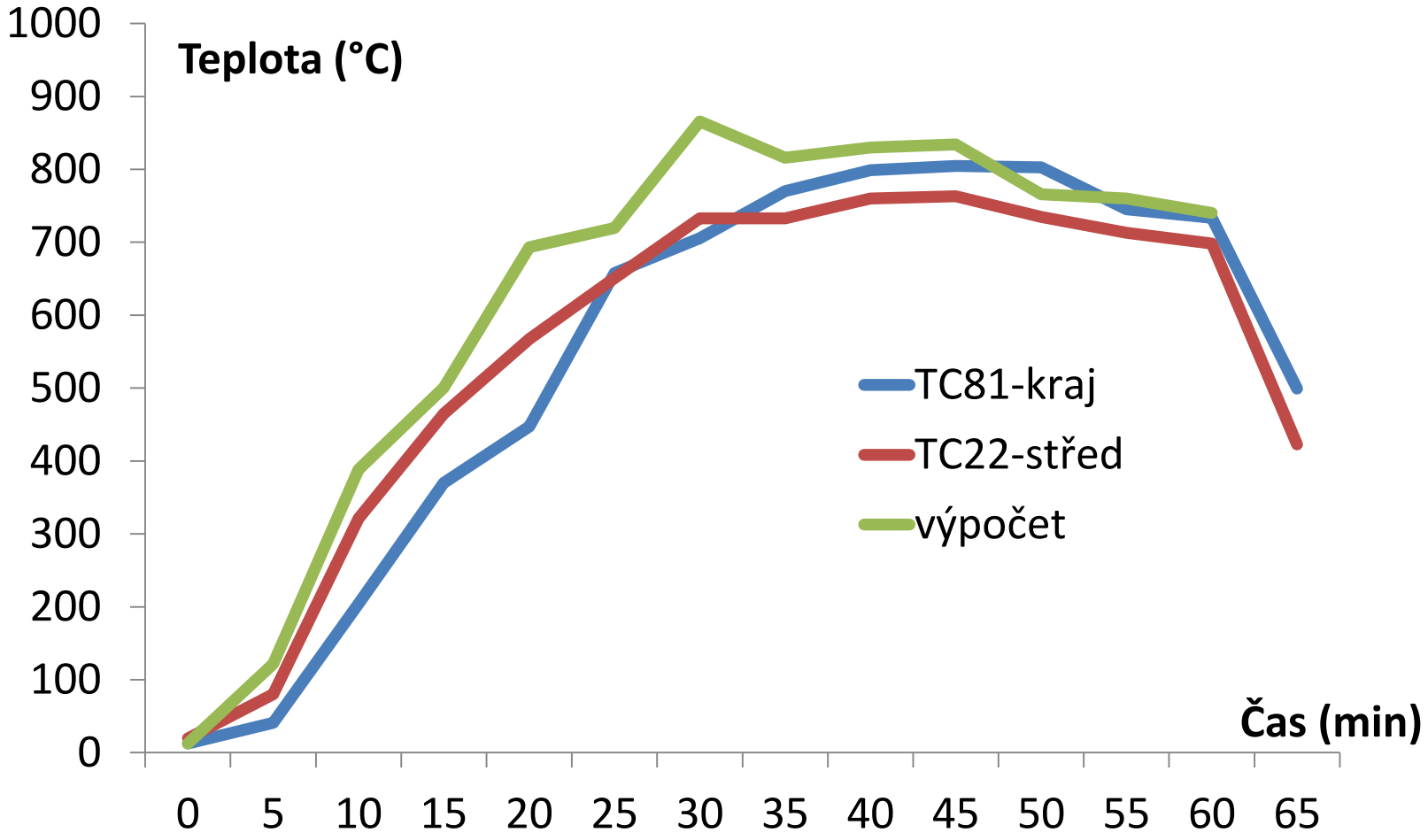
Mokrsko

- Temperature of the lower flange of the corrugated beam



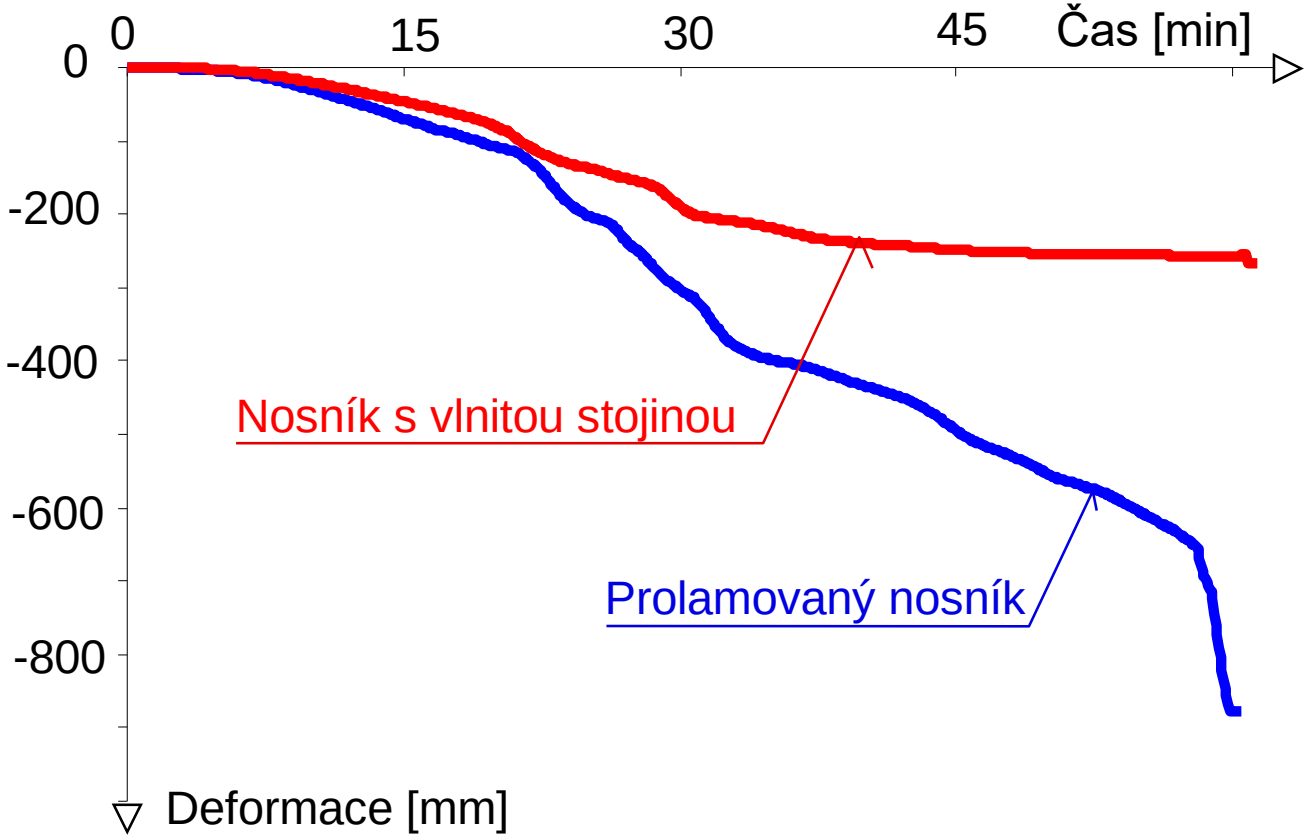
Mokrsko

- Temperature of the web of the corrugated beam



Mokrsko

- Deformation of beams



Mokrsko

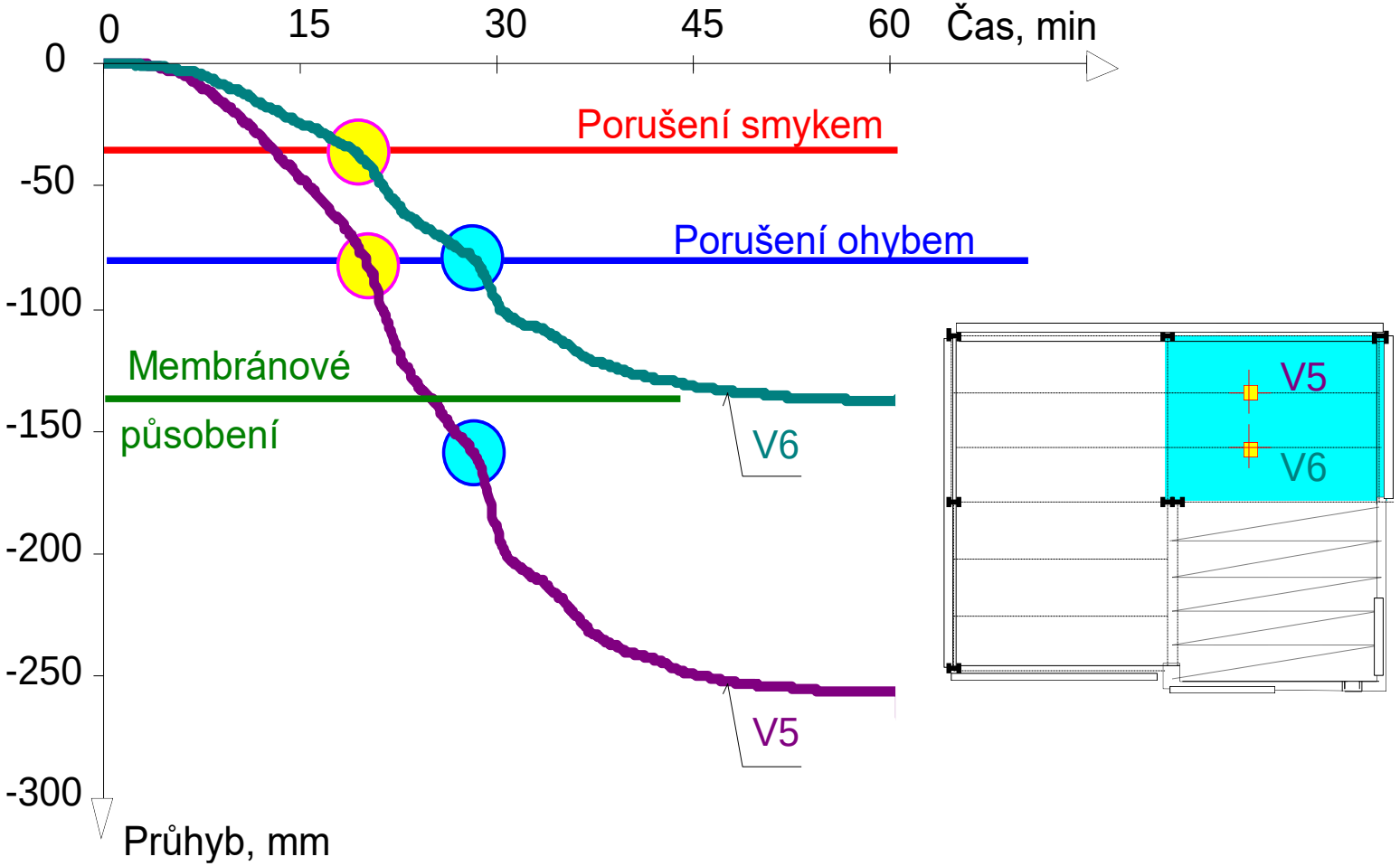
- Shear deformation of the beam after the test

Mokrsko

- Shear deformation of the beam after the test

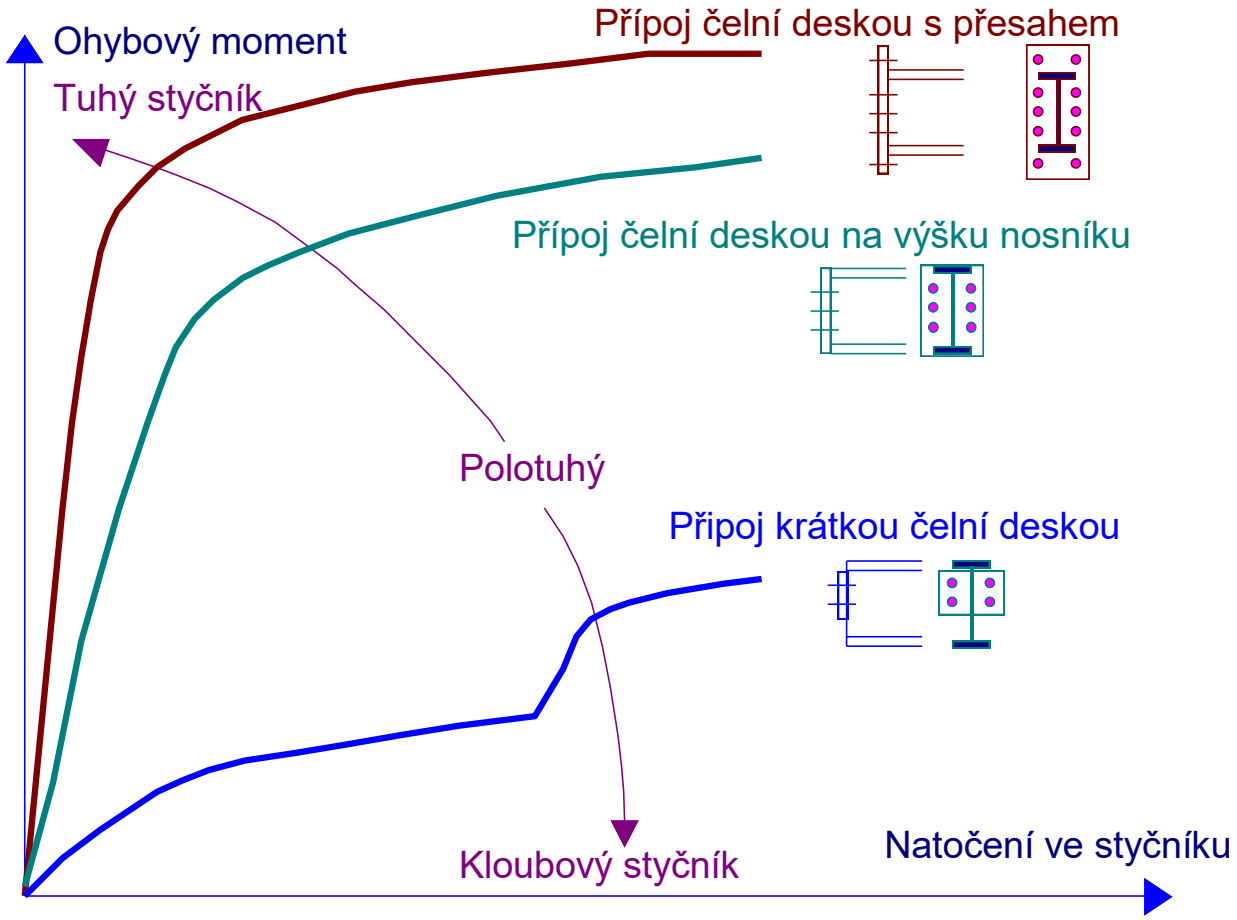
Mokrsko

- Deformation of the composite beam



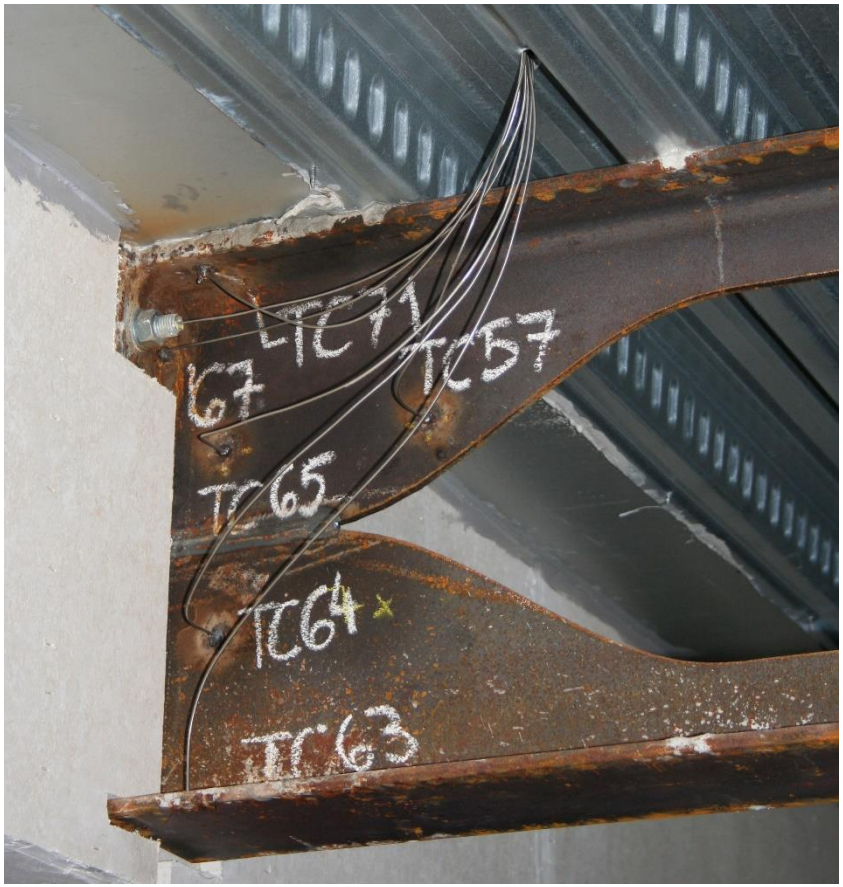
Mokrsko

- Connections in the structure



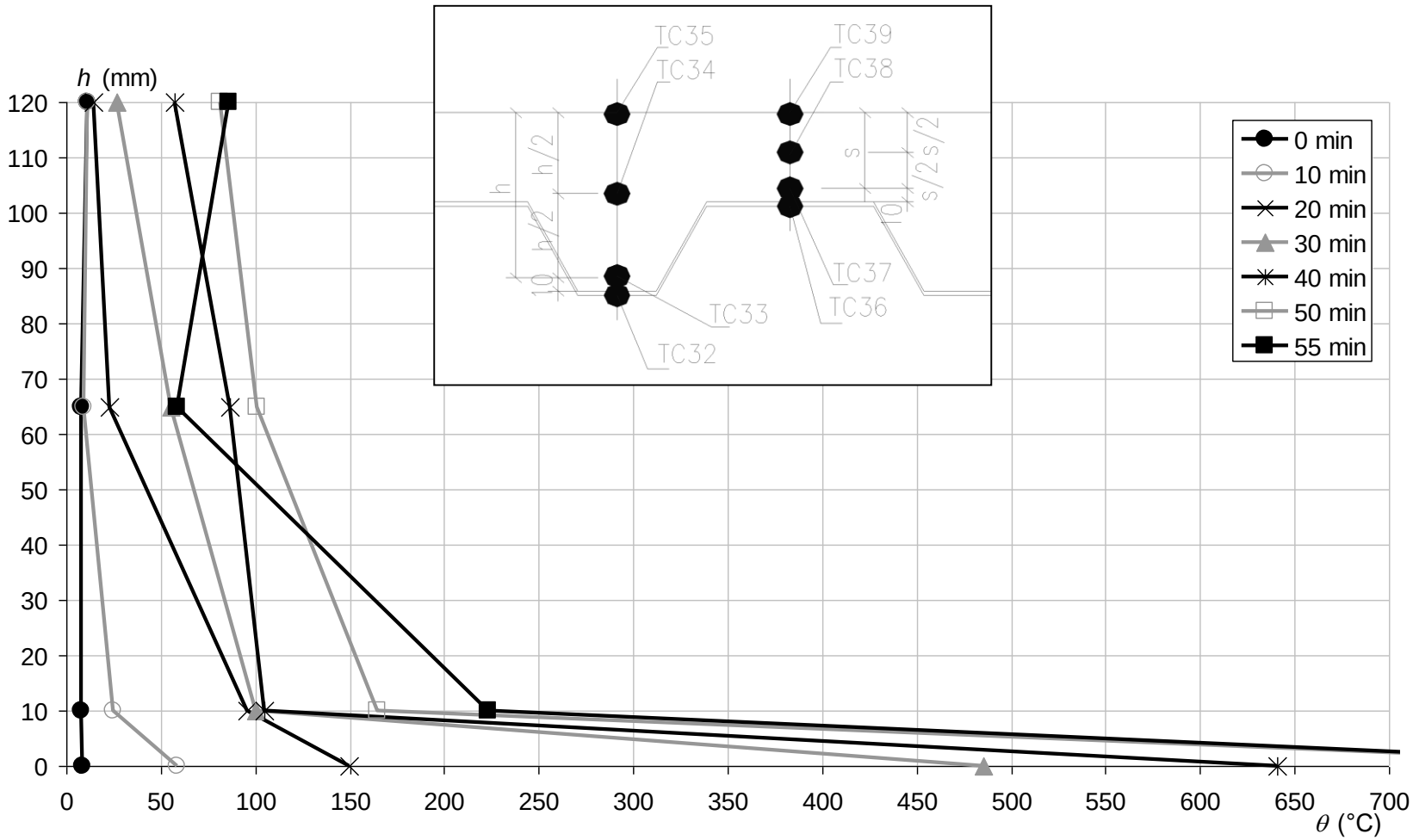
Mokrsko

- Connections after fire



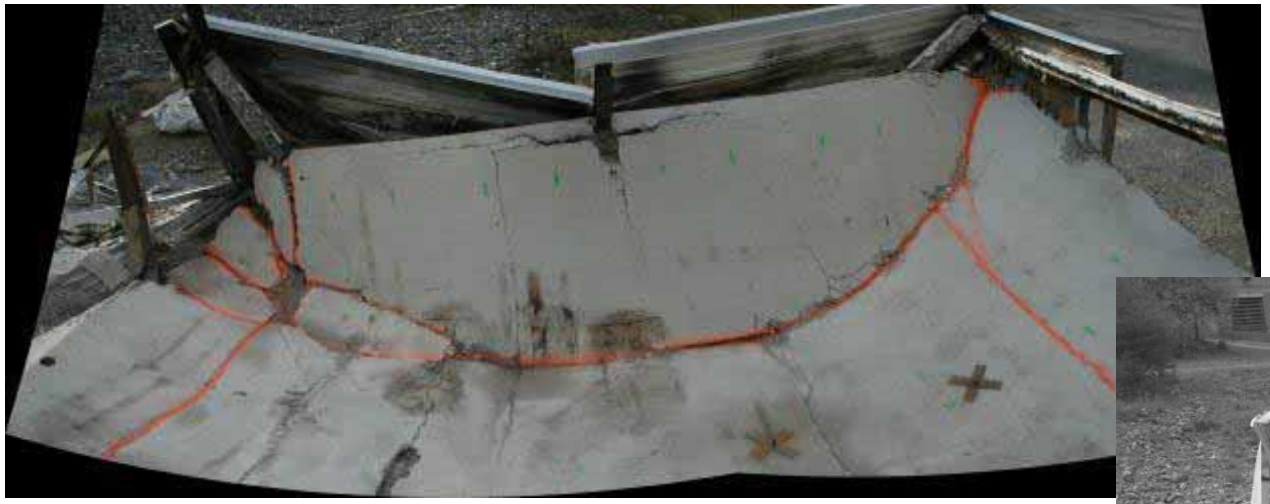
Mokrsko

- Floor slab



Mokrsko

- Floor slab after the fire test



Veselí n. Lužnicí

- CTU fire test in 2011
- In the upper floor - travelling fire test
- In the lower floor – fully-distributed fire

Veselí n. Lužnicí

- Mounting of the structure

Veselí n. Lužnicí

- Mounting

Veselí n. Lužnicí

- Mounting

Veselí n. Lužnicí

- Mounting

Veselí n. Lužnicí

- Mounting

Veselí n. Lužnicí

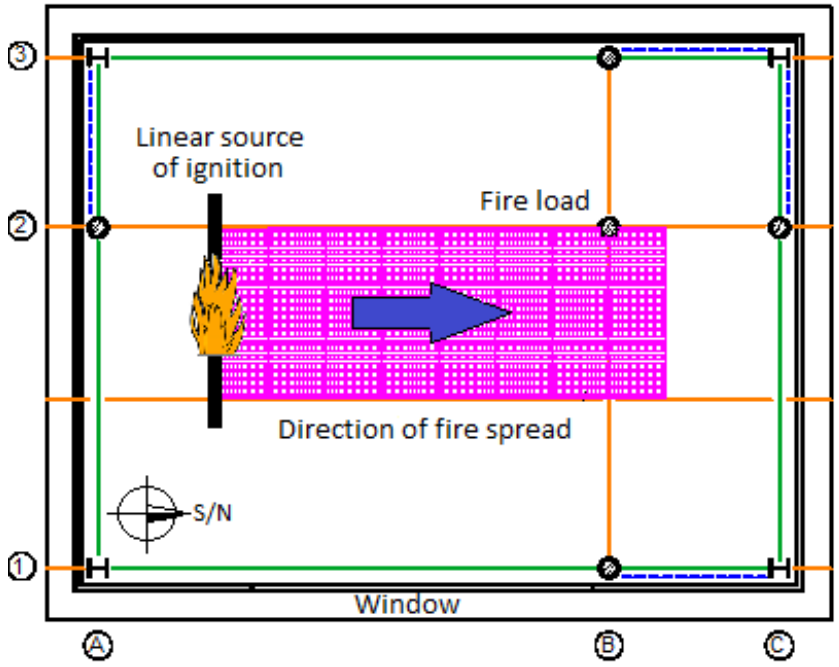
- Mounting

Veselí n. Lužnicí

- Mountin

Veselí n. Lužnicí

- Travelling fire

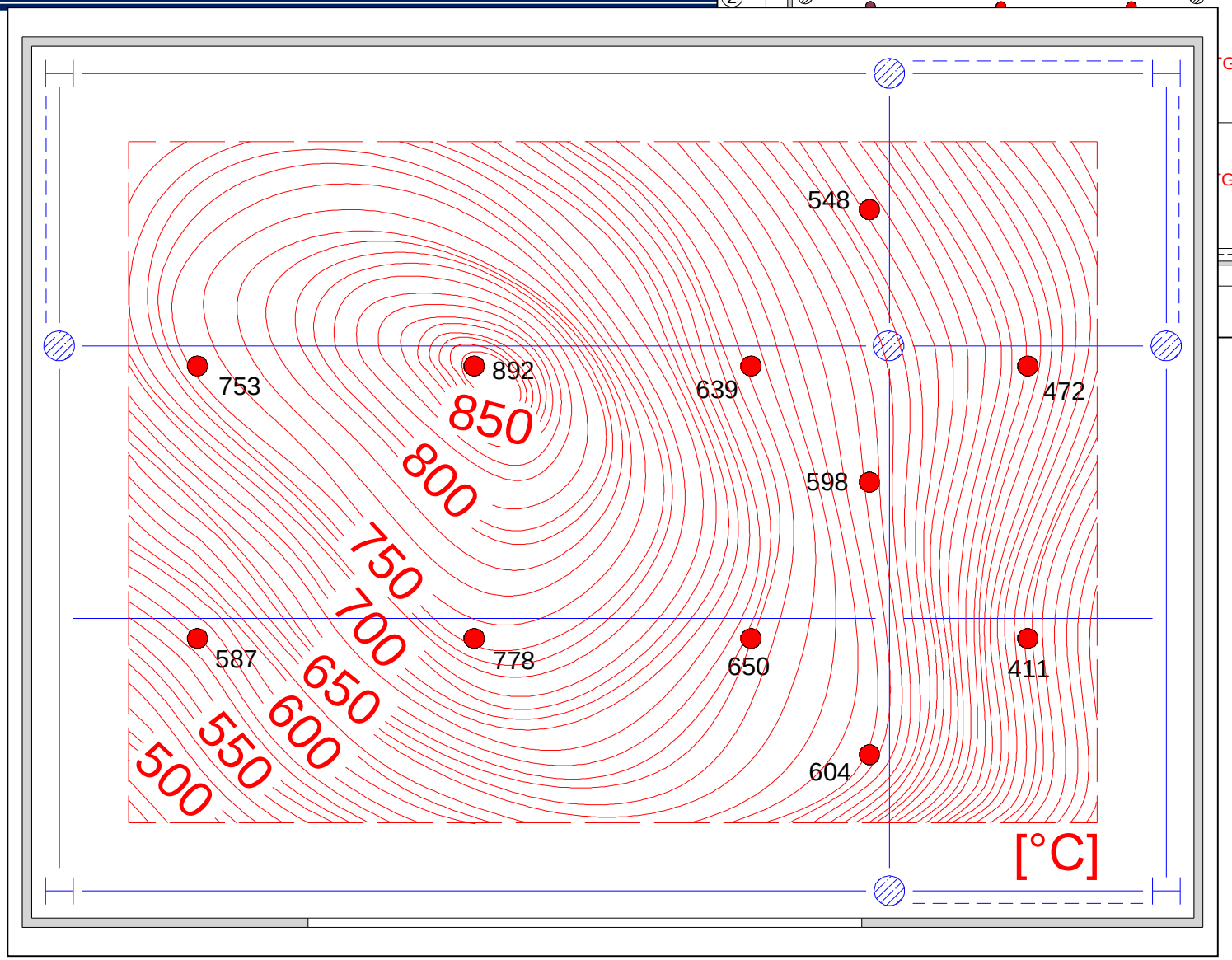


- 20 thermocouples of Ø 3 mm
- 7 plate thermometers

- 10,4 x 13,4 x 4,0 m
- Composite steel-concrete structure
- Opening 2,0 x 5,0 m
- Fire load
  - 24 piles from wooden cribs
  - 2,52 m^3 of wood
  - Lineare source of ignition

Veselí n. Lužnicí

Veselí n. L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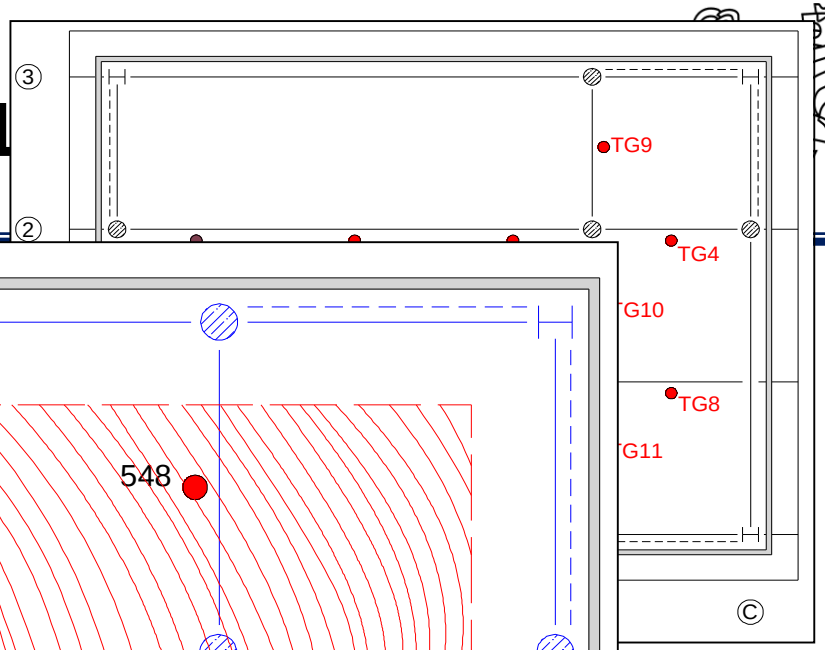
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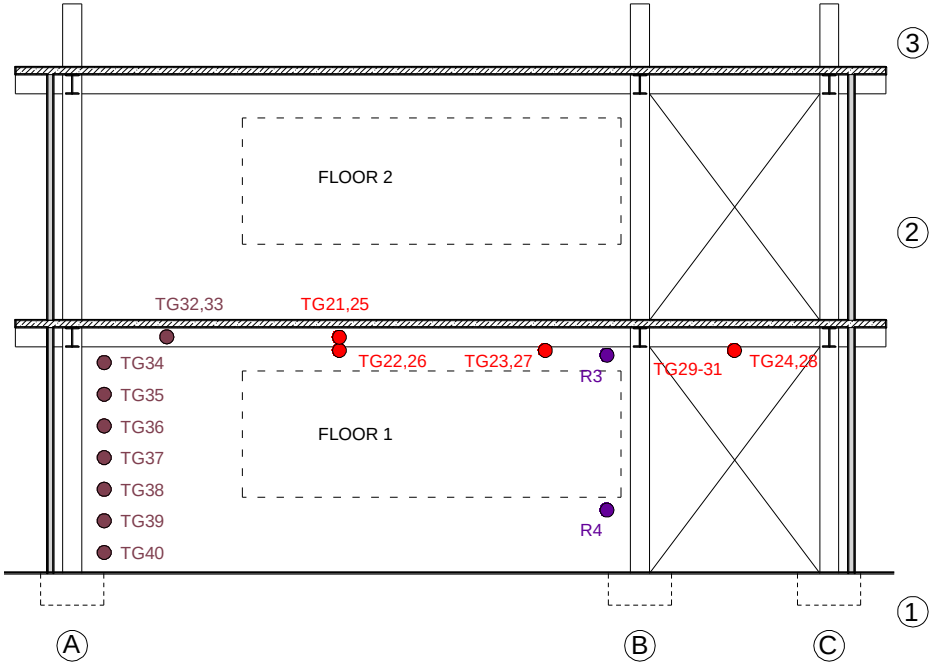
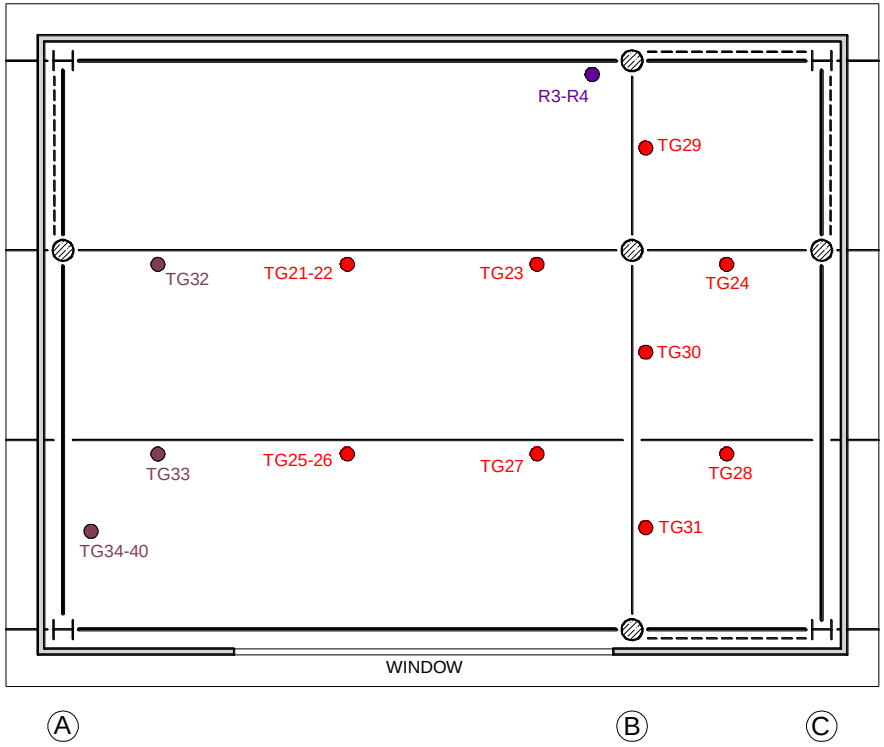
Veselí n. Lužnicí

- Fully-distributed fire

Veselí n. Lužnicí

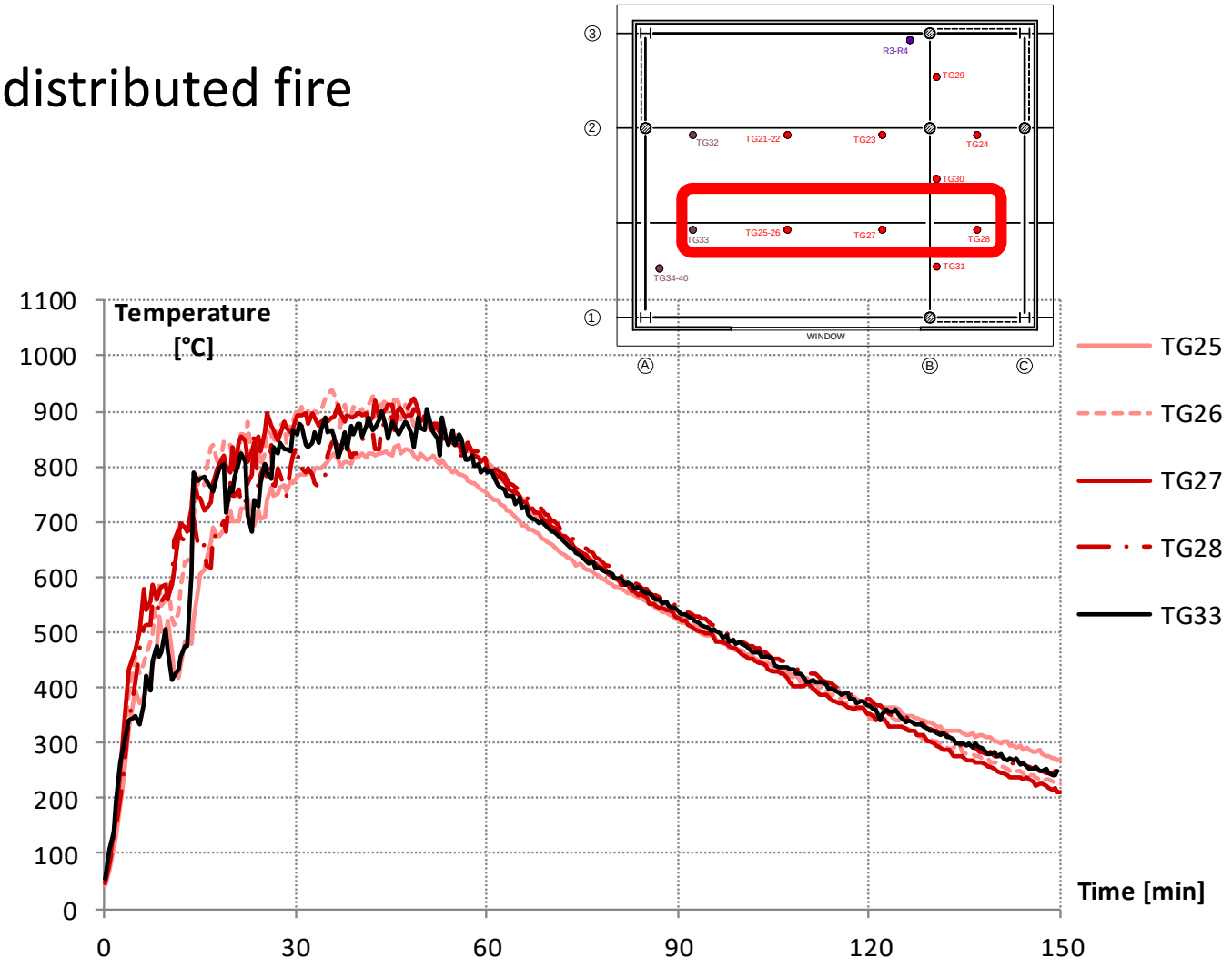
- Fully-distributed fire





Veselí n. Lužnicí

- Fully-distributed fire



Summary

Full-scale fire tests of structures

- Source of knowledge
- Only for research reasons (cost demands)
- Fire tests:
  - Cardington, Mokrsko, Veselí n.L.
  - Dalmarnock (Glasgow)
  - FRACOF
  - FICEB
  - COSSFIRE
  - etc.

Thank you for your attention!

kamila.cabova@fsv.cvut.cz