



# Heating and Cooling of Structure

Observations by thermo imaging camera  
during the Cardington fire test, January 16, 2003

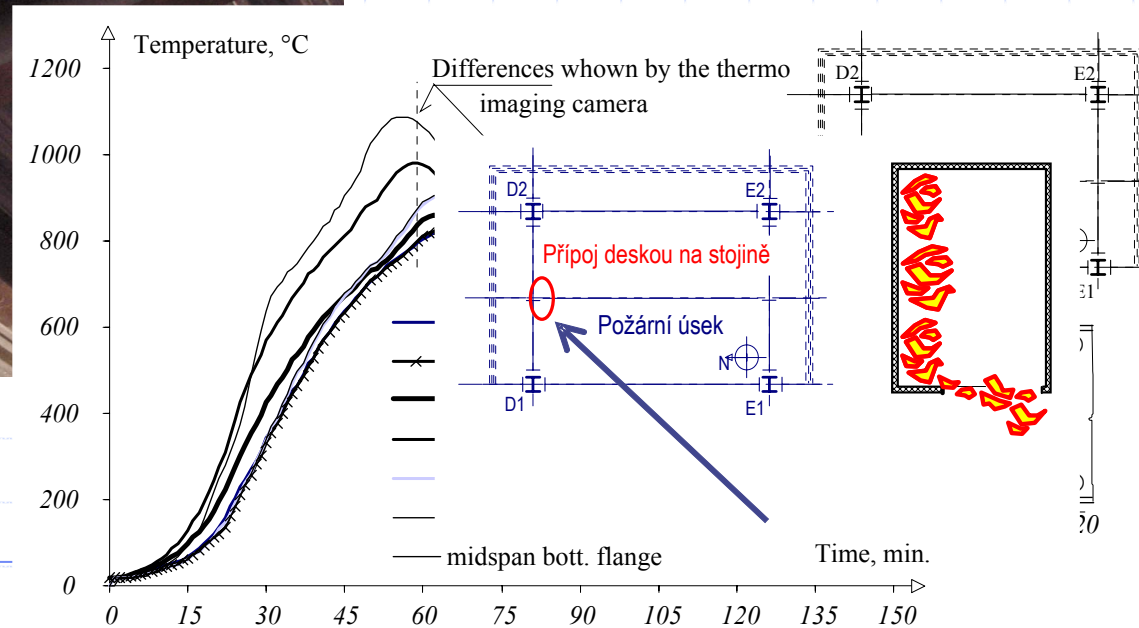
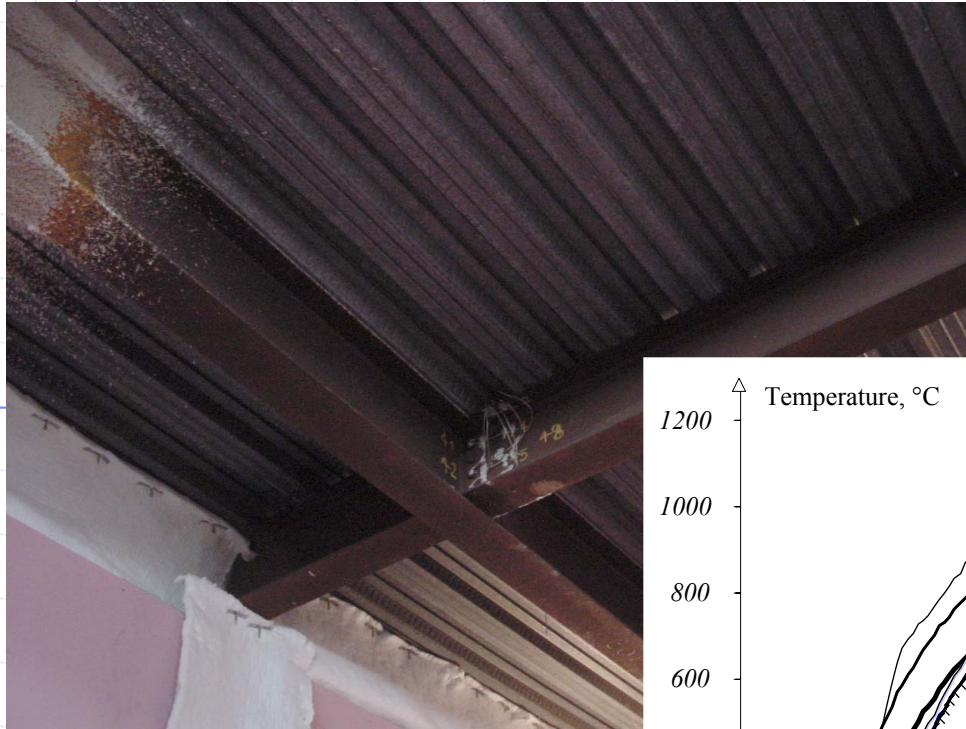
Pašek J., Svoboda J., Wald F.

Technical University in Prague has produced this lesson  
with the support of the EU Fifth Framework project No. CV 5535

Tensile membrane action and robustness of structural steel joints under natural fire"



# Fin plate connection before the experiment

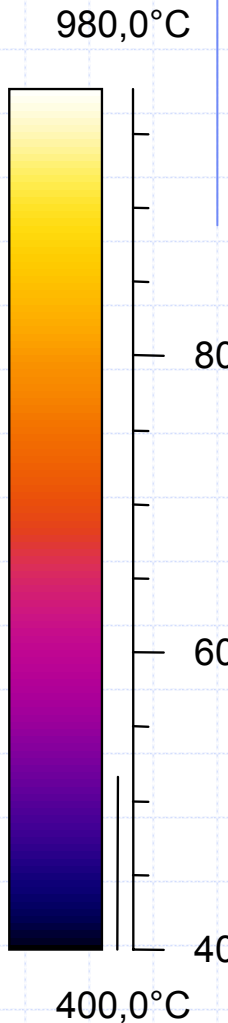
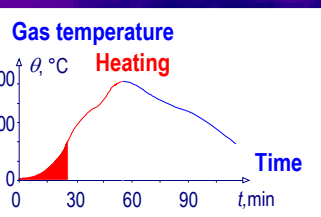




$t = 26 \text{ min.}$

$\theta_{\text{con},\emptyset} = 275 \text{ }^{\circ}\text{C}$

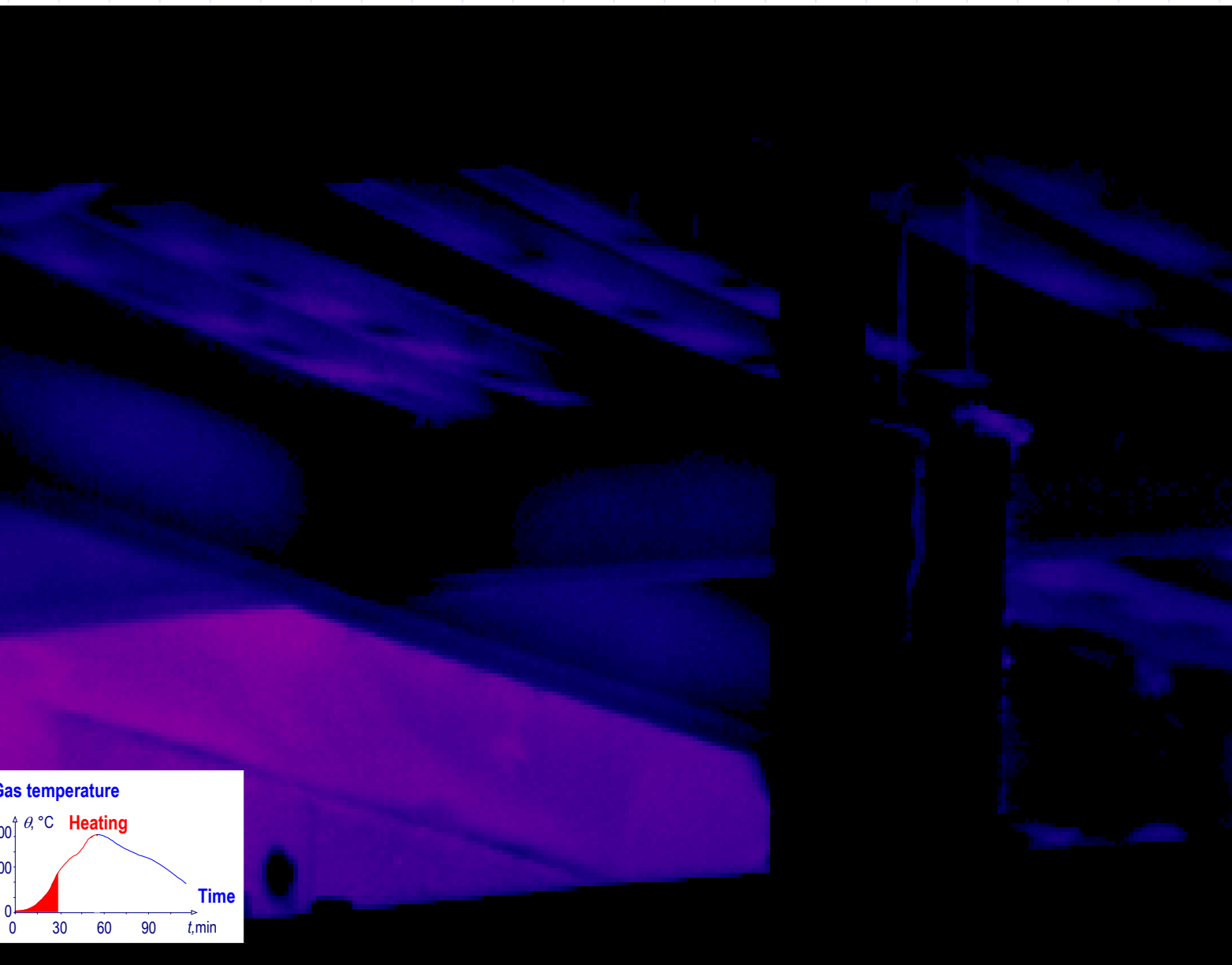
In 26 min. of fire is temperature  
of the structure under  $400^{\circ}\text{C}$ .





$t = 26 \text{ min.}$

$\theta_{\text{con},\emptyset} = 275 \text{ }^{\circ}\text{C}$



980,0°C

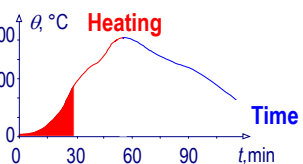
80

60

40

400,0°C

Gas temperature

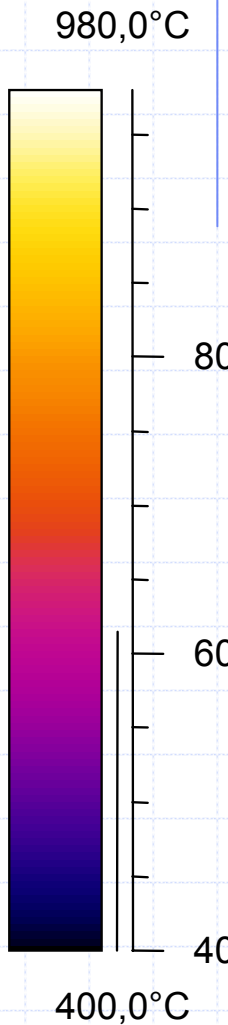
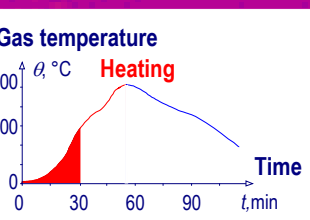




$t = 30 \text{ min.}$

$\theta_{\text{con},\emptyset} = 390 \text{ }^{\circ}\text{C}$

**By heating is connection colder  
compare to connected beam**





$t = 32 \text{ min.}$

$\theta_{\text{con},\emptyset} = 440 \text{ }^{\circ}\text{C}$

**By heating is connection colder  
compare to connected beam**



980,0°C

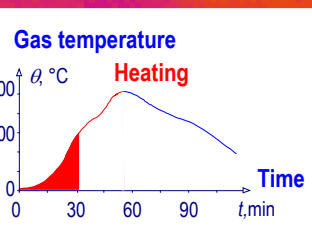


80

60

40

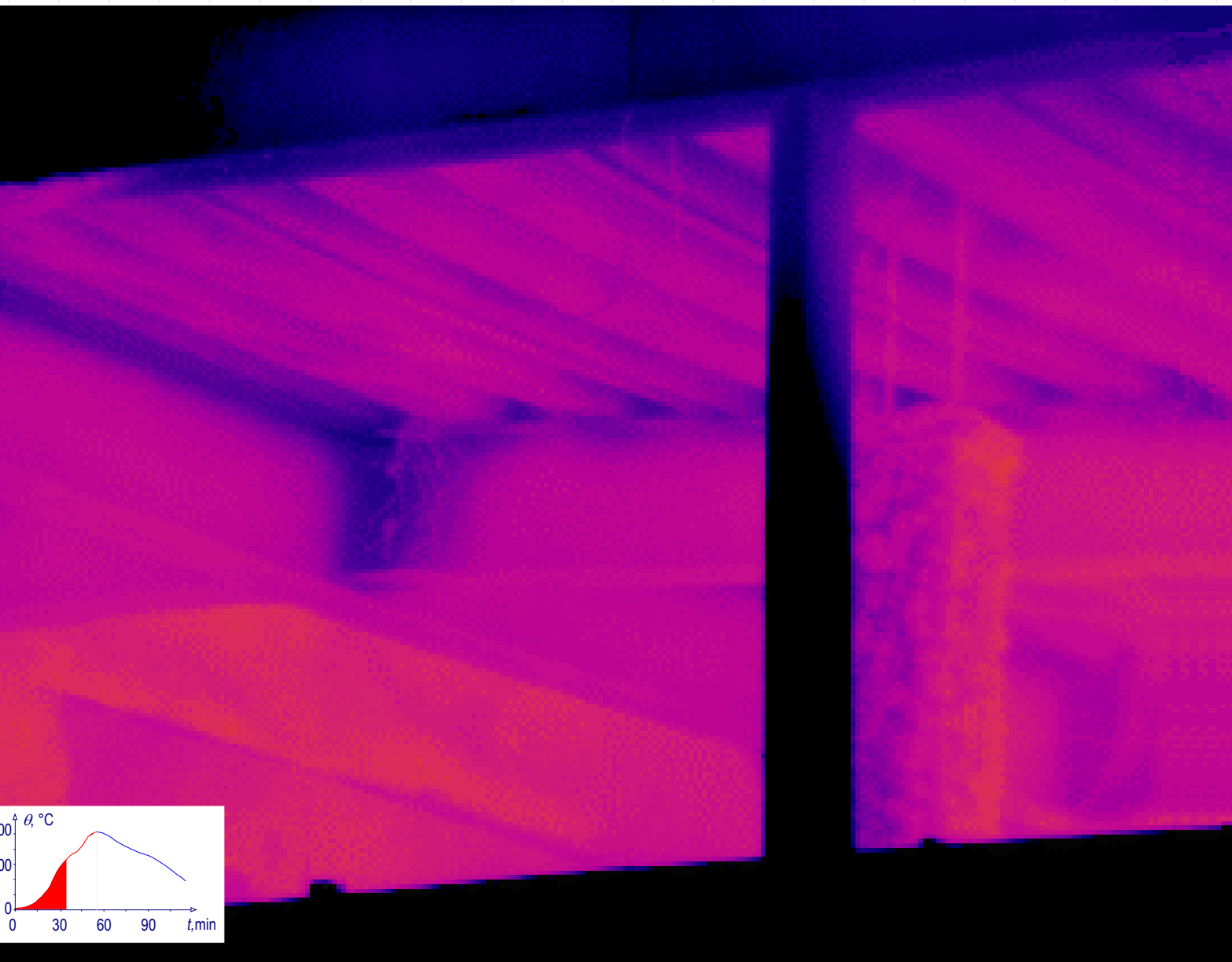
400,0°C



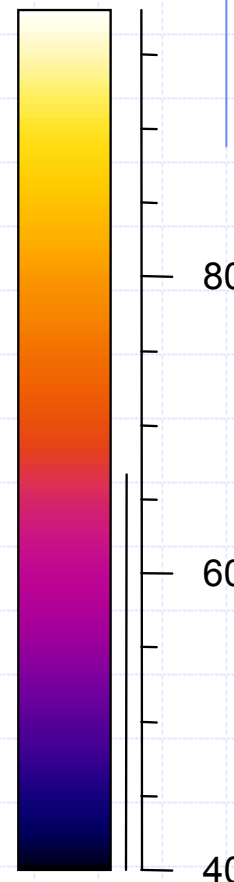


$t = 34 \text{ min.}$

$\theta_{\text{con},\emptyset} = 480 \text{ }^{\circ}\text{C}$



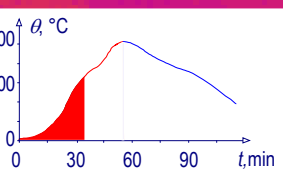
980,0°C



800,0°C

600,0°C

400,0°C





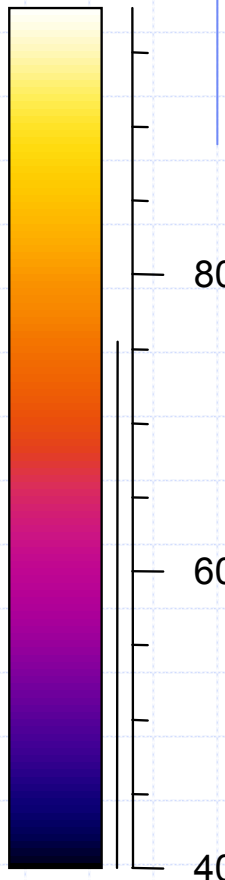
$t = 36 \text{ min.}$

$\theta_{\text{con},\emptyset} = 520 \text{ }^{\circ}\text{C}$

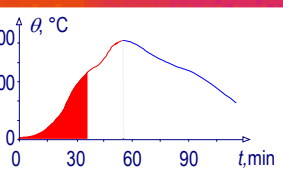
**Buckling of beam lower flange**



980,0°C



400,0°C



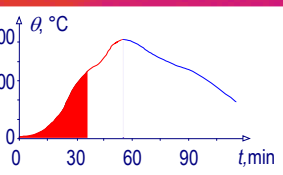
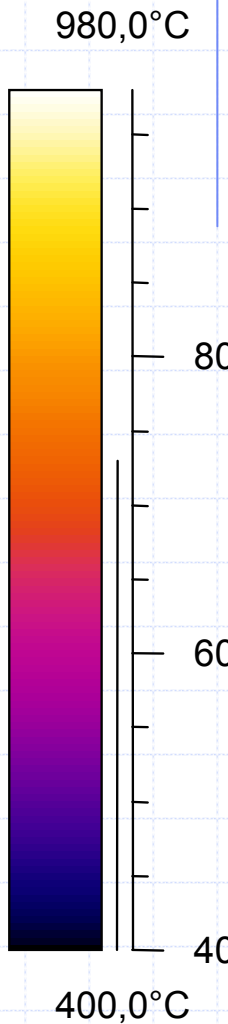




$t = 38 \text{ min.}$

$\theta_{\text{con},\emptyset} = 565 \text{ }^{\circ}\text{C}$

# Buckling of beam lower flange

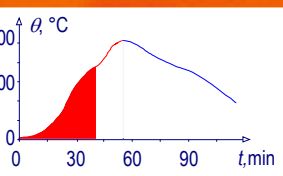
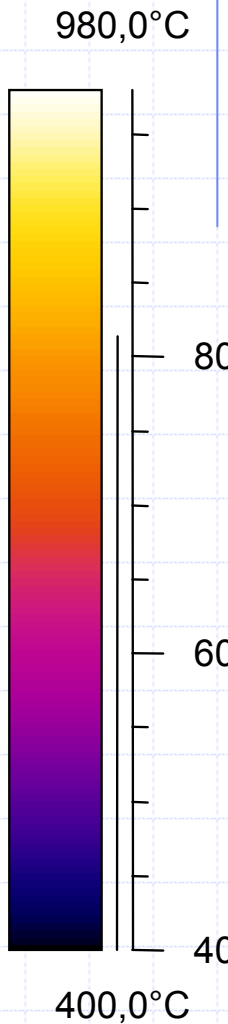




$t = 40 \text{ min.}$

$\theta_{\text{con},\emptyset} = 590 \text{ }^{\circ}\text{C}$

# Buckling of beam lower flange

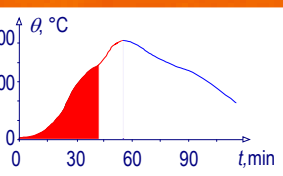
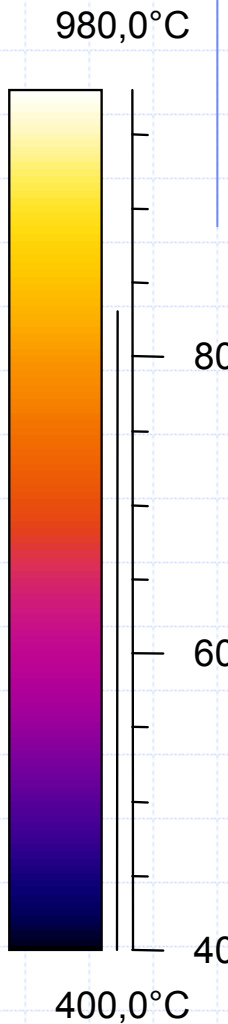




$t = 42 \text{ min.}$

$\theta_{\text{con},\emptyset} = 645 \text{ }^{\circ}\text{C}$

# Buckling of beam lower flange

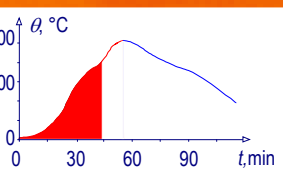
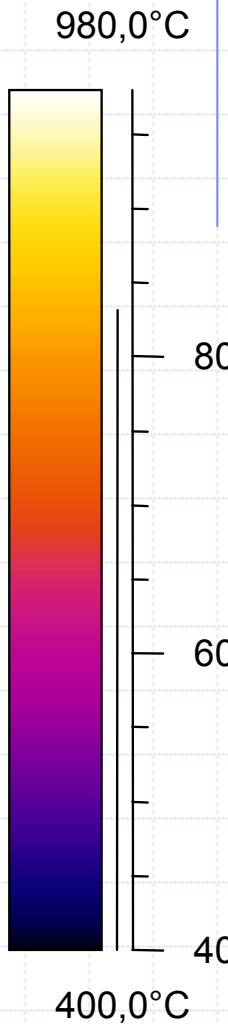




$t = 44 \text{ min.}$

$\theta_{\text{con},\emptyset} = 660 \text{ }^{\circ}\text{C}$

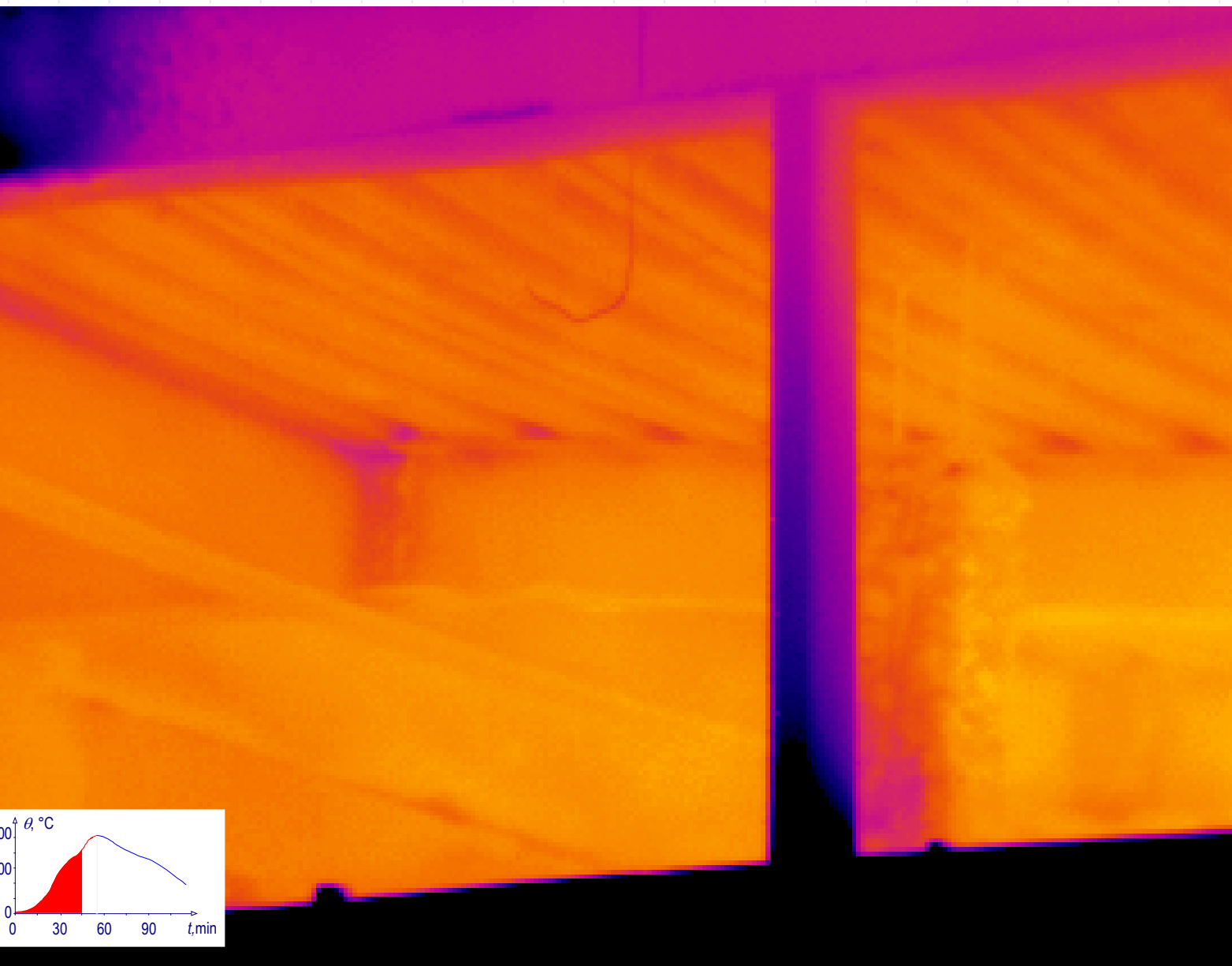
# Buckling of beam lower flange



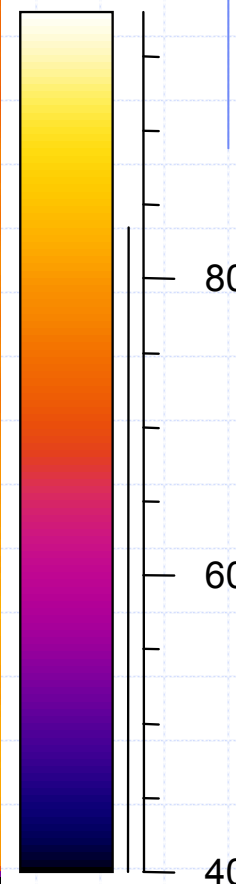


$t = 46 \text{ min.}$

$\theta_{\text{con},\emptyset} = 685 \text{ }^{\circ}\text{C}$



980,0°C

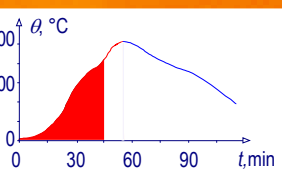


80

60

40

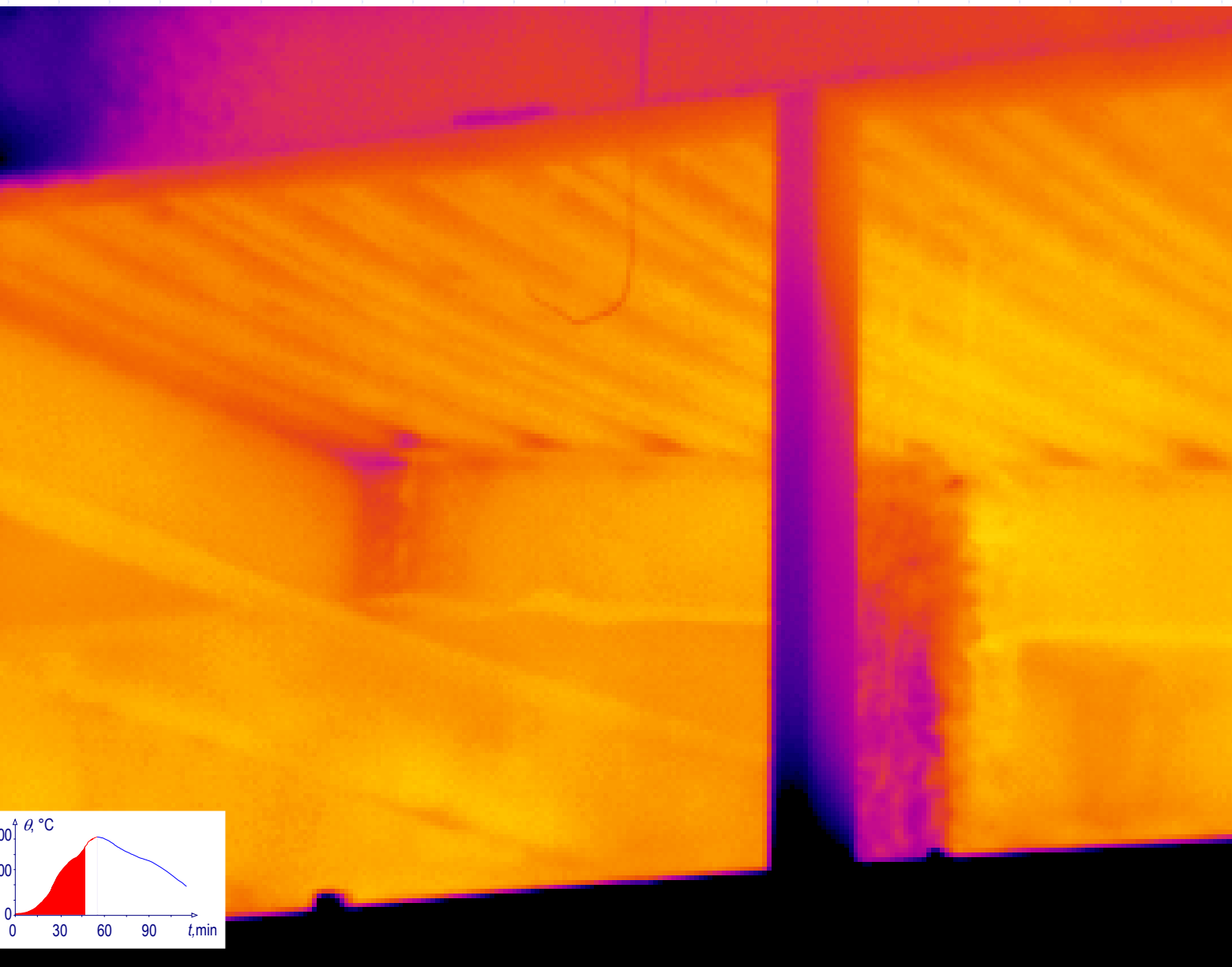
400,0°C



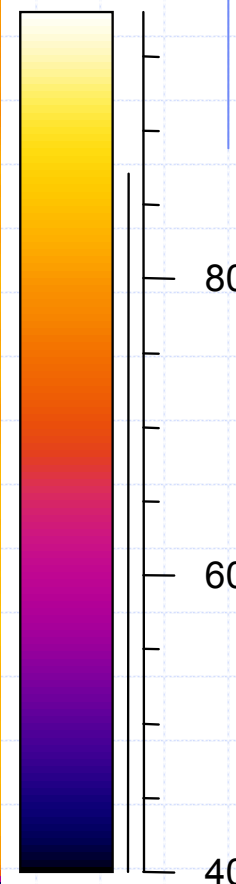


$t = 48 \text{ min.}$

$\theta_{\text{con},\emptyset} = 710 \text{ }^{\circ}\text{C}$



$980,0^{\circ}\text{C}$

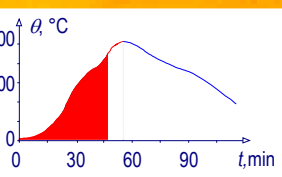


80

60

40

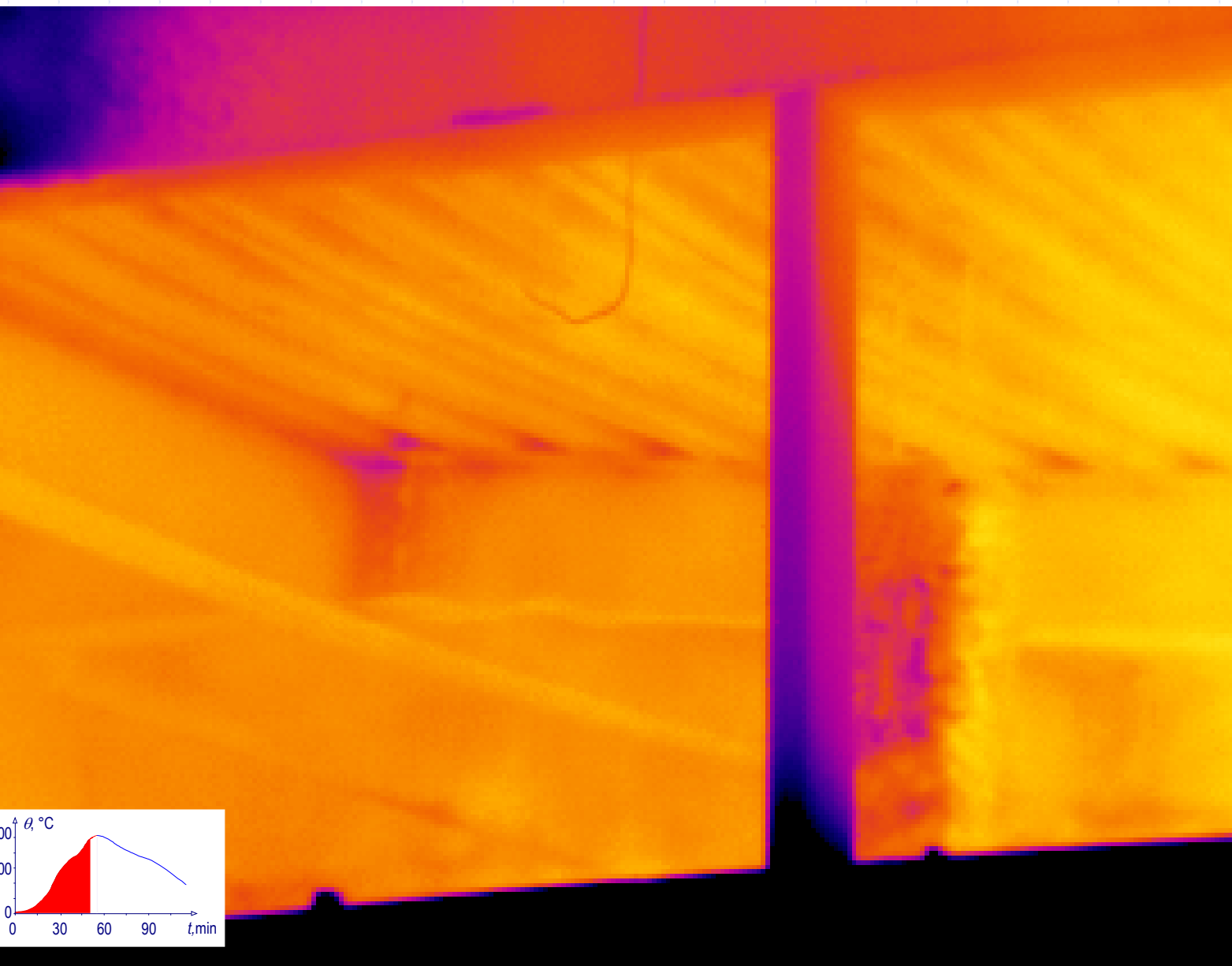
$400,0^{\circ}\text{C}$



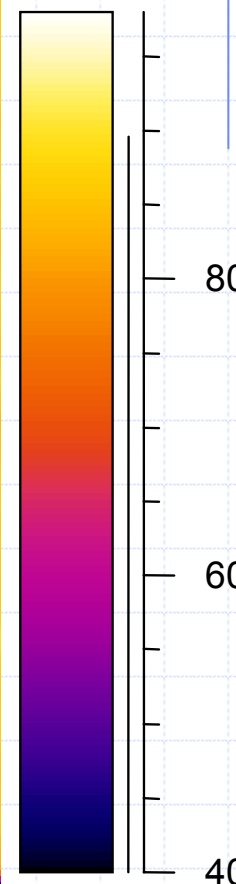


$t = 50 \text{ min.}$

$\theta_{\text{con},\emptyset} = 730 \text{ }^{\circ}\text{C}$



$980,0^{\circ}\text{C}$

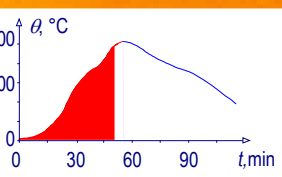


800,0°C

600,0°C

400,0°C

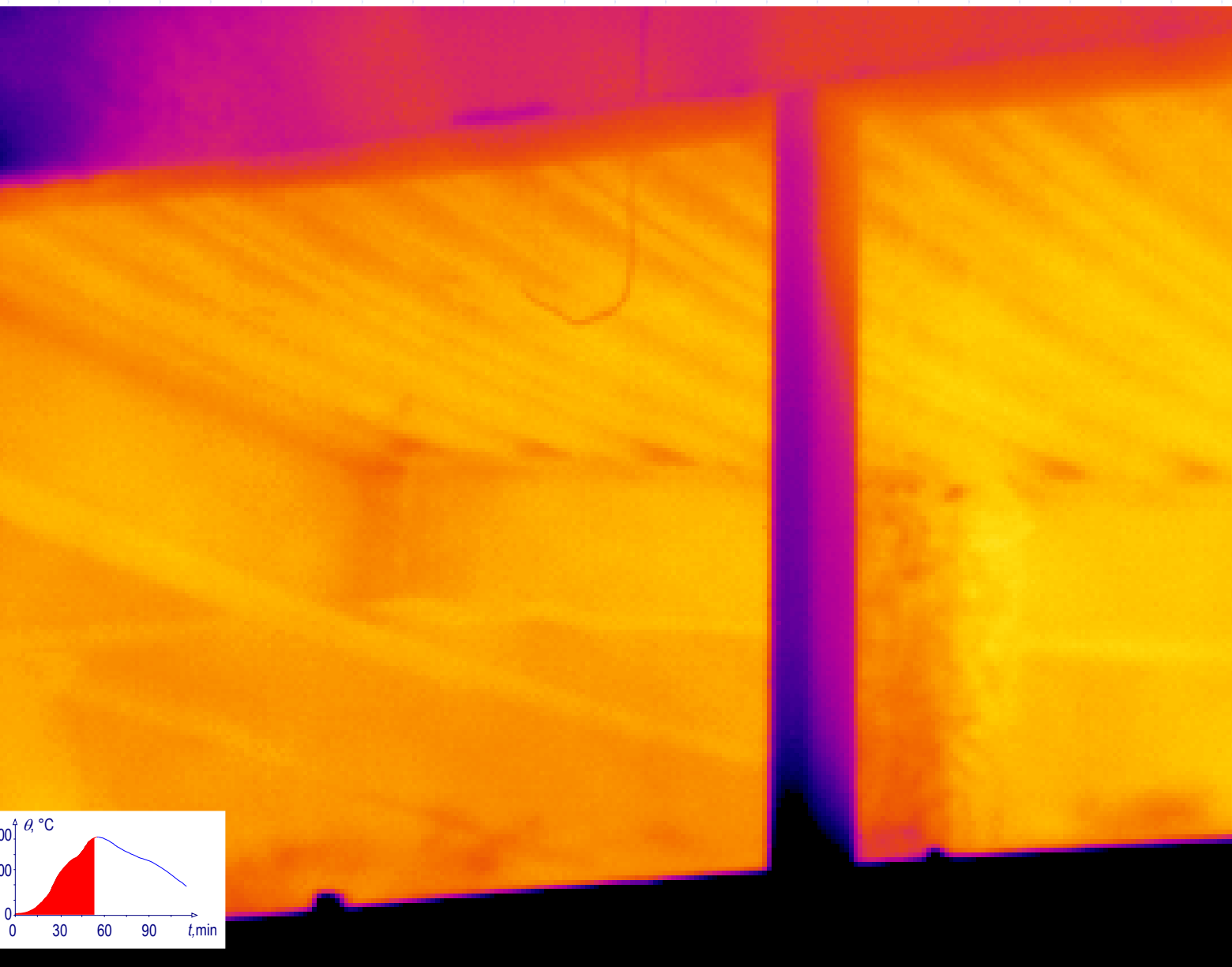
$400,0^{\circ}\text{C}$



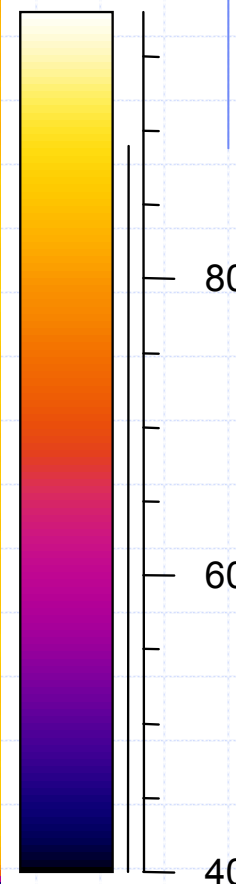


$t = 52 \text{ min.}$

$\theta_{\text{con},\emptyset} = 775 \text{ }^{\circ}\text{C}$



980,0°C

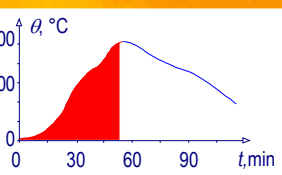


800,0°C

600,0°C

400,0°C

400,0°C

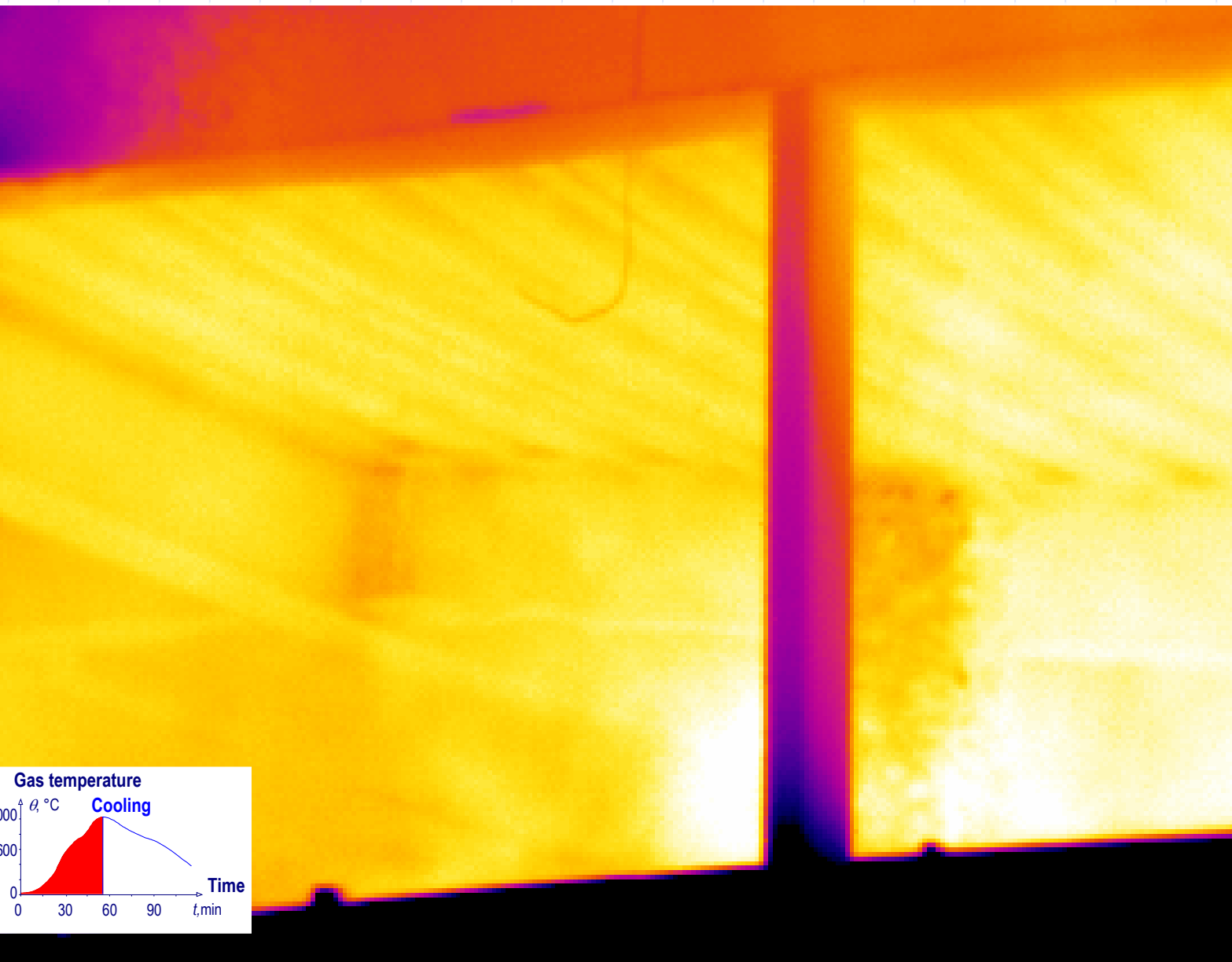




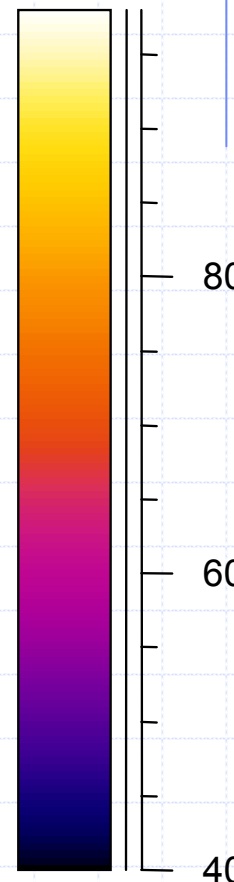


$t = 54 \text{ min.}$

$\theta_{\text{con},\emptyset} = 810 \text{ }^{\circ}\text{C}$



980,0°C

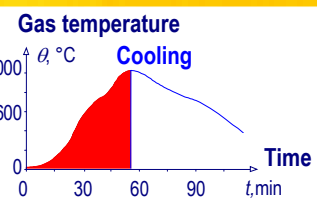


800

600

400

400,0°C

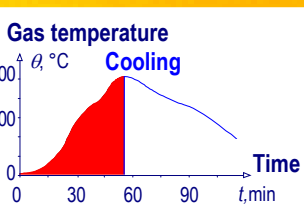
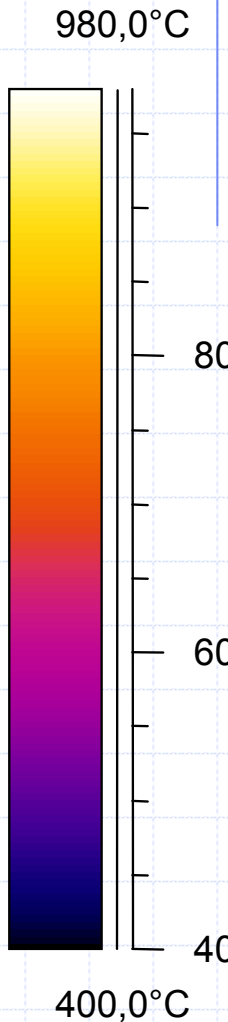
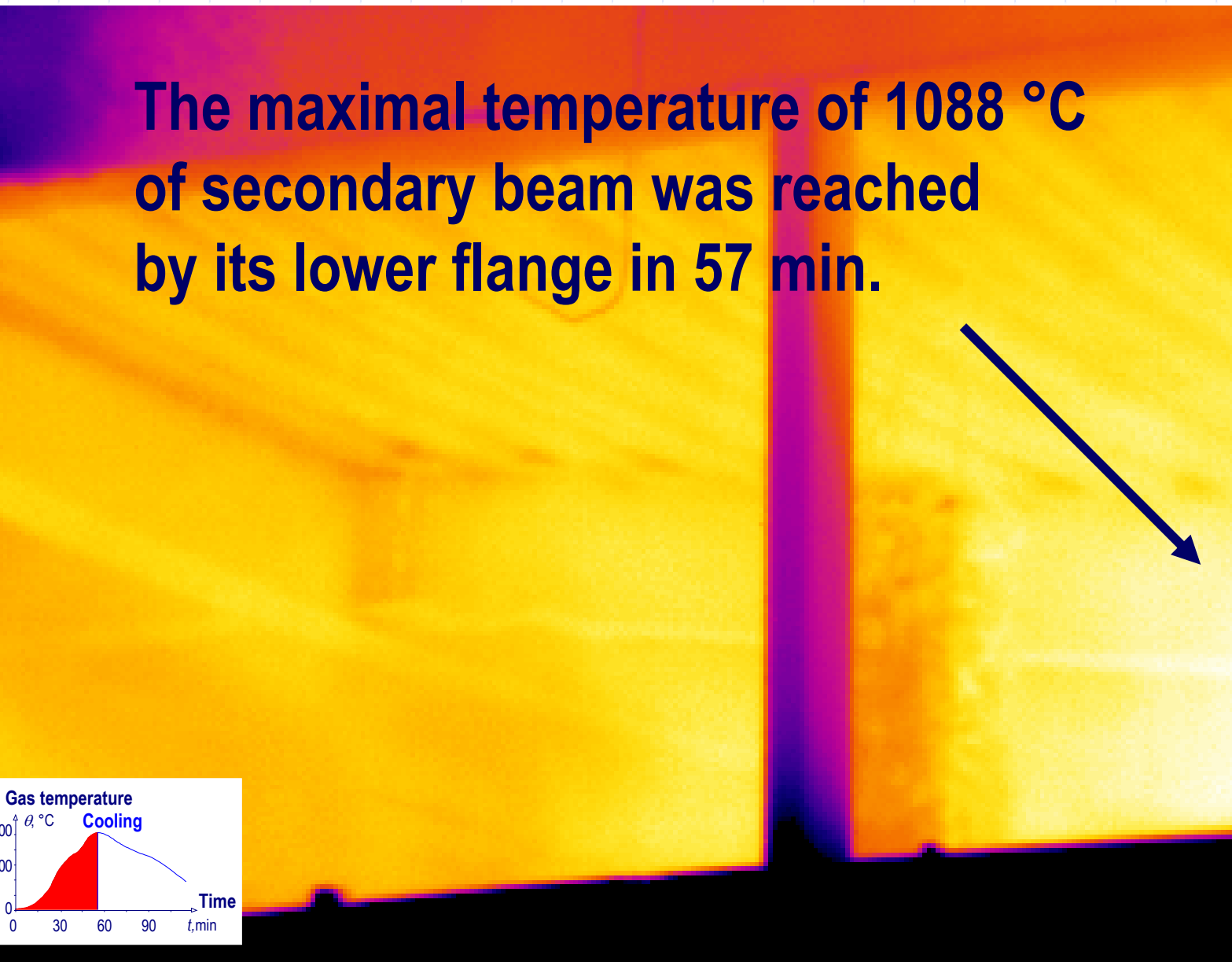




$t = 56 \text{ min.}$

$\theta_{\text{con},\emptyset} = 835 \text{ }^{\circ}\text{C}$

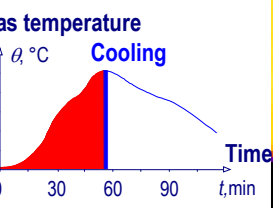
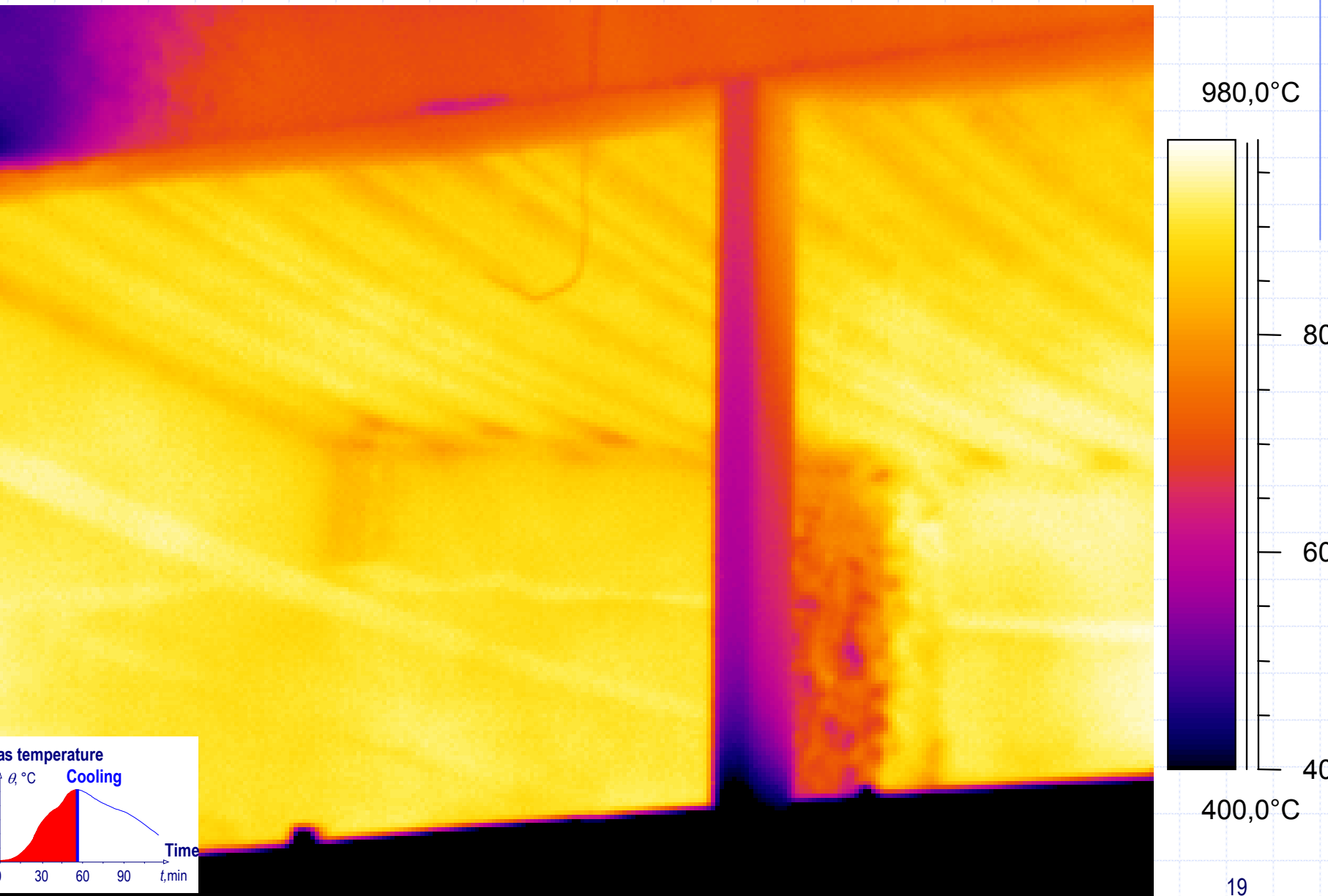
**The maximal temperature of 1088 °C of secondary beam was reached by its lower flange in 57 min.**





$t = 58 \text{ min.}$

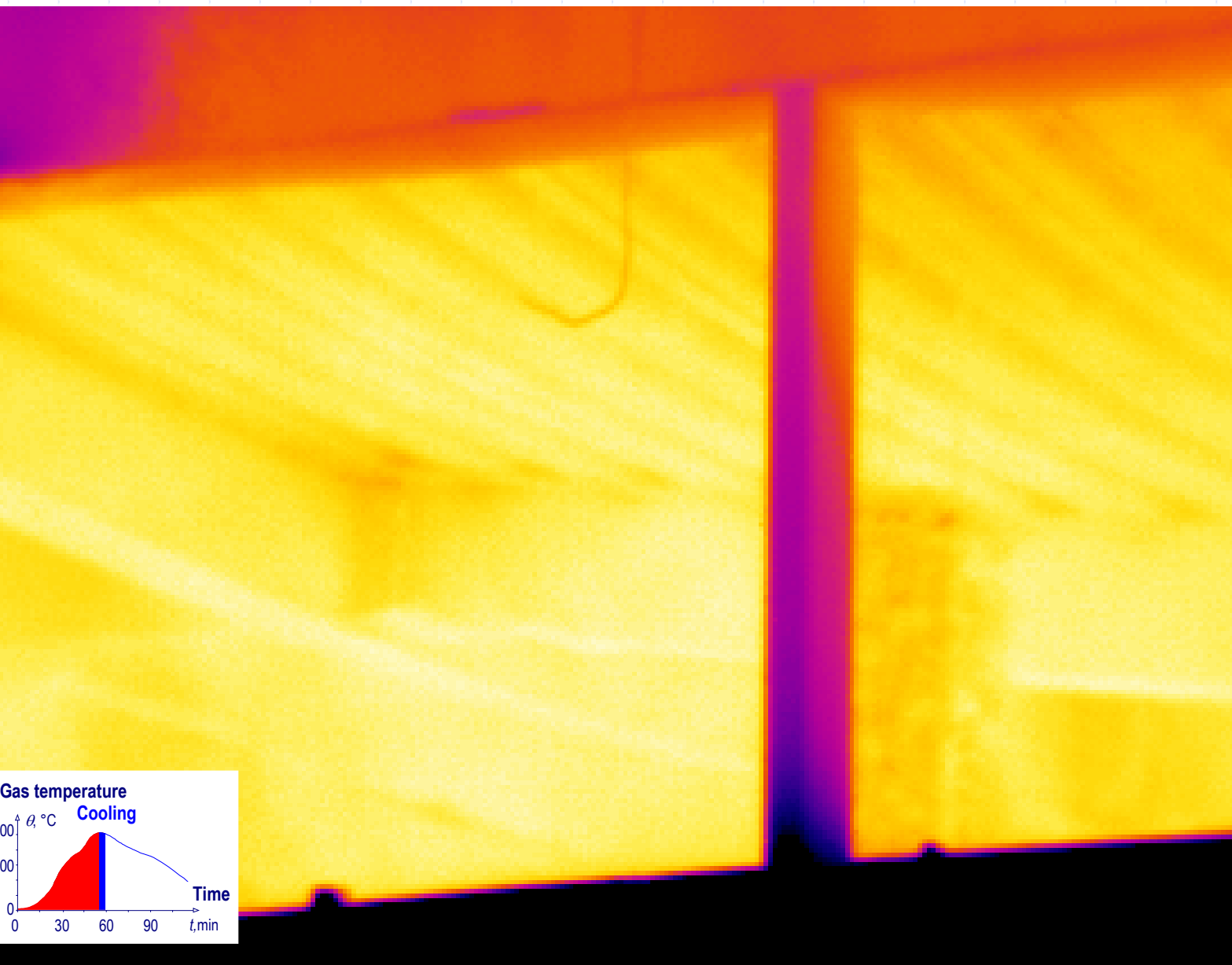
$\theta_{\text{con},\emptyset} = 855 \text{ }^{\circ}\text{C}$





$t = 60 \text{ min.}$

$\theta_{\text{con},\emptyset} = 880 \text{ }^{\circ}\text{C}$



980,0°C

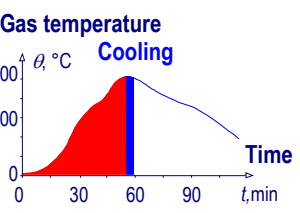
80

60

40

400,0°C

20

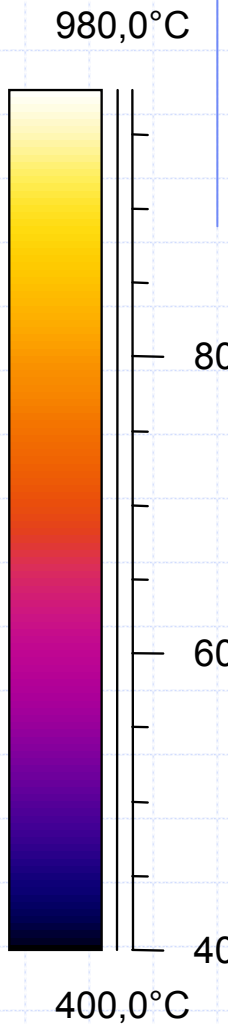
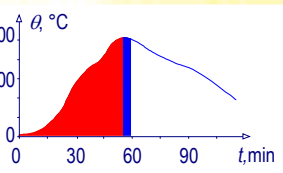




$t = 62 \text{ min.}$

$\theta_{\text{con},\emptyset} = 900 \text{ }^{\circ}\text{C}$

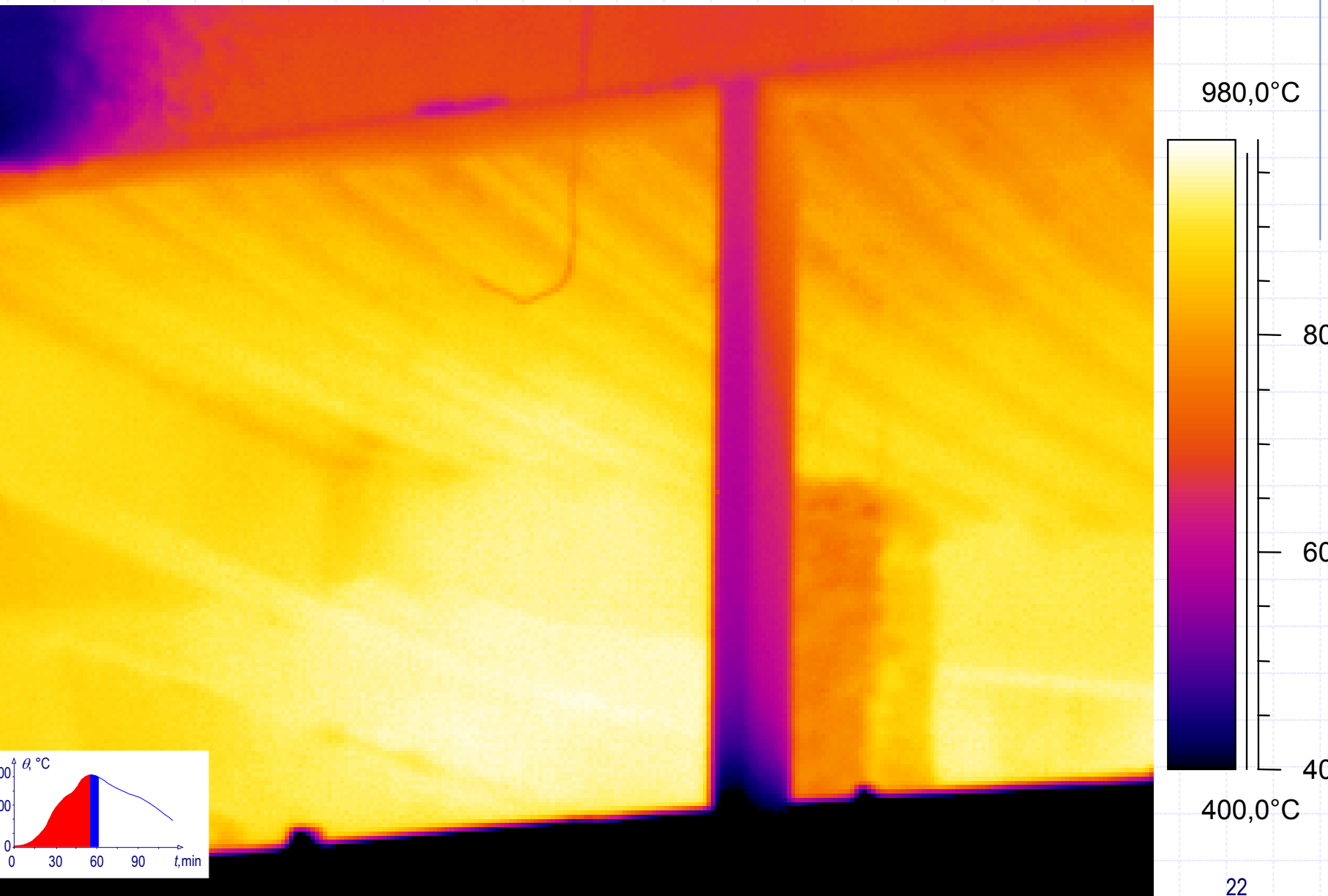
**Maximal temperature  
of fin plate connection  $908,3^{\circ}\text{C}$   
was reached in 63 min.**





$t = 64 \text{ min.}$

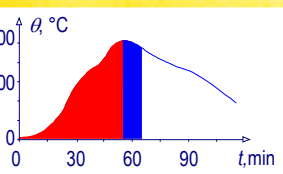
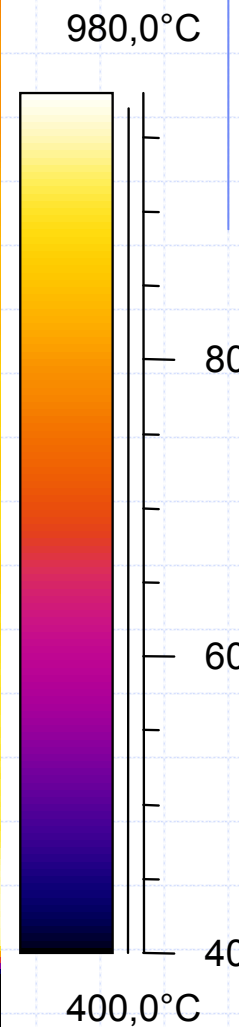
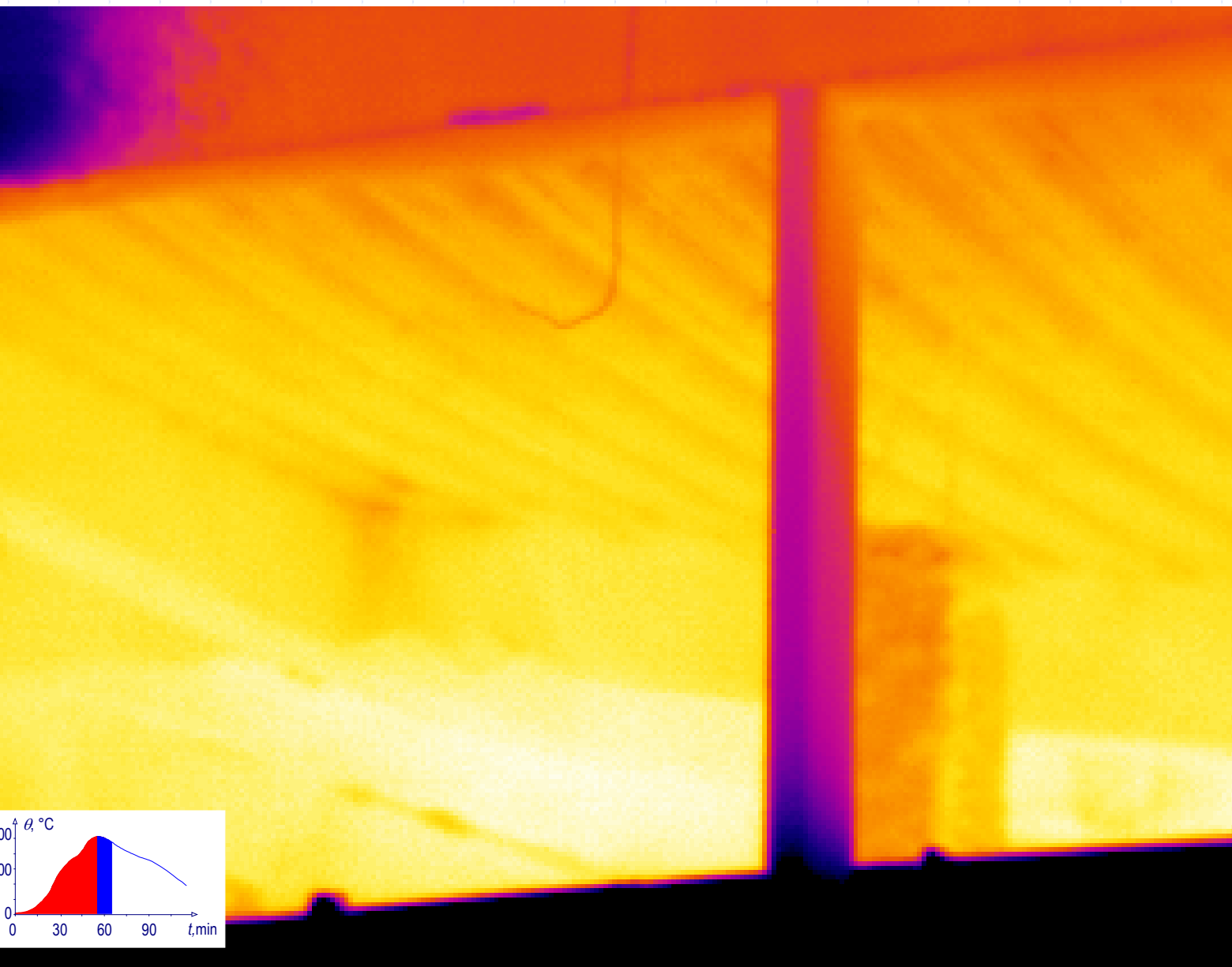
$\theta_{\text{con},\emptyset} = 885 \text{ }^{\circ}\text{C}$





$t = 66 \text{ min.}$

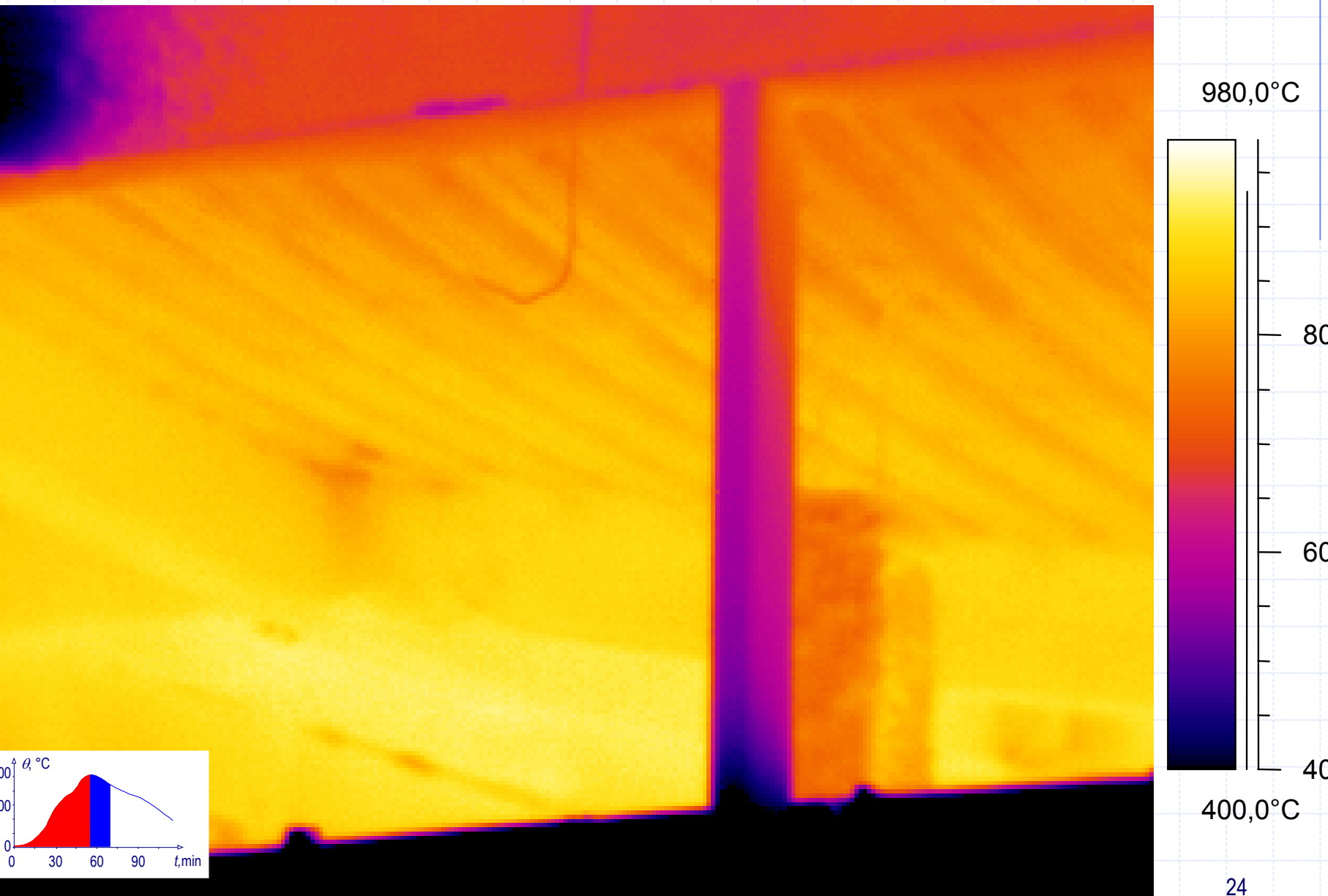
$\theta_{\text{con},\emptyset} = 860 \text{ }^{\circ}\text{C}$





$t = 68 \text{ min.}$

$\theta_{\text{con},\emptyset} = 840 \text{ }^{\circ}\text{C}$

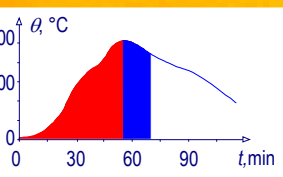
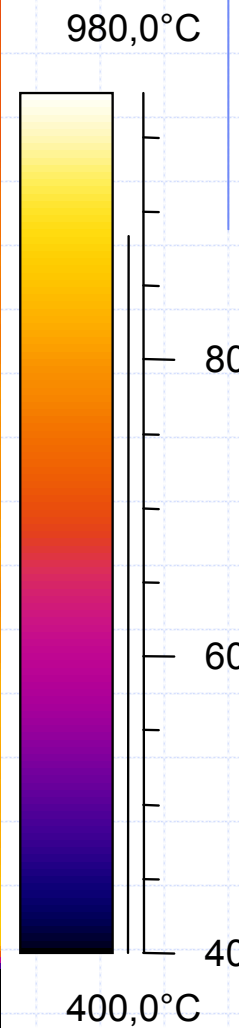
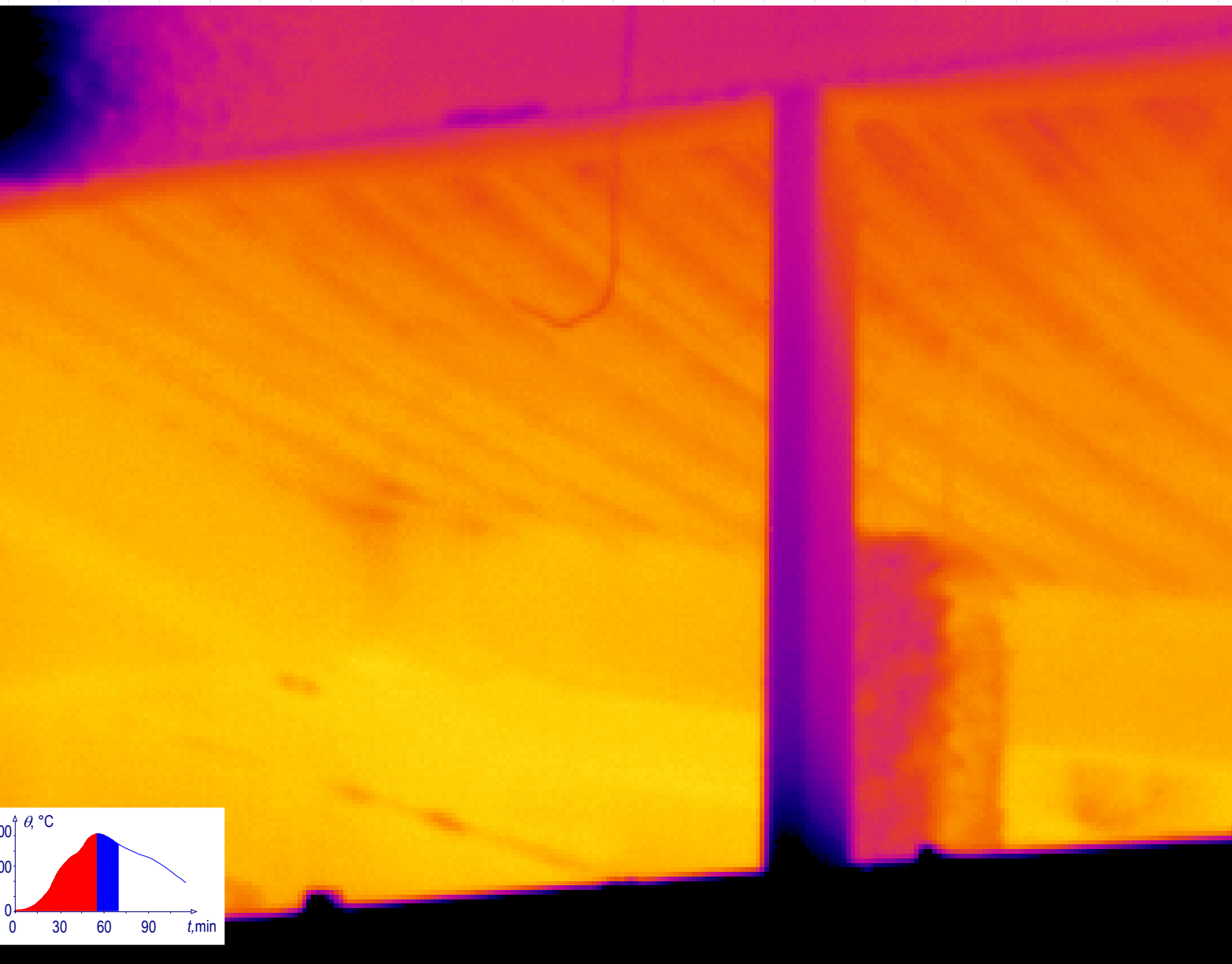






$t = 70 \text{ min.}$

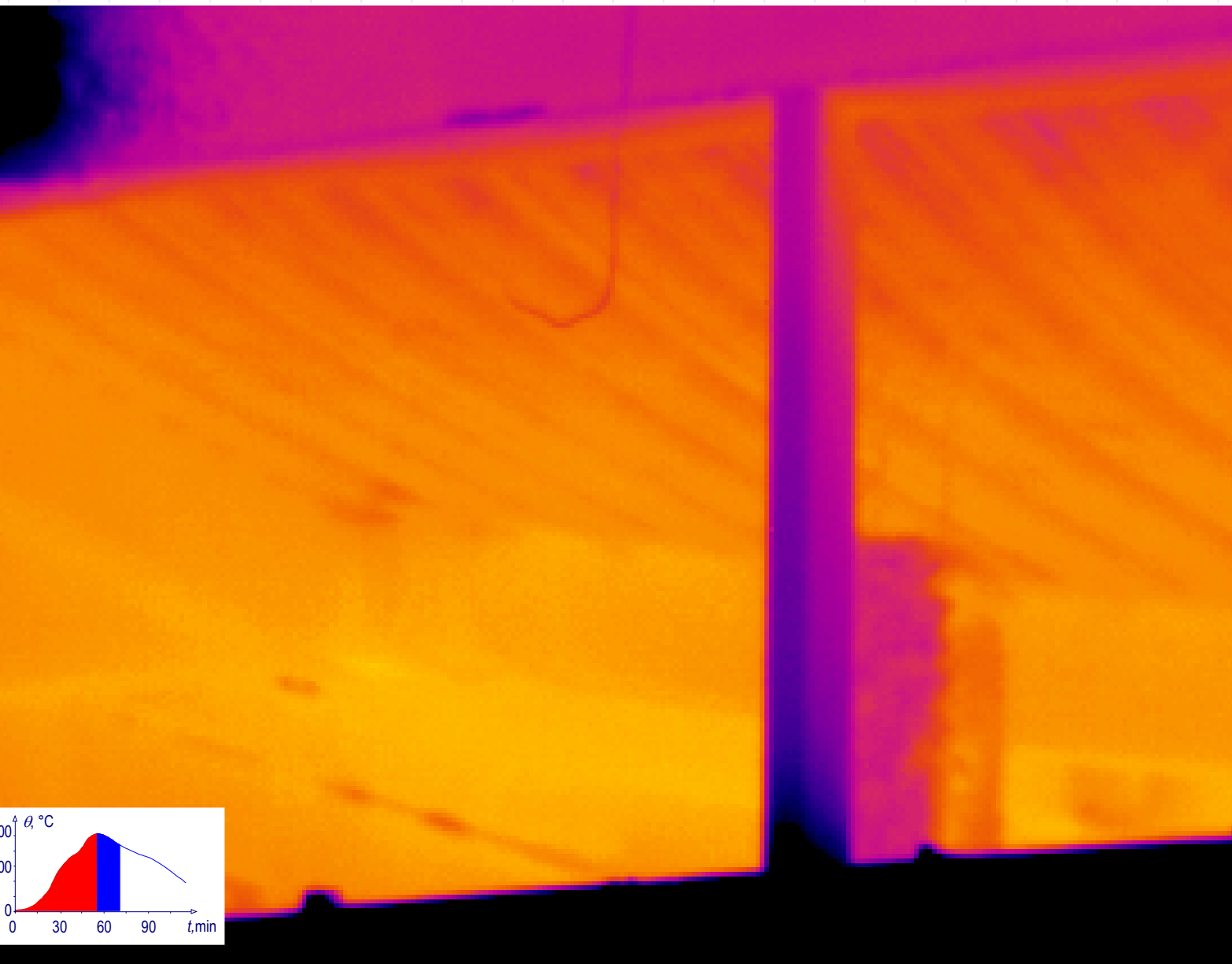
$\theta_{\text{con},\emptyset} = 820 \text{ }^{\circ}\text{C}$





$t = 72 \text{ min.}$

$\theta_{\text{con},\emptyset} = 800 \text{ }^{\circ}\text{C}$



980,0°C

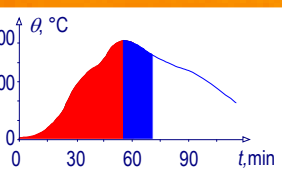


800,0°C

600,0°C

400,0°C

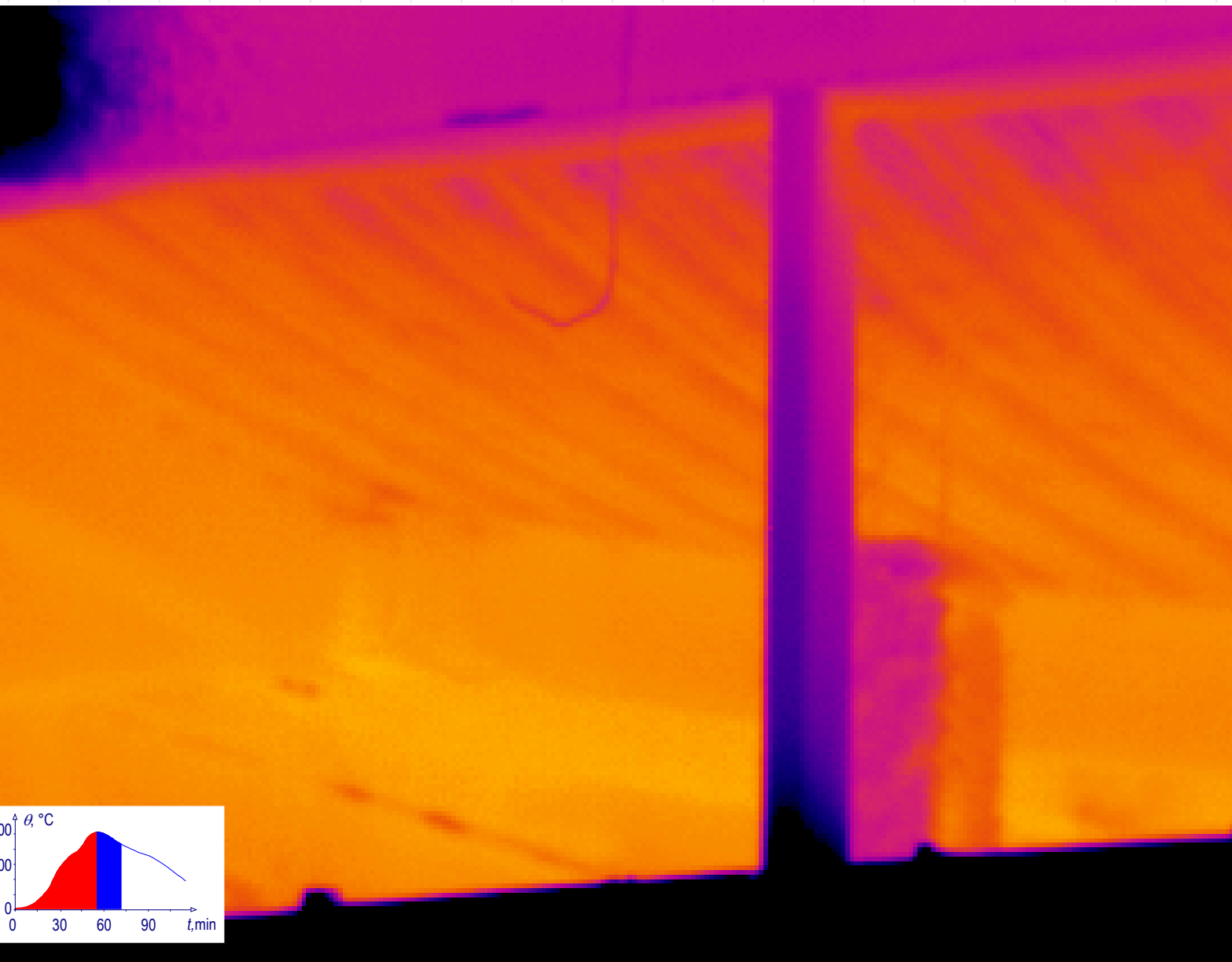
400,0°C





$t = 74 \text{ min.}$

$\theta_{\text{con},\emptyset} = 790 \text{ }^{\circ}\text{C}$



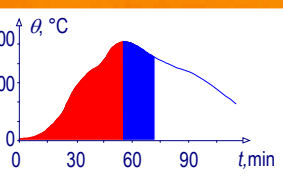
980,0°C

800,0°C

600,0°C

400,0°C

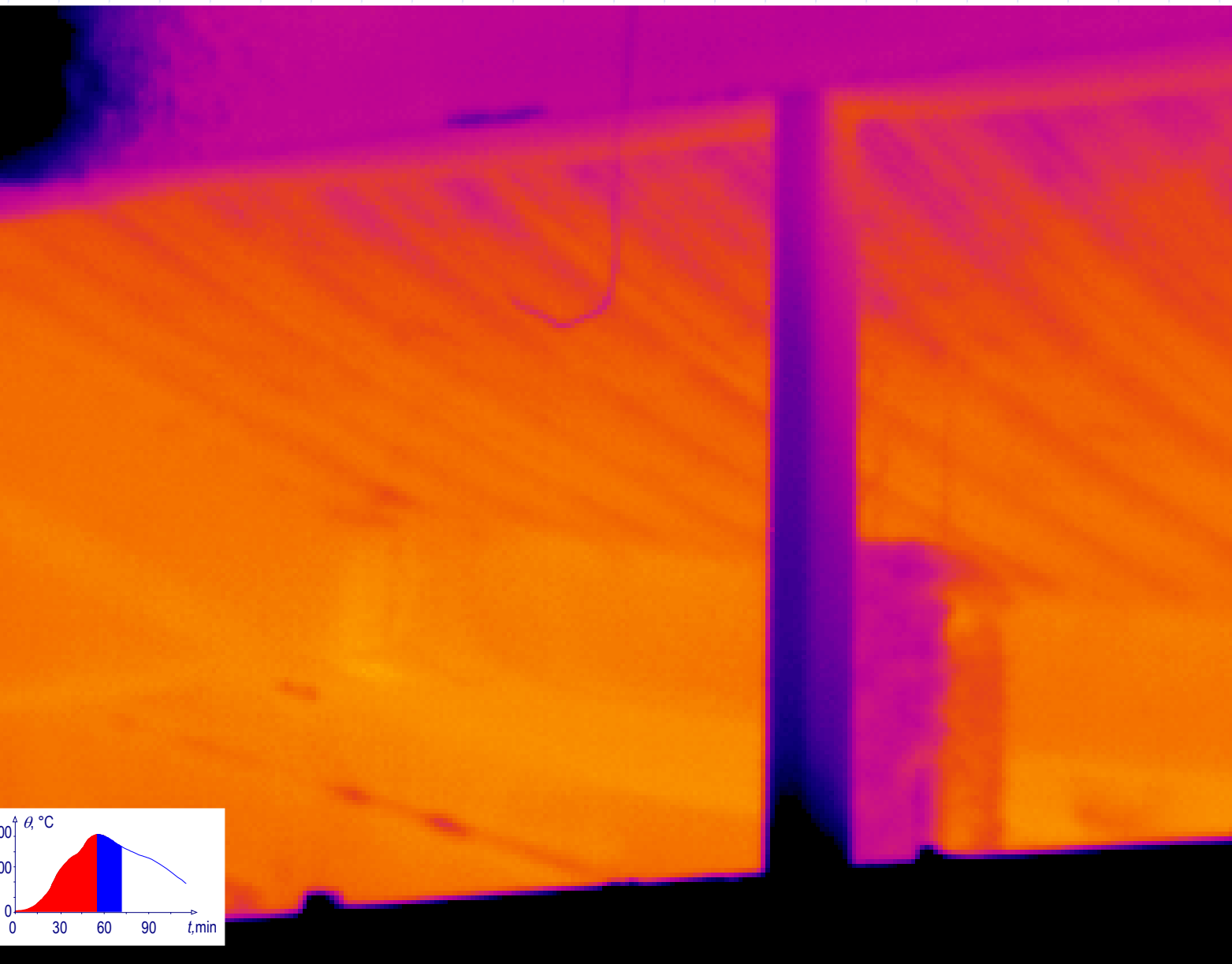
400,0°C





$t = 76 \text{ min.}$

$\theta_{\text{con},\emptyset} = 770 \text{ }^{\circ}\text{C}$



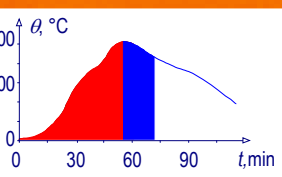
980,0°C

80

60

40

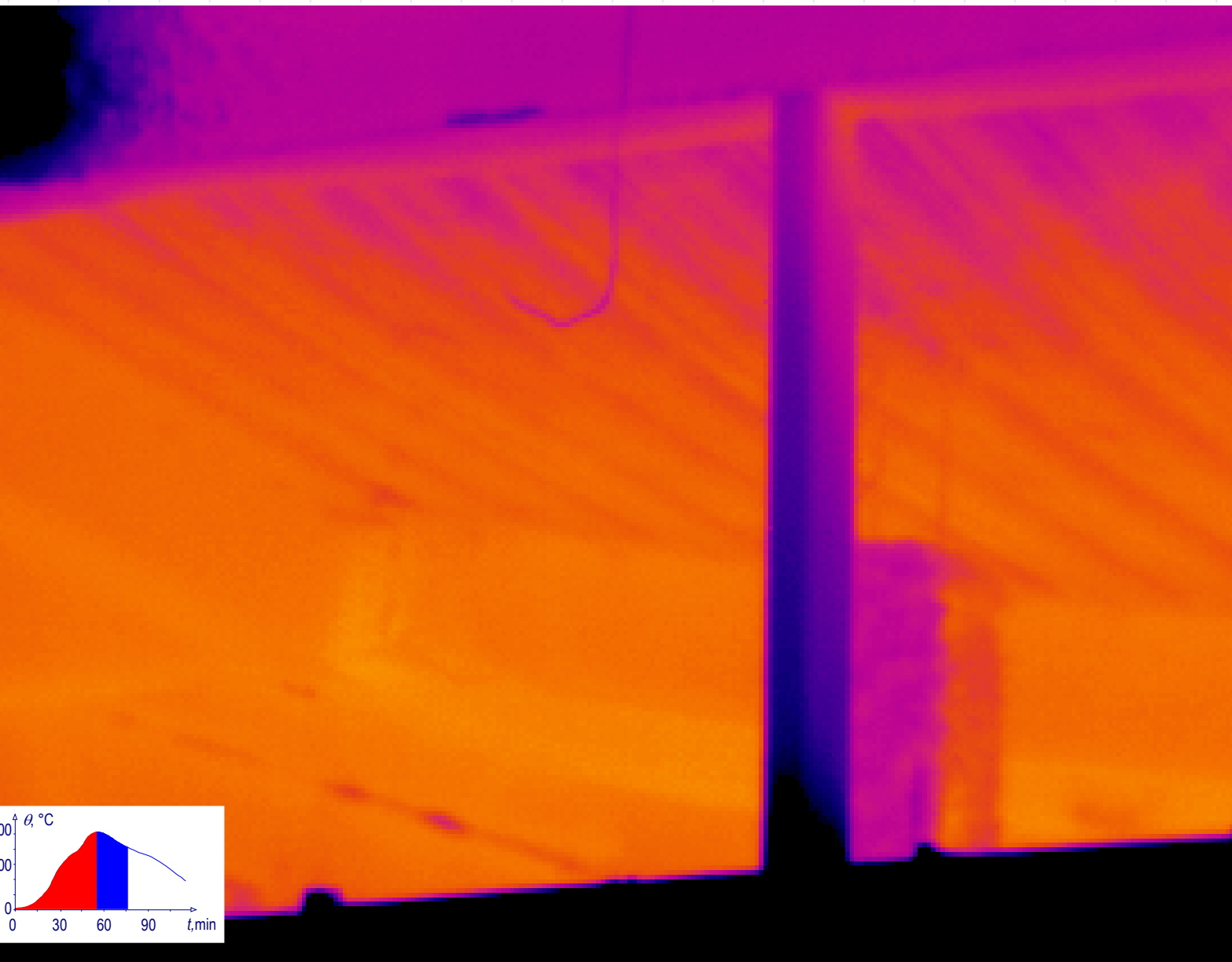
400,0°C





$t = 78 \text{ min.}$

$\theta_{\text{con},\emptyset} = 775 \text{ }^{\circ}\text{C}$



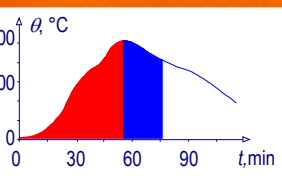
980,0°C

80

60

40

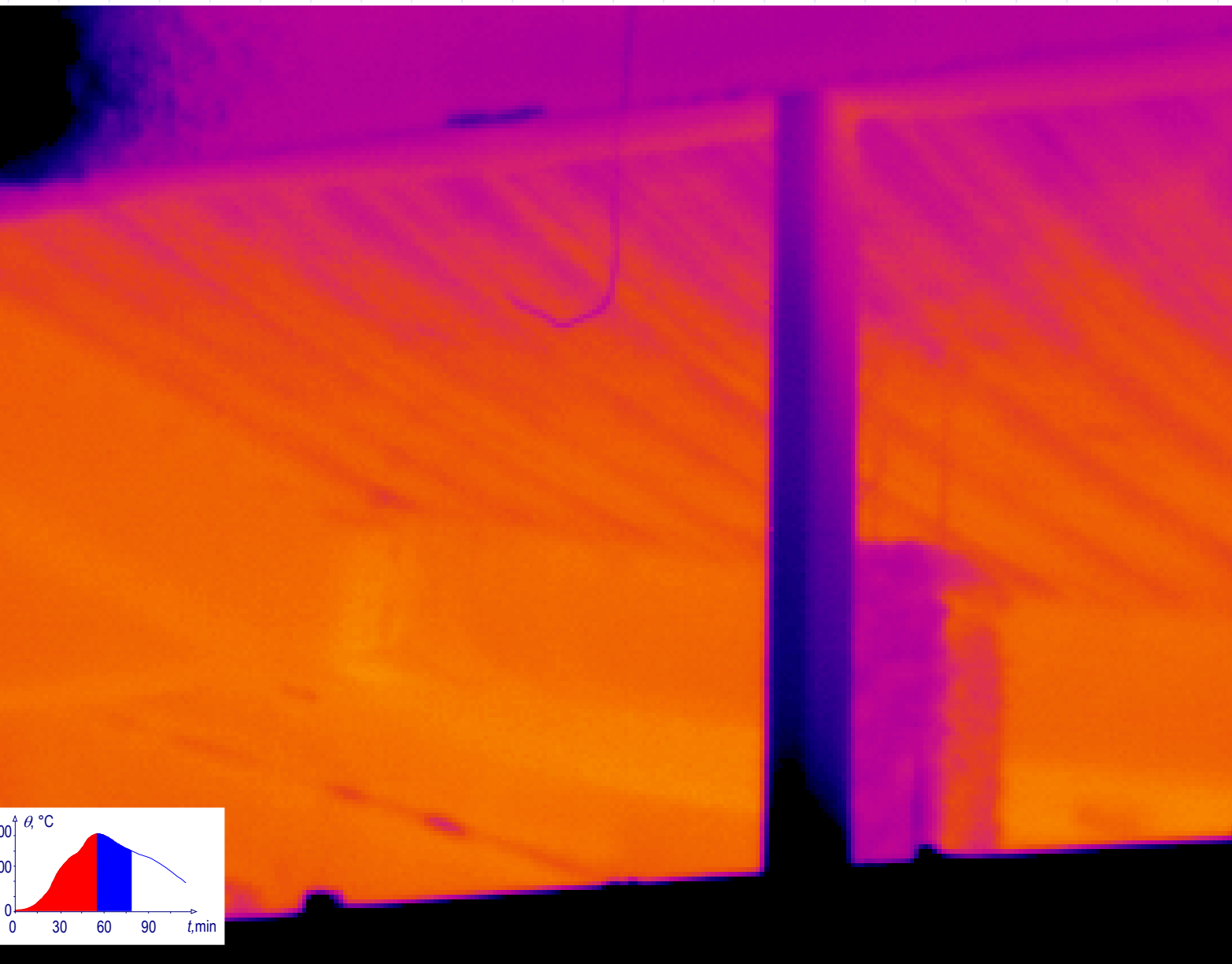
400,0°C



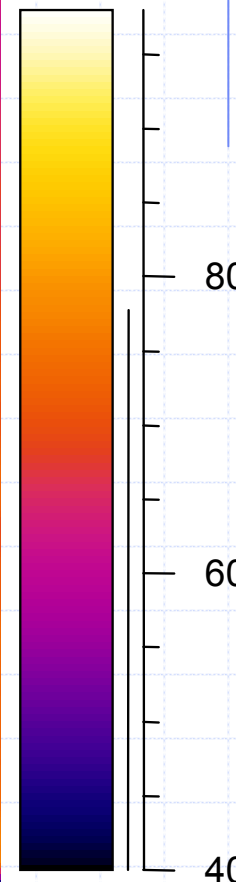


$t = 80 \text{ min.}$

$\theta_{\text{con},\emptyset} = 745 \text{ }^{\circ}\text{C}$



$980,0^{\circ}\text{C}$

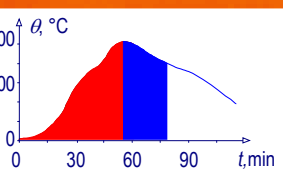


$800,0^{\circ}\text{C}$

$600,0^{\circ}\text{C}$

$400,0^{\circ}\text{C}$

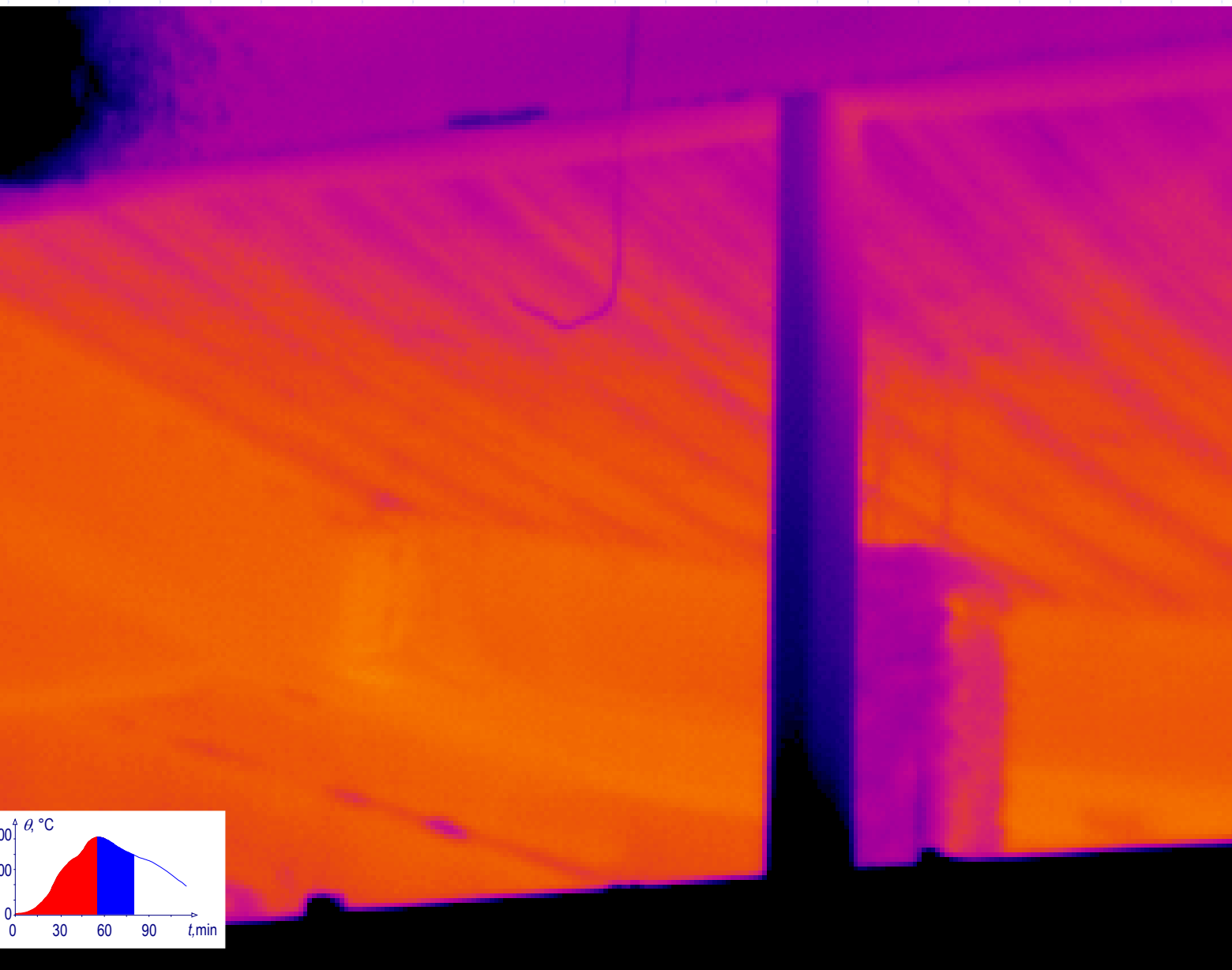
$400,0^{\circ}\text{C}$





$t = 82 \text{ min.}$

$\theta_{\text{con},\emptyset} = 740 \text{ }^{\circ}\text{C}$



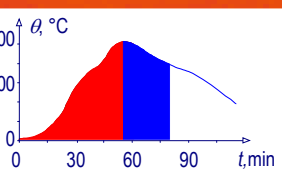
980,0°C

800

600

400

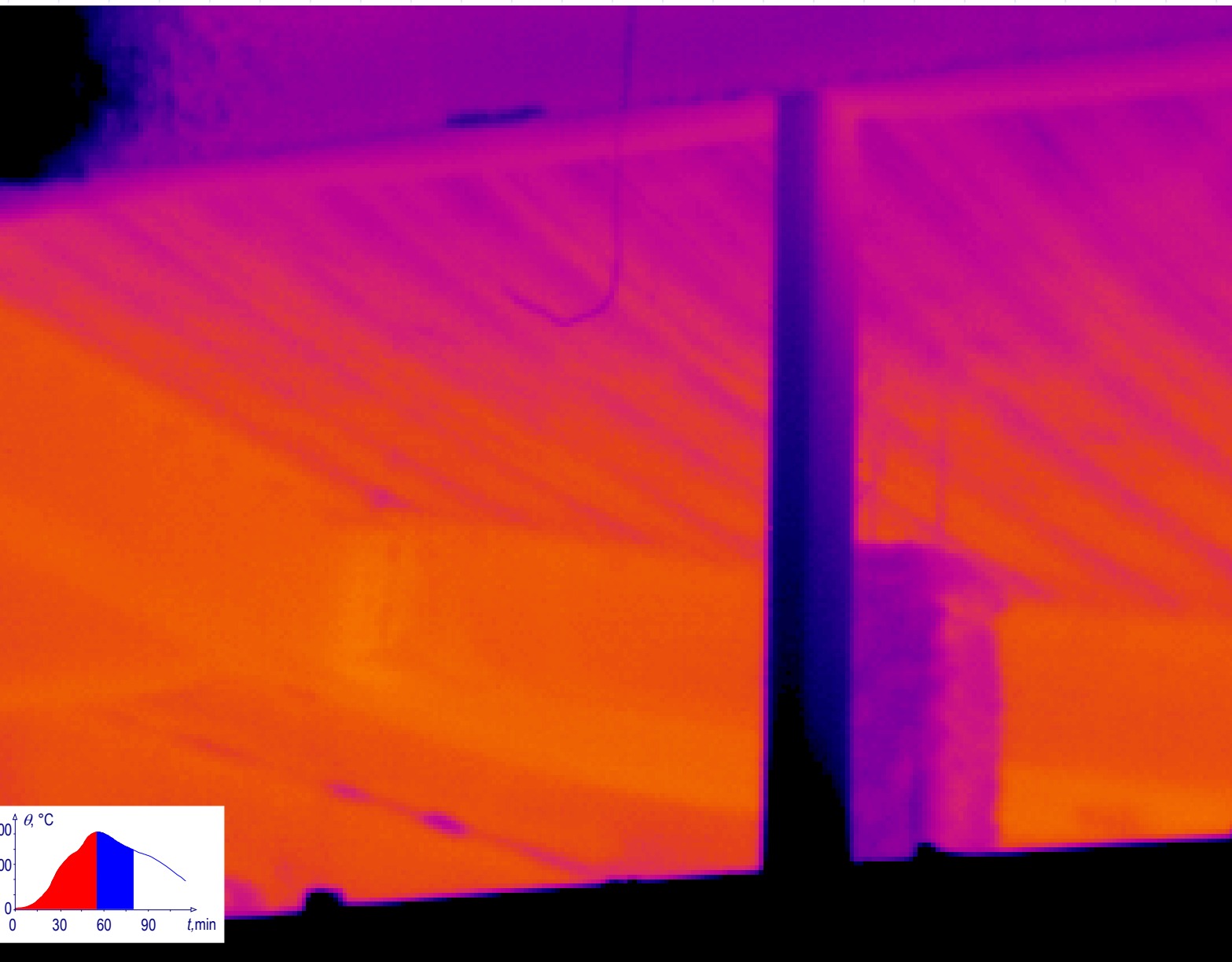
400,0°C



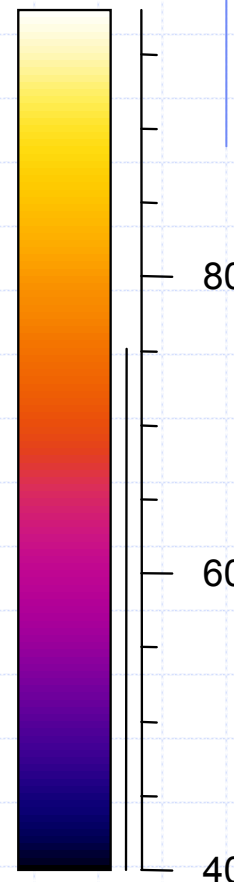


$t = 84 \text{ min.}$

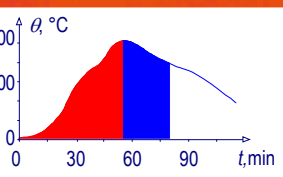
$\theta_{\text{con},\emptyset} = 730 \text{ }^{\circ}\text{C}$



$980,0^{\circ}\text{C}$



$400,0^{\circ}\text{C}$

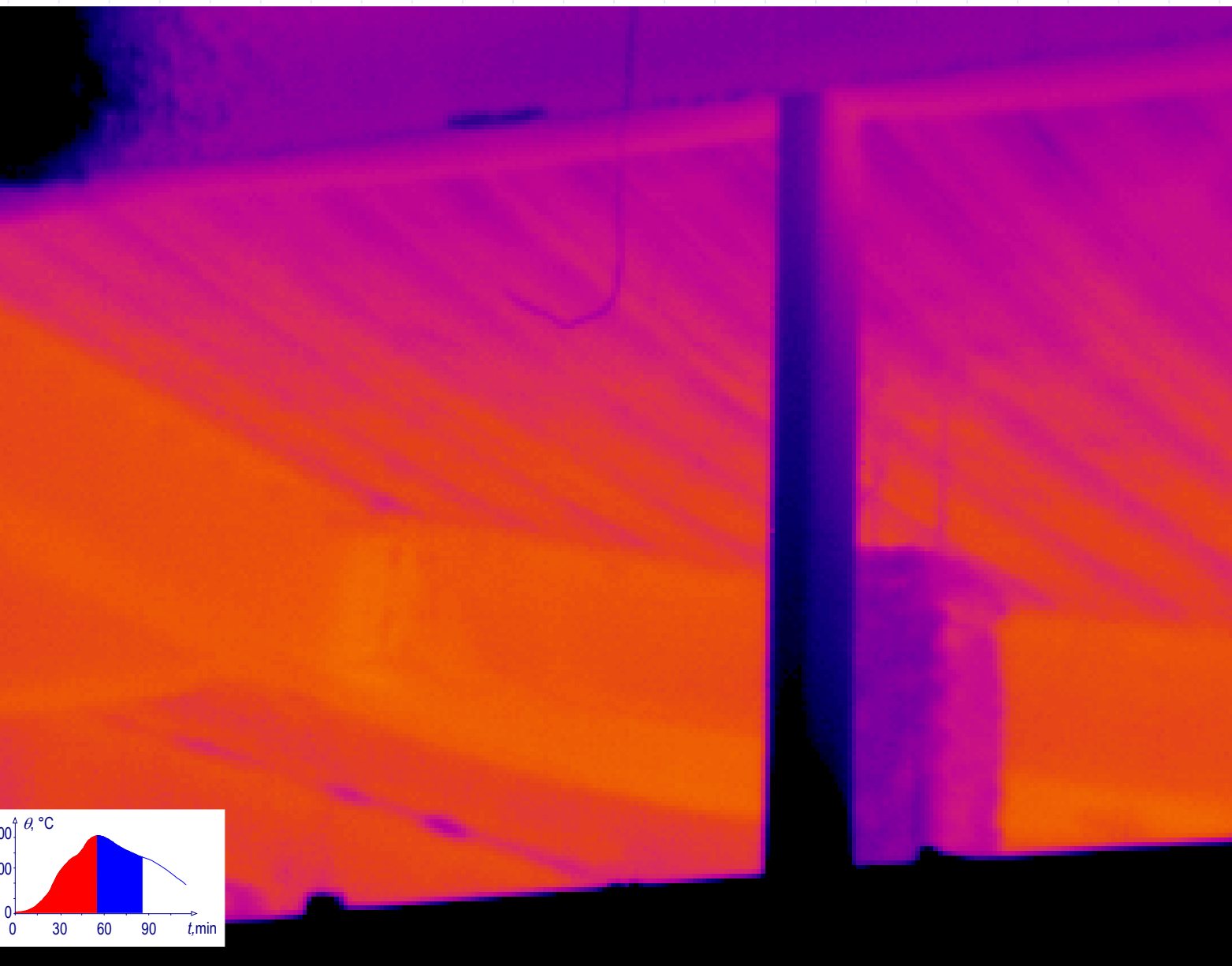






$t = 76 \text{ min.}$

$\theta_{\text{con},\emptyset} = 720 \text{ }^{\circ}\text{C}$



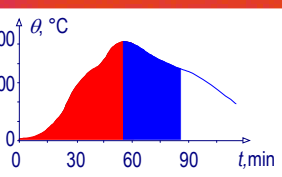
980,0°C

800,0°C

600,0°C

400,0°C

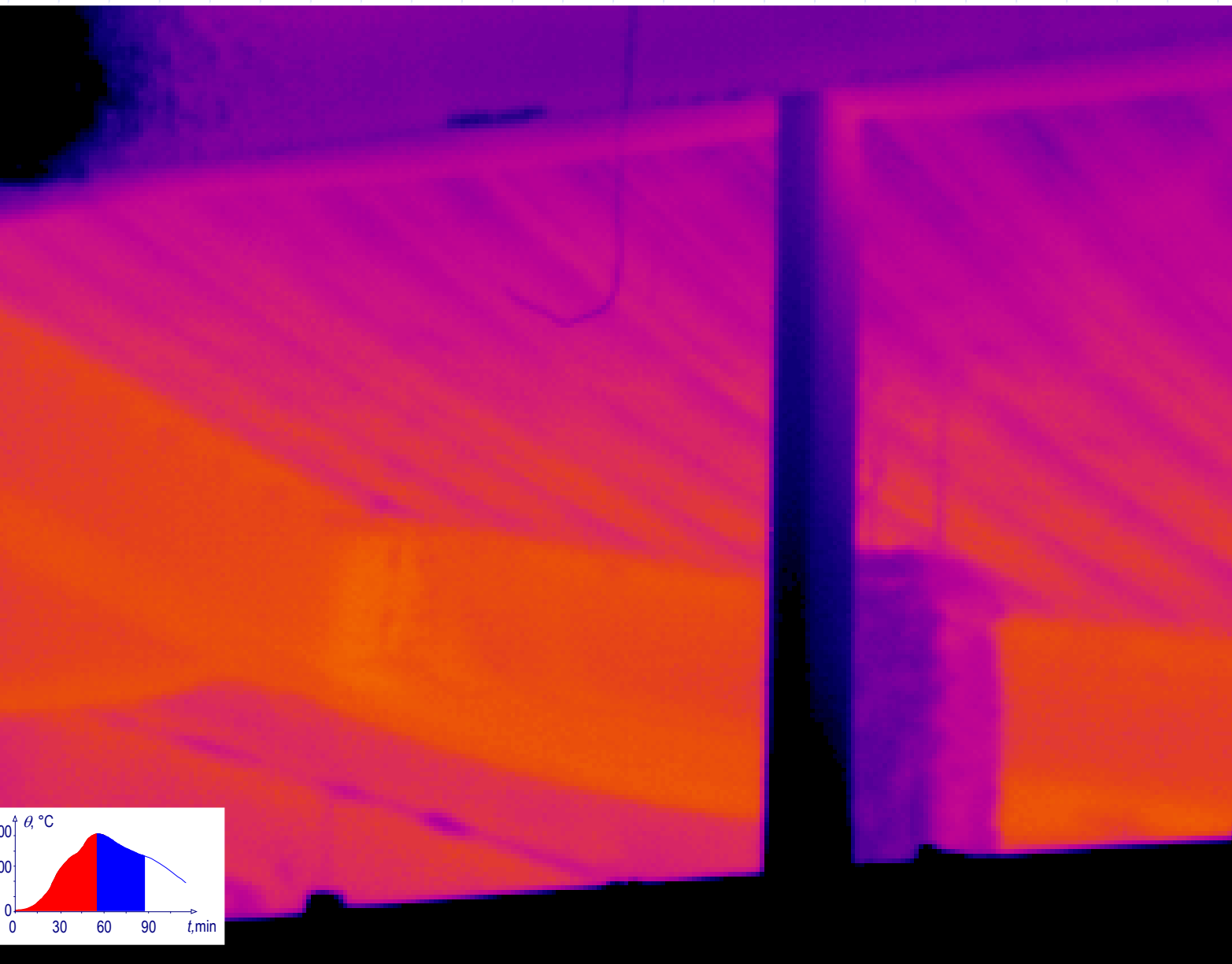
400,0°C





$t = 78 \text{ min.}$

$\theta_{\text{con},\emptyset} = 710 \text{ }^{\circ}\text{C}$



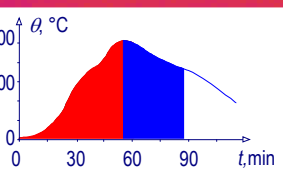
980,0°C

800,0°C

600,0°C

400,0°C

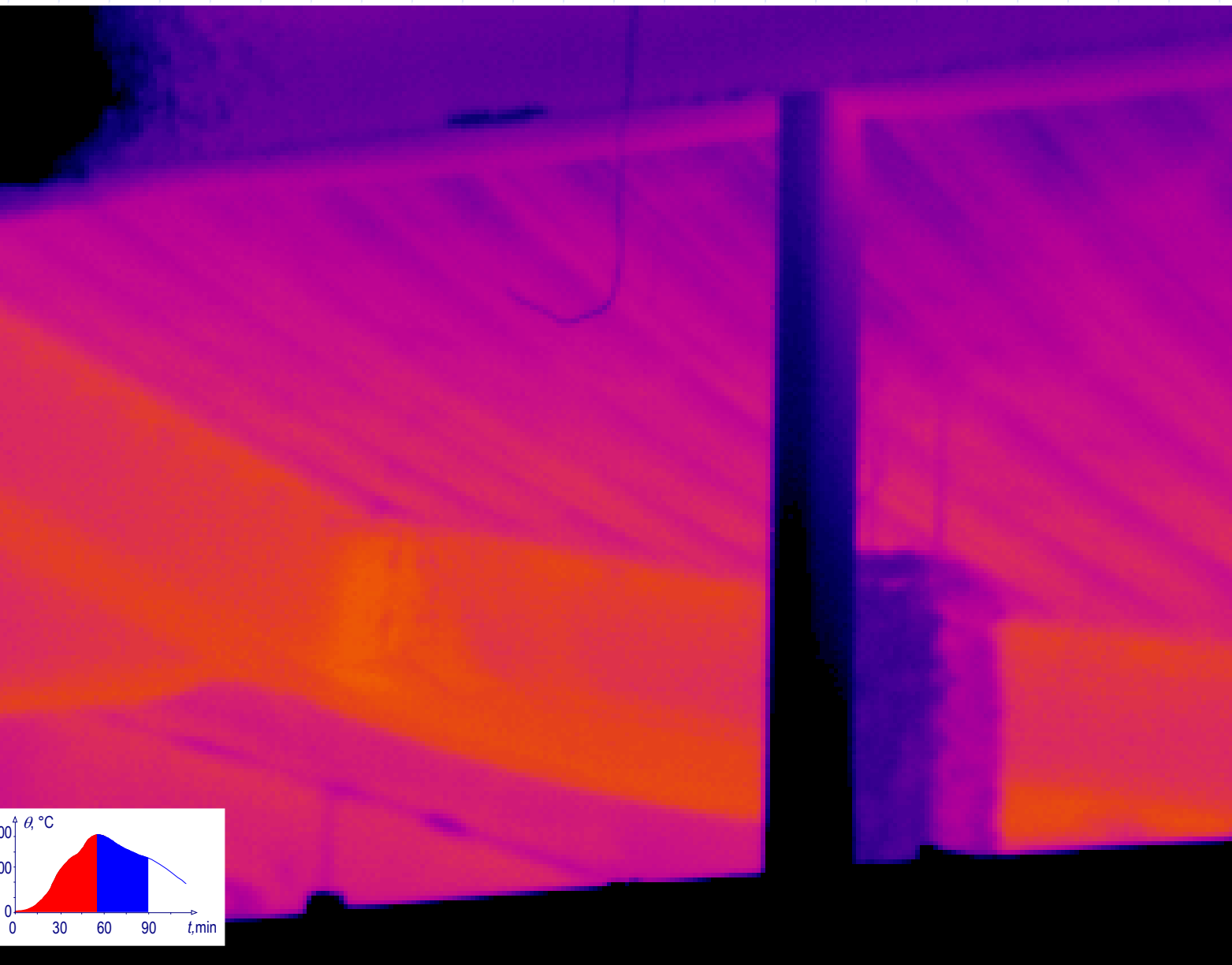
400,0°C





$t = 90 \text{ min.}$

$\theta_{\text{con},\emptyset} = 690 \text{ }^{\circ}\text{C}$



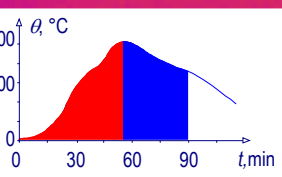
980,0°C

800,0°C

600,0°C

400,0°C

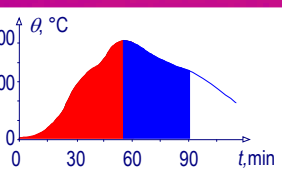
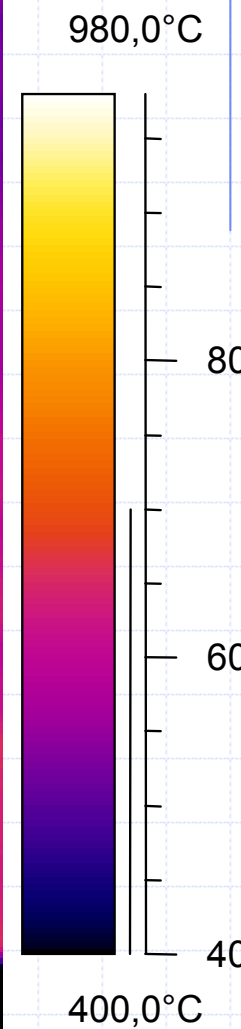
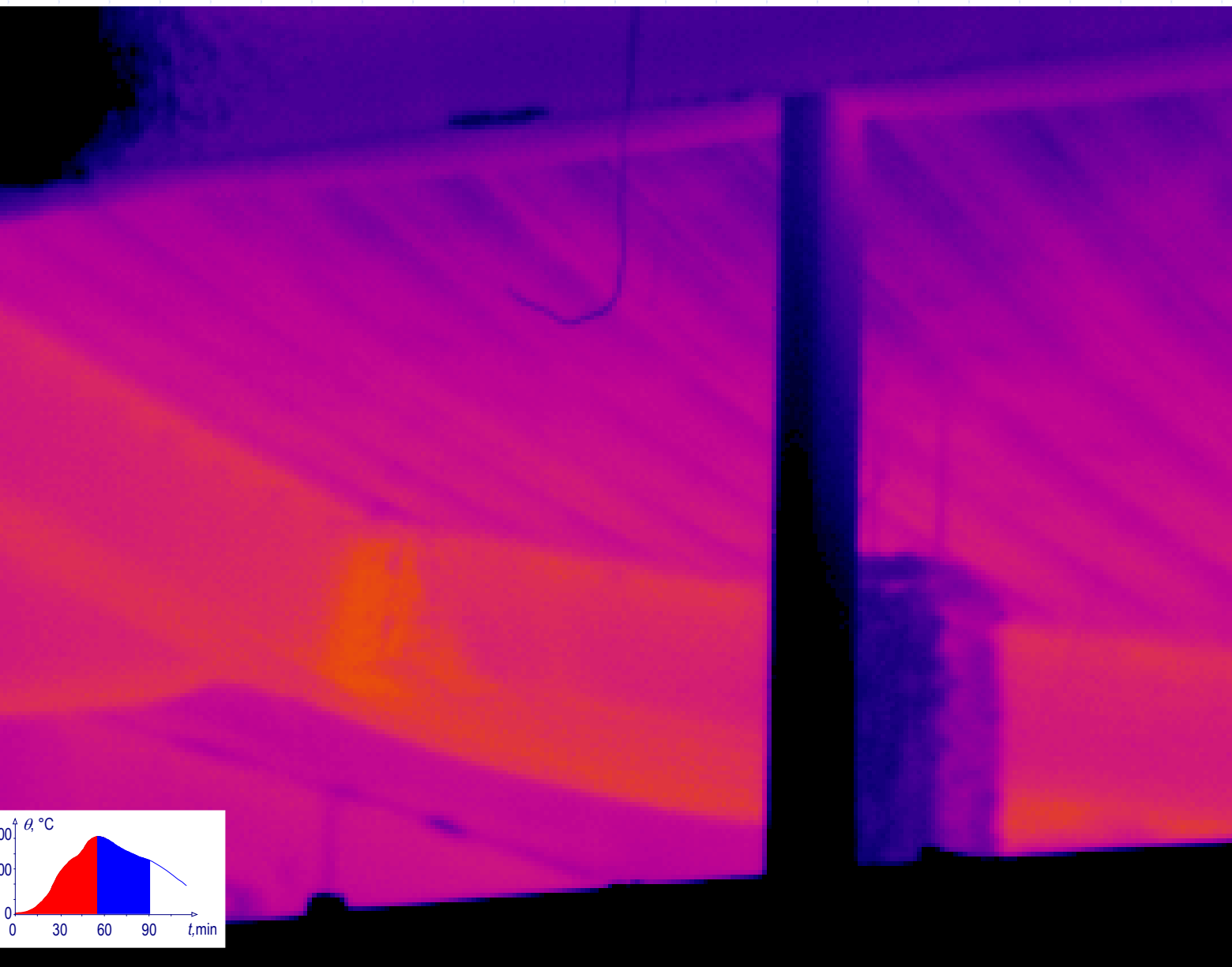
400,0°C





$t = 92 \text{ min.}$

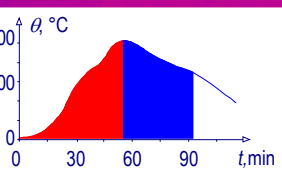
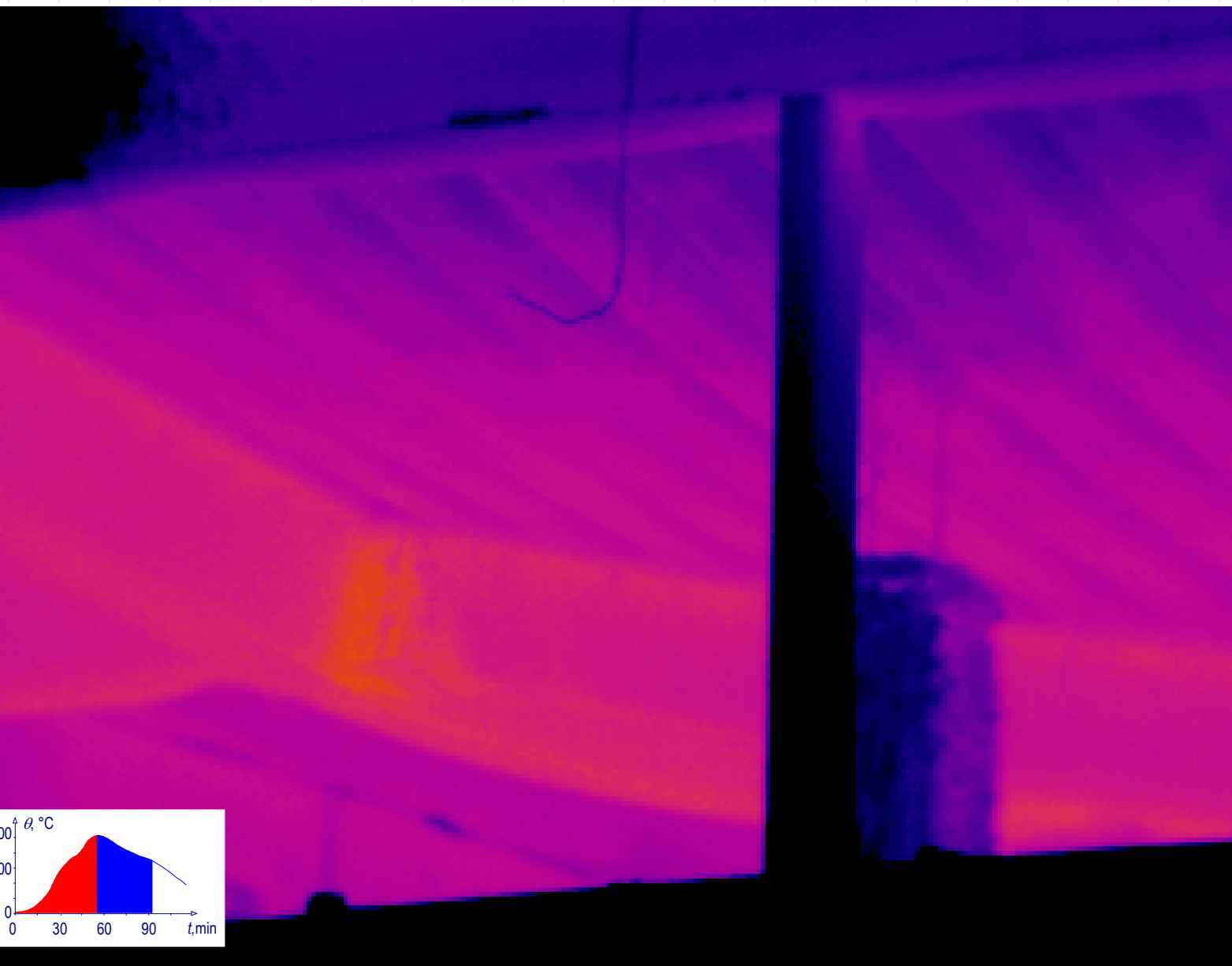
$\theta_{\text{con},\emptyset} = 680 \text{ }^{\circ}\text{C}$





$t = 94 \text{ min.}$

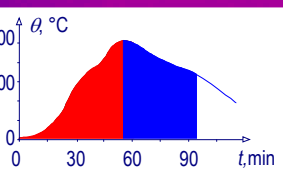
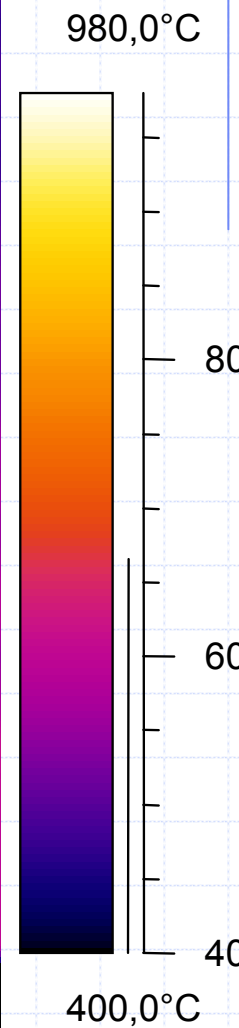
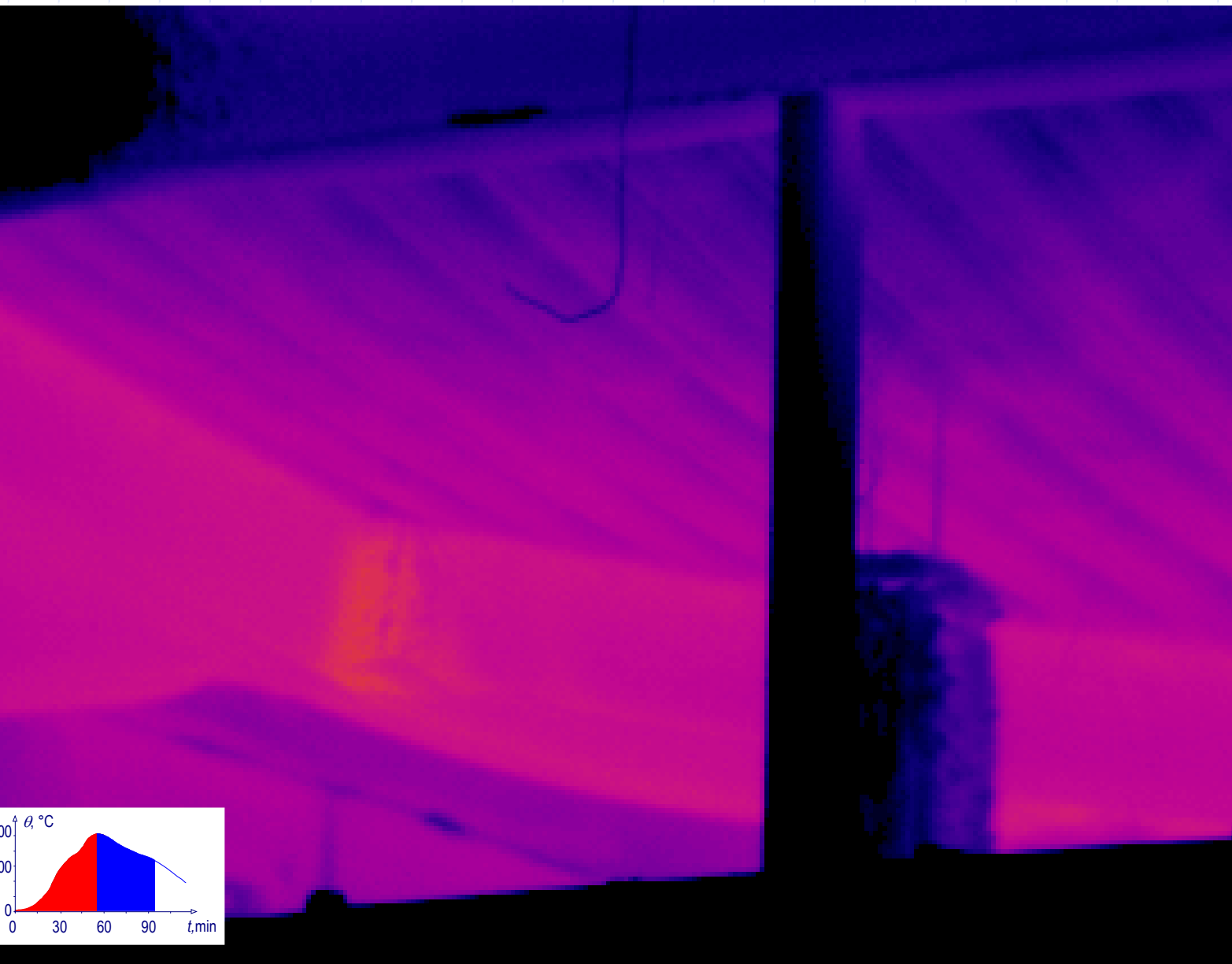
$\theta_{\text{con},\emptyset} = 670 \text{ }^{\circ}\text{C}$





$t = 96 \text{ min.}$

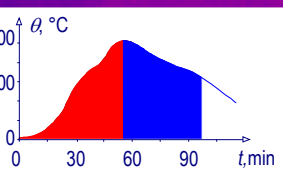
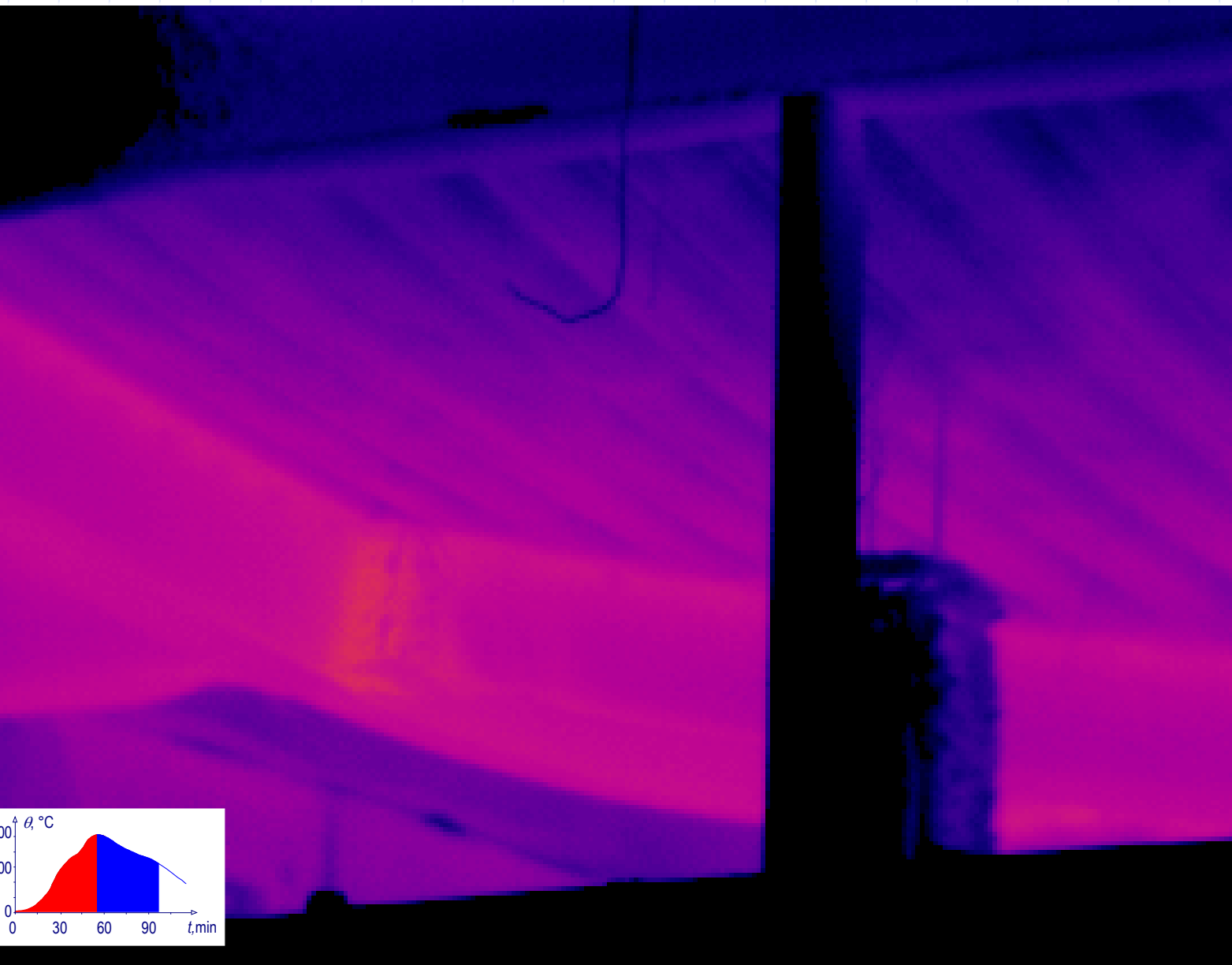
$\theta_{\text{con},\emptyset} = 650 \text{ }^{\circ}\text{C}$





$t = 98 \text{ min.}$

$\theta_{\text{con},\emptyset} = 640 \text{ }^{\circ}\text{C}$

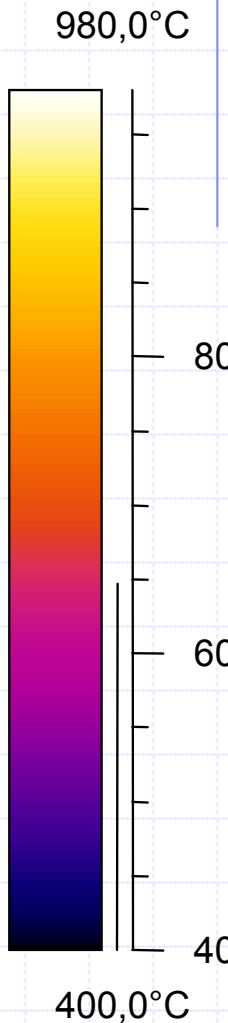
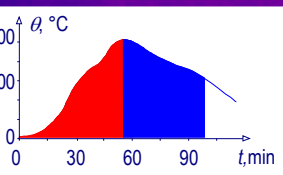




$t = 100 \text{ min.}$

$\theta_{\text{con},\emptyset} = 635 \text{ }^{\circ}\text{C}$

**The connection is warmer  
compare to the connected beam  
by cooling of the structure,  
but never reached the beam  
maximal temperature.**



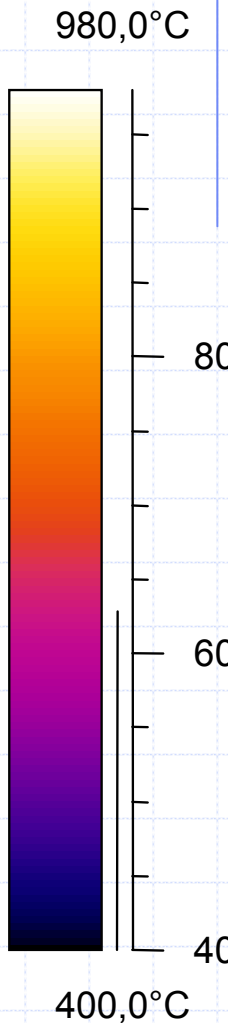
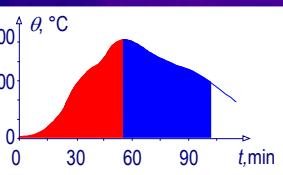




$t = 102 \text{ min.}$

$\theta_{\text{con},\emptyset} = 620 \text{ }^{\circ}\text{C}$

**The connection is warmer  
compare to the connected beam  
by cooling of the structure,  
but never reached the beam  
maximal temperature.**

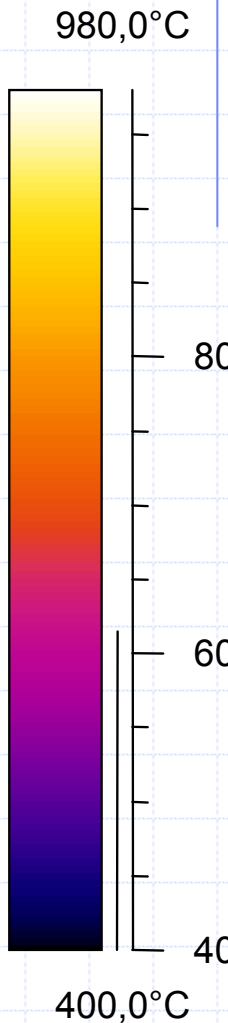
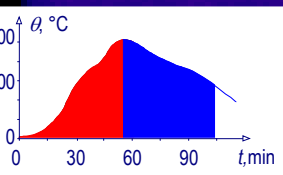




$t = 104 \text{ min.}$

$\theta_{\text{con},\emptyset} = 600 \text{ }^{\circ}\text{C}$

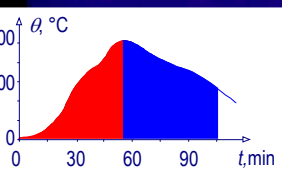
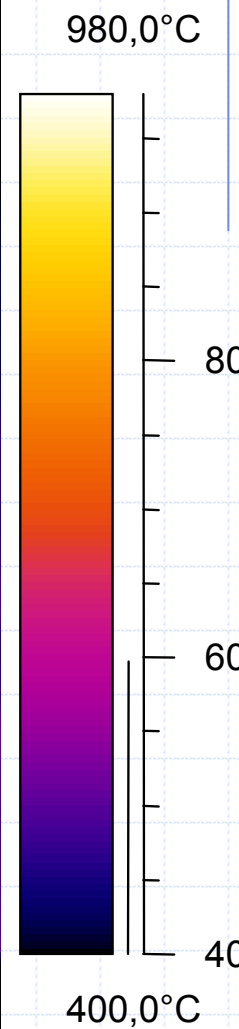
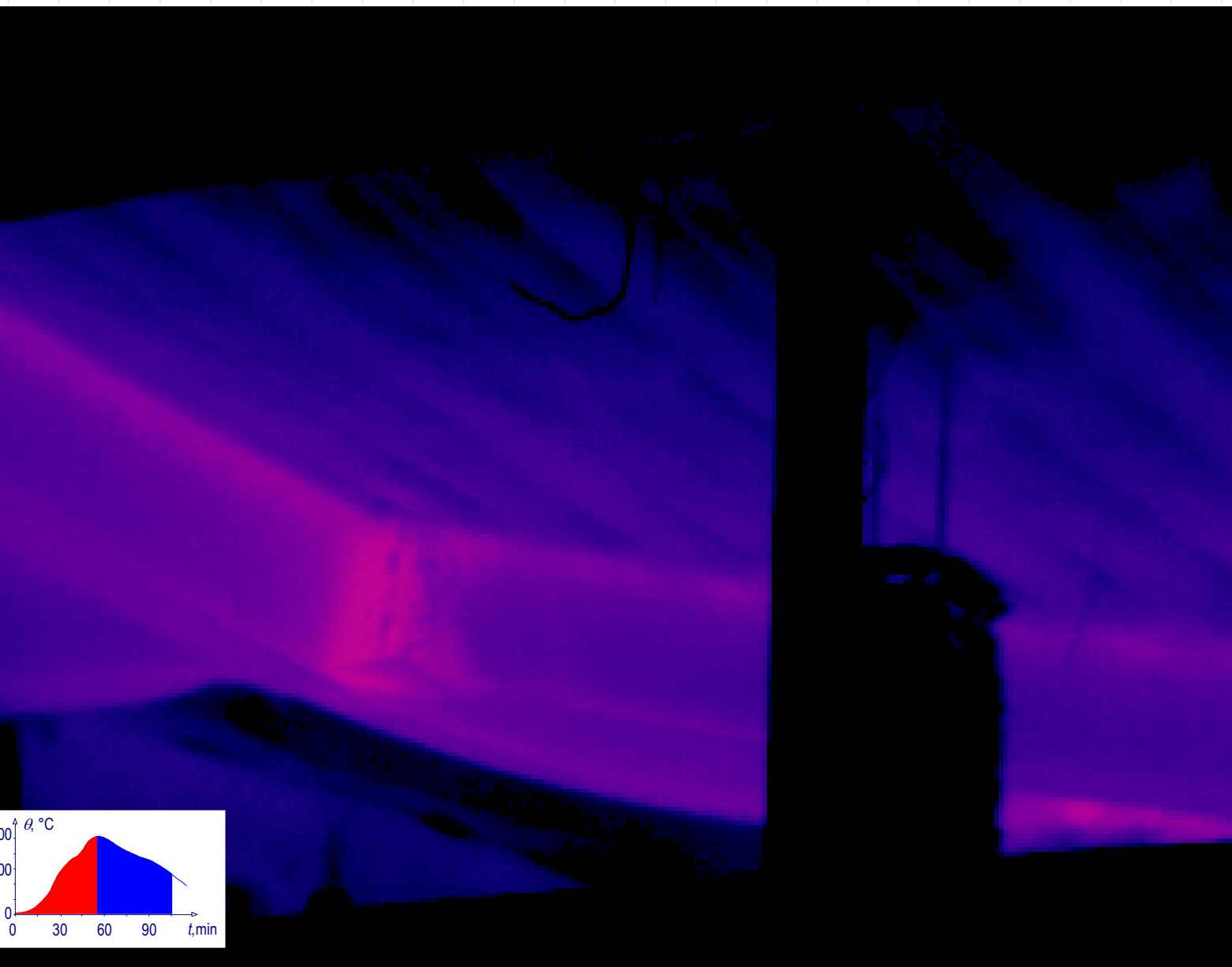
**The connection is warmer  
compare to the connected beam  
by cooling of the structure,  
but never reached the beam  
maximal temperature.**





$t = 106 \text{ min.}$

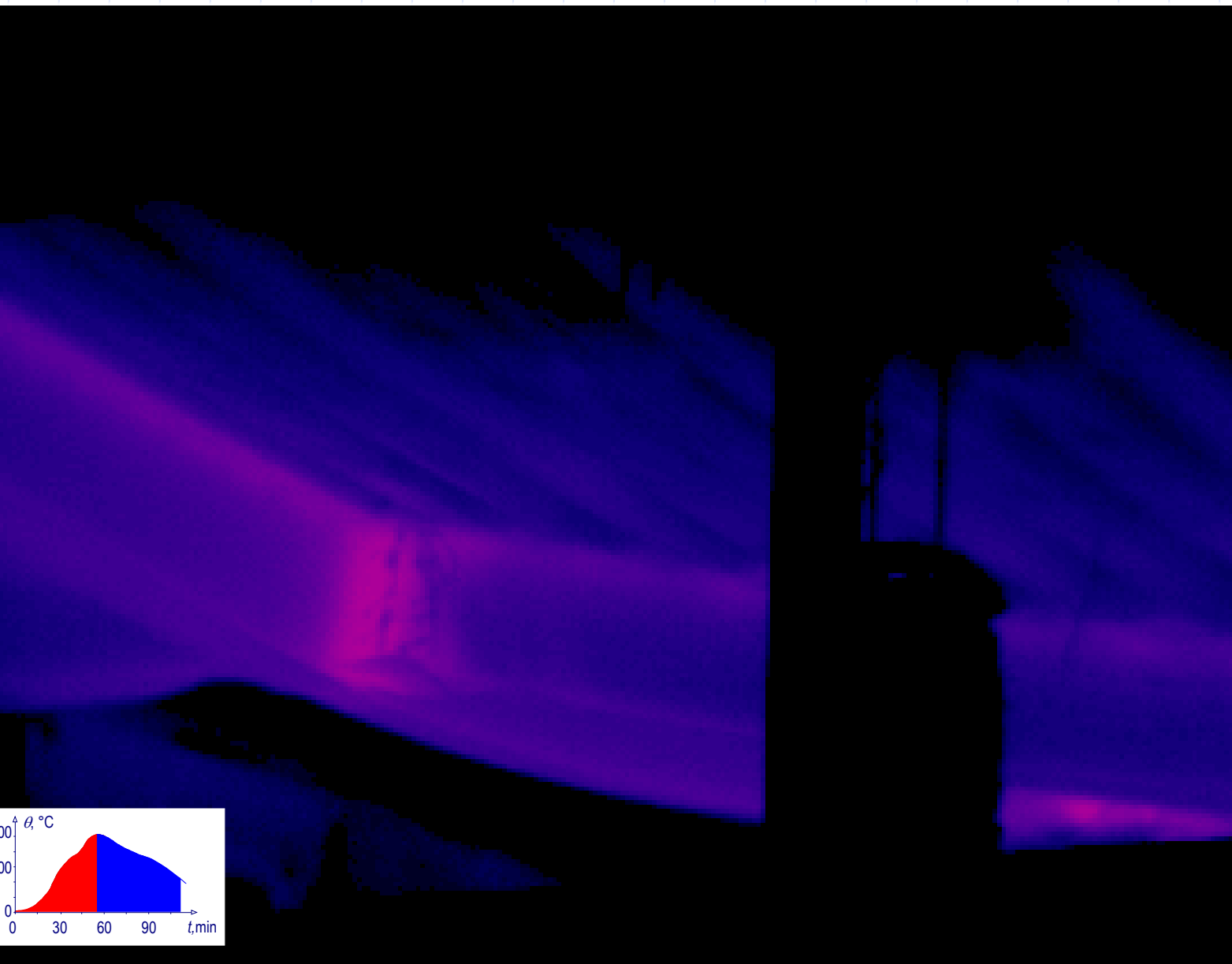
$\theta_{\text{con},\emptyset} = 585 \text{ }^{\circ}\text{C}$



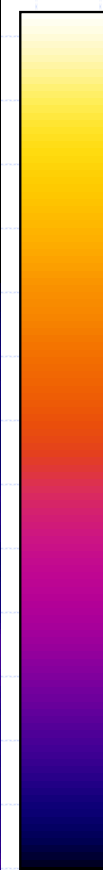


$t = 108 \text{ min.}$

$\theta_{\text{con},\emptyset} = 560 \text{ }^{\circ}\text{C}$



980,0°C

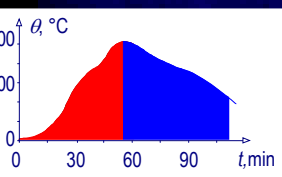


800,0°C

600,0°C

400,0°C

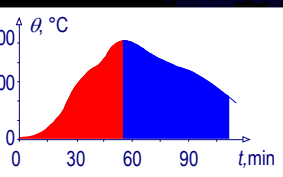
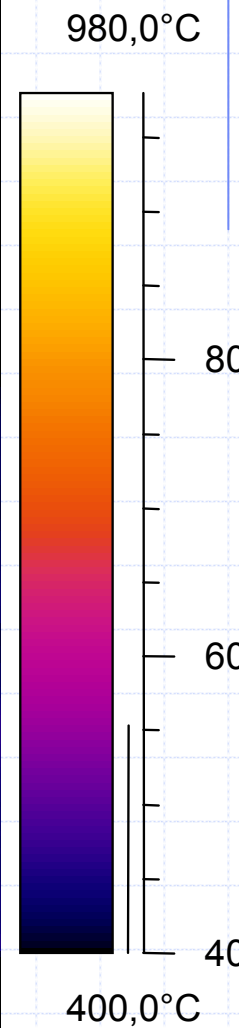
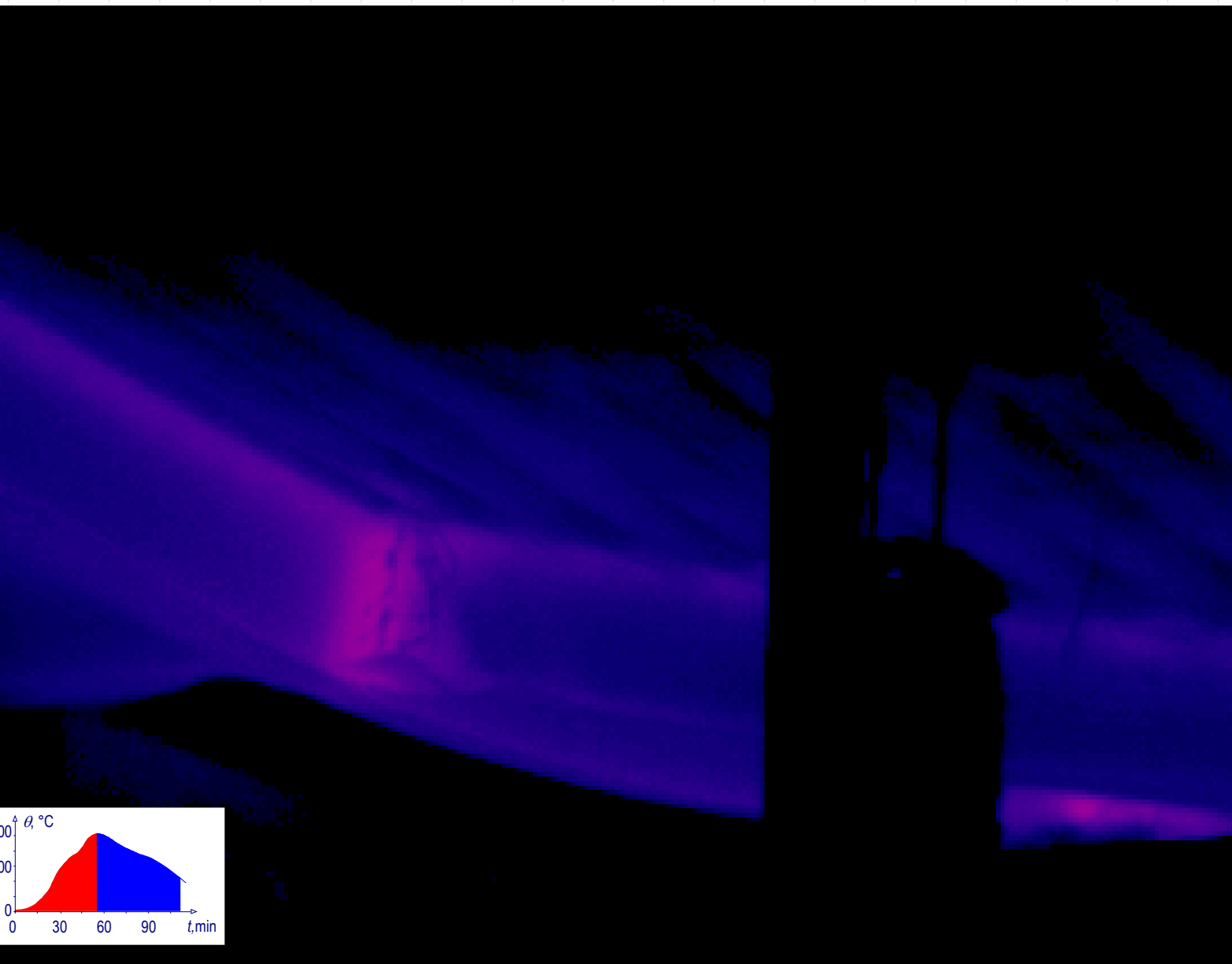
400,0°C





$t = 110 \text{ min.}$

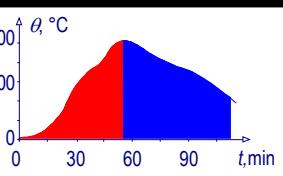
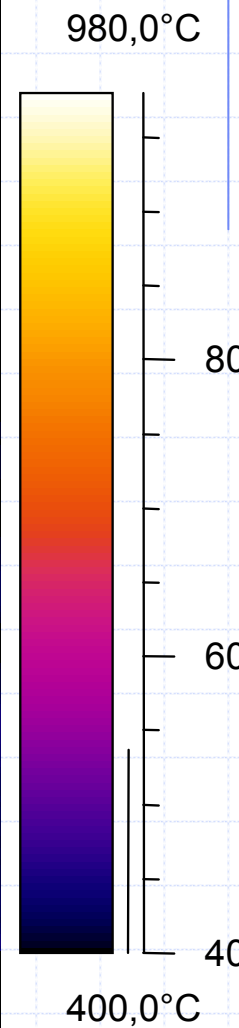
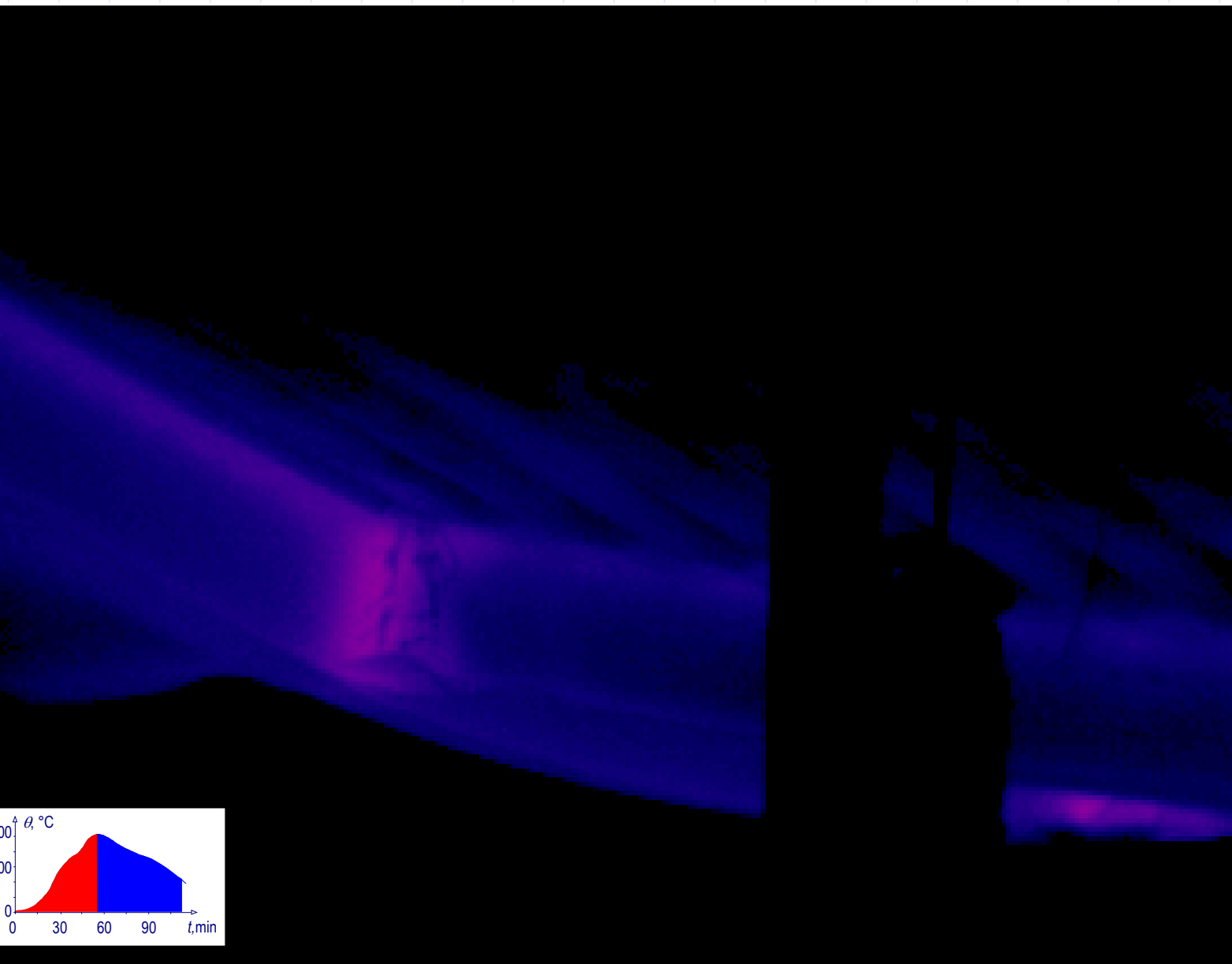
$\theta_{\text{con},\emptyset} = 540 \text{ }^{\circ}\text{C}$





$t = 112 \text{ min.}$

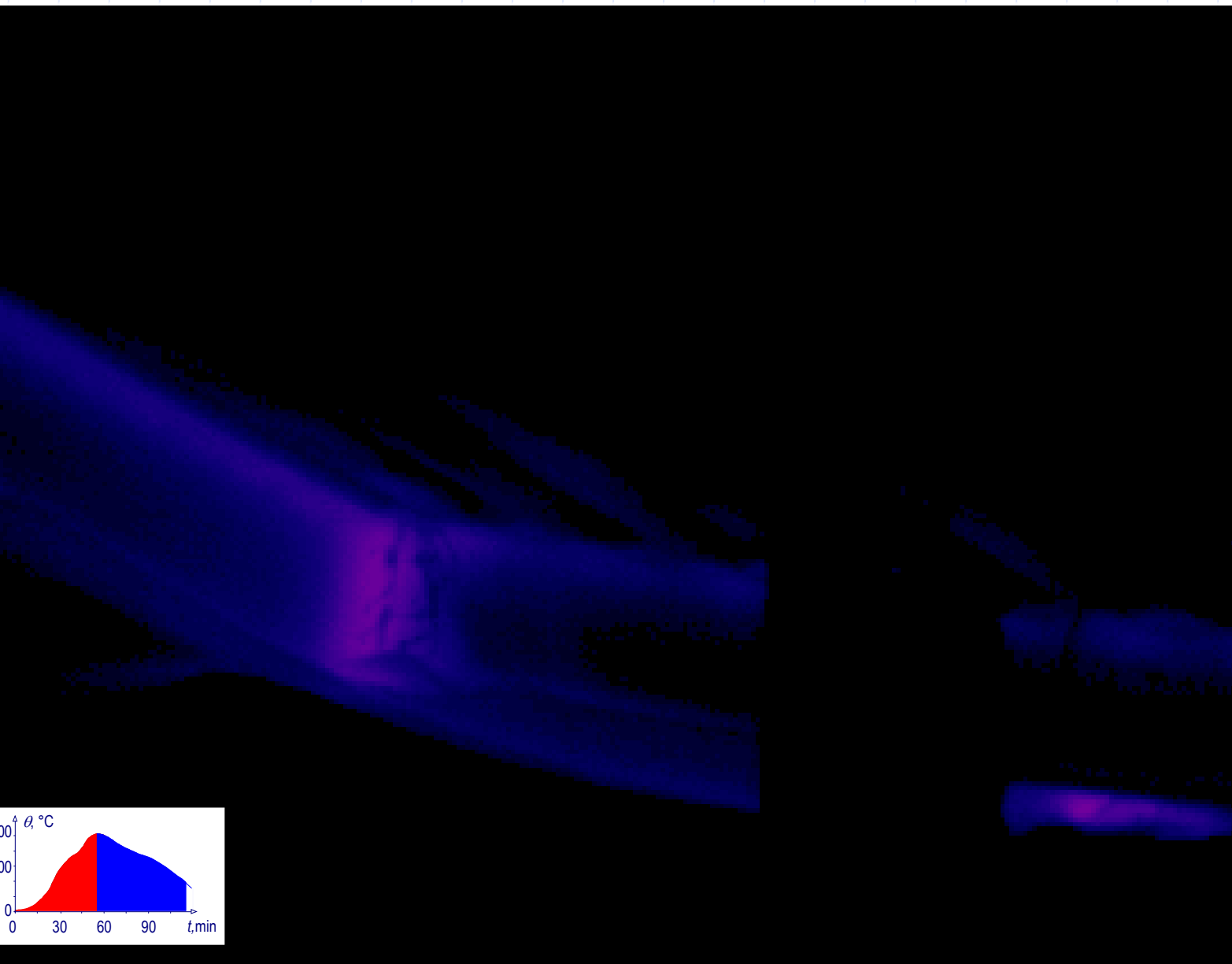
$\theta_{\text{con},\emptyset} = 520 \text{ }^{\circ}\text{C}$





$t = 114 \text{ min.}$

$\theta_{\text{con},\emptyset} = 505 \text{ }^{\circ}\text{C}$



980,0°C

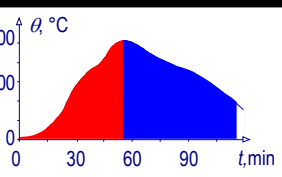


80

60

40

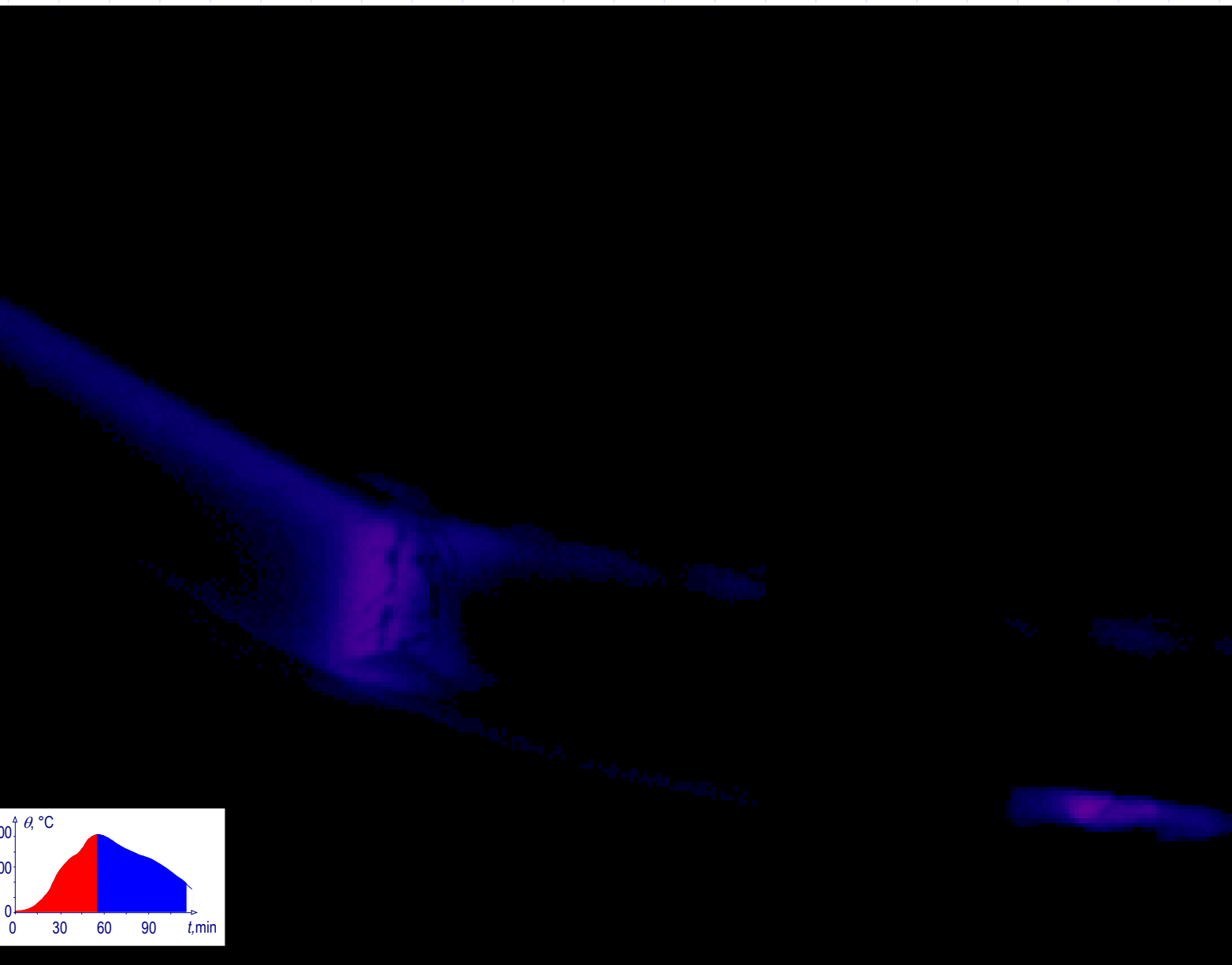
400,0°C





$t = 116 \text{ min.}$

$\theta_{\text{con},\emptyset} = 585 \text{ }^{\circ}\text{C}$



980,0°C

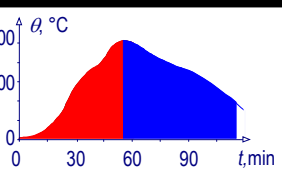


80

60

40

400,0°C

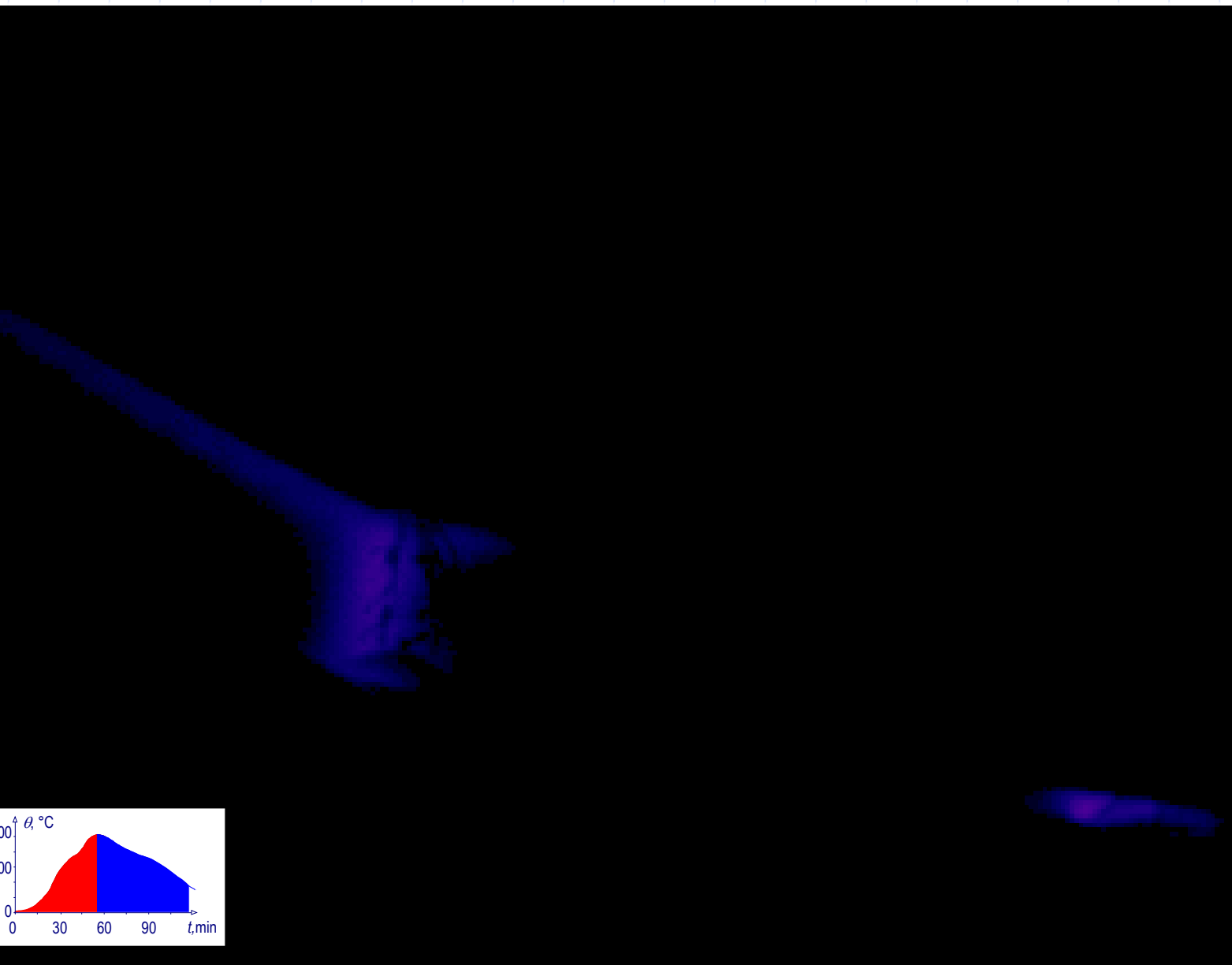






$t = 118 \text{ min.}$

$\theta_{\text{con},\emptyset} = 470 \text{ }^{\circ}\text{C}$



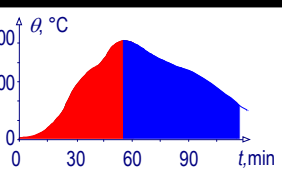
980,0°C

80

60

40

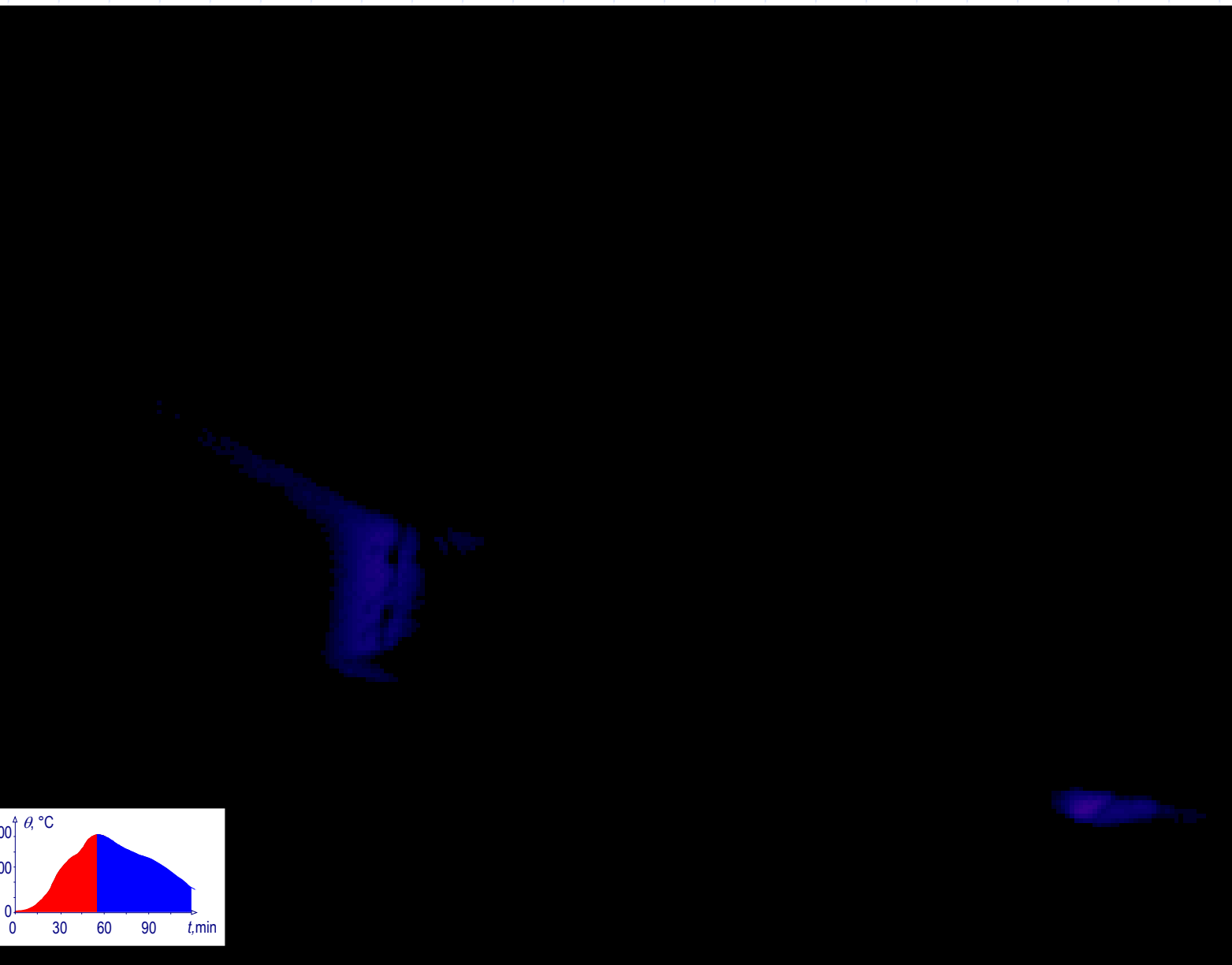
400,0°C



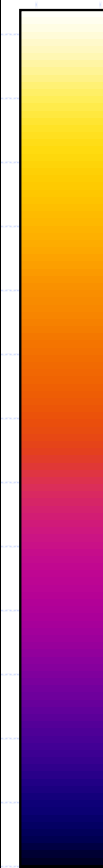


$t = 120 \text{ min.}$

$\theta_{\text{con},\emptyset} = 450 \text{ }^{\circ}\text{C}$



980,0°C

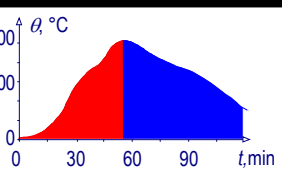


80

60

40

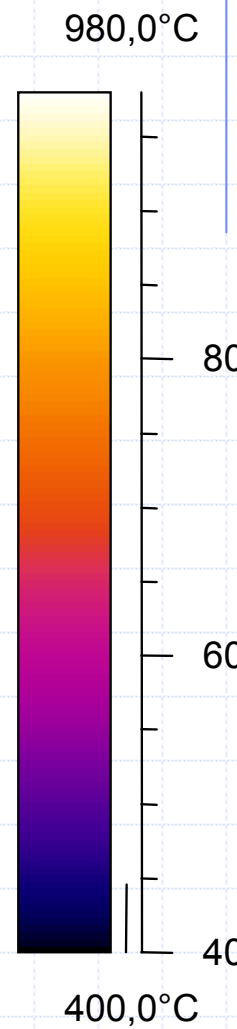
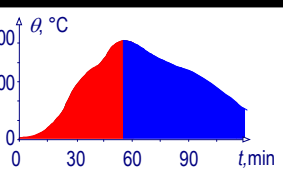
400,0°C





$t = 122 \text{ min.}$

$\theta_{\text{con},\emptyset} = 435 \text{ }^{\circ}\text{C}$

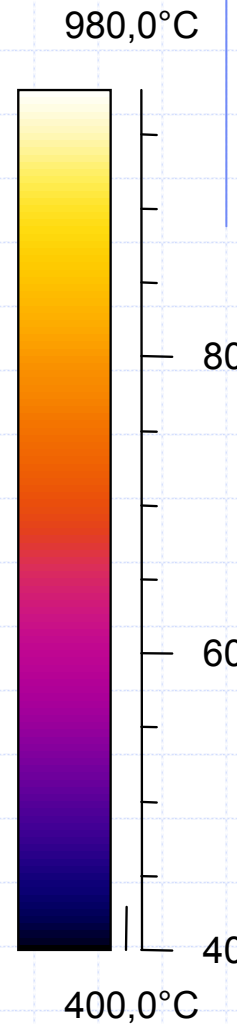
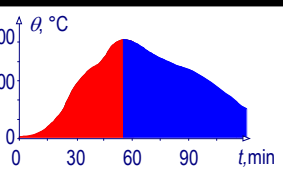




$t = 124 \text{ min.}$

$\theta_{\text{con},\emptyset} = 420 \text{ }^{\circ}\text{C}$

**After two hours of a natural fire  
is temperature of the structure  
under  $400^{\circ}\text{C}$ .**





## Fin plate connection after the experiment



Pašek J., Svoboda J., Wald F.

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Tensile membrane action and robustness of structural steel joints under natural fire.