INFRARED THERMOGRAPHY AND NUMERICAL METHODS IN CIVIL ENGINEERING

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Abstract

Thermography, as a contactless method for measuring temperature and temperature distribution on the surface of an object, has found its application in many human activities. On the basis of surface temperature measurement, the conclusions about the condition of the monitored object can be made. As far as the buildings are concerned, thermography plays an important role in quality control, heat losses measurement and inspection. In the paper the results of thermographic measurement, carried out during the winter and spring of 2004 on the facade of Jadrolinija Co. Rijeka main building, are given. It is a historical building, about hundred years old. The aim of the performed measurement was the estimation of the state of building and the necessity of its reconstruction.

Thermographic analysis includes qualitative and quantitative interpretation of the results. Qualitative analysis was done on some characteristic parts of facade and confirmed with numerical simulation. The paper also includes a comparison between thermograms made on the same place of the facade in winter and spring period, with different boundary conditions.

1. Introduction

Infrared thermography became very effective, as a thermal NDT method, in the determination of building thermal insulation quality, thermal bridges and wet spots on building envelopes. Beside that, a very significant field of application is finding and estimation of damage in the building envelope and flat roofs. Both are very important for defining financial plans and timing of reconstructions. When cultural heritage buildings are investigated, infrared thermography can be successfully applied to determine the structure of building walls below the plaster without destroying the existing state of the building. The paper presents the possibilities to apply thermography, combined with numerical methods, for the estimation of the type and grade of building envelope defects, as well as to determine specific elements in building wall structure.

The measurements presented were carried out on the headquarter building of Jadrolinija Co., Rijeka (in February and May) and the medieval church St. George in Matesko Selo, Croatia.

Fig. 1 *Photo of Jadrolinija Co. building facade in Rijeka, Croatia*

Fig. 2. *Photo of church St. George in Matesko Selo, Croatia*

Fig. 3. *Photo of flat roof (Jadrolinija Co. building)*

2. The structure of the building envelope

The walls of buildings dating from the beginning of the 19th century are usually made of stones and bricks or their combinations, and covered with two layers of plaster. The defects that mostly appear on the façade are air layers between plaster layers or between the basic wall structure and plaster, as well as fallen of plaster segments. In flat roof structure we find air or water layers beneath the bitumen membrane. For all mentioned defects the comparison of measured data and data obtained by numerical simulation are presented.

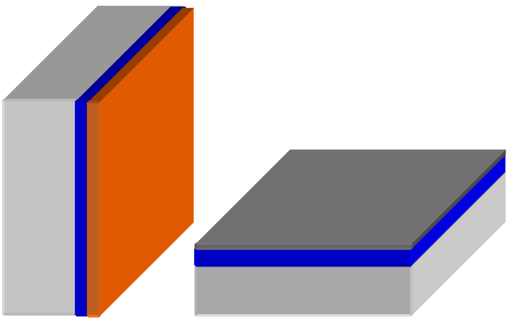


Fig. 4. *Intact wall and flat roof structure*

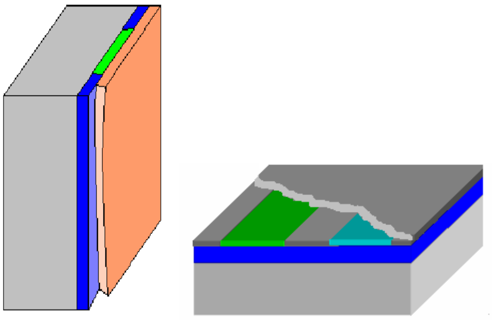


Fig. 5. *Damaged wall and flat roof structure*

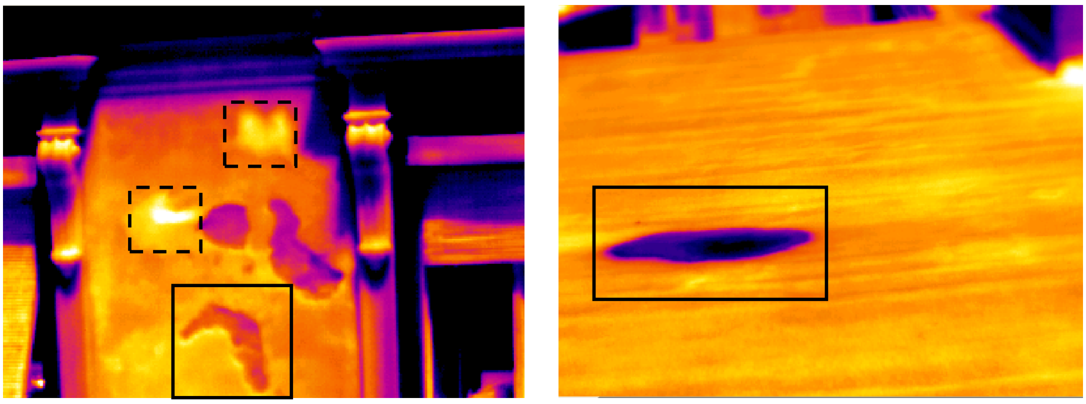


Fig. 6. *Thermograms showing damaged spots on façade and flat roof*

3. Numerical simulation

Numerical simulation of heat transport through the wall structure based on real boundary conditions provides basic information about defects. Even one-dimensional, non-stationary models of heat transport are acceptable in many cases.

For the purpose of this work, the numerical simulation has been carried out by using a model based on the control volume method for one-dimensional, non-stationary heat transfer. The number of control volumes does not exceed 112 and depends on the type of defect. By discretization of the differential equation for non-stationary heat transfer, the set of algebraic equations is obtained and its iterative solving gives the temporal progress of the temperature distribution in the observed wall segment. The thermal properties of wall building materials used in the numerical simulation are given in Table 1.

The initial condition is a uniformly tempered wall, and time increment is 4 seconds. The total process time was adapted to each thermogram to enable the comparison of the results. The boundary conditions are given on Figure 7. They suppose constant inside wall temperature and heat transfer by free convection at the outside. The air temperature is measured while the heat transfer coefficient and solar radiation are taken from literature for corresponding periods of the year, geographic position and surface orientation to the sun. Figure 8 presents details of the defects analyzed by numerical simulation.

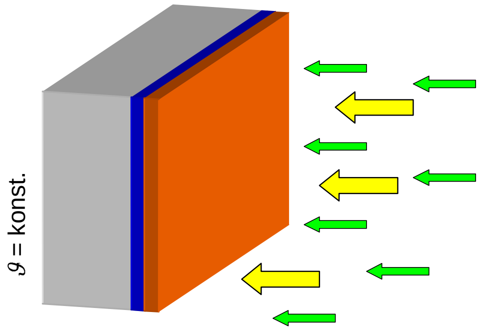


Fig. 7. *Boundary conditions for the observed wall segment*

Table 1. *Thermal properties of the wall structure*

Material	Density ρ kg/m³	Heat conduction coefficient λ W/(mK)	Specific heat capacity c_p J/(kgK)	Emissivity ε
Brick	1800	0,872	1047	0,911
Stone	2300	2,908	879	0,88
Basic plaster	1800	0,861	837	0,92
Outer plaster	1800	0,814	837	0,95
Air	1,164	0,0251	1012	-
Water	995,7	0,616	4176	-

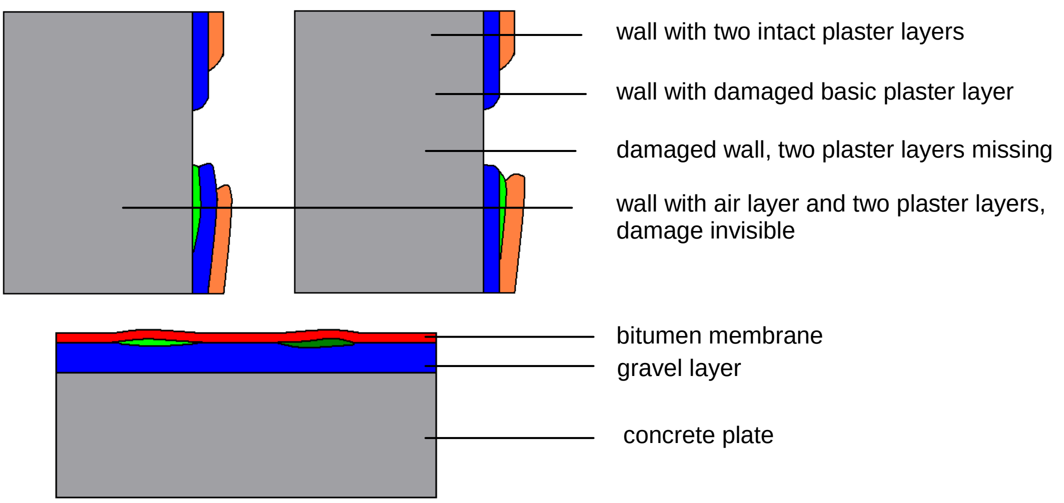


Fig. 8. *Types of damages on building envelope and roof*

3.1 The results of the numerical simulation of a non-damaged structure

The simulation was performed for the structure consisting of bricks and two plaster layers. The structure has a uniform temperature of 18 °C, and the following boundary conditions: inside wall temperature 18 °C, outside air temperature 19 °C, solar radiation 137,43 W/m^2, heat transfer coefficient on the outside 4 W/m^{2}K. The material properties and boundary conditions are constant during the simulation.

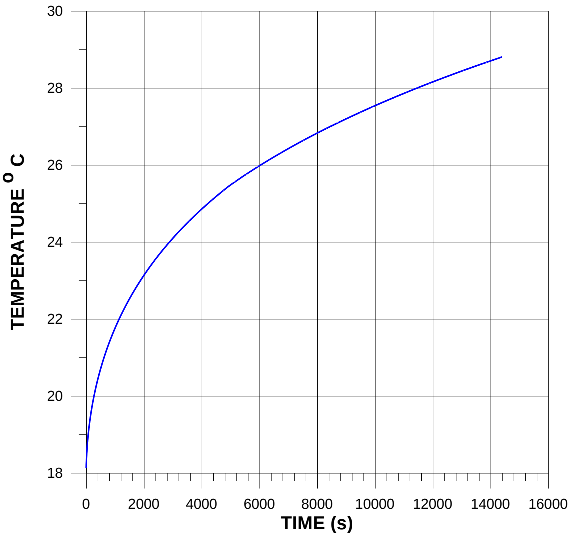


Fig. 9. *Temporal change of the outside wall temperature (intact structure)*

Figure 9 presents the results of outside wall temperature simulation for a time period of 4 hours. It can be seen that the maximum temperature gradient takes place in the beginning of heating of the wall structure. The temperature changes in the wall cross section is shown in Figure 10. The high heat capacity of brick and stone results in a very slow temperature change of this wall segment. Because of that it may be assumed that inside wall temperature will remain constant and independent on the changes of outside temperature during the period of simulation.

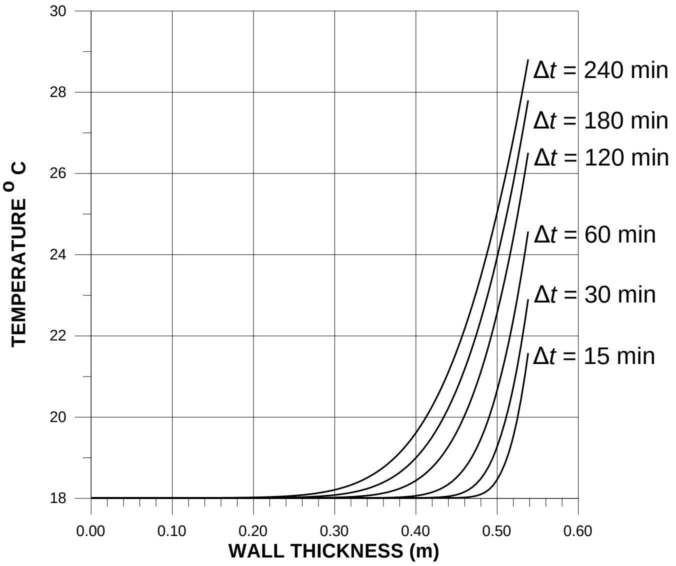
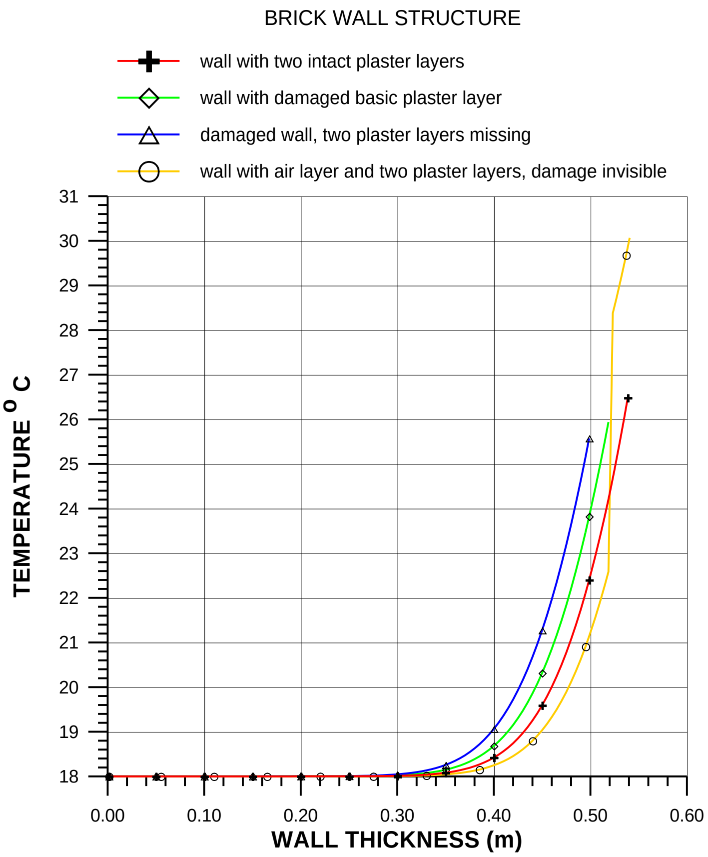


Fig. 10. *Temperature distribution through wall cross section in different time steps*

Simulations of the heat transport through wall structures with defects result in different temperature distributions across the wall structure and also in different values of boundary temperatures. These results are compared with thermographic measurements and become etalons for the estimation of façade condition for the whole building envelope. Figure 8 presents types of defects that have been analyzed by numerical simulation. Similar procedures have been performed for the flat roof structure, using adequate initial and boundary conditions.

3.2 Results of numerical simulations of different types of damaged wall structures

Figure 11 shows the results of the numerical simulation of the south façade of Jadrolinija Co. building, Rijeka. The elapsed time from the start of heating is 4 hours.



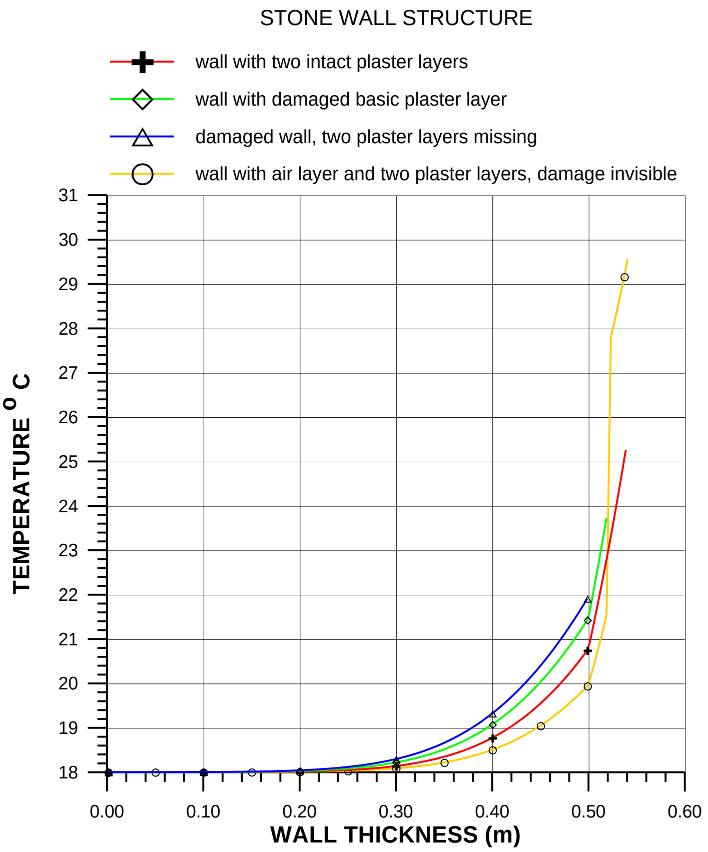


Fig. 11. *Results of numerical simulation for building envelope having different defects (south facade)*

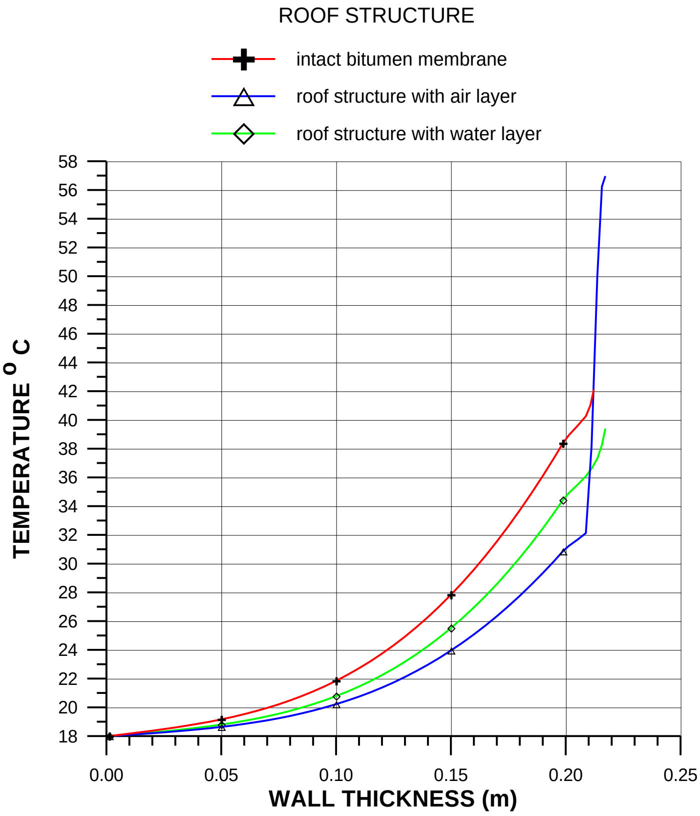


Fig. 12. *Results of numerical simulation for flat roof of the building*

The procedures carried out are an additional tool in the analysis of thermograms and quantification of the results.

4. The results of thermographic measurements

4.1 Building envelope

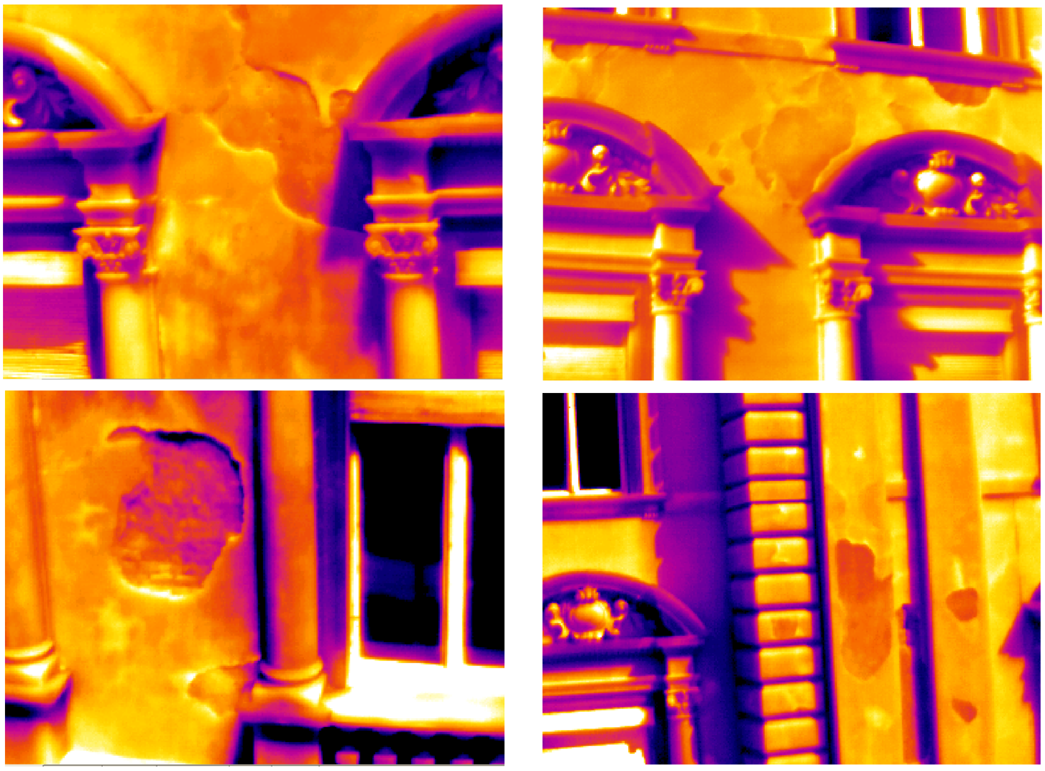


Fig. 13. *Results of thermographic measurement of Jadrolinija Co. building*

Figure 13 shows the results of thermographic measurements. The measurements were performed in spring (May) on sunny and calm day. Recordings were taken in the morning, during the warming period, and in the afternoon, during the cooling period. The numerical simulation indicates that during these periods sufficiently high temperature contrasts may be obtained.

On the thermograms the darker and lighter areas can be clearly determined. While the parts with fallen of plaster may be seen by the naked eye, it was more interesting for the analysis to inspect the lighter spots on the thermograms. They indicate delamination of the plaster so an air layer is present between the plaster layers. Such spots and their range are not visible.

4.2 Flat roof of Jadrolinija Co. building

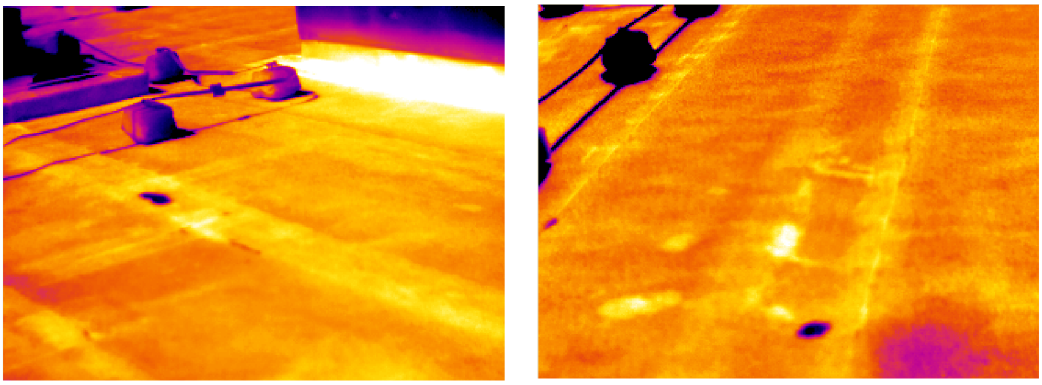


Fig. 14. *Thermograms taken on the flat roof*

Spots where air or water layers exist beneath the bitumen membrane can be clearly seen on the thermograms recorded during the morning hours.

5. Comparison of thermographic measurements and results obtained by numerical simulation

Figure 15 presents the comparison of the results obtained for the same time period by numerical simulation and thermographic measurements . The comparison was performed for initial and boundary conditions given in Chapter 3 and for a time increment of 4 hours.

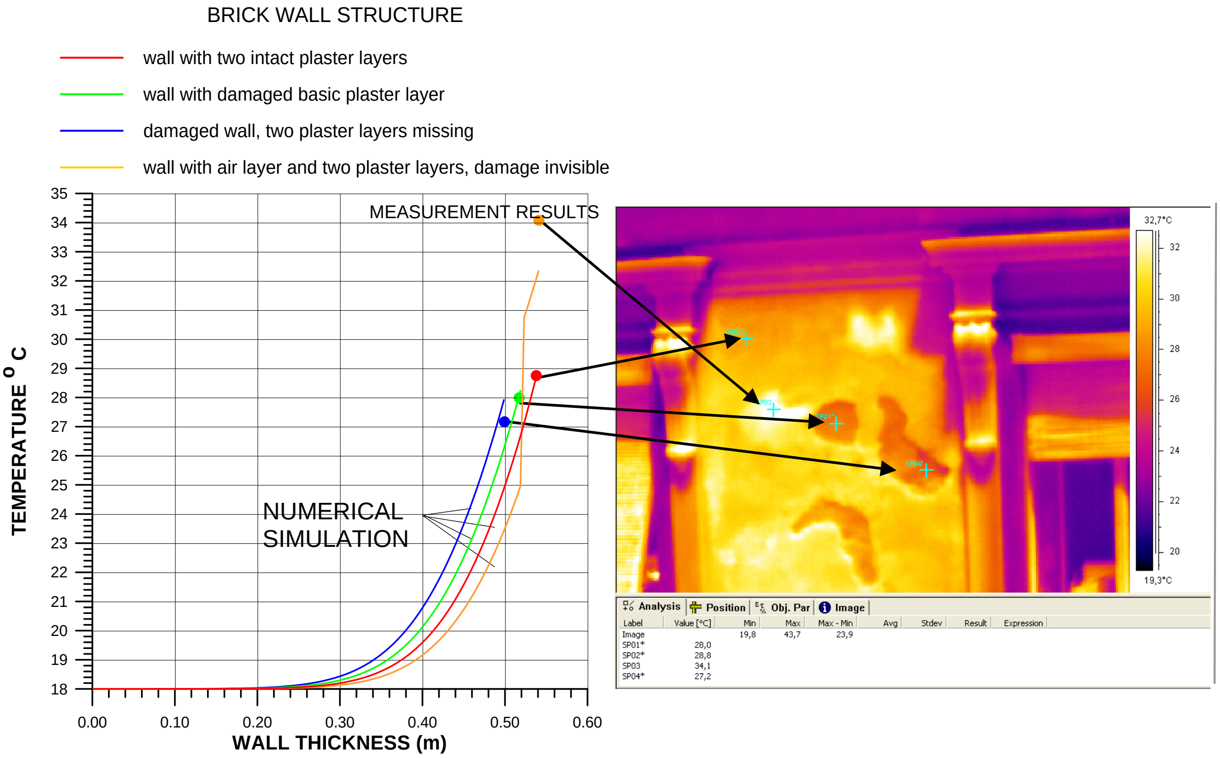


Fig. 15. *Comparison of the results*

6. Thermographic measurements performed on the St. George church walls, Matesko Selo

Beside the estimation of building envelope condition, thermography can be used to determine the wall structures below the plaster. Figure 16 shows thermograms that enabled the detection and location of large stones in wall structure of the medieval church of St. George in Matesko selo in northern Croatia. Later analyses established that they were parts of a Roman sarcophagus.

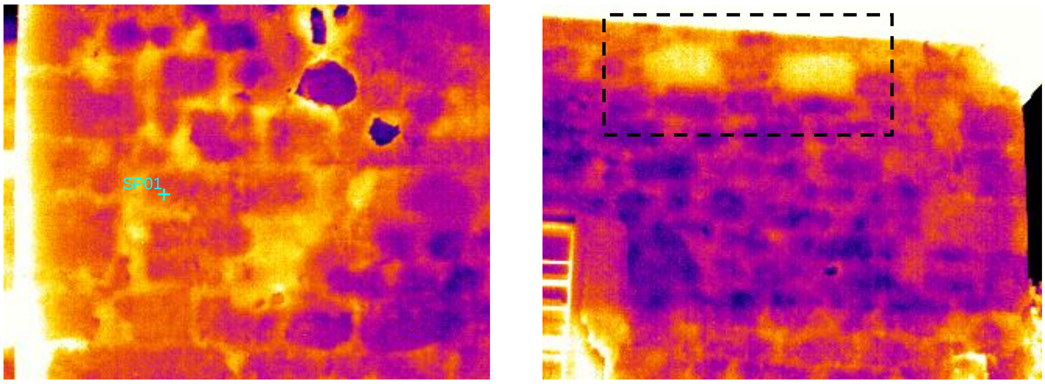


Fig. 16. *Thermograms of the St. George church walls*

7. Conclusion

The paper presents the results of thermographic recording done on Jadrolinija Co. headquarter building, Rijeka. The building envelope was investigated with the goal to get information necessary for the building façade reconstruction planning of . Some of the defects on the façade are visible, but most of them can clearly be seen only on thermograms as non-homogeneities. In the paper the results obtained by thermography were compared with the results obtained by numerical simulation. The simulation was performed in order to confirm that certain spots on thermograms indicate the presence of air or water layers under the surface. It may be concluded that numerical simulations represent an useful aid in the analysis of thermograms. On the thermograms taken in February and May it may also be seen that there are no large differences in the visibility of spots resulting from present defects. More contrast and more intense borders of defects are seen on thermograms taken in May.

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