

## **The indoor climate modelling and the economic analysis regarding the energetic rehabilitation of church**

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**Abstract.** The paper describes the behaviour of a heating system with radiators in a cult building. There has commonly used in many churches with many shortcomings. The temperature distribution in the analysed space is simulated in 2D. The simulation is based on an example, the Cathedral of the Assumption of the Virgin Mary in Jassy. The heating system with radiators simulated with the FLUENT program, the results being edifying for the factual state of the building. An important aspect is the impact of these heating systems on the works of art, the church being the 18<sup>th</sup> – century edifice. Current environmental issues lead to the continuous development of technologies used to reduce primary energy consumption. Churches are an invaluable wealth, sheltering heritage elements preserved in museums and historic buildings. Unheated churches have been used for centuries. Then, after installing one or more different heating systems, signs of rapid degradation appeared.

### **1. Opportunity and necessity of the research**

Buildings with the function of a place of worship, whether or they are not located within monastic settlements that also have heritage value, are usually painted churches, and the fresco is the one that gives value to the heritage. The preservation of interior paintings is or should be a major concern at the state level. Both national and world heritage is involved. This is the minimum requirement that is associated with heritage buildings, in the spirit of European Directive 31/2020 / EU. [1, 2, 3]

Churches are part of the heritage of our country, which must be preserved and cherished. Their construction meant the fulfilment of the Christian ritual that created sacred buildings, in which man would bring glory and honour to the Divinity. Throughout time, man has integrated into these constructions various techniques and technologies to increase their comfort. These have resulted in new methods of construction, better and more durable materials, impressive paintings and frescoes, uplifting as well as increased thermal comfort during the religious service through the adoption of heating systems.

The attraction represented by the heritage-painted churches included in intensely publicised tourist routes leads to a significant increase in the number of people temporarily attending the religious service, which from the internal microclimate represents a major disturbance with the reference situation. On the other hand, the modernization of buildings in order to achieve conditions of thermal comfort in the cold season amplifies the presence of tourists and the disturbance of the indoor climate, this being revealed in the appearance of condensation in the areas with high thermal bridges, at the intersections of the walls, at the base and the roof (Figure 1). [4]

Historic monument buildings that have a large number of operating hours per year, but which cannot be altered in appearance, must be energy efficient. Museums, schools, offices, hospitals, hotels, etc. belong to this category.

The norms C107/2005 and MC 001/2006 expressly mention that the provisions regarding the energy efficiency do not apply to the buildings of historical monument character. In the following, we analyse some variants of energy rehabilitation, applicable to these types of buildings. [6]

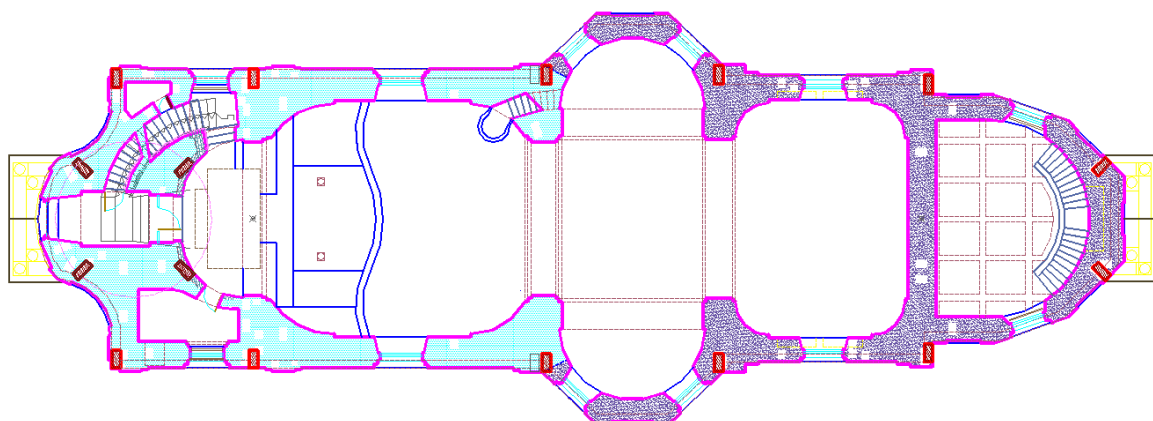


**Figure 1** a) Degradation due to the appearance of condensation at the base

b) Degradations captured in images with thermal vision render the areas with thermal bridges that favour the appearance of condensation

## 2. History of the study objective

The building belonging to the Roman-Catholic cult bears the dedication of the Assumption of the Virgin Mary located in the city of Jassy, in the Aeolian zone III and the climatic zone III of Romania with an outdoor temperature of  $-18^{\circ}\text{C}$ . The building has erected between 1782-1789. He underwent multiple interventions for rehabilitation, both following earthquakes and fires. Also, over the years, the church was enlarged with the area that now serves as an altar (Figure 2, Figure 3).[9]

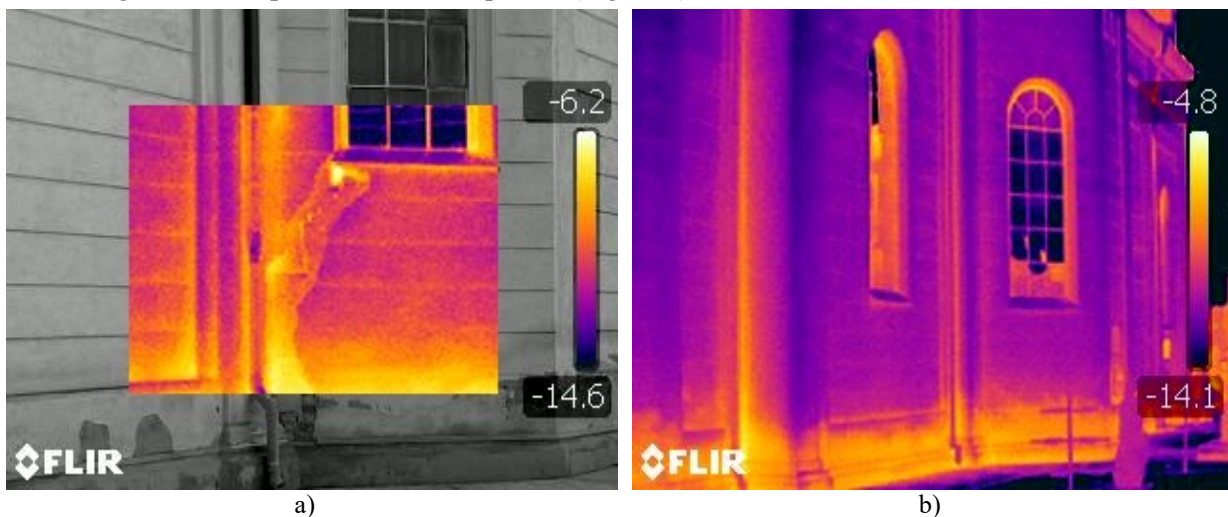


**Figure 2.** The current form in the church plan The Assumption of the Virgin Mary in Jassy



**Figure 3.** Old Roman Catholic Cathedral of the Assumption in Jassy

The monument with historical value has a space of 351.47 m<sup>2</sup>. The strength structure made of solid brick masonry. The age of the 233-year-old edifice, the materials used and the weather conditions have led to multiple degradations in the structure of the building. The exterior finishes degraded, these exhibiting cracks and partial falls of the plaster (Figure 4).[10, 11]



**Figure 4.** Thermal vision images that capture the cracks and thermal bridges in the outer walls

The roof is of a non-insulated roof type, with sheet covers. The floor above the useful space made of brick over which is a layer of reinforced concrete. The floor is of the cold type made of marble. The thickness of the walls varies from 110 cm to 85 cm. With the plan dimensions of 40.61 m and 15.04 wide and with an average height of 9.81 m, the church closes a volume of 2710 m<sup>3</sup> with a tire surface of 1370 m<sup>2</sup>. [12, 13]

### 3. Heating with radiators modelled with Ansys Fluent

Computational Fluid Dynamics (CFD) modelling done in a section plan in which the radiators located as in the church. The section has a length of 31 meters and a height of 12 meters. The thermo-technical characteristics of the tire are as follows: for the roof, the heat transfer coefficient is  $\lambda = 0.9 \text{ W} / \text{m}^2\text{K}$ , the floor has  $\lambda = 1.1 \text{ W} / \text{m}^2\text{K}$ , for the walls  $\lambda = 1.1 \text{ W} / \text{m}^2\text{K}$  and the windows have  $\lambda = 1.05 \text{ W} / \text{m}^2\text{K}$ . Free convection defined for each surface. The radiators have described with a temperature gradient of  $\Delta T=80^{\circ}\text{C}$ . [13, 12]

The resultant heat calculated with the relation:

$$Q = \dot{m} \times C_p \times \Delta T \quad (1)$$

where:

- $\dot{m}$  - fluid flow rate
- $C_p$  - Specific heat of the fluid
- $\Delta T$  the temperature difference between return and return

The software used for CFD analysis is ANSYS FLUENT. A fine discretisation was generated, with a minimum step of 5 cm and a maximum of 8 cm. The standard k- $\epsilon$  model with standard wall functions has defined because the heat was not introduced by forced ventilation but by the natural circulation generated by the radiators, Boussinesq's approximation used for air density.[14]

Figure 65 shows the result of the analysis. One can easily observe the profiles of the air layers with different temperatures, their arrangement and the way the church geometry influences them.

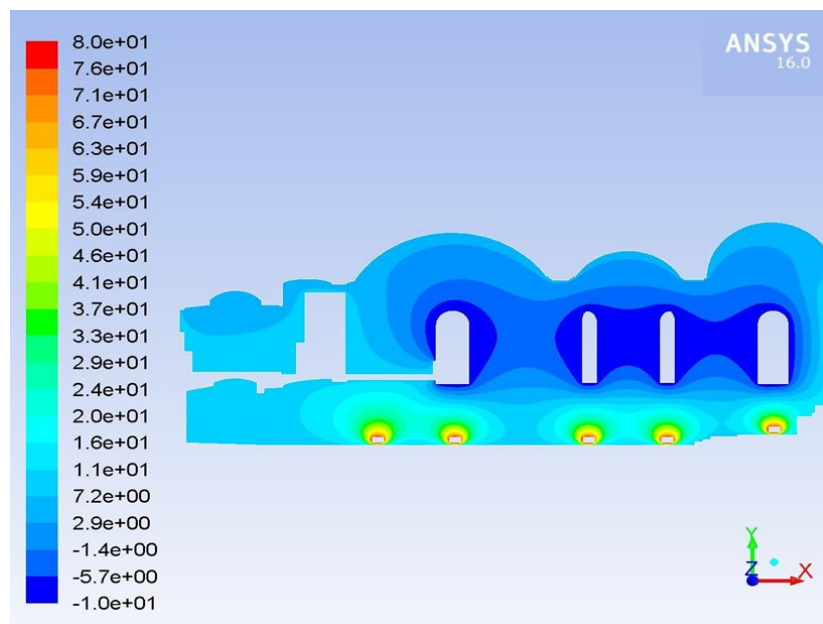


Figure 5 - Isotherms of temperature accounts in the church

### 3.1. Conclusions on heating with radiators

Although the radiators seem like inert objects placed in the church the way they work is so, the air around the radiator heats up, it becomes easier and rises on the wall behind it. In figure 3, this can be seen, the air currents entraining the dust particles, with negative effects on the paintings and frescoes.

At the same time from figure 4, we find a wide spectrum of the temperatures existing inside the churches. The warm air rises to the ceiling, forming a layer at the top. Colder, denser air accumulates on the floor. After an air circulation with different temperatures in the room, they tend to stabilise, forming a strong stratification of the air.

Other aspects noted are:

- The air circulation has negative effects because it generates a premature and rapid drying of all the objects with which it comes in contact, paintings, frescoes, different wooden objects of worship.
- The high volume of air that the churches were close makes the heating of the place of worship difficult, requiring a prolonged period, imposing a continuous operating regime during the cold season.

The analysis method using the CFD-Fluent program demonstrates the need for simulations regarding the thermal comfort study. For a more accurate and detailed analysis, an in situ investigation is needed, placing temperature and humidity sensors for a longer period. [16, 15, 14]

#### 4. Analysis of the studied building energy performance

Thermotechnical calculation of the envelope elements, according to C107-2005, is performed. The corrected thermal resistances of the closing elements  $R'$  [ $m^2K/W$ ] compared with the standard thermal resistances  $R'_{min}$  [ $m^2K/W$ ]. The criterion for satisfying the requirement of thermal insulation is as  $R' \geq R'_{min}$ . The comparative values presented in table 1.

**Table 1.** The thermomechanical characteristics of the existing tire

Elements	$A[m^2]$	$R'$	$R'_{min}$
		[ $m^2K/W$ ]	[ $m^2K/W$ ]
North wall 1.10 cm	147.16	1.121	1.800
North wall 0.85 cm	151.84	1.128	1.800
West wall	51.68	1.008	1.800
East wall	61.41	1.005	1.800
South wall 1.10 cm	147.16	0.924	1.800
South wall 0.85 cm	151.84	1.128	1.800
Roof	305.91	1.931	5.000
Decking	266.01	1.202	4.500
North exterior carpentry	30.23	0.270	0.770
West exterior carpentry	4.27	0.270	0.770
Exterior carpentry south	35.36	0.270	0.770

The analysis shows that most of the building envelope elements do not meet the minimum thermal insulation requirements. The estimation of this consumption serves the energy rating of the building to obtain the energy certificate.[8, 11, 12]

In this way the annual consumption has the values:

Year consumption for heating -  $Q_{Heat}^{year} = 257,35kWh / m^2 \cdot year$

Year consumption for hot water preparation -  $q_{hotwater}^{year} = 30,15kWh / m^2 \cdot year$

Year consumption for lighting preparation -  $W_{lighting}^{year} = 28.76kWh / m^2 \cdot year$

Total annual consumption -  $Q_{Heat}^{year} = 316.26kWh / m^2 \cdot year$

#### 5. Completion of the energy certificate

The energy certificate of the building elaborated based on the consumptions, and they attribute it the energy classification “D” and a value of  $Q_{Heating}^{year} = 316.26kWh / m^2 \cdot year$  for the annual consumption of heat for heating, hot water and lighting.

#### 6. Proposals on energy modernisation solutions

Based on the historical character, the façade cannot interfere with to increase the resistance to heat transfer. The only places where the thermal resistance can increase is at the level of the floor and the roof.

Two economic and technical rehabilitation models will analyse:

- a solution involves only the thermal rehabilitation of the building, involving only interventions on the construction site to improve the thermal protection of the floor under the bridge. It is proposed to

install a thermal insulation layer made of mineral wool, with a thickness of 15 cm. The new corrected thermal resistance created is  $R' = 3,367 \text{ [m}^2\text{K / W]}$ . To improve the thermal protection of the ground floor, it is proposed to install a layer of thermal insulation of extruded polystyrene plates, in a thickness of 10 cm, the corrected thermal resistance created being  $R' = 3,138 \text{ [m}^2\text{K / W]}$ .

- a second solution that proposes to make the operation of the installations more efficient, together with the first tire rehabilitation package as follows:
- mounting of modern equipment for domestic hot water preparation (studying the possibility of mounting equipment that uses renewable energy).[15,16,17]

### 7. Economic aspects regarding the two modernisation packages

These represent a simplified form of evaluation of the return on investments (table 2, table 3). The economic analysis based on the following assumptions and values:

- the average costs of the thermal energy at the date of the energy audit are:
- thermal energy (the current price of heating energy for heating is 55.16 Euro / Gcal- Gcal price = 250 RON):

**Table 2.** Individual consumption per consumption grid and total annual consumption in [kWh / year] for each type of proposed solution

Modernisation package	<i>Heating consumption</i>	Domestic hot water consumption	<i>Consumption of electrical installation</i>	<i>Total consumption of the source</i>
	[kWh/an]	[kWh/an]	[kWh/an]	[kWh/an]
Construction	70516	10598	10109	91223
Constructions and plumbing	43221	2552	7365	53138

**Table 3.** Comparison of the proposed solutions

Modernisation package	<i>Energy-saving - <math>\Delta E</math></i>	Lifespan - Ns	<i>Investment cost</i>	<i>Duration of recovery - NR</i>	<i>The cost of energy saved - E</i>
	[kWh/an]	ani	Euro	ani	[Euro/kWh]
Construction	19933	30	40256	13.46	0.0673
Constructions and plumbing	58018	20	43623	9.40	0.0376

### 8. Conclusions

The action of rehabilitation and thermal modernisation of buildings aims to reduce energy consumption for heating, preparation of hot water for consumption and lighting. Increasing energy efficiency has beneficial effects on the environment. The solutions adopted for the modernisation of heating, hot water and lighting systems, correlated with those of thermal rehabilitation, must also meet the aesthetic criteria that sometimes imply the historical value of the studied building.

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