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ANALYSIS OF PLASTER SOLUTIONS FOR THE REHABILITATION OF HISTORICAL BUILDINGS

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KEY WORDS: historical buildings, analysis, plasters, energy efficiency, global cost.

ABSTRACT:

Through this study, the analysis of 6 types of plaster suitable for the rehabilitation of historical monuments is proposed. The proposed types of plaster have superior thermal insulating properties compared to commonly used plaster. The study is purely theoretical and aims to compare the efficiency of each type of plaster when applied as a rehabilitation solution to a case study building. The case study building is an historical building located in Timisoara for which classical facade insulation system cannot be applied due to its historical status. Their analysis and comparison will be carried out from an economic perspective, thermal transfer and water vapour behaviour and impact on the energy consumption of the building. The purpose is to identify the solution that is the most cost-effective.

1. INTRODUCTION

1.1 General Instructions

At this time, in Romania and throughout Europe, the rehabilitation of historical, heritage buildings are very topical because statistics show that a large part of important buildings are old buildings of historical importance, which need to be rehabilitated. Therefore, in Europe, it is estimated that 14% of existing buildings were built before 1919, while 26% date back to before 1945. In Romania, 31% of buildings date back to before 1961.

The energy consumed by historic buildings is much higher compared to modern constructions, which is precisely why it is a priority that, for historical buildings that want to be rehabilitated, thermal rehabilitation is of major importance in reducing energy costs in the future. The law is largely related to newly constructed buildings, state requirements, and guidelines for energy demand. Reducing consumption needs can mean from trivial non-invasive adjustments such as the maximum use of natural light, cleaning natural ventilation systems, to replacing obsolete or energy-intensive equipment and appliances. Also, the responsible behavior of occupants can also contribute significantly to energy savings. However, regulating the law on historic buildings is very difficult due to the need to preserve the historical and cultural value that they represent. Fortunately, newly discovered technologies can support the transformation process, providing the most efficient solutions and increasing building performance. In Romanian legislation, the Law no. 372/2005 on the updated energy performance of buildings, at art. 7, letter a) provides that the requirements established in the methodology do not apply to protected buildings and monuments that are either part of protected built areas, according to the law, or have special architectural or historical value, to which, if the requirements were applied, their character or external appearance would be unacceptably modified.

According to the Annex to the Intervention Methodology for the non-invasive approach to energy efficiency in buildings with historical and architectural value, when we refer to buildings with historical and architectural value, the term "energy efficiency" does not imply obtaining energy savings similar to a new construction but optimizing its energy behaviour. It is estimated that following the non-invasive energy efficiency intervention, the energy consumption will be reduced by about 20 - 50% compared to the initial values. Below this percentage of 20%, it will be considered that the project does not have a significant component of reducing energy consumption.

2. DESCRIPTION OF PLASTER SOLUTIONS

The study includes the analysis using six different types of plaster available on the market which are suitable for use in historical buildings, The main characteristics are presented in the following paragraphs.

SA1: High-performance mortar based on natural hydraulic lime and eco-pozzolan. The recommended thickness according to the data sheet is 40 mm, has a thermal conductivity of approx. 1 W/mK and a water vapor permeability coefficient (μ) of 60. The consumption for this type of plaster is 1.7 Kg/sqm/mm thick.

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SA2: Thermal insulating plaster with Aerogel. The recommended thickness according to the data sheet is 80 mm, has a thermal conductivity of approx. 0.028 W/mK and a water vapor permeability coefficient (μ) of 4-5. The consumption for this type of plaster is 0.2 kg/sqm/mm thick.

SA3: Mineral plaster based on natural hydraulic lime. The recommended thickness according to the data sheet is 15 mm, it has a thermal conductivity of approx. 1.11 W/mK for P=50% and 1.21 W/mK for P=90% and a water vapor permeability coefficient (μ) of 12-15. The consumption for this type of plaster is 1.5 kg/sqm/mm thick.

SA4: Mineral plaster based on natural hydraulic lime. The recommended thickness according to the data sheet is 2 mm, has a thermal conductivity of approx. 0.7 W/mK and a water vapor permeability coefficient (μ) of V1. The consumption for this type of plaster is 2.8 kg/sqm/2mm grit.

SA5: The recommended thickness according to the data sheet is 40 mm, it has a thermal conductivity of approx. 0.10 W/mK and a water vapor permeability coefficient (μ) of 8. The consumption for this type of plaster is 1.6 kg/sqm/mm thick.

SA6: Eurosan primer plaster. The recommended thickness according to the data sheet is 30 mm, it has a thermal conductivity of approx. 0.10 W/mK and a water vapor permeability coefficient (μ) of 9. The consumption for this type of plaster is 1.1 kg/sqm/mm thick.

3. EVALUATION OF ENERGY PERFORMANCE

The energy performance was assessed following the monthly method using a software available in the Romanian market for the energy certification of buildings. Table 1 centralizes the CO_2 emissions, primary energy consumption and corrected thermal resistances for each solution. We can see that the aerogel plaster solution leads to the best thermal resistance, and the natural hydraulic lime plaster to the lowest corrected thermal resistance.

Variant	Primary energy	CO_2 emissions	R'
	kWh/(m^{2}an)	kgCO_2/(m^{2}an)	m^{2}K/W
SA1	520,25	95,42	0,9
SA2	381,19	67,33	6,53
SA3	535,43	98,49	0,85
SA4	553,81	102,20	0,826
SA5	461,80	83,61	1,62
SA6	477,72	86,83	1,42

Table 1. Centralizer of CO_2 emissions, primary energy consumption and corrected thermal resistances

Figure 1 shows how the primary energy and CO_2 emission increase/decrease compared to the base case situation (existing building). We can see that the most significant primary energy and CO_2 emissions reduction is obtained by using SA2 plaster, which is a plaster with Aerogel. The lowest primary energy consumption and CO2 emissions are achieved with the help of the aerogel-based plastering solution, and the highest consumptions are those resulting from the mineral plaster solution based on natural hydraulic lime Aeria plats silicone. The highest minimum corrected strength results from the implementation of the aerogel-based plaster solution, and the lowest resistance is also given by the natural hydraulic lime-based plaster solution Aeria silicone plaster. According to the Annex to the Intervention Methodology for the non-invasive approach to energy efficiency in buildings with historical and architectural value, the energy consumption must be reduced by about 20 - 50% compared to the initial values.

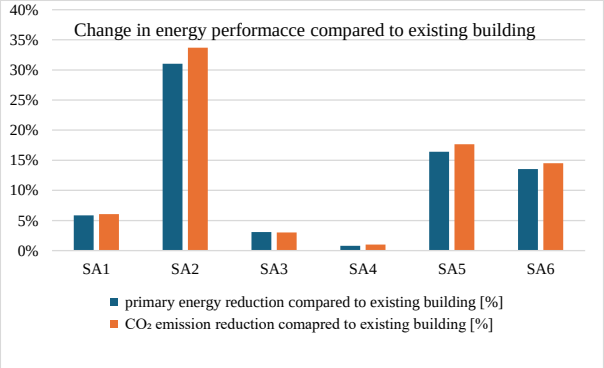

Figure 1. Figure placement and numbering

In the present case, only the solution with aerogel plaster (SA2) meets this criterion. However, reductions of 20-50% can also be obtained in the case of less performing plasters, such as the SA5 solution only by combining with other rehabilitation solutions (thermal insulation of bridge floors and roofing, rehabilitation of exterior carpentry, use of LED lighting fixtures) and the implementation of renewable energy production systems.

4. ANALYSIS OF WATER VAPOUR BEHAVIOR

The calculation of the amount of water for condensation was carried out using the Ubakus program. The input data used were those recommended by the program, and which comply with the Standard on Thermal Protection and Energy Saving of Buildings, Part 3 Protection against humidity subject to climatic conditions (DIN 4108-3): indoor temperature of 20 °C and 50% humidity and outdoor temperature of -5 °C and 80% humidity. In the case of SA1plaster solution, a total of 0.12 kg of condensation water accumulates/m^2. This amount dries in summer in 23 days. The relative humidity on the inner surface is 75% and the temperature is 13.6 °C. In this case, condensation forms on the outside of the wall as shown in Figure 2. To avoid mold formation, the surface temperature should be increased by additional insulation. In the case of SA2 Aerogel Thermal Insulation Plaster, a total of 0.124 kg of condensation water accumulates/m2. This amount dries in summer in 5 days. The relative humidity on the inner surface is 53% and the temperature is 19 °C. In this case, condensation forms on the inside of the wall (Figure 3). In this case, mold does not form. In the case of mineral plaster solution based on natural hydraulic lime SA3, condensation does not accumulate as shown in Figure 4. The relative humidity on the inner surface is 77% and the temperature is 13.2 °C. To avoid mold formation, the surface temperature should be increased by additional insulation. In the case of SA4 plaster solution, condensation does not accumulate, as shown in Figure 5. The relative humidity on the inner surface is 74% and the temperature is 13.9 °C. To avoid mold formation, the surface temperature should be increased by additional insulation. In the case of SA5 plaster solution, condensation does not accumulate, as shown in Figure 6. The relative humidity on the inner surface is 63% and the temperature is 16.3 °C. In this case, mold does not form.

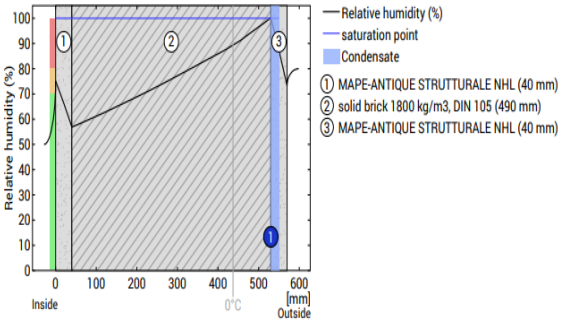

Figure 2. Moisture analysis in the case of SA1

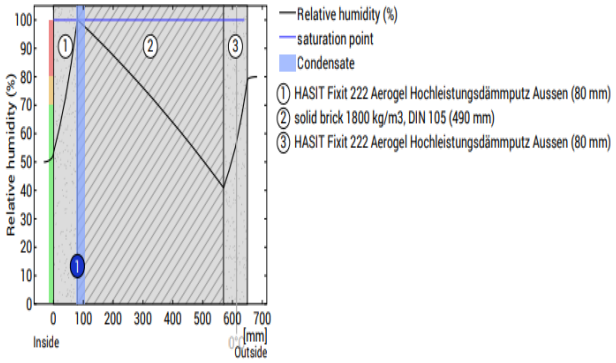

Figure 3. Moisture analysis in the case of SA2

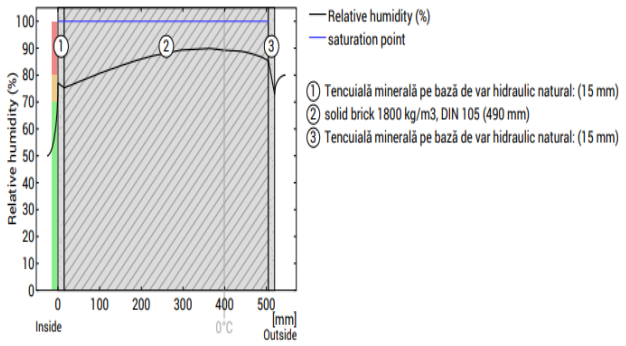

Figure 4. Moisture analysis in the case of SA3

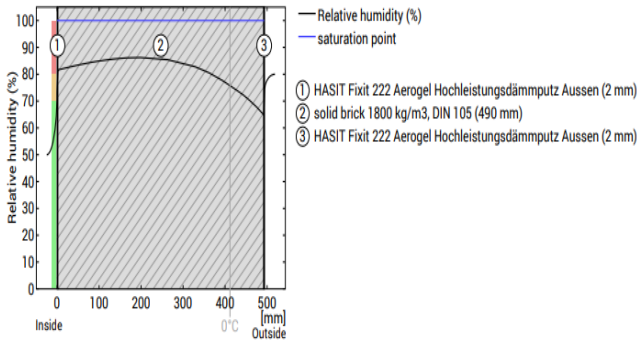

Figure 5. Moisture analysis in the case of SA4

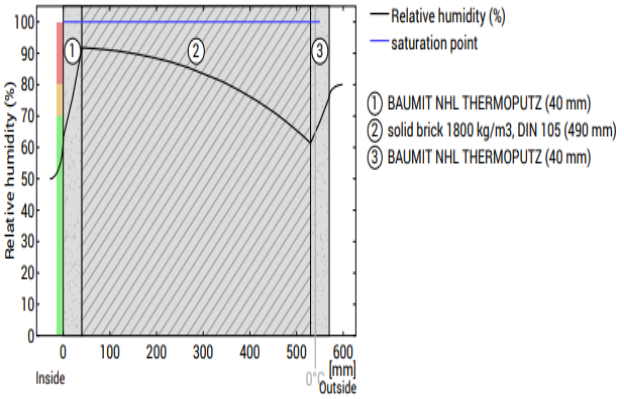

Figure 6. Moisture analysis in the case of SA5

In the case of the plaster solution SA6 based on Eurosan primer, condensation does not accumulate (Figure 7). The relative humidity on the inner surface is 65% and the temperature is 15.8 °C. In this case, mold does not form.

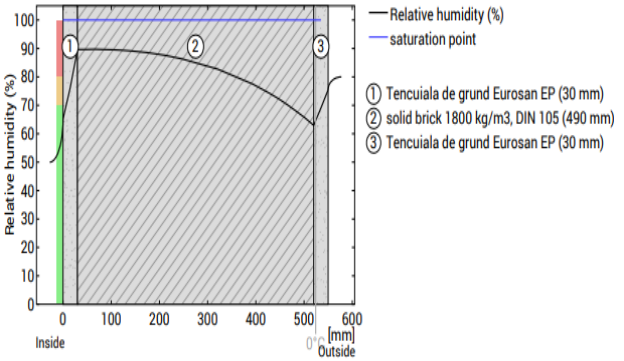

Figure 7. Moisture analysis in the case of SA6

5. ECONOMIC ANALYSIS

For the economic evaluation, the global cost method was used. The updated global cost is obtained based on scenarios, limits, and calculation data, and the result can be used to compare different options or solutions. It can be presented as the value of the updated global cost or as other adapted monetary units.

In the calculation of the global cost, as defined by the European standard EN 15459 and Mc001/2022, the following types of costs are included: the initial investment, the sum of annual costs, the residual value, and disposal costs (if applicable).

The financial data necessary for the economic calculation, used in this work and determined according to Mc001/2022, are as follows:

- Calculation period: 30 years
- Economic life cycle for the agreed solutions/packages of solutions: 50 years
- Estimated inflation rate, usually based on available economic data: 2.50%
- Discount/reduction factors generally set at the national level: 8.00%,
- Rate of change in energy prices: 5.00%

In order to be able to make a fair comparison between the types of plasters, we have adjusted their deliverable quantity, so that each solution is related to the deliverable quantity of 25 kg. The SA1 solution has a high consumption, but the required quantity is the highest.

Table 2 shows the required material quantity and cost of each of the analysed solution, data used to establish the initial investment. The SA2 solution has the lowest consumption, but the recommended thickness of the plaster layer is the largest. The recommended thickness of the plaster layer is reduced by half compared to most solutions, but a fairly high consumption. The SA4 solution has the highest consumption, but the recommended thickness of the plaster layer is the lowest.

The SA5 solution has an insignificantly lower consumption compared to the SA1, but the unit price is lower. The SA6 solution, although it has the second lowest consumption, the amount required is much higher compared to SA2.

Variant	Layer thickness	Material consumption	Required quantity	Cost
	[mm]	[Kg/mp/mm]	[kg]	[LEI]
SA1	40	1.7	62,512	350,069
SA2	80	0.2	14,708	2,031,579
SA3	15	1.5	20,684	58,743
SA4	2	2,8	5,148	41,184
SA5	40	1.6	58,835	204,746
SA6	30	1.1	30,336	78,875

Table 2. Consumption centralizer of proposed solutions

In figures 8-13 we can observe the global cost variation for each analyzed scenario during the period of analysis of 30 years in comparison with the existing building (building in its current state). The starting point represents the initial investment while the annual costs include maintenance and energy costs, considering the financial data presented earlier.

As we can see in Figure 8, the initial investment being quite high, it is not recovered within the established period, only at the end of the analysis period. Similarly, in the case of SA2 (Figure 9) the initial investment is not recovered within the established period of time. However, this solution has the advantage of having the lowest final primary energy consumption and CO_2 emissions.

In the case of SA3, the initial investment is recovered after 5 years, but it is noted that it is not a very advantageous solution because it is a very small saving compared to the initial building (Figure 10).

In Figure 11 we can see the situation of SA4. Even if the initial investment is low, the overall cost for this solution is high due to the high energy costs. During the reference period, the investment is not recovered, being slightly higher compared to the initial building.

In the case of SA5 (Figure 12), even if the initial investment is low, the overall cost for this solution is high. During the reference period, the investment is not recovered, being slightly higher compared to the initial building.

In the case of SA6 (Figure 13), the initial investment is recovered after 5 years. Although the initial investment is high compared to other solutions, the overall cost is lower, being a viable solution also in relation to final primary energy consumption and CO2 emissions.

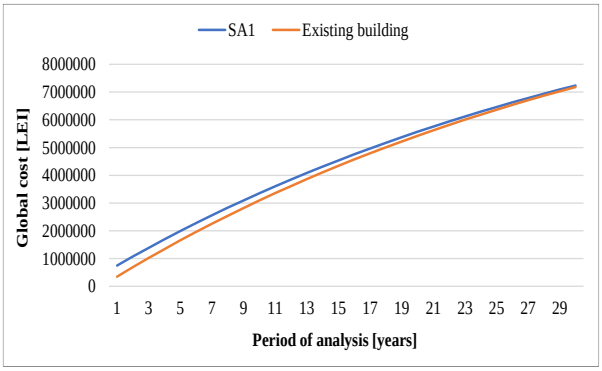

Figure 8. Global cost evolution – SA1 and existing building

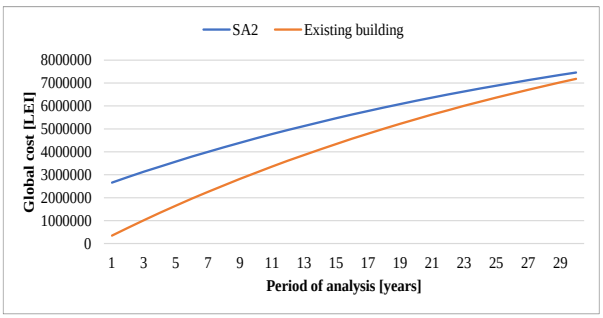

Figure 9. Global cost evolution – SA2 and existing building

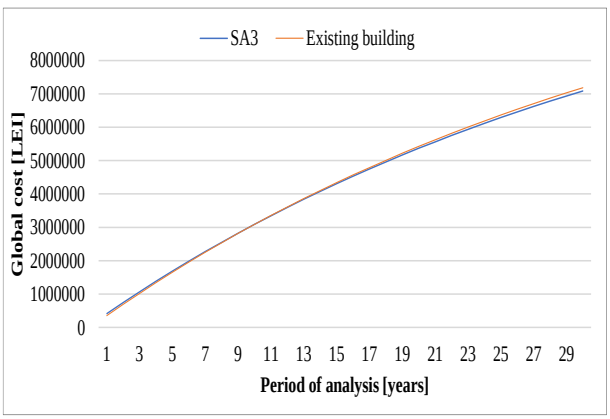

Figure 10. Global cost evolution – SA3 and existing building

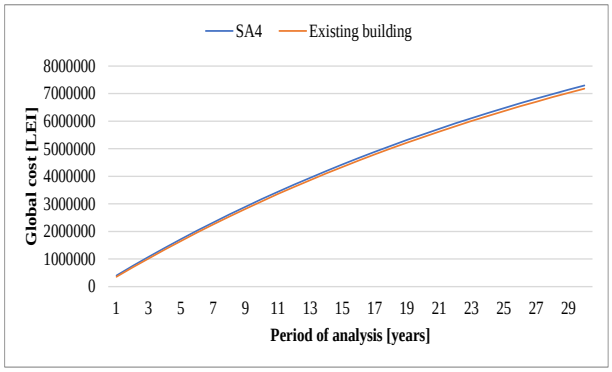

Figure 11. Global cost evolution – SA4 and existing building

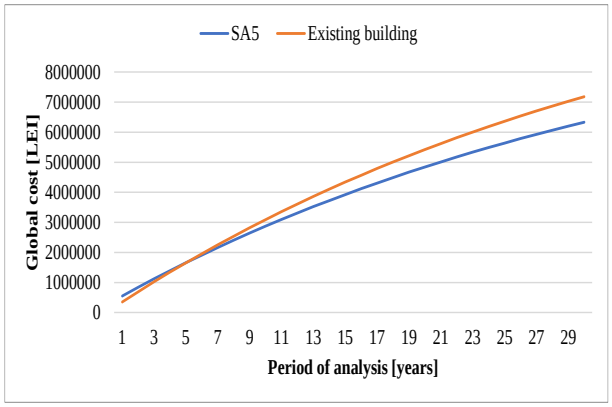

Figure 12. Global cost evolution – SA5 and existing building

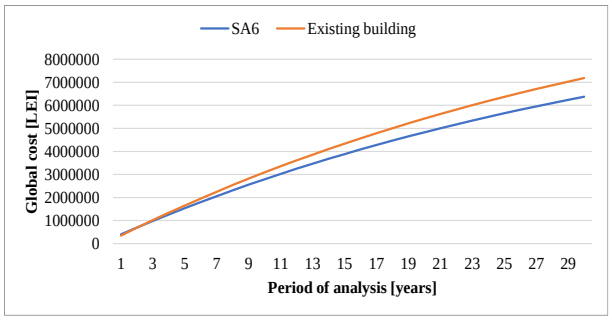

Figure 13. Global cost evolution – SA6 and existing building

Analysing table 3 we can see that although in the case of the SA4 solution the initial investment is the lowest, this package leads to very high overall costs. The aerogel-based plaster solution has both the highest initial costs and the overall costs in the case of SA3, SA5 and SA6 solutions, the investment is recovered during the reference period.

Variant	Initial investment	Global cost	Payback period
	[LEI]	[LEI]	[years]
SA1	416.820,63	7.380.847,91	>30
SA2	2.417.229,48	7.563.330,23	>30
SA3	70.142,49	7.232.541,86	5
SA4	49.247,72	7.451.926,63	>30
SA5	257.539,04	6.457.443,74	5
SA6	93.197,85	6.501.263,24	3

Table 3. Initial investment pool, global cost and payback period

6. CONCLUSION

The study presented in this article focuses on the analysis of different types of plasters used in the rehabilitation of historical monuments, a pertinent topic given the current emphasis in Romania on rehabilitating buildings to enhance their thermal insulation properties compared to commonly used plasters. This theoretical study proposes a comparison of the efficiency of various plasters selected for analysis, when applied as rehabilitation solutions for a specific case study building. The case study building is a historical monument located in Timișoara.

As it is a heritage building, the classic facade insulation system cannot be applied, necessitating the exploration of new solutions. The choice of the most efficient solution, in terms of initial cost recovery among all proposed solutions, is made after a thorough analysis and comparison.

This comparison considers economic factors, heat transfer efficiency, water vapor composition, and the impact on the building's energy consumption. The goal is to identify the most cost-effective solution for rehabilitating the historic building used as a case study.

Based on the analysis conducted in the article, the following conclusions can be drawn:

- The plaster solutions SA6 and SA5 are the only ones in which the initial investment is recovered within the established period of 30 years and with their help no condensation or mold is formed, respectively, having at the same time a sporty efficiency of primary energy consumption and increased thermal resistance. The initial investment is increased in the case of these solutions, but the overall cost is the lowest.

- Aerogel-based plaster (SA2) has the highest initial investment, but a small amount of condensation forms on the inner face of the wall. This solution has the highest corrected thermal resistance.

- In the case of SA1 plaster, condensation forms on the outside of the wall, but no mould is formed.

- SA3 mineral plaster based on natural hydraulic lime – no condensation forms.

- SA4 plaster has the lowest initial investment, and thanks to this, no condensation or mold is formed.

The study thus highlights the importance of considering both economic and technical aspects when selecting plasters for the rehabilitation of historical buildings.

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