The impact of thermal rehabilitation of the reinforced concrete water tanks ROMANIAN built fund over its lifecycle

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Abstract. Liquid storage tanks are special structures and strategically very important. In particular, water tanks are important to assure a continued operation of water distribution system in the event of unpredicted events. In order to ensure the operating conditions in normal parameters, the temperature of the stored liquid (drinking water) have to not exceed certain limits. The aim of this article is to investigate the most suitable thermal insulation system for a reinforced concrete overground water tank. In this regard, a comparative multicriteria analysis has been performed presenting the main advantages / disadvantages of each material (extruded polystyrene, basaltic mineral wool, organic ecological foam) taking into account several criteria. The scores obtained have been compared in order to highlight the most effective material in the case of the reinforced concrete water tanks.

1. Introduction

In Romania, the concept of quality in constructions is defined as the sum of all the requirements for the exploitation of an engineering structure, imposed by the current norms and by the conditions of their use [1].

Therefore, the defining factors (evaluated in order to assure the quality requirements) are defined by the structure’s durability and the sustainability of the process ensured by it.

In this sense, the life cycle analysis of a structure becomes mandatory for a special engineering structure (reinforced concrete drinking water tank), being a structure with a considerable life span (more than 100 years) and with high requirements of exploitation.

Life cycle analysis (LCA) is an environmental management technique for evaluating the environmental aspects of the product systems and their associated potential impacts (according to SR EN ISO 14040:2002 – Environmental management. Life cycle assessment. Principles and framework), which is led by going through four phases:

- defining the purpose and scope;
- inventory analysis for relevant input and output elements of a product system;
- assessing potential environmental impacts;
- interpretation of the results of the inventory analysis and the impact assessment phase.

Because, this life cycle is sometimes referred to as “from cradle-to-grave” it is necessary that any relevant environmental impact be analysed and all the processes for reducing its effects are taken into account.
Regarding the water tanks, for the design, construction and operation of a compliant structure, the following fundamental requirements are required to be maintained, during the entire exploitation period of the constructions:

- mechanical strength and stability;
- fire safety;
- hygiene, health and the environment;
- safety and accessibility in operation;
- sustainable use of natural resources
- energy saving and thermal insulation [2].

This last requirement imposes the analysis of a stage (less applied in Romania), namely that of thermal insulation (for those in the conception / execution stage) or of thermal rehabilitation (for those in operation).

This stage becomes compulsory following an LCA, because the absence of such a protective layer of the envelope decreases the life of the water tank, leading to a negative impact on the environment.

Thermal insulation in the final form, called thermal insulation system, includes:

- the thermal insulation layer;
- fasteners;
- protective cover;
- radiant barriers (optional);
- waterproofing / soundproofing and / or anti-corrosion coating (optional).

The major advantage of the thermal insulation layer is not only the reduction of mass transfer between the indoor and outdoor environment, but also the protection of the envelope (vertical circular wall and horizontal floor - roof - figure 1) against the aggression of the environmental agents, which cancels the possibility of degradation / significant structural damage.

![Figure 1. Envelope elements details – thermal insulated overground water tank: (a) vertical perimeter wall, (b) horizontal floor made of prefabricated reinforced concrete elements – roof.](image)

Moreover, operating conditions under normal conditions of the water tank require that the temperature of the stored liquid (drinking water) does not exceed certain limits. It is obvious that the thermal impact on the stored liquid will be high in the absence of the thermal insulation layer applied on the tank envelope [3].

The presence of the thermal insulation layer from the execution phase will significantly extend the time (T1 – figure 2) at which the intervention on the structure (structural rehabilitation) is necessary, because the moment of the degradation of the envelope elements will be delayed, which will reduce the
negative impact on the environment, it will have a positive economic effect and may even extend the operating period under normal conditions. The process of degradation of water tanks can have many causes (improper exploitation of the construction, cracking of the concrete, corrosion of the reinforcement etc.), which leads to the necessity of carrying out the rehabilitation works [4, 5].

It can be seen from figure 2, that the delay of the moment of beginning the rehabilitation process \( T_1 \) under the conditions of the occurrence and evolution of the degradation, prolongs the execution period of the rehabilitation works \( T_2 - T_1 \) which has as negative effects the temporary removal from the exploitation of the tank but also an increase of the financial resources involved [6].

![Figure 2. The relationship between the operating life of the structure and the level of degradation](image)

The thermal protection solutions used in Romania are multiple, but in the case of water tanks, their choice and application require special attention due to the curved surfaces of the vertical walls of the tanks (to be mounted).

The factors that influence the choice of thermal protection / rehabilitation method are:
- the energy efficiency of the insulation system (calculation parameters: the thermal conductivity of the material/s used and the thickness of the applied layer);
- the temperature difference between the external and the internal environment (calculation parameters: the extreme temperature of the external environment and the standard temperature of the stored liquid - water);
- mounting technology;
- the impact of using the system on the environment.

Are evaluated:
- the sustainability characteristics of thermal insulation materials,
- ecological origin: natural materials (organic / inorganic or synthetic)
- the price of the thermal insulation system;
- its effect (during the exploitation period) on the inhabited environment and on its inhabitants.

The ability of the material to be transformed from "industrial waste" or material from disassembly / demolition into "insulating material" (through reintegration) is also appreciated.

Of particular importance is in this regard the aggregation state of the insulating material used (the form of the insulating layer); such materials could be:
- rigid (plates / panels, blocks / bricks, segments);
- pulverous (foam / foam);
- fibrous (mattresses, strips, fibres);
- granular / powdery;
- pellicular (paint).
It is obvious that from a technological point of view, the pulverizing, fibrous and pellicular materials will be preferred.

2. Thermal insulation materials used in Romania
In Romania, the most used thermal insulation for thermal rehabilitation works for water tanks are made of extruded polystyrene, table 1 [7] and basaltic mineral wool, table 2.

Table 1. Graphite extruded polystyrene.

| Appearance: rigid plates | Advantages | Disadvantages |
|--------------------------|------------|---------------|
| - high thermal efficiency; | - difficult to mount on curved surfaces (such as perimeter walls on cylindrical tanks) |
| - presents the best thermal resistance / cost ratio; | - slightly flammable |
| - reduced load on the structural elements. | - high impermeability (water vapor); |
| | - relatively low durability due to the action of environmental factors (solar radiation, humidity etc.) |

Table 2. Basaltic mineral wool.

| Appearance: rolled material | Advantages | Disadvantages |
|-----------------------------|------------|---------------|
| - dimensional stability to thermal variations; | - low shock resistance; |
| - low thermal conductivity; | - reduced workability; |
| - increased resistance to aging and the action of aggressive environmental agents. | - immersion / diffusion water absorption; |

Recently, it has begun to be applied other thermal insulation systems based on pulverizing materials, such as closed cell polyurethane foam and organic foam (contains soybean oil, castor oil or reused synthetic material, recycled pet stain), table 3 [8] and thermal insulation paints.

Table 3. Organic ecological foam.

| Appearance: sprayed layered | Advantages | Disadvantages |
|-----------------------------|------------|---------------|
| - complete sealing of the coverage area; | - high degree of impermeability; |
| - recommended for easy application to curved surfaces; | - relatively low fire resistance; |
| - very good adhesion to the support layer; | - high costs (compared to other thermal insulation systems). |
| - ecological material; | - high durability. |

3. Multicriteria comparative analysis
As presented above, there are advantages and disadvantages of using these thermal insulation systems. For a good evaluation and the choice of the most efficient thermo-system (to satisfy the requirements imposed for water tanks), a multicriteria comparative analysis (most commonly used in Romania) has been performed, based on a scoring system, taking into account the following criteria:

- cost of the investment;
- duration of execution;
• durability of the material;
• technological process;
• environmental impact;
• fire resistance;
• thermal performance.

The evaluation system used awarded points from 1 to 5, corresponding to the ratings from “inefficient” to “very effective”.

For the parametric quantification, an overground water tank made of reinforced concrete (having a 5000 m³ capacity) was analysed. From a structural point of view, on the outside, the perimeter wall was rehabilitated by post-tensioning, figure 3 (a) and the roof elements by the use of carbon fibre reinforced polymeric (CFRP) composite materials, figure 3 (b).

![Figure 3](image)

(a) (b)

**Figure 3.** Strengthening of the structural elements: (a) post-tensioning of the vertical wall perimeter, (b) R.C. beams strengthened with CFRP strips.

### 3.1. Cost of the investment

The quantification of the first two criteria (cost and duration) for the 3 methods of thermal insulation analysed has been achieved by creating the bill of quantities with the related resources (material, labor, equipment, transport) using the software program Intersoft Deviz Professional (using the market prices from 2019), figure 4.

From the point of view of the estimated cost of the investment (figure 4), by applying organic foam thermal rehabilitation has an investment value of approximately 70% higher compared to the use of extruded polystyrene, respectively 27.9% in the case of basaltic mineral wool.

This fact significantly influences the investor's decision regarding the costs and the duration of the new construction.

![Figure 4](image)

**Figure 4.** Comparative analysis according to the value of the investment
Depending on the costs involved for each of the thermal insulation systems, the following score was given, table 4:

| Material                          | Degree of efficiency |
|-----------------------------------|----------------------|
| 1. Graphite extruded polystyrene  | 5*                   |
| 2. Basaltic mineral wool          | 4*                   |
| 3. Organic ecological foam        | 3*                   |

3.2. Duration of execution
The estimated duration of execution, figure 5, in the case of each proposed thermal rehabilitation solution, from a percentage point of view varies significantly. Thus, in relation to the execution time of the use of an extruded polystyrene thermo-system, in the case of the application of the basaltic mineral wool it decreases by 23.2%, whereas, in the case of using the organic foam, the percentage is a considerable one, decreasing dramatically by 82.2%.

![Figure 5. Comparative analysis according to the execution time](image)

In this case, the following score was given, table 5:

| Material                          | Degree of efficiency |
|-----------------------------------|----------------------|
| 1. Graphite extruded polystyrene  | 1*                   |
| 2. Basaltic mineral wool          | 2*                   |
| 3. Organic ecological foam        | 5*                   |

3.3. Durability of the material
Durability is the capacity of a material to maintain its properties for a long time without significant deterioration / degradation, having a low impact on the environment.

According to the analysed technical data sheets, the extruded polystyrene has an estimated life of about 25 years (considering that the technological steps have been properly respected).

Mineral wool has a much longer shelf life compared to extruded polystyrene, the correct thermo-system having a lifetime estimated between 25÷50 years, preserving its qualities while polystyrene degrades over time much faster, leading to the need for additional repair / maintenance work.

In the case of the thermal insulation system with organic foam, under normal operating conditions, the estimated service life is at least 40 years, no maintenance work required.

Based on the information gathered from the technical data sheets, the following score was obtained, table 6:
Table 6. Durability of the material.

| Material                        | Degree of efficiency |
|---------------------------------|----------------------|
| 1. Graphite extruded polystyrene| 2*                   |
| 2. Basaltic mineral wool        | 4*                   |
| 3. Organic ecological foam      | 5*                   |

3.4. Technological process
Technological procedure applied like thermo-insulation for a curved surfaced (eq. vertical walls of an r.c. water tank) impose qualified workmanship and a significant period to put in practice, because is a material from rigid plates. Unlike these, basaltic mineral wool is found on the market in the form of mattresses and is much more adaptable to the curved surfaces of insulation.

The insulation with organic foam represents an alternative to the one with polystyrene or mineral wool, in that it is applied as a mixture of two liquid materials and is applied by spraying in a layer of several centimeters on the outer face of the structural elements Depending on the thickness of the insulation to be made, a single layer or more layers of foam are applied [8].

In the case of constructions in operation, the thermal rehabilitation works are performed after the leak test of the tank has been performed. These are made mainly in the case of the overground / semi-buried tanks.

The quality of the thermal insulation works at the special structures of water storage, has a fundamental role because, by observing all the requirements, it ensures a long life of operation, without being necessary interventions for this purpose.

From the point of view of the complexity and efficiency of the technological process, the following score was given, table 7.

Table 7. Technological process.

| Material                        | Degree of efficiency |
|---------------------------------|----------------------|
| 1. Graphite extruded polystyrene| 2*                   |
| 2. Basaltic mineral wool        | 3*                   |
| 3. Organic ecological foam      | 5*                   |

3.5. Impact on the environment
In the manufacturing process of extruded polystyrene (98% air and 2% styrene), a quantity of gases is used that does not have relatively significant effects on the environment, compared to the basaltic mineral wool.

In Romania, organic ecological foam used in thermal insulation works contains only natural ingredients and is resistant to mold, moisture and fungi. This substance has no negative impact on the environment. From the point of view of the impact of the materials on the environment, table 8, the following score was awarded:

Table 8. Impact on the environment.

| Material                        | Degree of efficiency |
|---------------------------------|----------------------|
| 1. Graphite extruded polystyrene| 1*                   |
| 2. Basaltic mineral wool        | 2*                   |
| 3. Organic ecological foam      | 5*                   |

3.6. Fire resistance
In Romania, the fire safety measures of the constructions are regulated by the norm P118/1999. It determines according to the category of importance of the construction, the type of construction, destination and size, the strength and safety in operation of the construction in case of fire.

In the case of special constructions of water storage, for thermal insulation systems, the fire risk is defined by fire hazard categories, which express:
• categories A (BE3a), B (BE3b): very high risk of fire;
• category C (BE2): high risk of fire;
• category D (BE1a): average risk of fire;
• category E (BE1b): low risk of fire [9].

According to the data in the data sheets of the manufacturers of insulating materials and of the provisions of normative P118/1999, the following score was awarded according to the degree of efficiency, table 9.

| Material                                | Degree of efficiency |
|-----------------------------------------|----------------------|
| 1. Graphite extruded polystyrene        | 1*                   |
| 2. Basaltic mineral wool                 | 5*                   |
| 3. Organic ecological foam              | 3*                   |

### Table 9. Fire resistance.

3.7. Thermal performance

The thermal insulation performance of a material depends on the thickness of the material and the thermal conductivity (mainly) and the water absorption capacity (in the secondary). A high thermal resistance is achieved by using thermal insulation materials with a thickness (d) as high as possible and a thermal conductivity (\( \lambda \)) as low as possible. For the analysed materials, according to the studied technical data sheets, their thermal conductivity falls within close limits, table 10, for the same thickness of the thermal insulation layer.

| Material                                | Thermal conductivity  |
|-----------------------------------------|------------------------|
| 1. Graphite extruded polystyrene        | 0.040 – 0.042          |
| 2. Basaltic mineral wool                 | 0.035 – 0.038          |
| 3. Organic ecological foam              | 0.020 – 0.025          |

| Material                                | Degree of efficiency |
|-----------------------------------------|----------------------|
| 1. Graphite extruded polystyrene        | 2*                   |
| 2. Basaltic mineral wool                 | 3*                   |
| 3. Organic ecological foam              | 4*                   |

From the point of view of the thermal performance of the materials, the following score was given, table 11.

| Material                                | Degree of efficiency |
|-----------------------------------------|----------------------|
| 1. Graphite extruded polystyrene        | 2*                   |
| 2. Basaltic mineral wool                 | 3*                   |
| 3. Organic ecological foam              | 4*                   |

Based on the criteria described above, the information was centralised, table 12, creating a ranking regarding the thermal insulation materials proposed in the comparative analysis.

| Descriptive criterion | Graphite extruded polystyrene | Basaltic mineral wool | Organic ecological foam |
|-----------------------|--------------------------------|-----------------------|-------------------------|
| 1. Cost of the investment; | 5*                              | 4*                    | 3*                      |
| 2. Duration of execution, | 1*                              | 2*                    | 5*                      |
| 3. Durability of the material; | 2*                              | 4*                    | 5*                      |
| 4. Technological process; | 2*                              | 3*                    | 5*                      |
| 5. Impact on the environment; | 1*                              | 2*                    | 5*                      |
| 6. Fire resistance; | 1*                              | 5*                    | 3*                      |
| 7. Thermal performance. | 2*                              | 3*                    | 4*                      |

TOTAL: 14* 23* 30*
4. Conclusions regarding the comparative analysis

The aim of the multicriteria analysis was to quantify the proportions of advantage and/or disadvantage presented by each of the three thermal insulation materials commonly used in Romania, based on market information and the quotations drawn up, in order to select the most energy efficient and eco-friendly.

The most effective material proved to be organic ecological foam, which is recommended in terms of lead time, material durability and technological process.

The basaltic mineral wool is noted for its fire resistance (non-propagation of flame), the positive environmental impact being at a price / quality ratio in the average quantification class.

From the point of view of the costs involved and the impact on the environment (recycling process) extruded polystyrene is the ideal solution, but according to the awarded score, it is deficient in relation to the other criteria (except the technological process), thus occupying the last place.

In the application of the comparative analysis, the investor / beneficiary has the role to formulate and establish the net benefits of the proposed solutions. This leads to a high complexity of the comparison between gains / losses, because the value of today's investment (costs / benefits) is not directly compatible with the value over a certain period of time (for instance, 20 years).

References

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