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Editors: M. Trivunić, I. Džolev, M. Šešlija

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AEROGEL BASED MATERIALS POTENTIAL IN CIRCULAR ECONOMY, ENERGY EFFICIENCY AND CULTURAL HERITAGE BUILDINGS' RENOVATION

Liljana D. Sofronievska¹, Meri Cvetkovska², Ana T. Gavriloska³, Teodora Mihajlovska⁴

Summary:

Improving the energy efficiency (EE) and sustainability of the buildings is crucial for meeting EU climate targets. Circular economy (CE), especially in the building sector, strive to reduce the pollution, extend the building's lifespan, reduce the material waste and use long-lasting products. Proper renovation by using sustainable materials with low embodied energy will lead to the fulfilment of both goals, EE and CE. Aerogel-based building products are currently considered to be promising insulation materials due to their great thermal performances with limited thickness and their low embodied energy. This paper aims to explore the potential that aerogel materials have not only in terms of EE and CE principles but as well as the cultural heritage impact after the renovation process. Comparing to all of the researched types of aerogel based materials, the silica aerogel thermal plaster proved to be the most appropriate solution in terms of E efficiency, sustainability, circularity and historical buildings' compatibility.

Key words: circular economy, energy efficiency, aerogel based materials

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1. INTRODUCTION

The scientific interest in nano and biomaterials in energy efficient buildings has significantly increased in the last decade, especially after the introduction of "Nearly zero - energy buildings" - NZEB) according to Directive on the energy performance of buildings, 2010/31/EU - EPBD [1]. That means that the new building's energy consumption should be close to zero by 2030, which leads to great tightening of energy efficiency (EE) criteria and increase of thermal insulation materials thickness, which has important economic and technical consequences, especially high insulation costs [2]. Not only the material's thickness emphasizes the need for research and development of new materials, but more significant factors such as: finding solutions for reducing the embodied energy used for production and transportation, reducing toxicity and environmental pollution, as well as reducing material waste, favorite the use of long-lasting building materials and extending the building's lifespan. All these measures mark a new moment in the construction industry known as circular economy (CE). On the other hand, new buildings have a limited impact on overall energy reduction because they represent small part of the existing building stock [3]. It is estimated that only 1% of the buildings in Europe, per year are new buildings. Therefore, existing buildings represent the greatest opportunity for CE implementation. Moreover, new buildings use 4-8 times more resources than renovated ones [4], which is a sustainable argument in favour of buildings' renovation. An additional problem that arises during renovations is the preservation of the building's architectural appearance, that shouldn't be compromised. The selection of right materials and methods for application in renovation process are crucial for both, the EE and CE improvement, as well as for authenticity preservation.

This paper aims to explore the state of the art nanomaterials in the building sector, not only in terms of EE (energy consumption and cost improvements), but also in terms of CE (reduction of embodied energy, environmental toxicity, recyclability, adaptive reuse, as well as the relationship of the new materials to the cultural heritage buildings). The research brings the nanomaterials based on silica aerogel as well as the nano ceramic coatings are the most promising building materials, according to all of the above-mentioned criteria. This paper highlights the potential that aerogel have in EE and CE of the building sector, and therefore, the further analysis refer only to aerogel-based materials. Comparing to all of the researched types of aerogel based materials, the silica aerogel thermal plaster proved to be the most appropriate solution in terms of energy efficiency, sustainability, circularity and historical buildings' compatibility.

2. NANOMATERIAL SELECTION CRITERIA

In terms of improving the energy efficiency, the following commercially available nanomaterials have been developed so far:

- Expanded polystyrene with graphite powder based products (graphite nanotubes or carbon particles are added to the granular structure of polystyrene [94];
- Aerogel-based products - have a wide range of products for insulating transparent or non-transparent surfaces [5];
- VIPs - vacuum thermal insulation panels, based on nano particles, with high thermal insulation power and very low thickness [6];
- Nano-ceramic thermal insulation coatings (extra thin film coatings) for insulating transparent or non-transparent surfaces [7];
- PCMs - phase change materials based on paraffin nanoparticles and salt hydrate, whose paraffin globules with a diameter between 2 and 20 nm are encapsulated in a plastic shell. They can be integrated into building materials, whereby, with a concentration of about 3 million such capsules in one square centimeter, they

change their aggregate state from solid to liquid when the temperature changes, and thus maintain the required temperature in buildings [8].

The five types of building facade nanomaterials are analysed in this paper according to their properties in relation to the following established criteria, shown of Fig.1:

- Criteria 1 - thermal conductivity;
- Criteria 2 - environmental impact (toxicity, pollution and embodied energy);
- Criteria 3 - material thickness;
- Criteria 4 - cultural heritage impact.

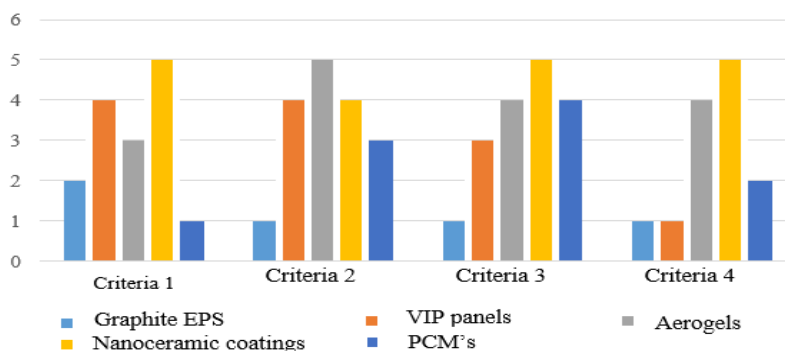


Fig. 1 Nanomaterials evaluation according to their properties and established criteria

From the conducted research, it can be concluded that aerogel based products and nanoceramic coatings showed the best results in terms of the established criteria. These materials have the lowest rate of toxicity to the environment, low embodied energy and pollution in their production process, high thermal insulation properties (thermal conductivity), availability in extremely small thicknesses and above all, small impact on the original architectural appearance after façade renovations.

3. SILICA AEROGEL BASED MATERIALS

Aerogel-based building products are currently considered to be promising insulation materials mostly due to their high thermal properties with small thickness. Furthermore, they have quite low embodied energy, lower than traditional insulation products and other nanomaterials [9]. Different types of aerogel-based building nanomaterials are investigated in this paper, in order to give an overview of the state of the art use of aerogel nanomaterials in construction industry and their potential and significance for the EE improvement, CE implementation and cultural heritage proper renovation. Silica aerogels have amazing thermal properties, ie. they have a density of 1.9kg/m^3 , a volume porosity of 99.8% or a specific surface of $400 - 1000\text{ m}^2/\text{g}$. Pure silica has an extremely low thermal conductivity $\lambda = 0.014\text{ W/mK}$, while for different silica aerogel products \ it varies ($0.01-0.02\text{ W/mK}$)[10]. They are great sound absorbers, especially due to their high porosity with a pore size of 1-100 nm. Due to the silanol in their composition, they are waterproof. Thermal insulation materials based on silica aerogel are present in many forms and under different commercial brands. The most common forms are: aerogel panels, blankets, plasters, light concrete, granules, transparent films etc. (Fig.2).

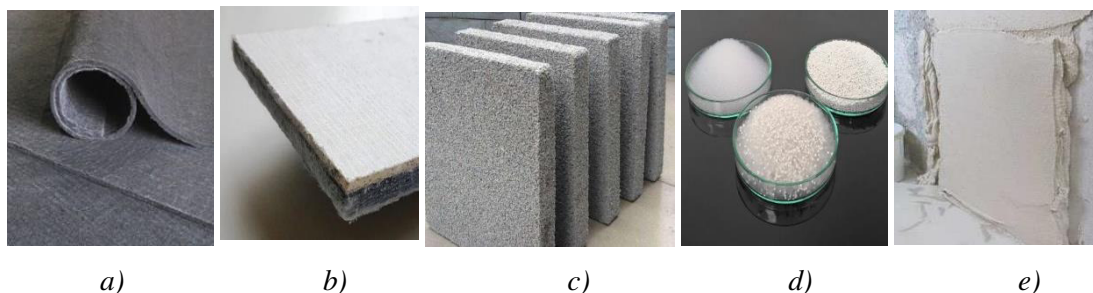


Fig.2 Silica aerogel products a)blankets; b)panels; c)light concrete; d)granules; e)plaster

4. AEROGEL BASED PRODUCTS ANALYSYS AND RESULTS

From the analysed types of aerogel-based products, it can be concluded that each of them has a similar composition, excellent thermal performances and above all, all of the aerogel based materials are sustainable, eco-friendly and since the silica based aerogel is mineral, it can be reused as an insulation material after a recycling process, which meets the CE criteria. Silica aerogel material has many applications and it can be modified to meet a number of specific purposes required by CE, since they have low embodied energy, lower than traditional insulation products [11][12]. Aerogel can be mixed to develop a green building material with unique characteristics and have a great potential for an application in green and sustainable buildings [12][13]. However, one of the criteria, such using the aerogel as a façade material in cultural heritage buildings is not possible for all types of aerogel based products, which also has an impact to the CE principles since building renovation and adaptive reuse is one of the main CE goals.

Tab. 1 Aerogel based products comparisons according to their cultural heritage impact

Type of aerogel product	Authenticity	Integrity	Reversibility	Compatibility
Aerogel blanket	Can be used where proportions cannot be changed (windows, doors) or where not enough space is available. Flexible for uneven surfaces	Removal and replacement of original material and necessary anchoring points should be minimised	Reversibility of the application is required. Possible addition to existing façade. Visual difference to original material is positive	Physical compatibility with historical materials and techniques is required. Vapour openness can be influenced by exterior render. Scientific proof of compatibility should be given
Panel/board	The authentic appearance should be preserved and cannot be covered by boards. Boards can only be used in the interior if there are no protected parts.	Removal and replacement of original material and anchoring points should be minimised. Boards can be used without anchors, but glued by glue.	Reversibility of the application is required. Possible addition to existing façade. Visual difference to original material is positive	Physical compatibility with historical materials and techniques (vapour open, durable) is required. Vapour openness can be influenced by exterior render. Scientific proof of compatibility should be given
Plaster/render	The original visual appearance of the building is possible to be reproduced by plasters. On uneven surfaces, mouldable render can be used for artistic and architectural details	Removal and replacement of original material should be minimised. The aerogel render can be an addition to the existing render	The aerogel plaster is considered reversible and can be removed down to original layers with a trowel and residues by hard brush. Its softness is considered a positive property	Physical compatibility with historical materials and techniques (vapour open, durable) required. Proof should be given scientifically.
Granular form	Authenticity not affected by filling of a cavity with granules if it is not exposed	Addition of granules do not affect the integrity of building	Reversible to previous status	Material can cause decrease of adhesion of other materials. If dust escapes, it can lead to skin and eye irritation. Increased hydrophobicity
Translucent panel	Daylighting of interior with diffusive effect can be achieved. Translucent elements are recognisable from original glazing. Better noise protection is achieved	Replacement of old translucent panels possible without change of integrity, depending on original frame. Additional structural frame might be required	Reversible to previous status	Compatibility is comparable with original forms of glazing. Panels might fit into original frames. Panels made out of glass and polycarbonate used for outer part of layered panel are considered as compatible

For this purpose, analysis of different types of aerogel based products are carried out terms to their methods of application in cultural heritage buildings and the results are explained in Table 1. The technical characteristics of the different aerogel products and their use and impact in the processes of cultural-historical heritage restoration and renovation are explained, according to four significant criteria for cultural heritage: authenticity, integrity, reversibility and compatibility. From the conducted analysis, it can be concluded that the most appropriate aerogel based material for renovation and preservation of historical buildings are the aerogel thermal insulation plasters (Table 1). Despite the fact that aerogel particles have the smallest impact of the authenticity and integrity, it is very difficult to be used in existing buildings. They are used to fill new hollow walls, to mix with the concrete or other materials in the process of creating the product, which usually correspond to smaller parts of the building such as architectural details, etc. but not to the façade walls which are responsible for the EE improvement.

The aerogel based thermal plasters or renders have the biggest potential in the application in existing buildings, especially cultural heritage buildings because of their soft texture and flexibility in applying on different surfaces [12][13]. According to the criteria for protection of historical buildings, aerogel plasters have a mild impact on their authenticity, but it is important that they are compatible with the chemical composition of the original materials, and can be easily removed without damaging them with no need for additional fastening that would damage the original material [14]. The application of the new material will not only improve the energy efficiency and sustainability of the building but also it will protect it from climate conditions and expand its lifespan. Due to the composition and method of application, aerogel plasters are available in different textures and colors and they can perfectly mimic the existing materials making it difficult for distinguishing, while the original material remains preserved (see Fig. 3 and 4).



Fig.3 Old renaissance building façade [15] original material before aerogel plaster application (left); after aerogel plaster application (right)



Fig.4 Old natural concrete façade, original material, before aerogel plaster (left), after aerogel plaster application (right)

5. DISCUSSION AND CONCLUSION

Improving the energy efficiency and sustainability of the building stock is critical for meeting EU climate targets. Circular economy (CE), especially in the building sector, strive to reduce the pollution, extend the building's lifespan, reduce the material waste and favour the use of long-lasting building materials and products. Adopting the CE principles in building sector can reduce the quantity of materials used for the renovation of existing buildings, improve their energy performance and sustainability and minimize harmful emissions embodied in building materials. This paper aims to show the potential that different aerogel based materials have, because of their excellent thermal properties, low embodied energy and different products and methods of application in the building sector. The analyses of different types of aerogel materials bring the conclusion that the aerogel plaster is the most convenient product according to all of the established criteria. By applying the aerogel thermal plaster, the EE of the of the building will be improved, along with the thermal comfort, sustainability and lifespan. Also, by applying the thermal insulation from the outside, thermal bridges will be eliminated and the façade will be protected from external influences, preventing premature aging and carbonization of the original materials. By keeping the authenticity, integrity, reversibility and compatibility of the historical building in the process of renovation, together with improvement of the thermal comfort which leads to cutting the buildings emissions for heating and cooling, aerogel thermal plaster application has a great potential in EE, CE and cultural heritage renovation criteria and practices.

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