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THERMAL INSULATION OF BUILDINGS USING INNOVATIVE MATERIALS BASED ON NANOPARTICLES

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Abstract

Nano Insulation is a liquid-consistency, colourable, paint-like thermal insulation material with many other beneficial properties in addition to insulation. It is a material that can be used both indoors and outdoors in industrial, civil and other types of constructions. Compared to conventional insulation materials, this photocatalytic system is beneficial for internal and external air purification and uses nanotechnology with Titanium Dioxide effective for preventing viruses, bacteria, cleaning polluted air from toxins, removing odours, stopping moulds and fungi, purifying water and more benefits. Among the essential features we list: Heat reflection by at least 60-70%, which reduces heat costs by at least 30%; Reduces the noise level by 0.6 mm up to 2 dB; its composition does not contain harmful or poisonous components; protects the coated surface against weather conditions and corrosion; retains its properties in extreme conditions for a long time; it has a lifespan of over 10 years; with implementation guarantee; with a side cover, the quality of incoming cold air is reduced by at least 30%, with both sides covered by at least 55%; 78% water absorption and high vapour permeability are excellent for the interior comfort; is non-combustible: does not fuel the combustion, helps to slow down the speed of the flame; simple and quick use with a sprayer.

Keywords*:* *thermal insulation, nanoparticles, nanotechnology, innovative materials*

Introduction

Amidst the rapid advancement and cost-effectiveness of living space development, there is a necessity to create a comfortable climate through the use of electrical appliances for lighting, ventilation, and heating-cooling systems with minimal expenses. Achieving energy cost reduction involves the implementation of a well-designed thermal system, using low-cost, low thermal conductivity insulation materials to minimise thermal energy losses or cooling costs. The design of an effective thermal system can contribute to reducing the impact of pollution, thereby addressing the negative consequences of global warming on the ecological and social dynamics, which remains one of the most pressing challenges facing humanity today [1].

To minimise heat transfer through external walls for both heating and cooling purposes, one of the most effective measures currently available is to use materials with excellent insulating properties [2]. Opting for organic materials is both cost-effective and offers low conductivity [3]. Nevertheless, the current insulation market is dominated by foam insulations such as polystyrene (PS), polyurethane (PU) and phenolic foam (PF), which contribute to greenhouse gas emissions. The latest materials considered to be the most thermally efficient insulators are Vacuum Insulation Panels (VIP), Gas Filled Panels (GFP) and Aerogels [4].

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Therefore, it is necessary to consider the evaluation method and quality standards considering all characteristics of the building insulation.

It is also known that the three main factors influencing thermal conductivity are: operating temperature, moisture content, and density [5].

Through empirical observations of various insulation materials, including expanded polystyrene, XPS and PU, it has been deduced that the relationship between effective thermal conductivity and temperature is linear. However, for other foams this relationship is non-linear and difficult to predict due to an increase in thermal conductivity at low temperatures [6, 7].

Several published studies focusing on the effective insulation of different types of buildings [8-10] suggest that the determination of the optimal thickness of thermal insulation for building envelopes depends on the analytical perspective, whether it's energetic, environmental or economic [11-18].

In this current study, our aim is to examine the application of an innovative thermal insulation based on liquid ceramic nanoparticles to the external walls of a building initially equipped with an expanded polystyrene (EPS 80) thermal system. The importance lies in the adoption of an appropriate building insulation system, which is crucial for the operational phase, in order to minimise the energy costs and environmental impact. The research focuses on achieving an enhanced thermal performance of the building envelope by employing the innovative nanoparticle-based insulation material. Existing literature highlights that the thermal and mechanical efficiency of EPS may diminish over the operational life of buildings, specifically in terms of reduced thermal conductivity. This decline (aging) in thermal conductivity is influenced by factors such as internal-external temperature variations, humidity levels, and the density of polystyrene (EPS). Fig. 1 provides a comparative analysis of thermal transfer resistance for various types of insulation materials.

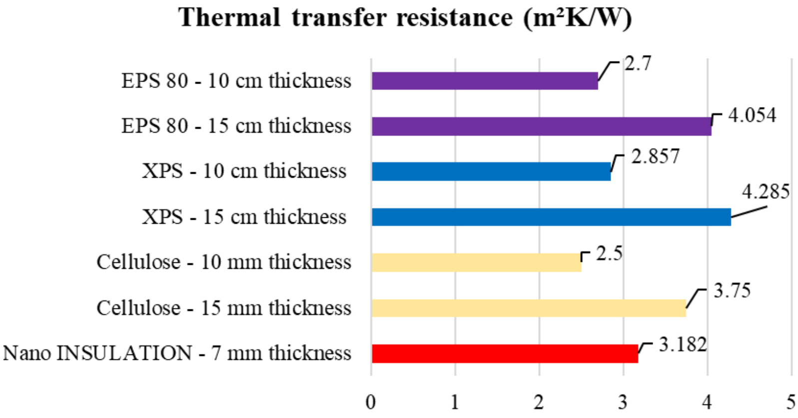

Fig. 1. Graphical representation of the thermal transfer resistance for insulating materials

Methodology of Production

The thermal insulation performances are represented by the heat transfer coefficient U expressed in W / (m^2•K) – Watt per square meter and degree Kelvin, or by the thermal resistance R (expressed in m^2•K / W).

As the efficiency of the wall increases, the U-value decreases, or the R-value increases. The most effective approach to achieve this goal is the application of thermal insulation materials on the wall. Thermal insulation of the walls has other advantages such as:

- reducing the risk of condensation and moisture formation on the inner surface;
- a reduction in energy consumption for air conditioning during the summer or an increased thermal comfort.

A high thermal resistance is achieved by using heat-insulating products with a thermal conductivity as low as possible and with a thickness as large as possible.

Throughout a building's lifespan, diverse forms of energy are utilized to facilitate functions such as summer cooling, winter heating (via air conditioning or climate control), artificial ventilation, lighting, and the operation of various devices. Minimising the use of energy for heating stands out as the most effective measure for reducing energy costs in a building. The energy consumption required for heating in residential buildings poses significant challenges from an environmental point of view.

The use of titanium dioxide nanotechnology materials is proving effective in eliminating odours, purifying air by removing toxins, preventing viruses and bacteria, stopping mould and fungi, and purifying water. It’s main features are:

- reduce heat costs by at least 30% with 60-70% heat reflection.
- reduces the noise level by 2 dB for every 0.6 mm.
- its formulation contains no harmful or toxic ingredients.
- protects the surface against weather conditions and corrosion.
- can be used between -60°C and +260°C.
- has a lifespan of over 10 years.
- with both sides covered the quality of incoming cold air is reduced by at least 55% and with one side covered, by at least 30%.
- excellent for increasing indoor comfort, with high vapor permeability and 78% water absorption.
- helps to slow down the speed of the flame and does not fuel combustion.

The aspect and dimensions of the nanoparticles were captured with a LEICA DMC 2900 microscope and are presented in Fig. 2 a)-f).

Materials and Methods

To evaluate the thermal insulation performance of nanoparticle-based thermal insulation, 10 types of external walls were designed, consisting of different layers arranged from the innermost to the outermost. These details and the calculation of physical-chemical performances have been performed in line with https://www.ubakus.de/, 2023 [19].

The same thicknesses and characteristics were used for the layers of mortar plaster, GVP brick masonry, mortar plaster, bonding adhesive and putty mass for the polystyrene thermal insulation and the thicknesses of the EPS expanded polystyrene thermal insulation with/without nanoparticle thermal insulation were varied, as shown in Fig.3-Fig.7.

The following illustrations show the simulation of the thickness and configuration of the layers that make up the thermal insulation of an external wall. Fig. 3 illustrates the configuration of the insulation layers, encompassing expanded polystyrene with a 150 mm thickness, along with the thermal insulation containing nanoparticles The total thickness of the assembly is 501 mm, consisting of a 20 mm cement mortar layer, 300 mm brick masonry layer, a 20 mm cement mortar layer, overlaid with a 5 mm adhesive mortar layer. This is succeeded by a 150 mm layer of expanded polystyrene EPS 80, coated with a 5 mm adhesive mortar layer, and finally, a 1 mm layer of thermal insulation with nanoparticles. Similarly, Fig. 4 (polystyrene thickness of 100 mm), Fig. 5 (polystyrene thickness of 80 mm), Fig. 6 (polystyrene thickness of 70 mm) and Fig. 7 (polystyrene thickness of 50 mm) show a comparable arrangement with appropriate overall thickness variations corresponding to the changes in polystyrene thickness.

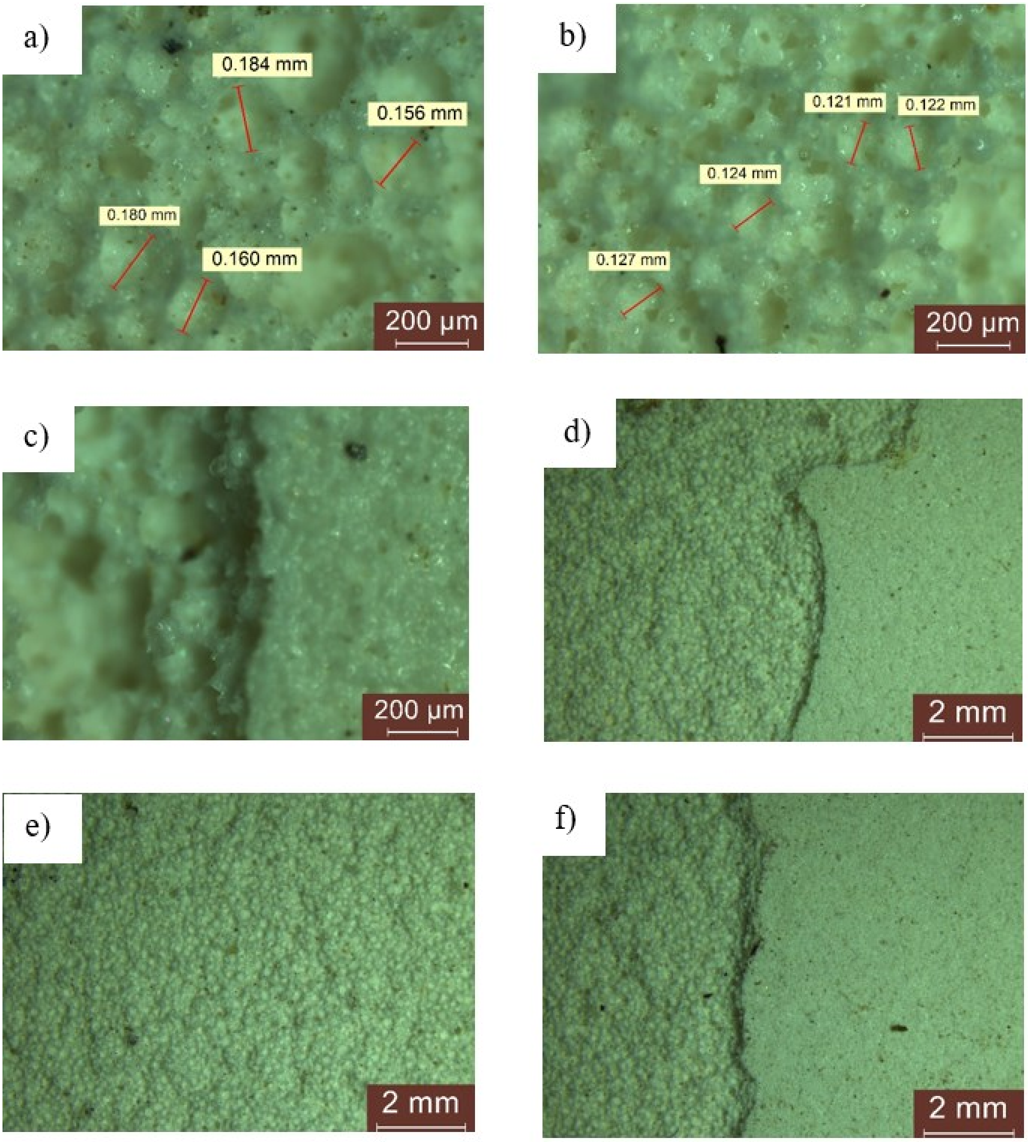

Fig. 2. a)-f) Optical microscopy images depicting aspects of thermal insulation with nanoparticles applied on support layers on LEICA DMC 2900 microscope

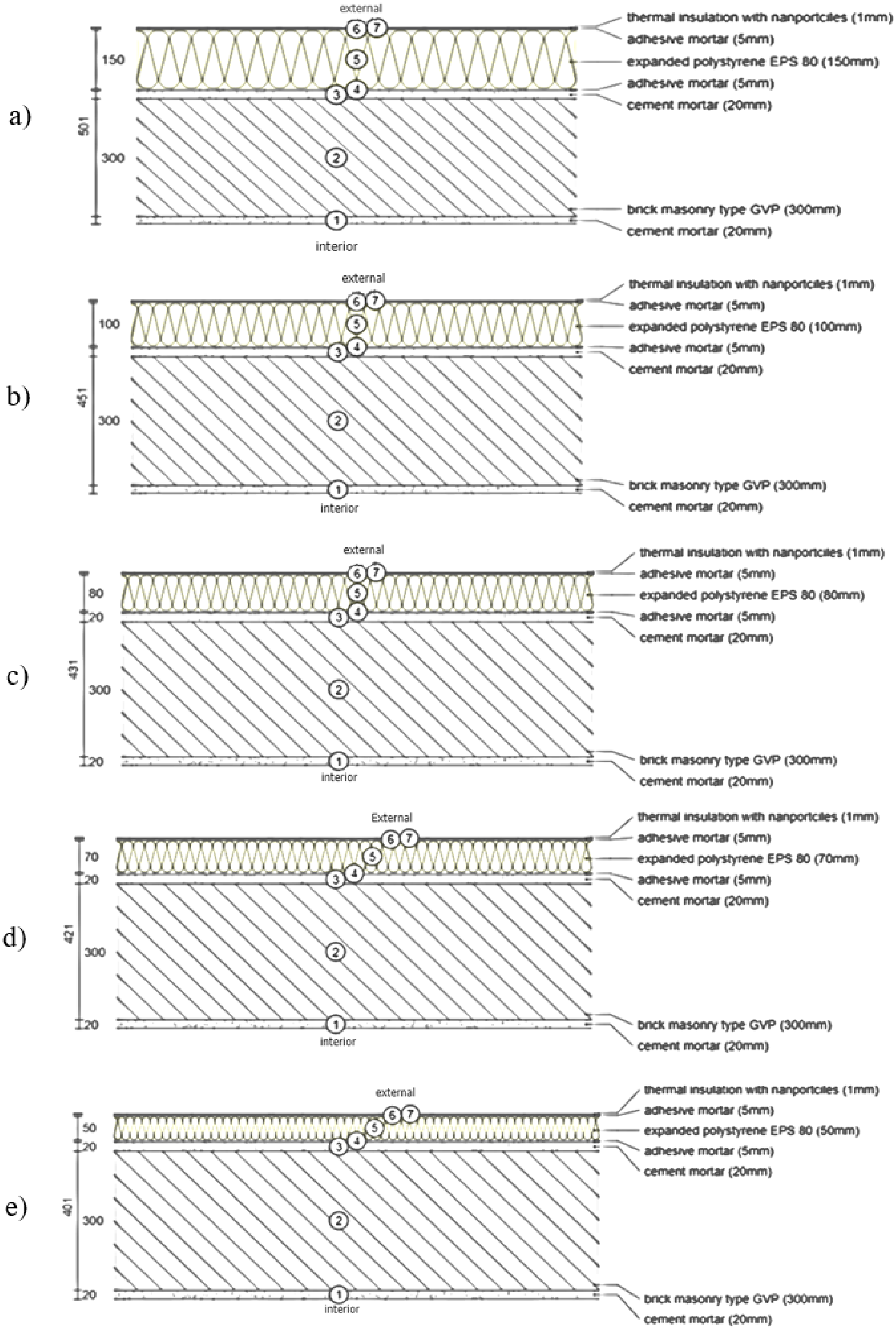

Fig. 3 Design simulation of an insulating layer configuration using a) 150 mm; b) 100 mm; c) 80 mm; d) 70 mm; and e) 50 mm thick expanded polystyrene EPS 80 and nanoparticle insulation

Tables 1 and 2 outline the main thermal characteristics of the materials used in the insulation layers considered in the design simulations above. They provide a comparison of thermal conductivity (λ) and heat flow resistance (R) for different thicknesses of expanded polystyrene (50 to 150 mm). Despite the constant thermal conductivity, the heat flow resistance varies considerably, increasing almost by a factor of four between thicknesses of 50 mm and 150 mm, and almost doubling between thicknesses of 100 mm and 150 mm. In terms of the minimum and maximum temperatures assessed at the end of each considered layer, the variation is relatively modest, with differences between two consecutive thickness values not exceeding 1°C.

Table 1. Thermal properties and temperature distribution in building structures with different polystyrene thicknesses (50 mm – 150 mm) and a nano particle enhanced thermal insulation layer

Material	**Layer Thickness [mm]**	**λ [W/mK]**	**R $[\mathrm{m^2K/W}]$**	**Temp. [°C] 150 mm**		**Temp. [°C] 100 mm**		**Temp. [°C] 80 mm**		**Temp. [°C] 70 mm**		**Temp. [°C] 50 mm**	
				Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Interior surface				19.4	20	19.4	20	19.3	20	19.3	20	19.3	20
cement mortar	20	0.930	0.022	19.4	19.4	19.3	19.4	19.3	19.3	19.2	19.3	19.2	19.3
brick masonry type GVP	300	0.142	2.133	14.6	19.4	13.9	19.3	13.5	19.3	13.3	19.2	12.9	19.2
cement mortar	20	0.930	0.022	14.6	14.6	13.8	13.9	13.4	13.5	13.2	13.3	12.8	12.9
adhesive mortar	5	0.540	0.009	14.5	14.6	13.8	13.8	13.4	13.4	13.2	13.2	12.8	12.8
expanded polystyrene EPS 80	150	0.037	4.054	**5.4**	**14.5**	-	-	-	-	-	-	-	-
	100	0.037	2.703	-	-	**6.8**	**13.8**	-	-	-	-	-	-
	80	0.037	2.162	-	-	-	-	**7.5**	**13.4**	-	-	-	-
	70	0.037	1.892	-	-	-	-	-	-	**7.9**	**13.2**	-	-
	50	0.037	1.351	-	-	-	-	-	-	-	-	**8.7**	**12.8**
adhesive mortar	5	0.540	0.009	5.4	5.4	6.8	6.8	7.5	7.5	5.4	7.9	8.7	8.7
thermal insulation with nanoparticles	1	0.002	4.545	-4.9	5.4	-4.9	6.8	-4.9	7.5	-4.9	7.9	-4.9	8.7
Exterior surface				-5.0	-4.9	-5.0	-5.0	-4.9	-5.0	-5.0	-4.9	-5.0	-4.9

Similarly, Table 2 presents the same thermal characteristic of the aforementioned materials used in the design simulations above, without the use of the nanoparticle enhanced insulation layer. Generally, the second table illustrates slightly lower temperature values across different layers and thicknesses compared to the first table, suggesting that the nanoparticle-enhanced insulation layer contributes to higher resistance to heat flow compared to the scenario without nanoparticles.

Table 3 provides a comparison of thermal performance between external walls with expanded polystyrene (EPS80) of varying thicknesses, combined with thermal insulation containing nanoparticles and without nanoparticles. As the thickness of EPS80 increases, the thermal transfer resistance (R) rises, indicating improved insulation.

Notably, the addition of thermal insulation with nanoparticles enhances the thermal resistance and lowers the heat transfer coefficient (U) compared to configurations without nanoparticles, demonstrating the effectiveness of nanoparticle-enhanced insulation in improving the overall thermal performance of external walls.

Table 2. Thermal properties and temperature distribution in building structures with different polystyrene thicknesses (50 mm – 150 mm)

Material	**Layer Thickness [mm]**	**λ [W/mK]**	**R [m²K/W]**	**Temp. [°C] 150 mm**		**Temp. [°C] 100 mm**		**Temp. [°C] 80 mm**		**Temp. [°C] 70 mm**		**Temp. [°C] 50 mm**	
				Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Interior surface				19.0	20	18.8	20	18.6	20	18.6	20	18.4	20
cement mortar	20	0.930	0.022	19.0	19.0	18.7	18.8	18.5	18.6	18.4	18.6	18.2	18.4
brick masonry type GVP	300	0.142	2.133	10.9	19.0	8.5	18.7	7.1	18.5	6.3	18.4	4.4	18.2
cement mortar	20	0.930	0.022	10.8	10.9	8.4	8.5	7.0	7.1	6.2	6.3	4.2	4.4
adhesive mortar	5	0.540	0.009	10.7	10.8	8.3	8.4	7.0	7.0	6.1	6.2	4.2	4.2
expanded polystyrene EPS 80	150	0.037	4.054	**-4.8**	**10.7**	-	-	-	-	-	-	-	-
	100	0.037	2.703	-	-	**-4.8**	**8.3**	-	-	-	-	-	-
	80	0.037	2.162	-	-	-	-	**-4.7**	**7.0**	-	-	-	-
	70	0.037	1.892	-	-	-	-	-	-	**-4.7**	**6.1**	-	-
	50	0.037	1.351	-	-	-	-	-	-	-	-	**-4.7**	**4.2**
adhesive mortar	5	0.540	0.009	-5.0	-4.8	-4.8	-4.8	-4.8	-4.7	-4.8	-4.7	-4.7	-4.7
Exterior surface				-5.0	-4.9	-5.0	-5.0	-4.9	-5.0	-5.0	-4.9	-5.0	-4.9

Table 3. Results obtained after determining the 10 combinations

External wall - thermal insulation	**Thermal transfer resistance**	**Heat transfer coefficient U**
EPS80 150 mm + thermal insulation with nanoparticles	10.944	0.091
EPS80 100 mm + thermal insulation with nanoparticles	9.592	0.104
EPS80 80 mm + thermal insulation with nanoparticles	9.052	0.110
EPS80 70 mm + thermal insulation with nanoparticles	8.782	0.114
EPS80 50 mm + thermal insulation with nanoparticles	8.241	0.121
EPS80 150 mm (without nanoparticles)	6.398	0.156
EPS80 100 mm (without nanoparticles)	5.047	0.198
EPS80 80 mm (without nanoparticles)	4.506	0.222
EPS80 70 mm (without nanoparticles)	4.236	0.236
EPS80 50 mm (without nanoparticles)	3.696	0.271

Consistent with the provided calculation model, there is a continuous increase in thermal transfer resistance values from 50 mm thick insulation without nanoparticles to 150 mm thick insulation with nanoparticles, reaching a maximum value of 10.944 [m²K/W]. This trend is visually illustrated in Fig. 4. At the same time, the U-value of the heat transfer coefficient shows a decrease from 0.271 for 50 mm thick EPS80 without nanoparticles to 0.091 for 150 mm thick EPS80 with nanoparticles, as shown in Fig. 5.

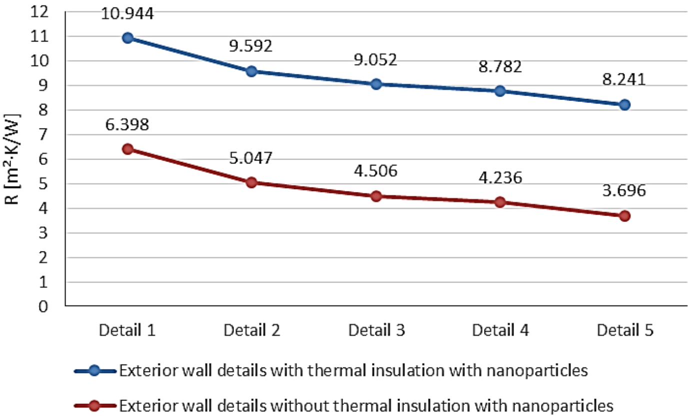

Fig. 4. Graphic representation of the thermal transfer resistance R for the analysed insulating layer configuration

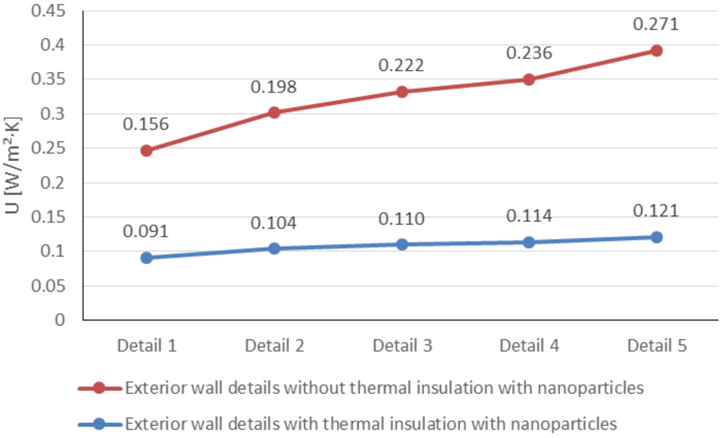

Fig. 5. Graphical representation of the thermal transfer coefficient U, for analysed insulating layer configuration

Conclusions

The focus on sustainable living involves adopting cost-effective thermal systems and low-conductivity insulation materials to minimize energy costs. The study introduces innovation by applying liquid ceramic nanoparticles to enhance the thermal performance of building envelopes initially equipped with EPS 80, addressing challenges related to aging thermal conductivity. This study assessed the thermal insulation performance of nanoparticle-based insulation by simulating the design of 10 external walls with varying layers and configurations, using a dedicated tool for physical-chemical performance calculations, involving cement mortar, brick masonry, bonding adhesive, and adhesive mortar. The simulations illustrated different thicknesses and arrangements, demonstrating the impact of nanoparticle-enhanced insulation on external wall configurations.

The analysis of insulation material thermal characteristics reveals a notable rise in heat flow resistance with different thicknesses of expanded polystyrene, along with a marginal decrease in temperature values in scenarios without nanoparticle-enhanced insulation. In the realm of external walls, the application of nanoparticle-enhanced insulation consistently improves thermal resistance and reduces the heat transfer coefficient, underscoring its effectiveness in enhancing overall thermal performance.

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