COMPARATIVE ANALYSIS OF WALL INSULATION LAYERS: INITIAL COSTS, MAINTENANCE, AND ENERGY EFFICIENCY

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ABSTRACT:

This research explores wall thermal insulation materials used today in construction of buildings, with a focus mostly on residential buildings in Bosnia and Herzegovina. Since the similarity of construction methods, climate and economy, results of this thesis can be applied to the Balkan region, but also parts of south-east Europe. Research explores key factors such are costs, maintenance and energy efficiency, which is becoming increasingly important due to the global rise in energy costs and the push toward more sustainable building practices. It is never an easy decision to choose correct insulation. It requires a balancing of cost with material durability and how much energy it will save. While many research papers examine insulation performance on a worldwide basis, there is still lack of region-to-region comparisons—specifically of regions such as the Balkans. This research addresses that gap by focusing on materials commonly used in Bosnia and Herzegovina, but yet capable to provide insights that can benefit professionals working in similar contexts elsewhere. This research is based on real-world case studies, published literature, and simulation models to compare the effectiveness of different insulation systems. Through this research it was found that various thermal insulation materials are applied to different parts of a building depending on their physical strength and adaptability to various spaces. In recent years, there has been a noticeable reuse of traditional materials, such is sheep wool. When processed, sheep wool achieves excellent thermal performance while maintaining a low environmental impact. Most importantly, it was concluded that graphite-enhanced expanded polystyrene (EPS) shows exceptional balance between cost and performance, making it a highly suitable as a façade insulation material for Bosnia and Herzegovina. Furthermore, it was determined that 10 cm thick graphite EPS becomes a cost-effective investment in just two years, compared to thicker layer of standard EPS.

KEYWORDS:

insulation, environment, material, thermal, cost, performance.

1 INTRODUCTION

The history of thermal insulation materials is somewhat shorter than the history of other building materials, such as wood. In prehistoric times, the first people built shelters to protect themselves from animals and to isolate themselves from natural disasters (rain, wind, etc.) [1].

Today, modern buildings consume approximately one third of the world's energy production. Ventilation, heating and cooling (HVAC) in modern buildings account for 50% of the energy used. Researches have shown that many factors play a key role in energy savings, such as the thermal insulation materials on the exterior walls, the material from which the wall itself is made, the geographical location and the orientation of the building itself. Using these suggestions, costs can be reduced by 20–40% [2].

By choosing a high-quality thermal insulation material in the design phase, we directly influence the reduction of the electricity used for HVAC, and the reduction of the quantity i.e. the price of installations and insulation of these installations. Reducing the use of electricity will not only reduce costs, but also reduce carbon emissions, thereby helping the environment [3].

It has also been proven through various statistical studies that a pleasant thermal atmosphere in the workplace has a positive effect on worker productivity and therefore on product quality. In addition, it reduces the risk of incidents at work and encourages good work communication [4].

2 MATERIALS AND METHODS

2.1 THERMAL INSULATION MATERIALS

Mineral wool, graphite expanded polystyrene, sheep wool, expanded polystyrene (EPS), and extruded polystyrene (XPS) are among the materials being considered. The reason for choosing specifically these materals is that EPS, XPS and mineral wool are mostly chosen in Balkan region as a thermal insulation materials. Graphite EPS is long time on the market, but it is rarely chosen in residential houses, while sheep wool is new to the market, and because of huge resource potential in Bosnia and Herzegovina, could quickly become on of the top choices for thermal insulation.

Mineral wool is a common name used for both rock wool and glass wool. However, when used in literature but also among the construction company circles, mineral wool is term commonly used for rock wool. Mineral wool is one of the oldest insulating materials in market. It is created by spinning molten rock or iron ore slag into fibers, which are subsequently covered with a binder and shaped into rigid boardstock or batts of different densities [5].

Table 4: Thermal insulation materials key properties

Materials	Initial cost per 10 cm (€/m²)	Thermal Conductivity (λ-value) (W/m·K)	R-value per 25mm (m²K/W)	vapor resistance factor (μ value)	Energy usage	Natural/ Artificial	Fire resistance
Mineral wool	5,25€	0,035 – 0,050	0,71	~1,0	Moderate	Artificial	Up to +900°C
EPS	4€	0,035 – 0,040	0,78	30 - 40	High	Artificial	Up to +85°C
XPS	12€	0,029	0,86	80-250	High	Artificial	Up to +90°C
Graphite EPS	6,13€	~0,028	~0,89	40-60	Moderate	Artificial	Up to +85°C
Sheep wool	15,75€	~0,0375	~0,67	~1,0	Low	Natural	Up to +250°C

2.1.1 Mineral wool

The primary characteristics of mineral wool include excellent thermal and acoustic insulation, fire resistance, water repellency, vapour permeability, resistance to chemicals and microorganisms and durability. Additionally, mineral wool maintains its dimensions despite temperature fluctuations, allows for easy installation, resists aging, and is recyclable [6].

Mineral wool mosly comes packed in rolls. It is easily transported to the site, and it can be easily carried in hands by workers. Mineral wool is among the easiest mounted insulation materials. It can be cut with knife or even torn apart, for desirable size. Since it contains small mineral particles, it is recommended to use at minimum, a tight-fitting dust mask, gloves, and coveralls, otherwise workers skin can get irritated [5]. When mounted inside the walls of prefab wooden houses, it is easily placed inside the wall, between the wooden pillars. However, in case of exteriod facade of concrete/brick or some type of rigid wall, the glue needs to be applied carefully and slowly on wool. After that it is glued to that wall, and in order to stay in place, plastic spacers are mounted through the wool and inside the rigid wall. After that, net and mortar can be applied together with finishing facade layer [7].

Mineral wool products are largely recyclable. Waste material generated during renovation and demolition, as well as cut-off remnants, is converted into new insulation. On average, 75% of stone wool production waste is recycled [8].

The main environmental effect caused by mineral wool insulation is due to its high manufacturing energy use, mostly due to its melting process, which involves high thermal input. As a result, mineral wool often exhibits higher embodied energy and carbon emissions compared to some alternative insulation materials [5].

The price for installation of one square meter of mineral wool façade in B&H, including all necessary materials is approximately 18.40€ per square meter. [9].

2.1.2 EPS

EPS (Extruded Polystyrene Board) is one of the most popular and most commonly used materials for thermal insulation. It is manufactured in various shapes, thicknesses, and dimensions, and the price depends on these characteristics. The advantages of

Styrofoam(EPS) over other materials are its low cost and ease of installation. Its disadvantage is that it is not resistant to temperatures above 80°C [10].

Expanded polystyrene (EPS) is produced by heat-expanding polystyrene beads containing 4–5% pentane. When exposed to high-pressure steam, the pentane vaporizes, causing the beads to expand 40 to 50 times their original size, forming a closed-cell, moisture-resistant foam. The expanded material is then cut into boards using hot wires. [5]

The price for installation of one square meter of EPS façade in B&H, including all necessary materials is approximately 19,42 €/m^2 [9].

Rigid insulation types such are EPS and XPS, are easier installed as external wall insulations, because of their stiffness. Good side is also lack of settling. However, they are not suitable for small spaces, such as around the pipes, which leaves those spaces to energy loss. EPS and XPS are strong, which means they are able to bear loads, including external loads from precipitation and wind. They are also applied faster on external brick walls in contrast to wool materials, and are impermeable to moisture. However, they are les vapor permeable than wool materials, which includes risk of condensation and mold within walls, if not applied properly [7].

In terms of production, expanded polystyrene (EPS) is notable for producing virtually no waste. During the cutting process—from blocks to insulation boards—or after its use in packaging and construction, EPS can be recycled in multiple ways [8].

EPS is an organic thermal insulation material. The energy required to produce 1 m^3 of EPS is approximately 400 kWh. It is considered harmless to soil, and contains no hazardous substances [8].

2.1.3 Graphite EPS

Graphite EPS is used for the construction of facade insulation systems. It contains graphite, which gives it a gray color and even better insulating properties [10]. In 1995, BASF—the original developer of EPS—introduced a graphite-infused version of the material, offering an R-value increase of 9% to 21% compared to standard EPS, depending on the type [5].

Graphite EPS requires installation process same as an ordinary EPS, therefor, since the price of the material itself is 6,13€ (a bit more expensive than ordinary EPS) per square meter, the price of total installation process of 10 cm graphite EPS is approx. 21,55 €/m^2 [9].

Installation and environment impact of graphite EPS is the same as for the ordinary white EPS.

2.1.4 XPS

Extruded polystyrene (XPS) is a rigid, closed-cell foam insulation made through the polymerization and extrusion of styrene. As a thermoplastic, it softens when heated and is available in various densities, offering different levels of compressive strength. Due to its excellent moisture resistance, high strength, and affordability, XPS is widely used, especially in below-grade applications such as foundation walls and concrete slabs [5].

Due to a different production process, it has closed cells and practically does not absorb water. Unlike regular white expanded polystyrene, XPS is coloured—light blue, light green, pink, and other shades characteristic of each manufacturer [11].

The price for installation of one square meter of XPS plinth for façade in B&H, including all necessary materials is approximately 24,03 €/m^2 [9].

XPS like EPS, is a rigid insulation type, therefore easier installed as external wall insulations, because of their stiffness. Good side is also lack of settling. However, they are not suitable for small spaces, such as around the pipes, which leaves those spaces to energy loss. XPS is stronger than EPS and able to bear greater loads, including external loads from precipitation and wind. They are also applied faster on external brick walls in contrast to wool materials, and are impermeable to moisture. However, they are les vapour permeable than wool materials, which includes risk of condensation and mold within walls, if not applied properly [7].

The production process uses gases that are harmful to the ozone layer and requires more energy, making it less environmentally friendly compared to the production of EPS [11].

The production of polystyrene involves the use of benzene, a well-known human carcinogen and mutagen, as well as styrene (also referred to as vinyl benzene), which is currently under evaluation for its potential carcinogenic effects [5].

2.1.5 Sheep wool

Sheep wool is relatively new thermal insulation material used in construction in Bosnia and Herzegovina. Sheep wool is a traditional, eco-friendly, renewable, and sustainable material that is closely linked to human needs. Additionally, it plays a role in mitigating climate change and reducing CO2 emissions during its processing, installation, and recycling. This material is beneficial for both the environment and human health. The total amount of wool that could be collected in Bosnia and Herzegovina reaches a value of 2.500 tons annually (1.515.000 sheep x 1,7 kg per head). It is estimated that 80% of the sheep population in Bosnia and Herzegovina belongs to the “Pramenka” breed (fibers classified between D and E, with an average micron diameter between 37 and 60), so it can be concluded that 80% of the wool, or approximately 2.000 tons, is coarse wool, while the remaining 20%, or about 500 tons, is finer wool [12].

According to company „Wool line“, which is one of rare companies which manufacture and sell sheep wool in Bosnia and Herzegovina as a thermal insulation material used in building construction, price for 10 cm of sheep wool insulation is 15,75 EUR [13].

The installation process is similar to mineral wool, therefor the price for a complete installation, together with all necessary materials, is approximately 29,65 EUR [9].

Sheep wool, contrary to mineral wool, is completely safe to touch and easy to work with and requires no special gear [14].

Sheep wool is a natural, recyclable, biodegradable and vapour-permeable material. It requires very little energy to produce, only 14% compared to mineral wool. The addition of polyester during production slightly reduces its biodegradability. When exposed to flame, the insulation material will not ignite but will instead melt, thereby reducing the spread of fire [8].

Insulation made from sheep wool has no harmful effects on human health. It does not release toxic gases when burned. No protective equipment is required for its use. These materials "breathe" and regulate humidity in the air due to their hygroscopic properties.

Additionally, these materials are naturally occurring, and their production requires significantly less primary energy and results in lower CO_2 emissions [15].

Table 2: Comparison of thermal transmittance and thermal conductivity coefficients of thermal insulation materials

Material	Required thickness in cm to achieve U = 0.35 W/m²K	Thermal conductivity coefficient λ for the specified thicknesses
Mineral wool	9-11	0,035 – 0,050
EPS	9-10	0,035 – 0,040
XPS	9-10	0,029
Graphite EPS	8-9	~0,028
Sheep wool	10-11	0,039

According to the comparison in table, graphite EPS requires the least thickness in order to achieve thermal transmittance, U value, of 0,35 W/m²K. Therefor with the same thickness of 10 cm, graphite EPS will achieve lower U-value, meaning less heat loss (or gain, depending on the climate), in comparison with other materials. The graphite EPS also shows lower thermal conductivity coefficient λ, which means it resists heat transfer effectively, and more efficient than other materials.

3 METHODS

This research presents comparative analysis of different wall insulation layers, with focus on their costs, maintenance requirements, and energy efficiency. The goal is to understand better how different insulation methods/materials perform over time and to promote energy-efficient building practices. Qualitative research method allows us to see both financial and technical factors over the long term. By examining real examples, the research reveals the advantages and disadvantages of various insulation materials.

Insulation materials are evaluated based on three primary criteria:

- **Initial Costs** – Exploring material prices, installation expenses and related building expenses
- **Thermal Efficiency** – Addressing materials based on their thermal performance and insulation effectiveness
- **Maintenance Requirements** – Analysing durability, common issues future maintenance costs
- **Energy Efficiency** – Analysing potential energy savings through the buildings life span

By this comparative analysis, the paper seeks to find out least expensive and eco-friendliest insulation options based on both financial and environmental effects. The

results will be evaluated through comparative matrix, giving each material rating on a scale from 1 to 5 (1 for worst, 5 for best), for each category (costs, thermal efficiency. maintenance and durability and energy efficiency).

4 RESULTS AND DISCUSSION

Detailed analysis of a two-story residential building is done with the aim of evaluating the impact of different EPS façade insulation thicknesses on thermal performance and cost efficiency in long time. The study focuses on a standard house model with a rectangular footprint of 8 m by 12 m, resulting in an exterior façade area of approximately 194 m² (excluding openings).

All thermal insulation data and performance characteristics used in the analysis are based on product specifications provided by Austrotherm, a leading manufacturer of insulation materials in the region. Three insulation scenarios are compared to assess the changes in thermal transmittance (U-value), estimated energy savings, and material costs.

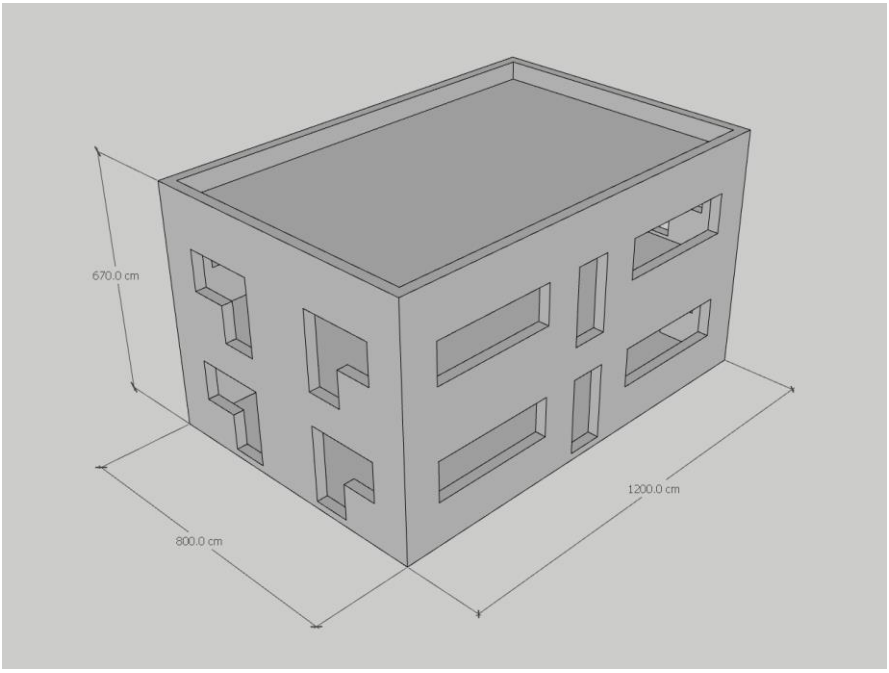

Figure 8. Volumetric 3D model of house

Input Parameters (Assumptions for the Calculation):

Location of the house is in Bosnia and Herzegovina. The heating season is assumed to last 6 months, from October 15th to April 15th. Heating is active 16 hours per day, resulting in a total of 2.880 heating hours per season. The energy source is electricity, with a 2012

electricity price of 16,16 KM/kWh. The reference building is a two-story house with a base area of 8 m by 12 m. The total external wall area, excluding windows, is 194 m^2.

Table 3: Heat losses through facade wall d=21 cm, Brick block 19 cm + interior mortar 2 cm

Heat loss through transmission & costs due to heat loss	Unit of measure	Thermal-insulation layer: WHITE FAÇADE EPS of different thickness		
		No insulation	Austrotherm EPS AF d = 5 cm	Austrotherm EPS AF d = 12 cm
Thermal transmittance coefficient [U-value]	W/m²K	1,72	0,52	0,26
Heat losses through the façade wall	kWh	14.895,30	4.502,70	2.250,40
Costs due to heat loss	BAM	2567,6	776,16	388,08

Input Parameters (Average Material and Labor Costs in Bosnia and Herzegovina)

- Retail price of EPS (Styrofoam): 3,80 KM/m² for 5 cm thickness and 9,24 KM/m² for 12 cm thickness
- Price of high-quality adhesive for EPS: 3,50 KM/m²
- Price of high-quality reinforcing mesh, including 10% overlap: 0,80 KM/m²
- Price of basecoat and finishing render: approximately 8,00 KM/m²
- Installation cost for EPS (gluing the boards and applying reinforcing mesh): 6,00 KM/m² (independent of insulation thickness)
- Installation cost of the complete ETICS ("demit façade"), including basecoat and finishing layer: 10,00 KM/m² [16]

As shown in the Table 4, the difference in investment between a complete external thermal insulation composite facade (ETICS or “demit façade”) with a 5 cm insulation layer and one with a 12 cm layer costs approximately 1000 BAM for the reference building/model. Comparing this extra expense to the total cost of building a residential family home, it is negligible. Additionally, the payback period for the two insulation scenarios is nearly identical. However, it is important to emphasize that after full cost recovery, the building insulated with 12 cm EPS will continue to generate twice as much annual savings compared to the 5 cm alternative. In particular, 388,08 KM is the annual cost of heat loss for the 12 cm insulation scenario, while for the 5 cm insulation scenario these costs are 776,16 KM.

This clearly shows the long-term financial and energy benefits of choosing a thicker insulation layer especially when shown in the wider context of sustainable building practices and life cycle performance.

Table 4: Investment in thermal insulation of the external wall

Investment cost & Payback period	Unit of measure	Thermal-insulation layer: WHITE FAÇADE EPS of different thickness		
		NO insulation	Austrotherm EPS AF d = 5 cm	Austrotherm EPS AF d = 12 cm
Cost of installed thermal insulation	BAM	0,00	2.566,62	3.551,44
Period of full (100%) cost payback	Years		1,4	1,6
Cost of installed complete ETICS ("demit façade")	BAM	0,00	4.848,06	5.832,88
Period of full (100%) cost payback	Years		2,7	2,7

5 CONCLUSIONS

This chapter brings together the findings from both the comparative analysis and the real-life case studies that explored five types of thermal insulation: Mineral Wool, Graphite EPS, Sheep Wool, standard EPS, and XPS. These materials were chosen for their widespread use or growing interest in Bosnia and Herzegovina and the broader Balkan region. The comparison was based on four key aspects—upfront cost, heat insulation performance, upkeep needs, and environmental impact—to offer a well-rounded perspective on which materials work best in residential buildings.

5.1 INITIAL COST

Price data was gathered from local suppliers for each material based on a standard thickness of 10 cm per square meter. Some of them were contacted directly, while some of the prices were collected from websites. Out of all the options, standard EPS turned out to be the most budget-friendly at 4,5 €/m². Close behind were mineral/rock wool (5 €/m²) and graphite EPS (6,13 €/m²). The most expensive one were XPS (6,5 €/m²) and, relatively very expensive, sheep wool (15,75 €/m²). EPS scores highest on cost comparison (5/5).

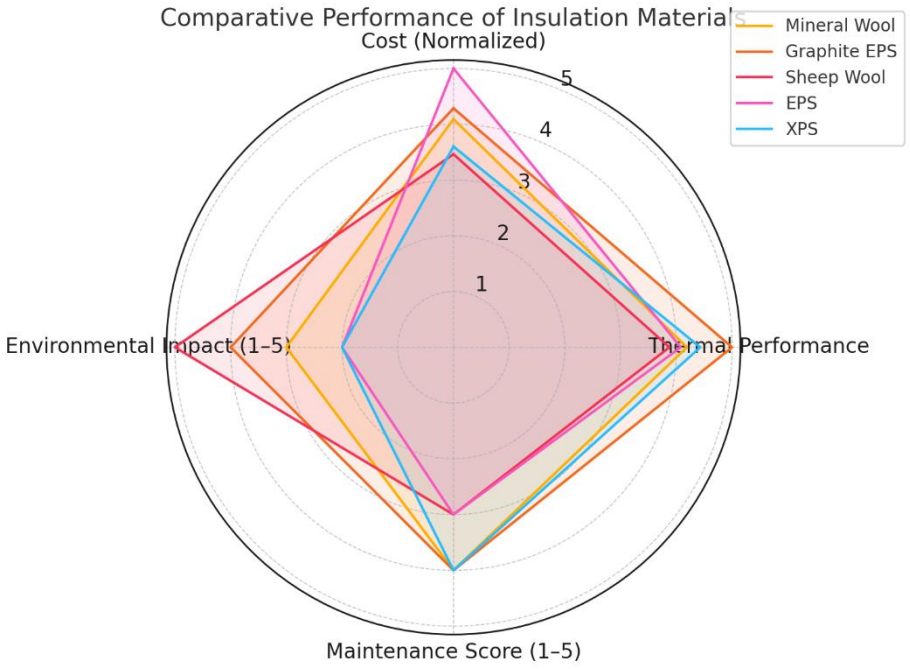

Figure 9.Comparative perfomance of insulation materials

5.2 THERMAL EFFICIENCY

Graphite EPS had the lowest value (0,031 W/mK), indicating superior insulation, and scoring 5/5 on thermal performance scale. To see how well each material insulates, thermal conductivity values were looked upon and basically, the lower the number, the better the insulation. Graphite EPS is first with a value of 0,031 W/mK, making it the top performer in terms of reducing heat loss. It is followed by XPS (0,035 W/mK) and mineral wool (0,037 W/mK). Although standard EPS and Sheep Wool have slightly higher conductivity, they still offered solid thermal efficiency.

What this shows is that while standard EPS is cost-effective, upgrading to Graphite EPS could be a smart move for those looking to boost energy savings without a huge jump in price.

5.3 MAINTENANCE AND DURABILITY

Mineral Wool, Graphite EPS, and XPS all scored highly (4/5) in terms of low maintenance needs, thanks to their mechanical stability, moisture resistance, and longevity. Sheep Wool, although gaining popularity for its ecological appeal, scored lower due to sensitivity to pests and moisture in humid environments unless adequately treated. EPS, though widely used, may degrade faster without proper protection from UV exposure or mechanical damage.

5.4 ENVIRONMENTAL IMPACT

Sheep Wool scored highest (5/5) on environmental impact due to its natural, renewable source and low energy manufacturing process. Graphite EPS followed with a moderate

score, as it incorporates recyclable materials and has improved thermal efficiency. In contrast, EPS and XPS received the lowest scores due to their petrochemical origins, lower biodegradability, and higher embodied energy.

5.5 OVERALL CONCLUSION

In conclusion, out of all thermal insulation materials compared, graphite-enhanced EPS stands out as a practical choice in today's market. It offers excellent thermal performance with only a slight increase in cost, which is easily justified by the long-term energy savings it provides.

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