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MULTICRITERIA COMPARATIVE ANALYSIS ON THE EFFECTIVENESS USE OF VARIOUS MATERIALS FOR THERMAL INSULATION IN ROMANIAN RESIDENTIAL BUILDINGS

D. COVATARIU[1] **D.T. BABOR**[1] **R.G. ȚARAN**[1]

Abstract: *Today it can already erect buildings with low-energy and passive houses at reasonable prices. Nowadays is being discussed more often the issue of the energy performance of the buildings already built.*
Improving energy efficiency in existing buildings allows owners of buildings to keep energy costs under control in order to be less vulnerable in the event of future fluctuations of the energy prices and, also, to protect the environment by assimilating some wastes as building material cycle.
This paper was carried out a multicriteria comparative analysis of efficiency of the use of various materials in Romania for buildings thermal insulation. The materials selected for this research are: polystyrene, glass fibre mineral wool, basaltic mineral wool, cellulose fibres and natural wool.
It was analysed the thermal insulation behaviour (for which it was calculated the heat insulation's global coefficient), the reaction to fire, the manufacture (the mounting technology criterion) and, obviously the economic criterion (price analysis for square meter).
The objective was not to give a radical conclusion, but rather to present the advantages and disadvantages of materials according to the requirement of each criterion.

Key words: e*xpanded polystyrene, natural wool, glass wool, basaltic wool, cellulose fibers, thermal insulation.*

1. Introduction

The quality of interior climate is given by a good insulation of the house and the automatic ventilation which changes the air frequency, assures enough quantity of fresh air in the interior of the house.

To prove pleasant indoor climate of passive houses, an agency from Germany conducted a study on 32 passive houses from German region of Kronsberg nearby Hannover. The study proves that the majority (96%) of the owners from those houses consider the indoor air quality very good (46%) or good (50%) (Agentur für Umweltkonzept, 2001).

The indoor climate it's useful to health and quality of living in that space.

Replacing only a part of the building (for example, woodwork) can generate into old

[1] Faculty of civil Engineering and Building Services, "Gheorghe Asachi" Technical University of Iași

and bad insulation buildings, issues bound to condensation and excessive humidity and the development of mould and bacteria in time , due to poor thermal insulation of opaque surface.

The lifespan of building is usually between 50 - 100 years or even more. Because building lasts a lifetime is fine to give attention to maximum energy efficiency in the construction of the building. In the lasts years the energy prices raised into a dramatic way and probably will never return to the low level in past years.

Choosing a building with low energy consumption and improving energy efficiency in existing buildings allows owners of buildings to control energy costs and be less vulnerable to future fluctuations in energy prices.

1.1. Example of energy consumption for a house

Fig. 1. *Energy consumption for different manners of building insulation*

For the owner of the house, the insulation is more than one way to reduce CO2 emissions. According to the German Energy Agency, renovation of a house of 150 sqm initially poorly insulated (from 1970) and its transformation into a building with low energy consumption by installing better insulation and quality windows and making other energy-efficient measures can reduce CO2 emissions by 11 tons per year.

The quantity of 3600 litres of liquid fuel saved is more than 3000 euro per year, at the prices in Germany by mid-2008. If the owner would like to save same quantity of CO2 moving bike instead of the car should travel every year about 70000 km or to surround the globe one and a half. Luckily not all buildings were built in 1970. However, it is proved that an ordinary building in the European Union every year can save up to five tons of CO2.

In this paperwork was performed a comparative analysis of five construction materials used in isolation to study their effectiveness in several ways. The materials selected for this study were: expanded polystyrene, fiber glass mineral wool, basaltic mineral wool, cellulose fiber insulation, natural wool. The objective is not to take a radical conclusion but rather will present the advantages and disadvantages of each criterion according to requirement.

Insulating materials were selected for this study based on the following criteria: best-selling insulation material in our country - expanded polystyrene; Fiber glass mineral wool being 2nd in products marketed in Romania; basaltic mineral wool manufacturers and retailers reveal phonic qualities and fire resistance of it, so we could not overlook this material in our study; insulation such as cellulose fiber and wool encourage environmental protection (by in waste disposal of natural circuit) to obtain funding for the economic development of our country.

The chosen criteria for the comparative analysis were the most often used building materials market to justify marketing Romanian one or other material:

1. Thermal insulation criteria - the most important. It was examined the impact (coefficient of thermal conductivity - λ) in the overall thermal insulation

coefficient (G). It was taken for analysis an important building - kindergarten.

2. Fire behaviour criteria - analysis of this criterion is one relative, because nowadays many construction materials have since the manufacturing process applied fire protection.
3. Technological criteria - a criterion that has been analyzed which the materials selected will have the most advantageous procedure laying. Sometimes building materials will be highly desired by the beneficiaries if the execution time is short one.
4. Economic criteria - analysis on the cost price was made by following-up the bill quantities. The costs of insulation were calculated by adding material price per square meter, transport costs, labour and equipment.

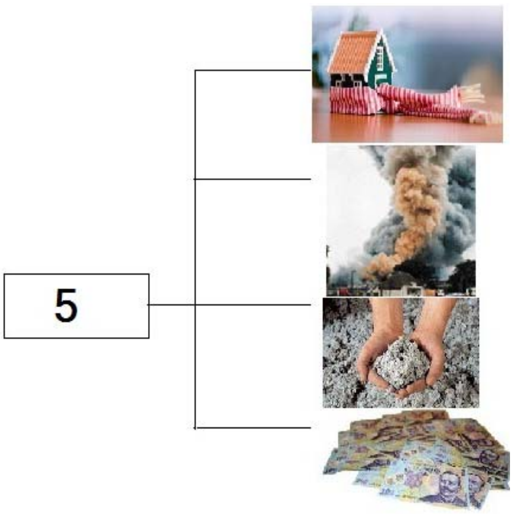

Fig. 2. *The analysis was prepared for 5 materials and 4 criteria*

2. Insulating materials chosen for the analysis

2.1. Expanded PolyStyrene

EPS stands for (Expanded Polystyrene) is an organic material containing air, having from 3 to 6 billion closed cells every cubic meter, which gives environmental characteristics of this material. Polystyrene is a liquid hydrocarbon produced commercially from petroleum by the chemical industry.

Polystyrene insulation protects the environment, emissions of CO_2, NO_X and sulphur dioxide thus reduced. The material contains approx. 98% air and is tolerated by the skin.

We chose for the study this type of expanded polystyrene because in terms of quality and price the product is situated at an average level.

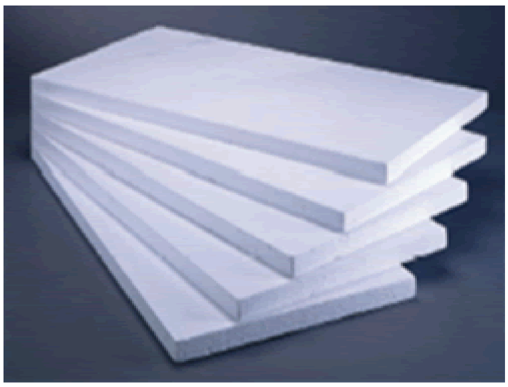

Fig. 3.a. *Expanded PolyStyrene – plates form*

Fig. 3.b. *Expanded PolyStyrene – surface presentation form*

2.2. Fiber glass wool isolates as well as cold and hot, because is a porous material made from substances that inhibit the heat transfer.

It is a material of high dimensional stability. This is extremely important for a building. In this way we guarantee that the insulation system retains original features that do not appear as heat loss, for example the possible separation of the plates that appeared by mechanical contraction.

Very small diameter fibers cause a network of microscopic pores, which immobilizes the air and turns it into a real thermal blanket.

Fig. 4. *Fiber glass wool – presentation form*

2.3. Basaltic wool

Basalt wool rigid plates of 2-layer integrated with organic resin binder, waterproof mass. The top layer thickness up to 20 mm, has a larger density which gives superior resistance to mechanical action and impact. The lower layer has a density which gives an improved heat transfer coefficient. The plates are printed on the upper surface to ensure proper installation.

Fig. 5. Basaltic wool– *presentation form*

Mineral basaltic wool properties:

- good thermal insulation,
- fire protection,
- protection against flame propagation,
- noise protection;
- hydrophobic plates (vapour permeable)
- dimensionally stable;
- resistant to an alkaline medium. resistant to pests
- not harmful to health.

2.4. Cellulose fibers

The physical properties of cellulose allow it to reach in spaces or narrow areas around installations in walls, such as pipes and electrical wires, leaving no open air areas that could reduce the effectiveness of the insulation. Also, the sealing wall and roof structures insulated with cellulose fibers system eliminate ingress of air, convection currents therefore effective to create a thermal barrier.

Additionally, the cellulose is acting in the uniform distribution of moisture of the cavities where is used, preventing the accumulation in an area and helps to a faster drying.

Thermal conductivity of the cellulose fibers is 0.037kW/mK.

Fig. 6. *Cellulose fibers – presentation form*

2.5. Natural Wool

Natural wool is an insulating material which retains its shape. Is also an insulating material that eliminates formaldehyde from air. The coefficient of thermal conductivity as the data sheet: λ = 0.0356 W/mK. But it is also a product treated and fireproof and an insulating material easy to put in place.

Excellent thermal insulation properties of wool are kept even wet. The moisture absorption and rapid release, attenuates excellent the extreme temperature variations. Wool retains its shape due to genetic fixation recurring wool fiber thickness and original density.

A property that is sometimes given too little attention: the wool has the ability to reduce noise. It proved to be a very good sound absorbing both walls and ceilings.

Fig. 7. *Wool –presentation form*

3. Multi-criteria analysis of the effectiveness of choice of different insulation materials

3.1. Analysis regarding thermal insulation:

Construction chosen for analysis is a building for social and humanitarian activities (kindergarten) carried on 3 levels (ground floor and 2 floors), the 3rd level being part of the area it occupies about three quarters of the construction plan. The last will include both bedrooms and classrooms, ancillary areas and ensure all utilities - water, sewer, electricity and heating.

Calculations were performed as follows:

a. Determination of specific unidirectional thermal resistance

$$R = R_{se} + \sum \frac{d}{\lambda} + R_{si} \quad \left[\frac{m^2 K}{W}\right]$$

• $R_{se/si}$ – superficial thermal resistance on the exterior/interior surface of the element [$m^2 \cdot K/W$]

• d – thickness of each layer from the element envelope [m]

• λ – thermal conductivity's coefficient [W/m·K]
- for expanded polystyrene – 0.040 W/m·K
- for fiber glass wool – 0.038 W/m·K
- for mineral basaltic wool – 0.036 W/m·K
- for cellulose fiber – 0.037 W/m·K
- for wool – 0.0356 W/m·K

b. Correcting the specific thermal resistances corrected due to the influence of thermal bridges

Final table concerning the corrected thermal resistances:

	Polystyrene	Fiber glass wool	Mineral basaltic wool	Cellulose	Wool
λ [W/m·K]	0.04	0.038	0.036	0.037	0.0356
R_{pe} [m^2·K/W]	3.689	3.82	3.966	3.889	3.989
R_{plic}[m^2·K/W]	3.15	3.28	3.427	3.35	3.45
R_{plir} [m^2·K/W]	3.197	3.328	3.474	3.397	3.497
R_{plsc} [m^2·K/W]	4.375	4.58	4.795	4.683	4.842
R_{plsr} [m^2·K/W]	4.41	4.61	4.826	4.714	4.873
$1/R_{pe}$ [W/ m^2·K]	0.271	0.262	0.252	0.257	0.251
$1/R_{pi}$ [W/ m^2·K]	0.315	0.302	0.289	0.296	0.288
$1/R_{ps}$ [W/ m^2·K]	0.227	0.217	0.208	0.213	0.206
$R`_{pe}$ [m^2·K/W]	1.808	1.838	1.873	1.855	1.876
$R`_{pi}$ [m^2·K/W]	2.74	2.84	2.95	2.89	2.96
$R`_{ps}$ [m^2·K/W]	3.802	3.952	4.1	4.02	4.13

c. Determining the global thermal insulation coefficient (G)

$$G = \frac{1}{V_{hea}} \cdot \sum \frac{A_{elanv} \cdot \tau}{R`} + 0.34 \cdot n$$

V_{hea} – heated interior volume of the building

n –natural ventilation speed of the building, number of air changes per hour [h^{-1}] =0.6

τ–correction factor of exterior temperatures =1

V_{hea}=3304.98 m^3

1. Polystyrene G = 0.4355 [m^3K/W]
2. Fiber glass wool G = 0.431[m^3K/W]
3. Mineral basaltic woolG=0.426 [m^3K/W]
4. Cellulose fiber G = 0.429 [m^3K/W]
5. Wool G = 0.425 [m^3K/W]

Global thermal insulation coefficient (GN), in buildings designed conforming to the norms after 1 January 2011; it is extracted from C107-1-2005 norm with changes from 2010, in terms of:

• Nr of levels = 3
• RatioA/V=0.473=>GN=0.4538 [m^3K/W]

Conclusions of the calculations carried out to determine the efficiency of thermal insulation are summarized in the following table:

No	Material	Efficiency's degree
1	Expanded polystyrene	*
2	Fiber glass wool	**
3	Basaltic mineral wool	****
4	Cellulose fiber	***
5	Wool	*****

* - most inefficient material
***** - most efficient material

3.2. Analysis of the reaction to fire action:

Buildings fire safety measures must fulfill the criteria and the levels of performance from P118 norm.

Depending on the reaction to fire,

materials and building elements can be incombustible C0 (CA1) or combustible. Combustible materials and buildings elements are classified into classes of combustion:

- C1 (CA2a) practical uninflammable;
- C2 (CA2b) difficult inflammable;
- C3 (CA2c) medium inflammable;
- C4 (CA2d) easy inflammable.

Fig. 8. *Reaction to fire – Comparison cellulose vs. Fiber glass wool*

According to technical reports, of the data from P118 norms and with experiments performed in specialized laboratories of the manufacturing companies of thermoinsulation materials we centralized all data in the following table to have a hierarchy of the analyzed products:

No	Material	Efficiency's degree
1	Expanded polystyrene	*
2	Fiber glass wool	**
3	Basaltic mineral wool	*****
4	Cellulose fiber	***
5	Wool	****

* - most inefficient material
***** - most efficient material

3.3. Analysis concerning technological criteria (workmanship):

Expanded polystyrene it is easily installed, follow-up we can observe some stages into installation of expanded polystyrene on the facades of the buildings:

1. After preparing the support layer it will be prepared the mortar for fixing the plates
2. In the bottom of the insulation boards are fixed the profiles from the base
3. The mortar is applied around the plate in the form of a strip with a width of 3-4 cm in the plate's centre in the form of bounces with a diameter of about 8 cm, so that after pressing to fill 40% of the plate.
4. The plates were applied side by side, beginning from the base, from one corner and going to the superior part of the walls, maintaining a straight line. In short, these would be the execution stages, therefore the polystyrene is easiest to mount and will have the best rating in this chapter.

Fig. 9. The manner to put in place the expanded polystyrene

Basaltic mineral wool, fiber glass mineral wool and wool have the same mounting system. The costs and complexity of mounting are more disadvantageous than expanded polystyrene because a metal / wood structure on which to put in place the insulating material. In this case the exception would be the basaltic mineral wool boards but their weight is greater than polystyrene, so the costs on the supporting and mounting are higher.

Fig. 10. *The manner to mount the layers of mineral wool layers*

Finally we discuss about the installation of cellulose fiber insulation which can be resemblance with that of mineral wool mats and wool (the use of mattresses of waste cellulose). The cellulose is most often presented in the form of granules or fibers which are specially treated and with the particular binder will be sprayed (with a compressor) on the surface to be insulated. Then the insulating layer will be protected from the weather by a special treatment (coating, spraying, painting). Labour will be quite uncomfortable for the construction of a large number of levels, but also because the material can be put into practice only by specialized institutions.

Fig. 11. *Method to mount the cellulose fibers insulation*

In the following table there where evaluate the material concerning technology assessment:

No	Materials	Efficiency's degree
1	Expanded polystyrene	*****
2	Fiber glass wool	***
3	Basaltic mineral wool	****
4	Cellulose fiber	**
5	Wool	***

* - most inefficient material
***** - most efficient material

3.4. Analysis on economic criteria

Economically plan and future, construction will be evaluated, required by professionals, according to the energy certification, costs can be found in the balance monthly rents, own maintenance, in one total dependence of the value heating bills, warm water, electricity, natural gas. All of these calculation elements will express, clear and to the point, market price of the property subject to sale, rent, buying.

In the specialized literature, in presenting the information made by manufacturers materials required thermal insulation and finishes, are defined and even known the price spread for the implementation of thermal insulation the building envelope. These prices are expressed per square meter insulated surface.

The comparative analysis on the economic point of view is made from the raw material costs, taking into account and expenditure on labour, transport and equipment (by drafting the bill of quantities).The results are revealed in the following table:

No	Materials	Efficiency's degree	Cost [€/m^2]
1	Expanded polystyrene	*****	7-8
2	Fiber glass wool	***	15-16
3	Mineral basaltic wool	**	17-18
4	Cellulose fibers	***	15-16
5	Wool	*	21-22

* - most inefficient material

***** - most efficient material

4. Conclusions regarding comparative analysis

In the table below we centralized all the information in the previous chapter then I collected all the marks obtained (*) achieving a rating on the building materials proposed for study.

We discussed the position of each material and which were strengths and their weaknesses.

The first is located mineral basaltic wool, although is leading only to resistance to fire other comparison criteria, is under the leadership, except for the economic criteria which is the main disadvantage rigid plates "Dual Density" their cost being very high compared to the other materials studied.

No	Material	Insulation degree	Fire resistance	Technologic	Economic	TOTAL
1	Expanded polystyrene	*	*	*****	*****	12*
2	Fiber glass wool	**	**	***	***	10*
3	Mineral basaltic wool	****	*****	****	**	15*
4	Cellulose fibers	***	***	**	***	11*
5	Wool	*****	****	***	*	13*

Sheep wool it ranks 2st position and the main criteria that rises to this level is a good global coefficient of thermal isolation (the best of the five the subjects followed) and fire resistance, the latter is due to special treatments that the manufacturer adds to the insulating material.

We can observe that there is not an advantageous material in economical and technological point of view.

In the middle place, 3rd position is the expanded polystyrene, the most efficient material economically and technology point of view and the most inefficient in terms of fire proofing and the degree of fire resistance. According to the study never reaches the middle of a criterion although in reality has a good degree of thermal isolation (middle). Fact that is leading without no doubt in the 2 criteria (technological and economic) explains the use in most of cases in our country.

4th position is occupied by cellulose fibers. The fact that none of the criteria is not the strength of this insulation type, the product taken only middle notes or even inferior that explains and place occupied, but we must consider is just one step away of expanded polystyrene and the main advantage (raw material is a waste) has not been taken into account.

Last position is occupied by fiber glass mineral wool although is a material with good properties in terms of thermal insulation, difference between the last 2 seats making by glass fiber lower fire resistance compared to cellulose fibers.

It is obvious that the present analysis can be improved by adding new criteria: durability over time of applied material, degree of environmental damage (over time and in the manufacturing), etc. Unfortunately, these criteria require a long analysis, stretched over a longer period of time, which can be achieved in the following years.

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