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Analysis and Typology of the Most Commonly Used Thermal Insulation Materials in the Construction Industry

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Abstract

A decisive factor in the energy efficiency of a building is undoubtedly the quality of the design and manufacture of the facade or envelope. The insulation of the façade is one of the components with the greatest impact on energy efficiency. As part of the concern for the environment, natural insulation is becoming an increasingly attractive alternative for any country. When choosing natural insulating materials, it is common that in addition to thermal criteria, environmental criteria must also be taken into account (13, 15, 27). The main objective of insulation is to reduce energy consumption, but what about the energy balance of insulation? The building must be seen as a whole that relates effective materials and efficient construction techniques.

The construction of low-energy buildings is an objective that guarantees environmental protection. Thanks to the use of new technologies, buildings could be perfectly healthy for the environment. These innovations, born from the awareness of the different ecological constraints, have led to an evolution of design, which has developed innovative and technological strategies capable of making the building energy efficient. A building with optimum energy performance is a structure that guarantees its inhabitants excellent comfort conditions, such as thermo-hygrometric, acoustic and lighting conditions, by means of appropriate technical solutions.

Keywords: thermal insulation, energy efficiency, construction, insulating materials

1. Introduction

The construction industry of the 1970s and 1990s did not try to minimize energy savings by maximizing thermal performance, but pursued quantitative construction at the expense of quality. Today, however, the trend is to construct buildings with good efficiency, using sophisticated and innovative techniques. One of the sustainable experimentation techniques is insulation (4). The growth of insulating materials on the market has led to the improvement of traditional insulators and to experimentation with new ones. The focus is mainly on innovative insulation materials that offer high performance in confined spaces. New insulating materials are an interesting solution to contain consumption and make the building more energy efficient (1). In the last decades, even traditional insulating materials have been improved, but not all of them are able to guarantee the absolute performance of a contemporary insulator.

2. Methodology and materials

The materials used in construction projects are of utmost importance because they determine the characteristics of the project, requirements and type of maintenance required. The variety of raw materials used is quite extensive and with the passage of time and technological advances, compounds have been developed that respond to the changing needs of the industry.

Generally speaking, construction materials can be classified into two types, natural and synthetic. Natural materials are those that are unprocessed or minimally processed by industry, such as wood or glass. Synthetic materials are manufactured in industrial settings after many human manipulations, such as plastics and petroleum-based paints. Both have specific uses. Mud, stone and fibrous plants are the most basic materials, apart from tents made of flexible materials such as fabrics or skins. Many people have used these three materials together to create dwellings that are adapted to their local climatic conditions.

But this study will focus on describing the materials most commonly used as thermal insulation and their application in the most basic typologies of them as internal, external or interlayer insulation.

2.1 Insulating materials most commonly used in the construction industry

2.1.1 Rock wool

Rock wool is a mineral-based material with high thermal and acoustic absorption properties. It does not absorb water or humidity and is a perfectly fireproof material. Production is entirely industrial, although it originates from volcanic sediments in Hawaii. The production process of rock wool insulation material involves the use of rock mixtures (dia base, basalt, dolomite).

This material was initially considered carcinogenic because it was made from rocks, but this hypothesis has been disproved because rock wool meets the safety require-

ments of Regulation (EC) No. 1272/2008 and new production processes ensure the manufacture of a pure, biosoluble mineral fiber. The cellular structure creates a barrier to the passage of heat and cold and is also capable of absorbing sound waves and insulating interior spaces from noise. Due to its versatility, rock wool is used in all fields of application except horizontal closures, both those in contact with the ground and in inverted roofs.

2.1.2 Wood fiber

Wood fibers are obtained from the remains of wood material (spruce, pine) from sawmill cuttings or clearings, which are mechanically or steam de-fibrated. It is a type of material available in various thicknesses and densities, and is always very manageable with hand tools (8). Wood fiber panels do not appear to be flame retardant, but have a capacity for comfort at the level of hygroscopicity and breathability. In this sense, it seems to be an excellent material against humidity, playing also the role of third skin of the building.

Wood fiber, being a natural material, is harmless to health and reusable, as it can be recovered and recycled. In recent years, mineralized wood panels have been produced with this material, but unlike wood fiber, it cannot be fully recycled, as the wood is mixed with mineral powders and added with cement.

2.1.3 Hemp fiber

Hemp is one of the natural materials with the highest performance in terms of sustainability. Today, hemp-based products are only present to a limited extent in the construction market, as their efficiency values are lower than those of other types of insulating material (10). The insulating material is produced by harvesting hemp plants, which are reduced to fiber and then processed with polyester fiber as a waterproofing agent and natural products to act as flame retardants. The manufacturing process is also low cost, as it does not require water or chemicals and requires little energy. This material is also used in a variety of fields, from fashion to kitchen products, construction and biomass fuel.

2.1.4 Cork

The cork used for thermal insulation comes from Quercus suber. This long-lived, evergreen plant grows throughout the Mediterranean region. The trunk of the oak tree is formed by a double layer of cork, the first, called the mother layer, is covered with phellogen and has the characteristic of being soft, elastic and spongy (2,16). The production process is characterized by obtaining the cork by peeling and after months it is seasoned, boiled and scraped. It is then dried and ground to a particle size of between 4 and 11 mm, so that if the particle size is larger, it can retain moisture longer between the cracks of the granules, and if it is coarser, it reduces the insulation value. Cork has both insulating and breathability qualities (19,21). It is able to absorb moisture returning it to the surrounding area providing oxygen releasing the moisture to the outside and not triggering the condensation process. Cork is used in the construction industry because it can withstand heavy loads, is resistant to biological corrosion and is not attacked by insects. Cork is commercially available in the form of panels, loose material and sheets, and can be used individually or in combination with other materials (20).

2.1.5 Sintered expanded polystyrene (EPS)

Expanded polystyrene was the first known polymer and its first polymerization process was discovered by Blyche and Hoffmann in 1875. It is a rigid, inert and lightweight material. It is presented in the form of beads to which an expanding agent called pentane is added, then in contact with steam the volume of the beads increases up to 20/40 times their size. The characteristic of this material is that it has a high technical performance and is competitive with the traditional market; in fact, it is an environmentally friendly material, easy to use and readily available. One of the harmful materials present in EPS is styrene, which has a high reactivity, high volatility and solvent action, which is hazardous to air, soil and water. When cutting and applying the material, care must be taken not to break the panel.

2.1.6 Aerogel

One of the most unique and innovative substances of the last century, it was accidentally created by Steven Kistler and Charles Learned in 1931. It is a compound that combines a gas with a solid substance. The result is a solid foam with high properties, the most important of which is its insulating effect. It is a light substance composed of 99.8% air and 0.2% silicon. Aerogels are hydrophobic by nature, but with the right chemical treatments they can be made hydrophobic, thus avoiding deterioration due to humidity. Today, aerogel is used in the construction sector in the form of mats with a thickness of 5 to 10 mm, which guarantees excellent thermal and acoustic performance; the super-reduced thicknesses make these materials unique in the market.

Thermal insulation materials	
Rock wool	
Wood fiber	
Hemp fiber	
Cork	
Sintered expanded polystyrene	
Aerogel	

Table 1. Most used materials for thermal insulation

3. Discussion

The realization of insulation in a house is a design that must be thought through very carefully, because a building, a wall, that is not well insulated drastically reduces the performance of the entire construction. The purpose of insulation is to prevent condensation and mold in structures. Thermal insulation should be considered for the entire building, taking into account the roof, foundation, perimeter walls, partitions and foundations. In the case of new buildings, insulation is quite simple, because the building is under construction, and it is possible to choose the type of insulation that best suits the client's needs (3,5,9). The problem is when insulating an existing building; to insulate this type of structure it is first necessary to carry out an energy diagnosis, identifying possible technical solutions to improve the energy efficiency of the building and reduce consumption. Specifically, insulation solutions for opaque walls will be studied. Insulation measures vary depending on the position of the insulating material: interior insulation, cavity insulation, exterior insulation or exterior insulation and insulating blocks.
In this discussion we will highlight various types of insulation to be used for interior, exterior and between-wall (interlayer) walls, analyzing the pros and cons of each applicable solution.

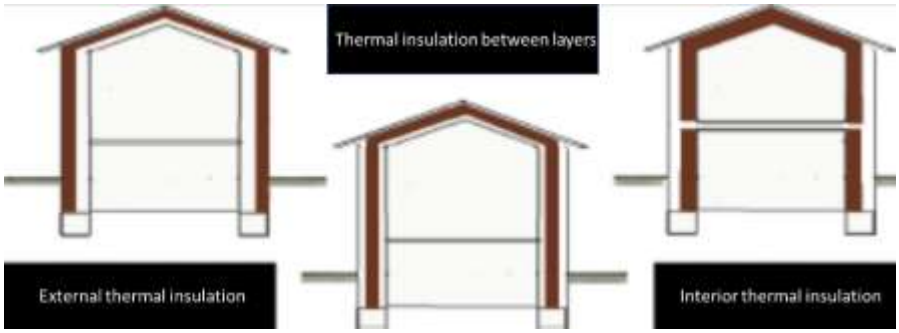


Figure 2. Different types of insulation in a building

Next, the typologies of integration of the different materials used in construction to achieve greater efficiency and comfort in housing will be presented.

3.1 Types of architectural integration

3.1.1 Interior insulation

Interior walls and ceilings are lined with insulation, but this insulating layer reduces the living area and, in addition, it is difficult to eliminate the numerous thermal bridges. This type of insulation is used when there is an energy rehabilitation project and it is not possible to use another type of insulation (exterior or cavity) (11,12). It is possible to improve thermohygrometric damage such as interstitial condensation (in winter, water vapor migrates to the outside and when it passes through the insulation layer in contact with the outside wall temperature it can

condense) by applying a vapor barrier before the insulation layer. One of the limitations of using insulation indoors is that the wall does not accumulate heat, as the room heats up quickly, but at the same time cools down quickly after the heaters are turned off, and application can be difficult in some areas of the house, such as behind large furniture, the kitchen or radiators.*3.1.2 Aislamiento exterior*
Among the exterior insulation solutions, the best known is the thermal insulation system also known as ETICS (External Thermal Insulation Composite System). It was conceived and disseminated about 40 years ago in northern Europe, and is now the solution par excellence for insulating civil, industrial, existing or pre-existing buildings (14). The insulation system improves thermal performance in both summer and winter, as well as ensuring excellent acoustic qualities, and is essential for eliminating thermal bridges, as it can be applied continuously to structural elements. In this way, it is possible to create a real protection, thanks to the reduction of stresses, derived from the difference in thermal oscillations. It is important to eliminate thermal bridges, as they generate sudden drops in temperature with the consequent formation of condensation. In addition to thermal bridges, exterior insulation prevents the formation of mold, since it is difficult for it to reach the dew point, since the entire structure is uniformly warm. In order to achieve good thermal insulation, it is necessary to use a good insulating material with excellent performance qualities to reduce the U transmittance value: rock wool, cork, expanded polystyrene, EPS or wood fiber (17,18,26).
The variation in thermal transmittance is also due to the type of thermal insulation thickness; in fact, greater thickness corresponds to greater insulation (22). When installing thermal insulation, attention must be paid to several elements:

- The substrate and air temperature: they should not be lower than 5°C and not higher than 35°C.
- The surface should not be exposed to direct sunlight;
- In case of damage due to major impacts, it is advisable to use a coating with a double reinforcing mesh or to create a skirt at the base of the insulation.

3.1.3 Cavity insulation

To improve thermal efficiency, cavity filling can be used. Cavity insulation can be performed in two ways:

- Cavity insulation with loose, liquid material.
- Cavity insulation with rigid boards

Cavity insulation with loose-fill or blown-in material is a fast and economical way to protect the building from cold and heat, while reducing costs compared to other types of insulation installation. To obtain blown-in insulation, holes are drilled in the top of the wall and loose material is blown into the cavity to fill the wall voids; thus, the thickness of the wall will not be affected. Before blowing, it is necessary to check that the existing wall can withstand the strength and compression parameters due to the pressure of the injected insulation material. Insulating materi-

als to insulate the cavity are: cellulose, cork, glass wool, urea resin and polyurethane (28,29).
Cavity insulation with rigid foil can only be applied to buildings under construction or to the renovation of existing buildings. In fact, insulation is placed in at least one of the two layers of the double skin by inserting rigid foils such as: mineral fibers, polyurethane and polystyrene.To ensure adequate performance, it is preferable to add a vapor barrier, to be placed on the surface of the insulation, to prevent the passage of vapor into the insulating layer with consequent condensation.

3.1.4 Insulation blocks

In recent years, the production of masonry blocks (brick or concrete) with insulating material inside has been particularly developed. This process accelerates the construction of the vertical envelope and ensures high performance in terms of thermal insulation. In concrete blocks, the insulating material is inserted in such a way as to ensure the continuity of the insulating layer, so that the concrete is poured inside the block where the insulating material was previously placed and cured (30). The blocks are designed taking into account:

- The cavities of the block, so that the thermal behavior can be improved.
- The thermal transmittance of the wall, the permeability and the ease of installation of the block (31).
- The use of suitable insulation, generally synthesized expanded polystyrene (EPS) or cork.

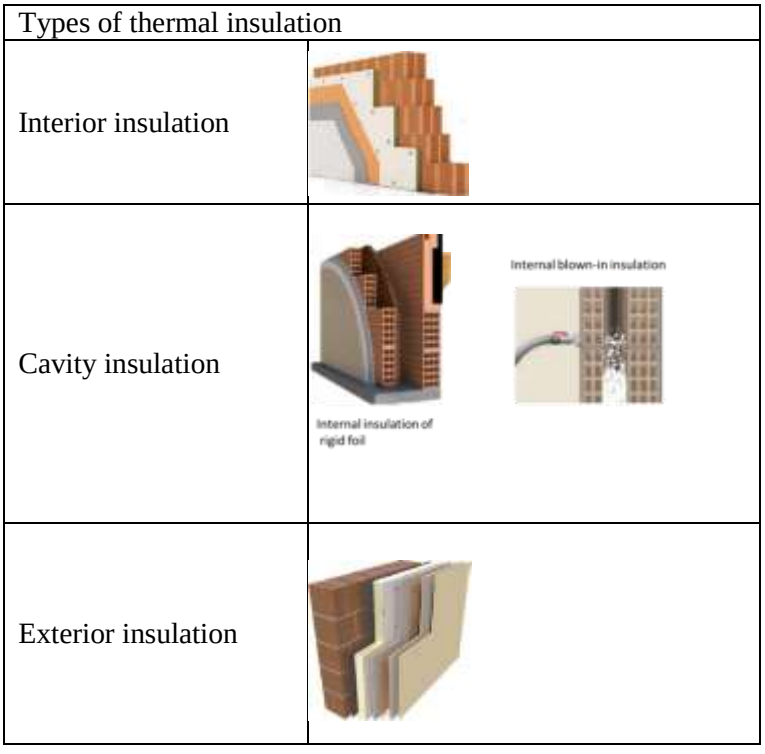


Figure 3. Different types of thermal insulation

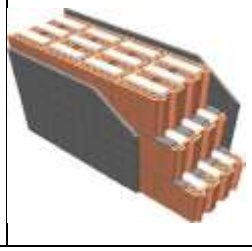
Insulating blocks	

Figure 3 (continued). Different types of thermal insulation

4. Conclusions

Contemporary design has changed as user needs have changed and as a result of increased attention to environmental impact (6,7). This issue has led to the construction of more efficient buildings in terms of environmental performance; the determining factor for a building with optimal performance values is the choice of good thermal insulation. This analysis has tried to show the potential of different insulation materials and, in particular, the high potential of the latest generation of insulation, Aeropan. Of course, the choice of insulation material is one of the many factors that influence a project. The study was to show the materials most commonly used as thermal insulation in a house and to show the different construction typologies where these materials can be used. It will be necessary to look for new materials or other combinations to achieve a higher performance in energy efficiency of the house with the minimum thickness of the building envelope (32). This is quite a challenge for construction scholars, the introduction of new materials and their application to thermal insulation in dwellings.

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