

ENVIRONMENTAL IMPACT OF INSULATING MATERIALS AT THE END OF THEIR USEFUL LIFETIME

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ABSTRACT

Insulating materials are the most powerful tool for the designer and the constructor to achieve high energy efficiency in buildings. However, there are also have side effects from the stage of their production until the end of their useful lifetime, i.e. when a building is rebuilt or demolished. The present paper discusses results, which emphasise on the last stage of the material's lifetime. The research carried out focuses on the classification of the most widely used insulating materials, by their chemical composition, i.e. the inorganic fibrous and the organic foamy. The possibilities of re-using them, or recycling them is discussed, as well as the option of using them as primary energy sources and raw materials, in relation with their embodied energy.

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ΠΕΡΙΛΗΨΗ

Τα θερμομονωτικά υλικά αποτελούν το ισχυρότερο εργαλείο του μελετητή και του κατασκευαστή στην προσπάθεια κατασκευής κτιρίων χαμηλής κατανάλωσης ενέργειας. Έχουν, όμως, και αυτά τις επιπτώσεις τους, από το στάδιο της παραγωγής τους ως το τέλος της ωφέλιμης ζωής, κατά την κατεδάφιση ή την ανακατασκευή ενός κτιρίου. Στην εργασία παρουσιάζονται αποτελέσματα που αφορούν κυρίως το τελευταίο αυτό στάδιο της ζωής ενός κτιρίου. Η έρευνα αφορά στην κατηγοριοποίηση των ευρύτερα χρησιμοποιούμενων μονωτικών υλικών, κυρίως των οργανικών αφρωδών και των ανοργάνων ινωδών. Συζητώνται οι δυνατότητες και οι περιορισμοί επανάχρησης, ανακύκλωσης ή χρήσης ως πρώτες ύλες και τα προβλήματα διαχείρισής τους ως απορρίμματα.

1. EVOLUTION AND SIGNIFICANCE OF INSULATION IN BUILDINGS

Thermal insulation is the major tool to improve a building's energy behaviour, particularly in the densely built urban landscape, where the basic principles of energy design, like orientation, insulation and sun-protection are not easily applicable. The insulating materials make buildings more energy efficient, reduce the quantities of fossil fuels needed primarily for heating and secondarily for cooling and thereby reduce the amount of carbon dioxide and sulphur dioxide emitted into the atmosphere, particularly on a micro- and mesoscale. Furthermore, given the strong urbanisation monitored throughout the 20th century, and as carbon dioxide is one of the principal green house gases contributing to global warming, and sulphur dioxide is the major component of acid rain, the energy thriftiness achieved plays a significant role on a global environmental scale. The first systematic efforts made towards more energy efficient buildings date back to the oil crises of the 1970's. Thermal insulation became mandatory in most European countries and the national legislative framework has become tighter ever since. As a result, in northern and western Europe the estimated energy consumption for heating a given contemporary building is up to six times lower compared to the consumption of a building constructed before 1970. In order to achieve this, new insulating materials were developed, like extruded polystyrene. At the same time the average thickness of the insulation needed to achieve the tighter regulations has increased significantly, rising for example in Germany from 5 cm (1st Thermal Insulation Regulation, 1975) to the current valid 20 cm (4th Thermal Insulation Regulation, 1996), leading to more than 29 million m³ of insulating materials being annually used in the German market. The impact on the average specific annual consumption was profound, reducing figures such as 300 kWh/m²a monitored in 1970 to present figures such as 50 kWh/m²a [1]. The resulting reduction in carbon dioxide emissions was respectively important. The new European regulation EN-832 for energy conservation in buildings and the proposed European method for the experimental evaluation and classification of residential buildings are expected to strengthen this trend even more. [2] Similarly, for the U.S.A it has been estimated that thermal insulation of buildings is responsible for the reduction of carbon dioxide by 780 million tones annually. [3] It is therefore clear, that the role of insulating materials in the building sector has become dominant over the last 30 years, both in terms of results achieved and of quantities implied consumed.

2. DEVELOPMENT OF THE EUROPEAN INSULATING MATERIALS MARKET

The necessity to improve the buildings' energy behaviour, forces the designers and the constructors to use materials with very low (of less than 0,04 W/mK) thermal conductivity values, which at the same time need to fulfil high standards relating to a series of mechanical and physical properties. Given also the fact that the constructive constraints call for a diversity of shapes, properties and, not least, low cost, it is only natural that a significant number of insulating materials can be met in the European market. The most frequently used are the inorganic fibrous materials (glass-wool and stone-wool), next follow the organic foams (expanded and extruded polystyrene and, to a smaller extend, polyurethane), whilst all other materials cover the remaining 10% of the market (mainly wood-wool). More exotic materials like cork and foam glass are used in special cases with high requirements for specific physical properties, mainly pressure and humidity resistance. Transparent insulating materials are a fairly recent development, appearing in the early 90's. They provide the advantage of utilising solar gains simultaneously with the reduction of thermal losses by means of conductivity. Their impact on the market, however, remains limited due to their high cost. The same remark applies to the so-called ecological materials, like sheep-wool and cotton wool. The participation of the various materials in the European markets, based on data for 2000, is depicted in Figure 1. [1] It is noticeable that the interest is not focused only on the issue of energy conservation during the building's operation, but on its entire life cycle. Therefore it is important to focus on a

series of aspects like the energy consumption during the materials production, their recycling possibilities etc.

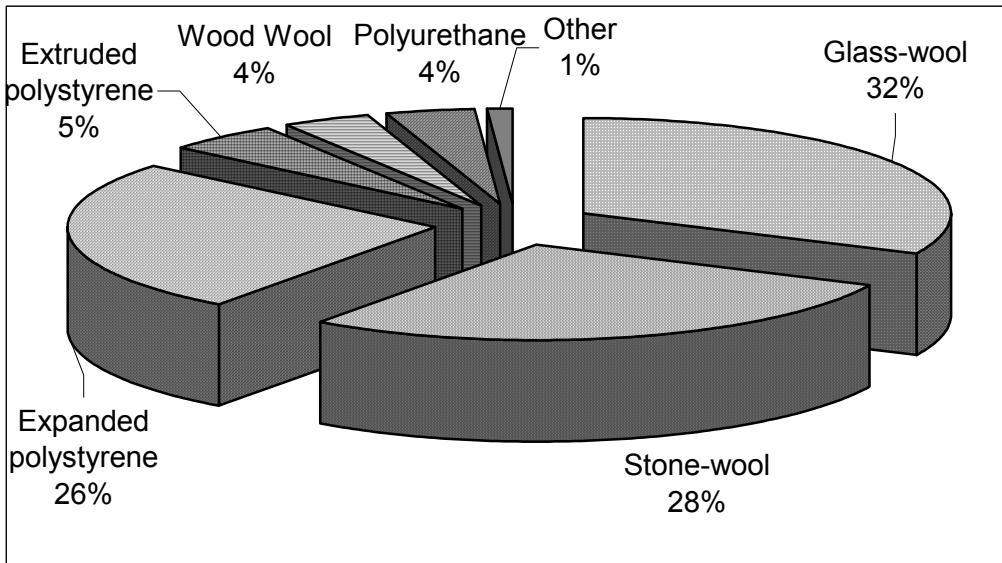


Figure 1: Distribution of insulating materials in the European market

3. CLASSIFICATION AND PROPERTIES OF INSULATING MATERIALS

Insulating materials can be classified according to their chemical or their physical structure. The most widely used insulating materials can be classified as shown in Figure 2 and a short description of their basic features is given followingly.

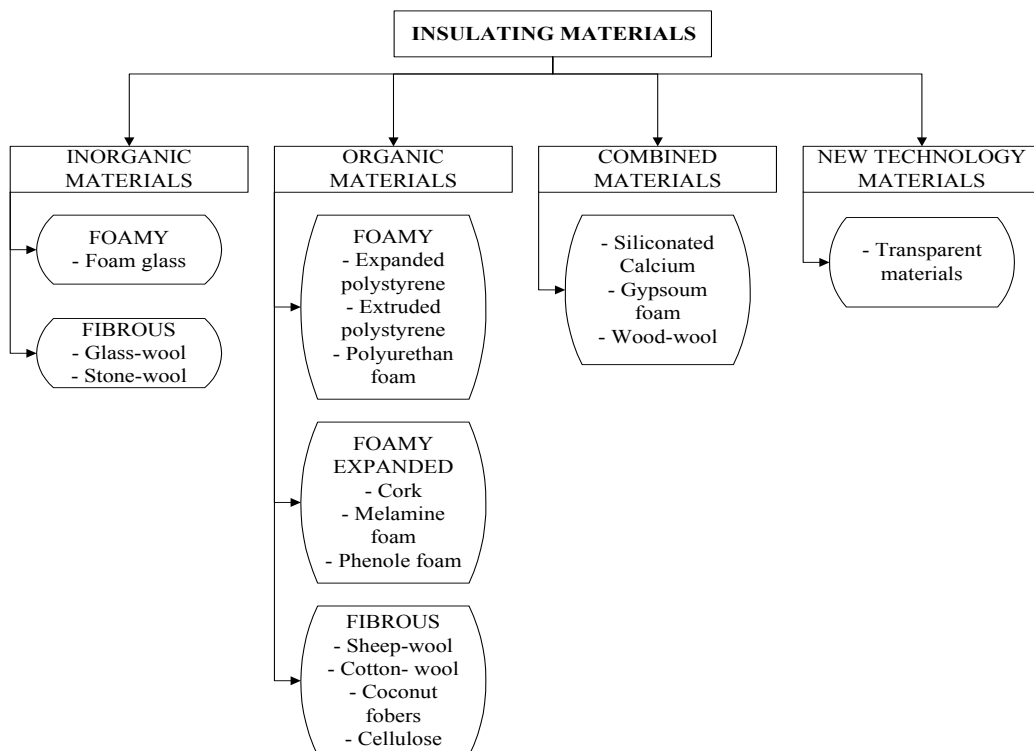


Figure 2: Classification of the most used insulating materials

Inorganic materials

Glass-wool consists of quartz sand, dolomite, resovit and limestone. Furthermore, adhesive materials and water-repellent oils are added, in order to increase the mechanical strength of the materials, though the use of these elements must be kept within limits to achieve a high fire-resistance.

Stone-wool consists of the same basic materials as glass-wool. Its main differences concern the higher melting temperatures during the production process and the different size of the fibres. These differences make stone-wool heavier, with a higher melting point and hence better suited for high temperature applications.

Foam glass consists of quartz, dolomite and carbonic sodium. Small quantities of carbon are also added, to form the material into blocks, as well as small quantities of H₂S.

Organic materials

Expanded polystyrene consists of polymerised polystyrol (1.5 - 2%) and air (98 – 98.5%). Pentane is used as a propellant gas in the expansion process. Hexanbromcyclododecan is used, to a percentage of 5 – 7%, to improve the fire-resistance properties.

Extruded polystyrene is also based on polymerised polystyrol. Carbon dioxide is used in a percentage of 3 – 7%, as propellant gas and s fire-resistance additives are used to 1 – 6%, together with talcum powder and coloring elements.

Polyurethane foam is based on poly-isocyanic associations. The propellant gas used initially was R11, which was forbidden in the late 1980's and was substituted by carbon dioxide or pentane. This modification lead to an increase of the thermal conductivity of polyurethane foam.

Combined materials

Wood-wool is produced of wood fibres, magnesite or white cement and adhesive elements.

The most important physical properties of these materials, with respect to their energy behaviour as part of the building's shell, are summarised in Table 1:

Material	Density ρ [kg/m³]	Thermal conductivity factor λ (U) [W/mK]	Useful life-time [Years]
Expanded polystyrene	15 – 30	0.04	50
Extruded polystyrene	25 – 35	0.028 – 0.032	50
Hard polyurethane plates	30 – 35	0.025 – 0,030	50
Polyurethane foam	35 – 50	0.030 – 0.035	30 – 50
Glass-wool	18 – 40	0.035 – 0.050	30 – 50
Stone-wool	30 – 150	0.035 – 0.050	30 – 50
Wood-wool	360 – 570	0.090	75 - 100
Combined plates of Wood-wool and polystyrene or wood-wool and stone-wool	n/a	0.040 – 0.045	50 - 75
Cork	120 – 200	0.045 – 0.055	50 - 80
Foam glass	100 - 150	0.045 – 0.050	50 - 80

TABLE 1: Physical properties of the most used insulating materials

4. ENVIRONMENTAL IMPACT OF INSULATING MATERIALS

In the 1980's, and to some extent in the1990's, the scientific and public debates focused on the environmental and health issues arising during the production of insulating materials and the construction and operation of the building. Restrictions, in form of national and European

directives, lead to tighter controls of the production processes and to increased alert on safety precautions in the construction sites. It took some time, and the growing public awareness about the environmental issues as a whole contributed to the realisation that a key factor was also the treatment of the insulating materials at the end of their useful life time. This issue became dominant in western Europe particularly as a large number of rather poorly constructed buildings, built before or immediately after World War II, were beginning to be beyond economic renovation, whilst at the same time the changes in the use of urban land made their cost the dominant factor. The data depicted in Figure 3 indicate the extent of this development. [4]

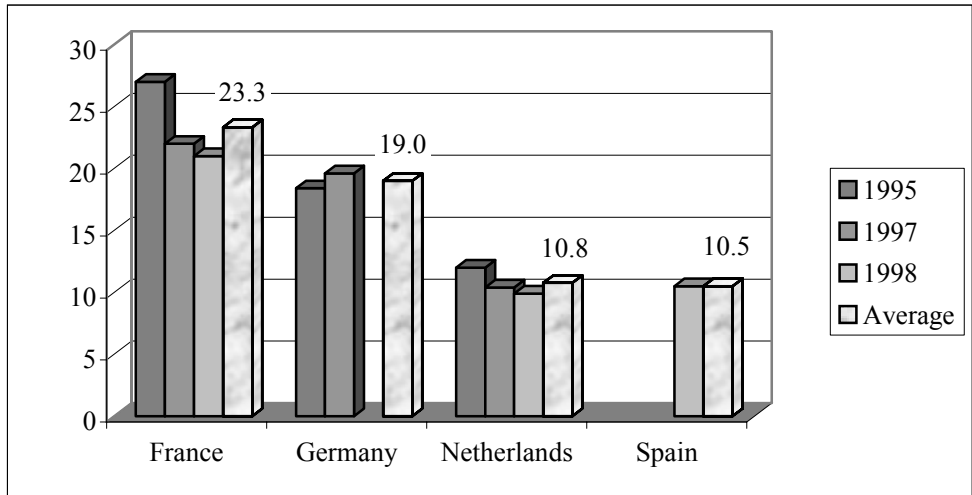


Figure 3: Number of dwellings demolished in four EU countries [in thousands]

At the same time increasing public pressure in the field of waste management and deposition and the internalisation of, up till then vague, environmental cost factors, led to legislative measures, both national and European, which resulted in an new scenery in the construction sector. The influence of the Life Cycle Analysis approach is evident, when considering the environmental impact phase model of the building process, depicted in Figure 4.

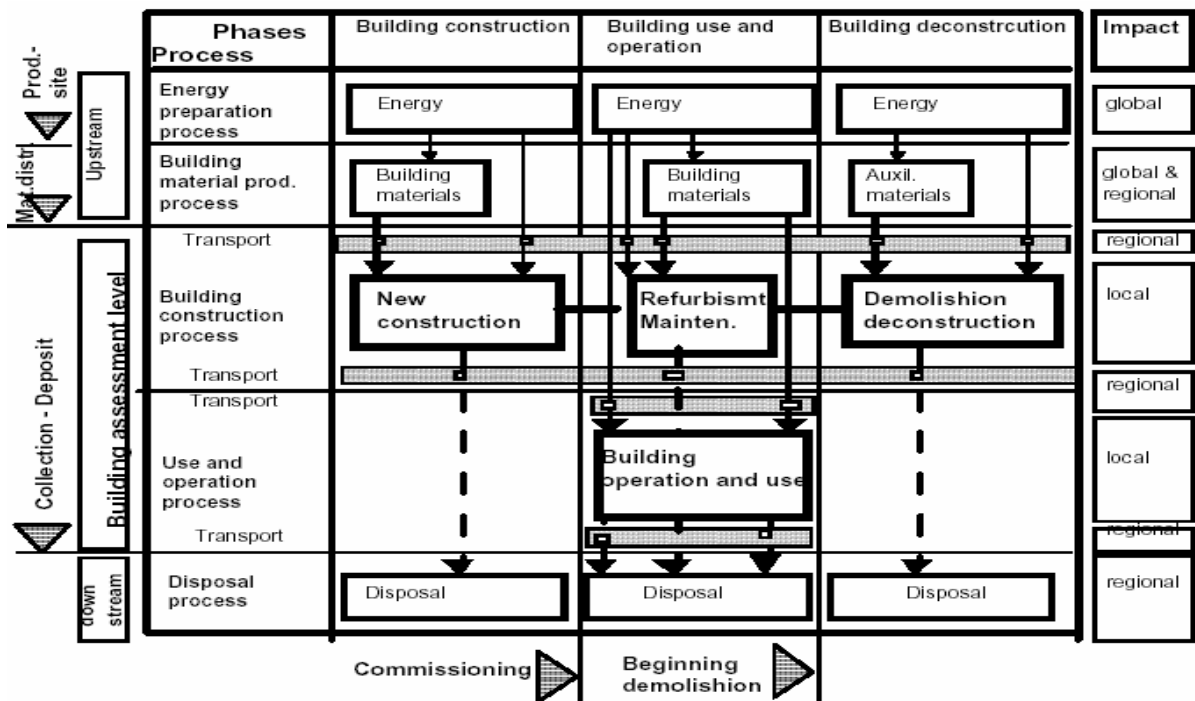


Figure 4: Building process and environmental impact phase model [3]

With respect to the insulating materials, regulations have been implemented since the mid-nineties and they foresee additional waste management costs, for the collection and disposal of materials, which are not being recycled after the end of their useful lifetime. Alternatively, bonuses, in form of tax rebates are given for recycling and re-using the materials. The comparison between organic foamy and inorganic fibrous materials is the most interesting point in the environmental aspect of insulating materials, particularly as these two groups dominate the market making thus the scientific debate a basic factor in the market competition. The most important results of the research are presented briefly in the following paragraphs.

4.1 Production, construction and operation

The production of materials, affects the people involved in it and the surrounding environment. The exposure times are high and, in that sense, this coincides with the examination of the materials' impact duration the operation of the building.

Inorganic fibrous materials

The production of glass-wool and stone-wool implies no environmental hazards, but is associated with possible burdens for the employees during the production process. Fibres with a length of more than $5\mu\text{m}$, a diameter of less than $3\mu\text{m}$ and a rate of length/diameter less than 3 could be harmful. The concentration of these fibres in the production areas must therefore be lower than $500\,000\text{ fibres/m}^3$ of air. Measurements relating to this have shown that in 90% of the factories, the fibres concentration in the air was less than $225\,000\text{ fibres/m}^3$, being hence safe. In order to achieve this there has to be adequate and sufficient ventilation. Long-time measurements in residential and office buildings have proven that the indoor concentration of fibres did not exceed a value of 600 fibres/m^3 , a figure considered to be negligible. [5]

Organic foamy materials

Relevant research has proven that there are no serious dangers during the production of expanded and extruded polystyrene. The main emissions are styrol, pentane, benzol and hydro-carbonates in small quantities. However, adequate ventilation measures need to be taken during production. After the final products have been left to dry for a few days there are no gaseous emissions from the materials during construction and operation. The most dangerous point during the production is the styrol leakage, in its liquid form, to the environment, which is toxic. Data available for Germany indicate that 6 000 tones of styrol leak to the environment annually. [6] A serious problem occurs in cases of fire, when CO and CO₂ emissions are monitored, together with small quantities of styrol and bromine-hydrogen. In the case of polyurethane highly toxic cyanic oxides are produced. Furthermore, from the structural point of view, there is always the danger that plastered insulation plates, attached to roofs and wall insulation, may collapse, as it happened in the Dusseldorf airport fire in 1998. Since this, the use of polystyrene plates in public places was forbidden in Germany.

4.2. Insulation at the end of its useful lifetime

It is a proof of the technical developments, that a state-of-the-art, energy efficient building, the so called low-energy building, may consume less heating and cooling energy, over a 30 years' period of operation, than the energy required to construct it. At the same time, the energy consumption over its whole life-cycle is significantly lower than the respective consumption for the buildings dating prior the introduction of thermal regulation. In that sense, the additional energy consumed and embodied in energy saving 'tools', like insulation and high-efficiency HVAC systems, is more than offset from the savings achieved during the building's life time. [1] Still, there are limits and it is worth mentioning, that the idea of an energy autonomous, solar house remains an energy inefficient proposal, as it can be seen in Figure 5. It is therefore of interest to focus some attention (a) on the energy embodied in the insulating materials and (b) on the opportunities and limitations occurring in the treatment of insulating materials as waste.

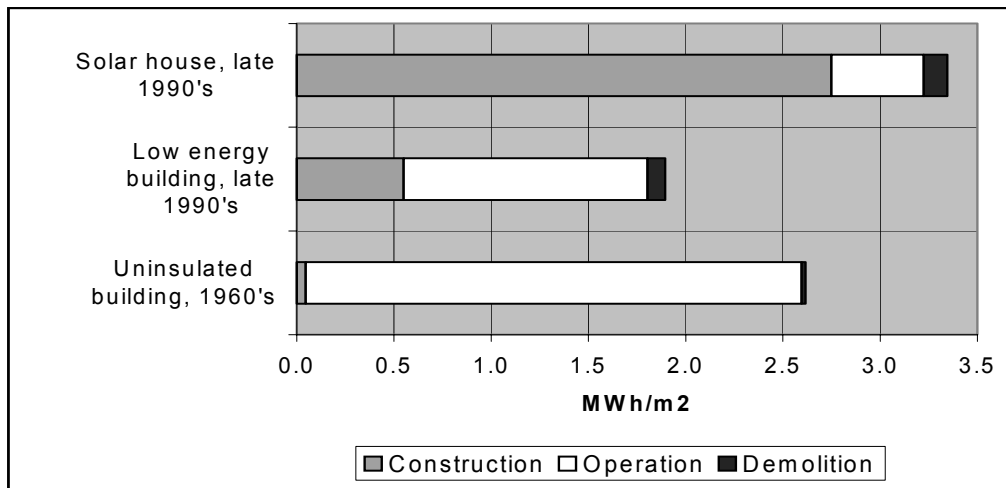


Figure 5: Energy analysis of a building's life-cycle

The embodied energy of the most widely used insulating materials is presented in Figure 6, in form of energy consumed to produce 1 kg of the materials. Further on, and this is more important, we present the energy embodied in the equivalent amount of material needed per square meter of surface on the building's shell, to achieve the conductivity value foreseen by the regulations. [7,8] In the case of this paper the results refer to the Greek thermal insulation regulation and the demands valid for Northern Greece. The embodied energy is important for the choice of the material in two ways: (a) a material with a lower embodied energy is more energy efficient during the useful life-time of the building, (b) a material that can be re-used, recycled or produce again energy is more efficient if considered independently. Both options, however, depend on the ease with which the insulating materials can be separated, during the demolition of the building, in order to be used again.

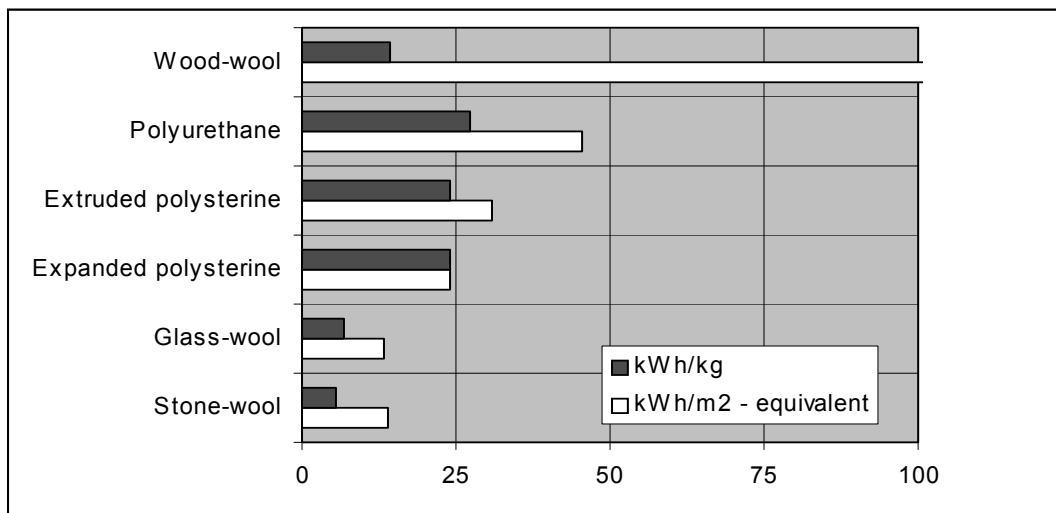


Figure 6: Embodied energy of the most used insulating materials [4,5]

If none of the options mentioned under point (b) applies, one has to examine the environmental impact of the insulating material as waste. A description of these options for the materials is given below.

Inorganic fibrous materials

Glass-wool and stone-wool can in theory be reused, i.e. if it is possible to remove them carefully from the building element. In most cases this is not possible, but in some cases it is used as raw material for the production of new products. In most cases, however, they are treated as waste

which is fairly, due to the low content in organic carbon (less than 1.5%) and their high compressibility, which allows densities of up to 1000 kg/m³, with a respective reduction in volumes.

Organic foamy materials

Extruded and expanded polystyrene in good condition can be directly re-used, or otherwise be used as a raw material for high quality, light concrete and for 'second-class' polystyrene for packaging products. In a different case, they can be burned in special incinerators and produce useful energy, without any environmental hazard, utilising the high embodied energy values. They should not be treated as normal building waste, due to their high organic content, their persistence and high life-time.

Wood-wool, finally, can be reused, or treated as normal waste, as it decomposes very fast.

5. CONCLUSIONS

For twenty years interest was focused on the building's energy behaviour and the physical properties of the materials used. In the process of enforcing energy conservation and environmental protection, attention shifted to more environmental friendly building materials, insulating materials being one of the most interesting areas. The life-cycle analysis approach focuses, in the case of insulating materials, on the embodied energy, the re-use/re-cycling options of the material or its safe disposal.

Considering the materials dominating the European market, the inorganic fibrous materials are less energy consuming in their production and easier to handle as waste. The organic foamy materials are easier to handle in the construction, more energy consuming, but this embodied energy can be regained if they are re-used as raw material or primary energy sources. Given the fact that both classes of materials are equally effective in their insulating role, the final choice depends on the economics and the logistics of the whole cycle. Inorganic fibrous materials are significantly cheaper for the constructor, but do not allow gains at the demolition. Organic foamy materials are more expensive for the constructor, but allow profitable buy-back schemes. The logistics of separating and collecting the materials depend strongly on local and national conditions, like the degree of urbanisation and the population's density. Aim of an effective policy should be to utilise these factors to enable a feasible scheme of sustainable development in the building sector.

REFERENCES

1. Papadopoulos A.M. and M.A. Papadopoulos (2001) 'Recent insulating materials and energy planning of buildings' Proceedings of the **1st National Conference on Building and Environment**, Athens, (in Greek).
2. Santamouris M., (2001) 'Euroclass: A European method for the experimental evaluation and classification of residential buildings', Proceedings of the **SAVE Conference on energy legislation in the building sector**, Athens, (in Greek).
3. Crane A.E. and D.W. Ware '**Insulation Products Environmental Comparison – A Life – Cycle Approach**', published at <http://calc.naima.org/lifecycle.asp> .
4. UNECE (2000), '**Annual Bulletin of Housing and Building Statistics for Europe and North America 2000**'.
5. Schum H., Beutler M., Marfels H. (1994) '**Bericht über die Untersuchung von Produkten aus künstlichen Mineralfasern (KMF) im Hochbau hinsichtlich ihres Faser- freisetzung-Verhaltens**', TÜV Südwest e. V., (in German).
6. Fisher M. (1995) '**Gesundheitliche Bewertung künstlicher Mineralfasern und ihrer Alternativen. Fasernkgress- Asbest und künstliche Mineralfasern**', UTECH BERLIN, (in German).
7. REGENER Project, EU (1997) '**European methodology for the evaluation of Environmental impact of buildings**'.
8. Rockwool international A/S (2000), '**Environmental report 2000**'.