Composite insulating materials as a tool for the reduction of cooling loads

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ABSTRACT

A considerable potential exists for energy conservation in buildings, by means of reducing the heating loads and especially the cooling loads. This necessity emerges strong, given the fact that internal loads are continually increasing, due to the propagation of electric and electronic appliances. In that sense, insulating materials are the most powerful tool for the designer and the constructor to achieve high energy efficiency in buildings by improving the buildings’ shell thermal protection and hence control the transmissivity of the shell. Nowadays, a significant number of modern insulation materials can be met in European market; they are characterized by their very low thermal conductivity factor and good overall performance in terms of physical properties. The most widely used materials are extruded polystyrene and stone wool.

However new trends in the construction industry led the market to solutions that are easily applicable and workable, particularly suitable for renovation of existing buildings, having the advantages of adaptability and low environmental impact. In this environment the Aristotle University Thessaloniki together with the University of Athens, the insulation materials’ production company FIBRAN S.A. and the buildings’ construction company, TETRAS O.E. studied the possibilities of a new series of integrated composite insulating products based on stone wool designed for application in existing and new buildings. The composite materials based on stone wool maintain the advantages of the main material, i.e. high thermal and acoustic efficiency and competitive cost, whilst they aim at compensating the two major drawbacks i.e. low resistance to vapor diffusion and low resistance under mechanical stress. This is achieved by a combination with other materials, as well as by a different orientation of the material’s fibres. The latter is based on corrugated fibres resulting in higher mechanical strength properties.

1. THE ROLE OF BUILDING THERMAL INSULATION

In the last three decades an impressive progress has been made in the energy behavior of buildings, due to the application the basic principles of energy design and enhanced thermal protection. However, since a building’s orientation and its sun-protection are not freely applicable in the densely built urban environment, thermal insulation remains a vital tool towards optimisation of building's energy behaviour.

The necessity to improve the buildings' energy behaviour and therefore to develop better insulation materials initially came from the efforts to reduce the building’s energy consumption since buildings consume large amounts of energy, in Europe traditionally for heating purposes. The energy consumption in the building sector in EU constitutes a major part (40%) of the annual EU final energy use (European Commission, 2001). The most significant part of this amount of energy is consumed for space heating while the cooling demands, although still relative small, show a steeply increasing trend. Therefore, the efforts focused on the minimisation of the significant losses through the building’s shell via the application of thermal insulation materials and improved glazings. Improving thermal comfort conditions is a further important factor in this development.

However, and besides energy conservation purposes, the need for an optimisation of the buildings’ energy behaviour has been enforced by the scientific and public debates focused on matters of the urban environment. More energy efficient buildings reduce the quantities of fossil fuels consumed and thereby reduce the amount of carbon dioxide and sulphur dioxide emitted into the atmosphere, particularly on a micro- and mesoscale.

A point that became important over the last decade is the environmental and health aspect arising during the production of insulating materials and the construction and operation of the building. This became apparent when considering the fact that insulation materials have side effects from the stage of their production until the end of their useful lifetime, which exceeds by large the typical building’s lifetime (Papadopoulos et al., 2005).

Two representative examples present the impact of thermal insulation on the buildings’ energy consumption and environmental improvement. The tighter national legislative framework in Germany have led to an increase of thermal insulation thickness from 5 cm (1st Thermal Insulation Regulation, 1975) to the current valid 20 cm (4th Thermal Insulation Regulation, 1996) which have resulted a reduction of the average specific annual consumption from 300 kWh/m^2a in 1970 to 50 kWh/m^2a in present (Papadopoulos et al., 2001). As far as the environmental impact of such actions is concerned, it has been estimated in U.S.A that thermal insulation of buildings is responsible for the reduction of carbon dioxide by 780 million tones annually (Crane at al., 2002).

Thermal insulation became mandatory in most European countries and the national legislative framework has become tighter ever since. The DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings shifts towards the direction of improving the buildings’ overall energy efficiency (European Commission, 2003). It suggests that buildings should be designed and built in such a way that the amount of energy required in use will be low and that further measures to improve the energy performance of buildings should taken in action. It also introduces the “energy performance certificate of a building”. The directive must be implemented to all member-states in 2006. Soon, the Greek Regulation for Rational Use and Energy Conservation is expected to be introduced soon, which embodies the old Thermal Insulation Regulation, features the aspects of the building’s total energy consumption and institutes the building’s energy certification on a regular basis.

2. THE ROLE OF COMPOSITE INSULATING MATERIALS

In order to minimise the building’s energy consumption by means of thermal protection of its shell, insulating materials with low conductivity values, less than 0.04 W/(mK), have been developed. Nowadays, in the market is offered a plethora of insulating materials with different properties and therefore respective advantages and disadvantages, which fulfil specific requirements like mechanical and physical features according to the specifications set by certain applications. The most widely used categories of insulating materials are inorganic fibrous (glass-wool and stone-wool) and organic foamy ones (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, transparent insulating materials and ecological materials have limited penetration in the market mainly because of their high cost. The properties of the most widely used insulation materials and the participation of the various materials in the European markets, based on data for the year 2000, are depicted in Table 1 and Figure 1 respectively (SAPPEK, 2004).

However, new trends in the construction industry create the need to detect improvement possibilities as far as insulating materials are concerned. The increase of number of specialised buildings such as office and commercial buildings and the systemisation of refurbishment and reconstruction of old buildings in order to upgrade their energy behaviour have created new requirements that insulating materials have to fulfil. These new requirements apply both to thermal and acoustic

properties, to the application easiness like limited and “clean” in situ work and prefabri-

Table 1: Properties of the most widely used insulation materials.

		GLASS WOOL	STONE WOOL	EXTRUDED POLY-STYRENE	EXPANDED POLY-STYRENE	POLYURETHANE FOAM
Density [kg/m^3]	min	13	30	20	8	30
	max	100	180	80	50	80
Thermal conductivity factor λ [W/mK]	min	0,030	0,033	0,025	0,029	0,020
	max	0,045	0,045	0,035	0,041	0,027
Temperature application range (^{o}C)	min	-100	-100	-60	-80	-50
	max	500	750	75	80	120
Resistance factor in vapor diffusion	min	<1	<1	80	25	50
	max	1	1	200	200	>100
Fire resistance class		A1 A2 B1	A1 A2 B2	B1 B2	B1 B2	B1 B2
Tensile strength [N/mm^2]	min	0,005		0,30	0,15	
	max			0,35	0,52	
Noise absorption rate (at 125 Hz)	min	0,10	0,05			
	max	0,79	0,19			
Embodied energy [kWh/m^3]	min	90	110	85	151	15,8
	max	430	660	114	269	36,1

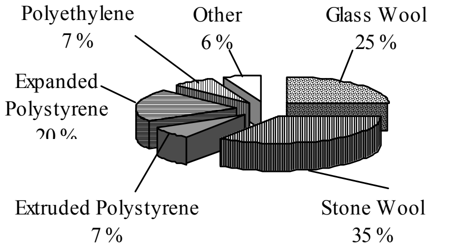

Figure 1: The participation of the various materials in the European markets (2000).

cated composite building elements, always under the aspect of competitive cost.

Especially as far as the upgrading of thermal protection in existing buildings is concerned, the application of thermal insulation is more complex since there are constructive and architectural restrictions. There are also frequently limitations to the disruptions that are allowed during the work in the building's interior. Furthermore, since the major problem concerning the thermal insulation efficiency in buildings often implies deficiencies in the construction, composite products offer certain advantages. These advantages derive by the fact that the application of composite insulation materials simplifies the workmen's work, since they can be installed quickly, easily and with small margins for constructive deficiencies. The increased demand for composite insulating materials enables large production lines which results in lower production cost. Therefore, the detection and design of new innovative composite insulation materials constitutes an interesting research field.

3. COMPOSITE INSULATION MATERIALS BASED ON STONE WOOL

The most representative insulation materials of each family are extruded polystyrene and stone wool. Although there are many differences between their physical properties, due to their different nature and chemical composition, both are characterized by their very low thermal conductivity factor. On the other hand stone wool outperforms extruded polystyrene in a few crucial features as Figure 2 presents. Stone wool has a wider temperature range of use, high sound-proofing qualities, which have become a vital characteristic of building structures over the last years, and high fire resistance, which is important in face of the tightening fire protection standards. Furthermore stone wool is a more environmental friendly material than extruded polystyrene since it presents lower embodied energy and CO and CO_2 emissions during the production process. In Figure 3, a comparison of stone wool and extruded polystyrene is made, based on the embodied energy and equivalent embodied energy. Is it clear that stone wool – and generally the inorganic fibrous materials – is the least energy consuming materials for their production and installation.

On the other hand stone wool has two major disadvantages in relation to extruded polystyrene. While extruded polystyrene presents high moisture resistance since it is a hydrophobic material and high tensile strength, stone wool is inferior with respect to these two properties.

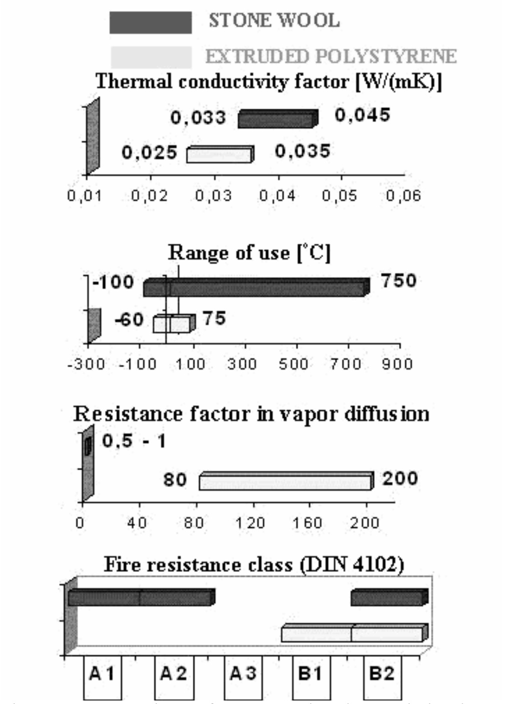

Figure 2: Comparison of stone wool and extruded polystyrene.

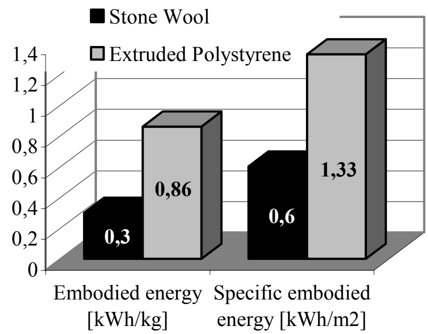

Figure 3: Comparison of stone wool and extruded polystyrene based on the embodied energy and equivalent embodied energy.

However these two important weak points of stone wool can be overcome through its combination with other materials and its fibres' interconnection and orientation respectively.

4. INNOVATIVE COMPOSITE INSULATION MATERIALS BASED ON STONE WOOL

As mentioned before stone wool has two weak features: (a) low resistance to vapor diffusion and (b) low resistance under mechanical stress. The first characteristic prevents the use of stone wool when moisture resistance is essential, such as insulation of concrete elements, floors, basement walls etc. However, covering stone wool with aluminum or polyethylene sheet can solve this problem. The final product has increased moisture resistance and it is appropriate for use in the aforementioned applications. The second issue limits stone wool's applications because it can be used only if it is situated in "safe" places, where there is no access to human activities, such as in the cavity of double-brickwork walls and over furred ceilings, in order to protect it from structural damages. The solution to this problem is stone wool to be covered with particle or plasterboards. The final product, which is actually an easy applicable prefabricated product, is appropriate for external or internal walls insulation and floor insulation.

However, covering stone wool with particle or plasterboards may constitute a major problem. The layer that is added to insulation material due to its weight causes pulling tensile in the insulation material's maze. Therefore, only insulation materials with high resistance to tensile strength can be used. In the case of stone wool, the internal pulling tensile can exceed the cohesion strength of the binding resins that are used to keep the fibers together. That causes fibers to break apart from the insulation material's body and finally, the abruption of the additive material, as it is depicted in Figure 4.

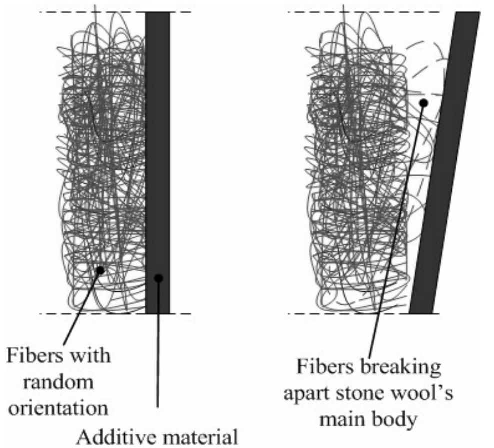

Figure 4: Mechanism of fibers break and material additive abruption.

Similarly in composite materials that are going to be used in floors, the developed compression loads can cause a fracture of fibers. That's why only extruded polystyrene can be used combined with other materials, due to its high compression and tensile strength. Stone wool can be combined with other materials, when the fibers are cross linked. Using a relatively new production method, the fibers are intertwined with each other. In that way the cohesion strength increases, which macroscopically results in an increase of stone wool's tensile strength.

5. APPLICATIONS OF THE INNOVATIVE COMPOSITE INSULATION MATERIALS BASED ON STONE WOOL

The new innovative composite insulation materials based on stone wool will meet the needs and the lacks of insulation market. According to a market study carried out, the new integrated products concern the thermal insulation of walls, floors, facades, chambers, tilled roofs, steel structures (such as industrial buildings and sport facilities) and applications of dry building. The specifications for each of these applications can be ranked in five categories of composite materials in accordance to their use: a) low density stone-wool single-side covered with aluminum foil, b) low density stone-wool both side covered with aluminum foil, c) low density stone-wool single-side covered with gypsum plate or other light organic material, d) low density stone-wool both side covered with gypsum plates or other light organic material and e) high density stone-wool covered with hard material resistant to percussive loads. In Figures 5 and 6 are presented the sketches of two forms of the new products.

6. CONCLUSIONS

The need to improve the thermal protection of buildings is a direct result of the new European Directive on the evaluation of energy behaviour of buildings and also of the imminent new corresponding Greek regulation and the new trends in construction industry have created new requirements as far as insulating materials are concerned. A new series of composite insulating products based on stone wool have been de-

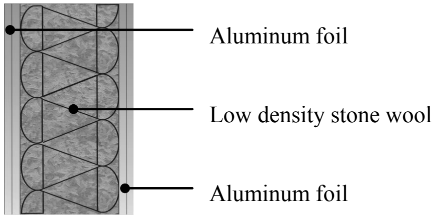

Figure 5: Low density stone wool both side covered with aluminum foil.

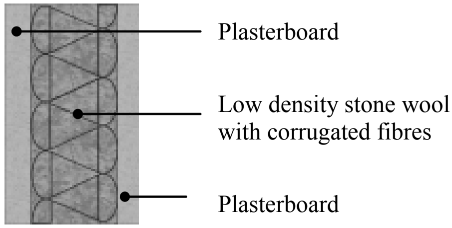

Figure 6: Low density stone wool with corrugated fibres both side covered with plasterboard.

signed, applicable in external walls, suspended ceilings, flat roofs, floors and partitioning elements. These composite products correspond to high mechanical strength requirements. Since the horizontal orientation of stone wool fibres produce materials with low performance in compression and tensile strength, the new innovative composite products are designed with cross linked fibres.

Natural ventilation is a useful tool in order to minimise energy consumption caused by the air conditioning but it is not a panacea since it has some constraints. In that sense the improvement of thermal insulation still remains a fundamental technique of building energy design.

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