A HOLISTIC APPROACH OF THE DEVELOPMENT AND APPLICATION OF INNOVATIVE COMPOSITE COOL-THERMAL INSULATING MATERIALS

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ABSTRACT

The need to improve the energy performance of buildings, both new but also, and in particular, existing ones, is more imperative than ever. The "traditional" approach of thermal insulation is quite satisfactory for the reduction of thermal heating losses and loads, but it is not enough for coping with the problem of increased cooling loads, that are evolving to the single most influential problem, mainly for buildings in the densely built urban environment in Mediterranean and Southern European countries.
Aim of the ongoing DICOM project, which is co-funded by the Hellenic General Secretariat for Research and Technology, is the design, development, production, evaluation, certification and introduction to the market of innovative, composite cool - thermal insulating materials based on the new generation of extruded polystyrene (XPS) with improved vapour permeability (lower water vapour diffusion resistance factor μ) as well as with use of special plasters as a final coating with specific features of low emissivity coefficient ε. The products will be shaped in a way that makes them easily and effectively applicable for the energy upgrade of existing buildings, but will also correspond to the construction techniques of new state of the art buildings.
At the current stage, the specifications for the new products have been elaborated and their production has been launched. The whole process has been carried out in a holistic way, addressing the demands of the new energy and environmental requirements, the needs for a speedy and easy application of the materials in the construction site and the requirement to be competitive in the challenging European thermal insulation market.

KEYWORDS

Innovative insulation material, buildings, extruded polystyrene

1 INTRODUCTION

The need for the improvement of the energy efficiency of buildings, either new-built or existing ones, is already coherent and imperative. It was initially expressed by means of the Directive 2002/91/EC for the Energy Performance of Buildings, which was harmonized in the Greek legislation by the Law 3661/08 for the improvement of the energy performance of buildings and finally the Regulation for the Energy Efficiency of Buildings, and represents the main application act of the law. Common goal of the relevant legal framework is to achieve a reduction of at least 20% in the energy consumption related to the building sector. In order to realize this aim there is a need for substantial changes regarding the existing buildings and, in addition, a new holistic approach for the thermal protection of new-built constructions (Karkanias et al., 2011). The EPBD-recast, in form of 2010/31/EU, which aims at the zero, or nearly zero, energy buildings provides a quantum leap, as it makes the ambitious goals mandatory, both for public and residential buildings. This new Directive has been harmonized in the Greek legislation by means of Law 4122/2013, which will be accompanied by a revision of the Regulation for the Energy Efficiency of Buildings.

The traditional approach of thermal insulation is quite satisfactory in reducing the thermal loads, especially considering the heating loads of buildings, as it has been proven since the introduction of the first thermal insulation regulations in Europe in the mid 1970s. On the other hand, there are limits in confronting the problem of cooling loads, especially in the warmer climatic regions, like the Mediterranean. The latter evolves to the actual problem that is traced in buildings of the dense urban environment (Papadopoulos et al., 2002; Santamouris 2001).

Cool materials present an interesting solution for the reduction of cooling loads, especially in horizontal building elements. The project discussed in this paper aims to design, develop, produce, evaluate, certify and introduce to the market highly innovative, **composite thermal insulating cool materials**, on the base of the new generation extruded polystyrene (XPS) with improved water vapor permeability properties (low water vapor diffusion coefficient μ) and with the implementation of special thermal reflective plaster, which is used as the final coating layer and comprises particular emission coefficient ε characteristics. These materials could be easily and effectively used for the energy upgrade of existing buildings, but could also cover the construction techniques of the new-built constructions (Synnefa et al 2007, Karlessi et al., 2009).

Additionally, these materials should be used for the thermal insulation of horizontal and pitch roofs, according to the current EN standards for materials and kit solutions, and for covering vertical building elements (walls and concrete elements), as it is already introduced in the External Thermal Insulation Composite Systems Guideline (ETICS, according to ETAG 004).

That project aims consequently at gaining and modulating the appropriate know-how, which will lead to the combined confrontation of the two major problems that are commonly faced in the energy performance of the building envelope today: the reduction of thermal losses through the solid building elements during the winter period and the avoidance of the overheating occurring at the same elements, which has as an impact on the reduction of cooling loads during the summer period (Papadopoulos and Giama, 2007).

Thus, on the whole, the improvement and expansion of the composite thermal insulation technological solutions, through the development of a group of products based on new generation extruded polystyrene and on new coating material with special reflection properties, for use in integrated insulation applications, in new-built and existing constructions is its scope.

At the current stage, the specifications for the new products have been elaborated and their production has been launched. The whole process has been carried out in a holistic way, addressing the demands of the new energy and environmental requirements, the needs for a speedy and easy application of the materials in the construction site and the requirement to be competitive in the challenging European thermal insulation market.

2 DICOM'S SCIENTIFIC AND TECHNICAL GOALS

In order to structure the methodology which should be implemented for combining the new insulation material in depth research analysis, theoretical, in laboratory and applied industrial, was required. That not only led to the specification of the properties but also helps to consist the need of complex insulation materials and coating matters with special thermal reflection characteristics to the widespread use in construction activities.

Major advantage of the new products, which are ranked at the peak of the technological solutions available in market is the development of an operationally, energetically and environmentally optimum manufacturing process for the generation of products which will fully cover the demands of standards, quality assurance and environmental management systems and finally, the competitiveness goals in the tough building materials market.

Also, the newly introduced products will have the ability of fast and simple in-situ application, with small inaccuracy margins, resulting in high economic competitiveness, both in new constructions and in the refurbishment and energy renovation of existing buildings.

Moreover, those new products can take advantage of the adaptability and the characteristics of cool – thermal insulating materials, consisting of ready or semi-ready thermal insulated building elements, which will feature optimal insulation properties, ease of use, minimum application cost and, additionally, will present capabilities of fire resistance, durability to impregnation and low resistance to water vapor diffusion. The thermal reflective plaster coatings will assure the maximization of the useful impacts of thermal insulation during the winter period, and simultaneously will offer overheating reduction properties during the summer period, being in the position in this way to contribute to the improvement of the exterior microclimate and ensuring quite low external surface temperatures on the applied buildings.

In parallel, the environmental friendly fabrication demands will be adopted, through modern manufacturing and managing methods of primary and secondary resources, by adopting a very lean production procedure and by using state of the art equipment, minimizing thus, the environmental impact in the production stage, and in that sense also in its entire life cycle. Finally, the material produced will be certified for the current technical directive ETAG 004 from a certified body.

As far as it concerns manufacturing, the composite product is going to allow simple and flexible high-scale production conditions. The combination of a new generation extruded polystyrene and thermal reflective plaster coatings will be achieved through a technically correct and economically viable way. The transition from one member of the family product to another member will be rapid, without the need of a major rescheduling of the production line.

Also, the methodological advantage of the Life Cycle Analysis (LCA) method was utilized in order to perceive the maximum possible of recyclable raw materials and will have the minimum possible energy and raw materials consumption (Klopffer et al., 2003; Anastaselos et al., 2008). Specifically, an extensive LCA was implemented during the distinct stages for the environmental assessment of the composite material. These stages consist of the construction, the use, the dismantling and the end of life management. The first phase includes the inventory analysis. This stage deals with the input and output flows of all the procedures concerning the under study insulation material. The inputs and outputs flows contain data of materials and energy consumption. The second phase refers to the environmental impact assessment. At this phase the environmental load calculated from the inventory analysis is transformed into environmental impacts. The environmental impacts categories' examined mainly include climate change, acidification, eutrofication and photochemical oxidation and finally the use and application of the results. At this phase and

after having analyzed the system, the crucial points are identified in order to focus on the procedures which need to be improved.
As it was mentioned before, DICOM's new composite material main goals were:

1. Simple and quick installation in new-built constructions, having low demands in planarity and parallelism of the underlying constructive layers.
2. Application without the need of major reforming works in roofs and walls of existing buildings, when the building envelope is unacceptable condition, resulting in minor charge of the present construction.
3. In any case, ability of easy transport and storage on worksite, convenience for the preparation and manufacturing of special plaster coatings (where applicable), cut and fixation.

At present, the specifications for the new products have been elaborated and their production has been launched. The whole process has been carried out in a holistic way, addressing the demands of the new energy and environmental requirements, the needs for a speedy and easy application of the materials in the construction site and the requirement to be competitive in the challenging European thermal insulation market. Thus, the product and in extension the methodology has not been tested yet because the applicability of products and techniques will arise during the implementation phase, but an effort will be made to highlight the void in ready standardized products, which will be used in the external thermal insulation of conventional existing buildings and in thermal insulation of steel construction buildings through ready building elements. In this way, the energy re-planning of existing buildings will be accomplished, having in Greece an immediate implication in near future, as a result of the aged buildings on one side, and the implementation of the Regulation for the Energy Efficiency of buildings, on the other side. Finally, these products could be used in most conventional thermal insulation practices, having the advantage of simple application.
To be more specific, their advantages are focused on:

a. The improvement of the energy performance of buildings through the substantial improvement of heat transfer and solar radiation absorption coefficient of the solid building elements of the building envelope.
b. The assurance of high thermal comfort conditions, as well as air quality in the internal environment of buildings, through the improvement of the internal surface temperatures and air permeability of the solid building elements.
c. The cost reduction compared to the currently used solutions, which apply a number of different materials and techniques, in order to achieve a comparable result.
d. The capability of microclimate improvement in local level, in case that the technology will be implemented in wide scale, e.g. in a number of continuous building blocks.
e. The overall improvement of the environmental efficiency of the building, throughout its life cycle, in terms of energy and manufacturing, use and future disposal of specific building materials.

3 LABORATORY RESULTS

The new products that will emerge should meet the requirements of European regulations. Specifically, the new composite material will be processed in accordance with the European standard EN 13164 for mechanical strength (mechanical compression and tension), behavior toward the water and thermal conductivity. Also, its suitability for applying to external insulation systems (according to Directive ETAG 004) and to inclined roof will be tested. In

the current phase, the properties of the extruded polystyrene has been evaluated (table 1) in order to meet the requirements of the new composite material.
Additionally, the new material should be included to the catalogue of cool materials (Karlessi et al., 2009; Kar1essi et al., 2011).
All in all, the new material should comply with the European Directives and marked with the CE in order to be competitive to the European market.

Table 1: Physical Properties of Extruded Polystyrene

Properties		Measure units	EN standard	
Shape of profile				I / L
Surface				Waffle
Board dimension		mm	EN 822	1250/600
				1000x600
Thickness tolerance			EN 823	T3
Declared value of compressive strength at 10% deformation		kPa	EN 826	200-300
Tensile strength perpendicular to faces		kPa	EN 1607/ ETAG 004	550
Shear Strength τ		N/mm^2	EN 12090	0,24
Shear Modulus G		N/mm^2	EN 12090	6.7
Declared thermal conductivity (after 25 years)	**20mm≤d≤60mm**	W/(m*K)	EN 12667	0,033
	>60mm			0,034
Long term water absorption by immersion	**Rough surface**	vol. %	EN 12087	1,5
Water vapour diffusion resistance factor		-	EN 12086	50
Temperature of use		°C		From -50 to +75
Reaction to fire		Class	EN 13501-1	E

4 CONCLUSIONS

The innovative composite cool-thermal insulating material that are already in the stage of pre-production combines very good mechanical and physical properties, like low thermal conductivity factor, high compressive strength, low vapor diffusion resistance factor, with the increased solar reflectance coefficient of specific plasters used for final coating.
The proposed composite material will result in lower energy consumption for heating and cooling during the use phase, compared to common insulation practice. As the use phase accounts for more than 70% of the energy consumption and hence of the total emissions, it is vital at this stage to achieve high performance in all those aspects, towards the reduction of environmental impact imposed during material's life cycle.
For the composite material's production, a combination of raw and recycled materials has been used. Sufficient quantities of the recycled materials have been supplied by a fully operational recycling line that is already installed. At the same time the manufacturing process was modified in such a way that results to the reduction of the material's ecological footprint.
The composite materials are going to be manufactured in such a way that it can be easily dismantled at the end of its useful service life. Constitute materials can be retrieved in a clean shape without mixtures and can be send either in a facility for closed-loop recycling, or to a thermal process plant for energy production. Re-use of the composite material is also possible if it's mechanical and thermal properties remain at the desirable levels.

The LCA combined with the experimental measurements that has been conducted will eventually lead to the adaptation of the eco-label sign. Finally, at the end of the research project the final products will be available to the market at a reasonable price.
The results of the project will refer to the full record of the current situation it the insulation materials' market focusing on technical and scientific attributes and to the formulation of accurate predictions for the future, that are covered in the first deliverable. Mechanical and thermal properties, manufacturing processes, potential of the usage of composite materials based on extruded polystyrene will also be thoroughly examined in order to promote energy design of new buildings and energy upgrade of existing buildings.
The design of new insulation materials, their extensive life cycle analysis and their properties specification that are covered in deliverables enhance the amplitude of scientific knowledge regarding insulation materials and provide the research organizations with the ability to evaluate and compare specific, under study, materials, in order to notify the developers and manufacturers about the environmental performance of their products.
Efficient planning of the production line, pilot study and manufacturing of the final products are the main issues examined. More specifically, from the design and the pilot study of the final products the close connection between scientific research and industry are going to be established. From the university organizations point of view industrial know-how expertise will be acquired, whereas from industrial parties' point of view several innovative insulation solutions will be produced.
Extensive laboratory measurements under real conditions will be conducted, from which certain deliverables will be produced regarding the results of these laboratory checks and measures. In this way collaborating industrial parties will improve its researching structures and quality control capabilities of their products while the university organizations will evolve and upgrade their laboratory equipment with simultaneous broadening of their research activities.

5 ACKNOWLEDGEMENTS

The authors would like to thank the Hellenic General Secretariat for Research and Technology, for providing the funds under the contract EYDE – ETAK 2787/9.11.2011

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