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ECO-FRIENDLY MATERIALS FOR THE ENERGY RETROFIT OF EXISTING BUILDINGS

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Abstract

Today is widely recognized that the main cause of CO2 production and of non-renewable energy consumptions in Europe is due to the building field. For this reason, to improve the energy performance of existing houses through an energy retrofit action (adapting their performances to those required by regulations) is an important strategy to reduce energy consumptions since they are much more than new ones, also representing an economic opportunity. In particular, an important approach in the reducing energy needs consists in the thermal insulation of the envelope, through the application of innovative technologies and materials. The paper will present the result of a research about the possibility to carry out different energy retrofit measurements, with different economic implications: it can be possible to evaluate the effectiveness of strategies proposed by examining a typical house of Palermo and measuring the improvements obtainable through the application of a new eco-friendly panel on the external walls.

The new panel, made with scraps of pruning of prickly pear crops, has been patented (n. 1402131) by using the cladodes of Opuntia Ficus-Indica, a widespread plant in the Mediterranean Basin, according to the principles of sustainable and eco-friendly development.

The eco-friendly panel has shown thermal performance that can be considered satisfying and competitive with those of other commercially available panels, helping, at the same time, to the waste disposal: the nature of the plant makes the material highly recyclable and easily disposable.

The study has been carried out by comparing the thermal and dynamics improvements obtainable adding different panels on the external walls of the house.

The final output will show the results, by assessing the energy and economic savings after the retrofit interventions.

Keywords

Cost-benefits analysis, Energy retrofit, Housing, Insulating materials, Sustainable design.

Introduction

The introduction of new standards for the levels of indoor comfort required the adaptation of existing buildings. These, in most cases, do not satisfy the required value of thermal transmittance. This has resulted in the development of new strategies for the adaptation of the building envelope, beginning in northern Europe and concerned the adjustment of the energy performance in the case of cold climates.
Later on, also for Mediterranean areas, and then in the case of hot climates it became an important strategy to introduce thermal insulation systems for the building envelope.
The need to improve the thermal insulation of the building envelope determine a growth of the industrial field based on the production of insulating materials of different origins, for example, the cheaper, but less sustainable, are the synthetic ones.
At the same time, it has developed the production of eco-friendly insulating materials.
This new materials field could contribute, as well as the use of renewable resources of energy, also to economic development in those countries where, at the present time, these resources are found in abundance but they and are not well used.

The energy retrofit

The energy retrofit consists of all the actions aimed to renovate the existing buildings stock, by adapting their performances to the ones required by current laws.
To act on existing buildings means the possibility to choose between different strategies, each that cannot however dispense with proper thermal insulation of the building envelope, the main regulator of the heat exchange between external and internal environment.
Among the most common retrofits we can find the following ones:

- Insulation of the building envelope;
- thermal inertia increasing;
- replacement of windows with innovative systems;
- introduction of solar shading devices;
- replacement of air-conditioning systems;
- replacement of lighting systems;
- use of natural sources of thermal energy;
- introduction of renewable energy.

Among the systems above, there are methods of intervention that allow to work directly on the building structure increasing its thermal performance, by reducing therefore the use of mechanical systems of air-conditioning.
These passive actions, provide above all initials contained expenses, easily amortizable over the short term, thanks to the considerable reduction in energy bills due to their implementation.
In recent years, the research and experimentation on the building envelope have spread different kind of materials and technologies, ever more efficient, able to significantly increase the energy efficiency.
To insulate the opaque envelope, in fact, allows to contain the main heat losses and to ensure adequate levels of interior comfort for extended periods of time.
The choice between the insulating materials changes depending on the case, not only relating to the level of thermal conductivity of each panel, but also to the geographical context and, therefore, the needs which must be meet.
Furthermore, such a choice implies that the requirements ever more restrictive than the law now imposes in each climate zone (Italian Law no. 10 of 1991 "Regulations on the rational energy use,

energy saving and development of renewable energy", as amended).
Before implementing any retrofit action, it is appropriate to evaluate it through a detailed analysis of the cost-effectiveness ratio, in order to estimate, since the phase of the project, the possibility of not only saving energy but also economic, and time return of the investment.
The research presents a typical case of energy retrofit of a residential apartment located in the city of Palermo, where outdated construction techniques and uncontrolled economic speculation have produced low-quality buildings with very poor energy performance.
The case of study is exemplary because it allows to demonstrate how it is possible to get a clear energy saving through simple interventions on the building such as, the thermal insulation of the external vertical walls.
It was finally compared the result obtainable in different stratification configurations of the wall, each through different insulation panel, so as to demonstrate the functionality and efficacy of the innovative panel realized with the waste material of Opuntia ficus-indica plant, compared to other materials already present in the market since many years.

Innovative materials to the envelope insulation

Insulating the building envelope is the first action to carry out on an existing building. The old building systems and sometimes the lack of attention to the environmental conditions, determine the increase of the thermal energy demand and the use of air conditioning mechanics in order to ensure suitable levels of indoor comfort.

Most common insulating materials in the market

Today available in the market there are a lot of different insulating materials. They can be divided on the basis of the following key requirements:

1. physical-technical: density, thermal conductivity, resistance to water and compression, resistance to fire, etc .;
2. Environmental: impact on human health and on the environment, possibility of recycling, low (or zero) CO2 emissions;
3. Economic: cost per unit (€/mq);
4. conformity: CE label (for certifying the conformity of the product with the declared performance, but without imposing performance limits) and certification testing laboratory.

On their choice also influence: the shape (panels, foams, etc.), the origin (animal, mineral or synthetic), the hygroscopicity level, the fire resistence and the capacity of heat protection during the summer.
In the building applications, moreover, it is necessary to classify the insulating materials according to the following scheme:

1. Rigid panels, with the possibility to associate them with other layers of different materials (wood, plasterboard, laminate, etc.) that confer a greater resistance to the whole system and that can also serve as finishing;
2. Soft panels (rolls, mats, etc.) which are mostly used in interspaces playing, therefore, the only function of insulation;
3. Bulk materials (fibers, granules and flakes) for the dry-filling of walls and roofs cavities.

The most common natural insulating materials used in buildings are the wood fiber panels. However, there are other natural products on the market: cotton, cork, lime expanded, cellulose and even sheep's wool. The main synthetic insulation materials are the expanded polystyrene or "EPS", the extruded polystyrene, and the polyurethane. The insulation of mineral origin, is mainly constituted by rock wool and glass wool.

Figure 1: Materials commonly used for the insulation of the opaque envelope. From left to right: polystyrene foam (synthetic), rock wool (mineral) and wood wool (natural).

Also the air (λ = 0.026 W/mK) is often used as insulating element, by the apposition of an empty cavity between two layers, allowing good levels of thermal insulation, with low cost of implementation.

The new eco-friendly panel in Opuntia ficus-indica

The proposed innovative panel comes from the pruning of Opuntia ficus-indica plant used for the cultivation of the table fruit (Figure 2). The original plant is native to the American continent and has spread in all hot and arid climate areas. It is currently present in spontaneous forms or grown in many countries, including Mexico, the United States, Chile, Brazil, Italy, North Africa, South Africa, Middle East and Turkey.

Figures 2 - 3: Cultivation of Opuntia ficus-indica plants and table fruit

It is a plant belonging to the Cactaceae family which can reach 3-5 m in height. The stem is composed of cladodes. The cladodes, of flattened form and ovaliforme, from 30 to 40 cm long, from 15 to 25 cm wide and about 1.5-3.0 cm thick, formed of the branches. The fruit is a fleshy berry with numerous seeds, very appreciated in the food industry. The waste material of the plant is not yet fully used and its disposal often causes problems.
In Italy the cultivation of prickly pear are located in particular in Sicily, Calabria, Puglia and Sardinia regions. The most recent statistics attribute to only the Sicily about 90% of the area cultivated with about 2,500 hectares of cultivation. The pruning is performed in spring or late summer, in order to prevent the contact between the cladodes and to eliminate those malformed or damaged. For the realization of the prototype of the panel were selected cladodes from one to ten years old (Figure 4).

Figure 4: Cladodes of Opuntia ficus-indica

In order to realize a prototype of a rigid panel, suitable to the building envelope insulation, the mixture obtained was tied using as adhesive a polyester resin so as to obtain a compact layer resistant (Figure 5) having specific weight of about 450 kg/m^3.

Figure 5: Final product: the Opuntia ficus-indica rigid panel

Application of the insulating panels into an existing dwelling

In order to evaluate the thermal efficiency of new panels Opuntia ficus-indica, it is necessary to verify the possibilities of use, by comparing the benefits achievable through other panels most common on the market.

The comparison was made on a selected case study, simulating their individual application to the building envelope. the case study is an exemplar dwelling of the city of Palermo, in need of an intervention to increase its energy performance, starting from the opaque external walls.

Methodology of action

The analysis takes into account the main thermal and dynamic characteristics of the envelope that affect its energy performance, both during the cold and the warm seasons.

The improvement of the energy efficiency of the opaque walls, by the application of insulating panels from the inside, means not only better U-value and lower conductivity of the walls, but also it affects the analysis of the energy demand and, therefore, the annual energy costs of the dwelling.

Each material is then, from time to time, assessed through the linear thermal transmittance U achievable in the related final system, consisting of the initial stratigraphy with the addition of the insulating panel.
This analysis must be conducted according to the current regulations on the thermal requirements of the building envelope, such as the UNI EN ISO 6946:2008 "Building components and building elements - Thermal resistance and thermal transmittance - Calculation method".

Cases of study

In the case of residential buildings, it must act in order to respect of the common rules, such as the planning instruments or the regulations inside the apartment building of belonging. This case it is problematic in the case of an intervention that acts on the exterior, which could deface or modify the original shape of the envelope. In these conditions, the most suitable solution, especially in the case of an energy retrofit of individual building units and not of the whole apartment building, provides for the intervention from the inside, by acting through the affixing of insulating panels placed on the inner face of the wall.
The dwelling being examined has a floor area of 170 square meters and is used as private residence. (Figure 6).
The building was built according to a common technique in the construction of the 60's-70's in Palermo, through a frame system in reinforced concrete, and vertical closures in pumice concrete blocks.

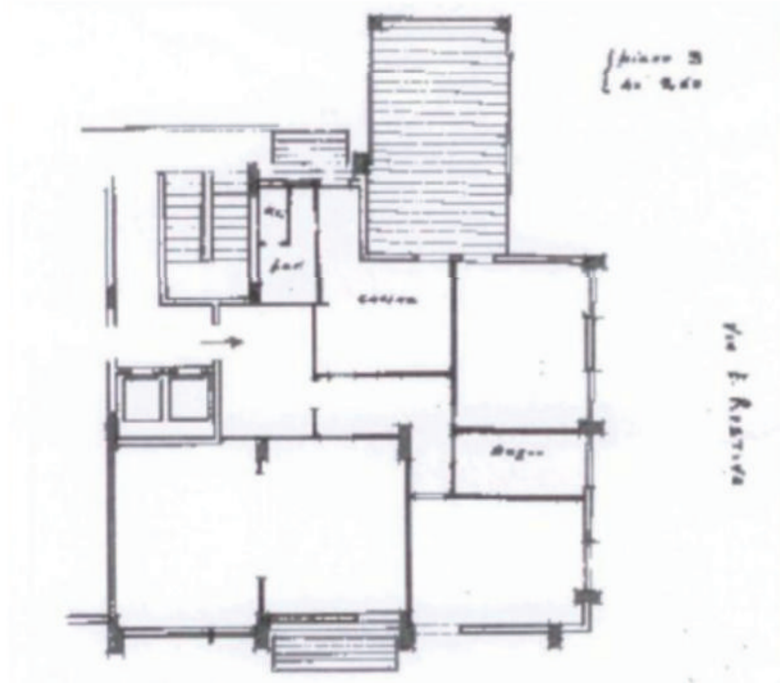

Figure 6: Plan of the dwelling chosen as object of analysis.

The initial stratigraphy, having a total thickness of 25 cm, is as follows (Table 1):
- Outer surface layer: plaster type «Li Vigni», 3 cm;
- Concrete blocks of pumice stone, 25 cm thick;
- Inner layer of civil plaster and gypsum, total thickness of 2 cm.
Each layer, taken with the relative values of thermal conductivity λ and of the thickness (cm), allows to understand the total resistance Rtot, which is in turn equal to the inverse of the transmittance U.

Table 1: Layers and transmittance value of the vertical walls in the current state

STRATIGRAPHY	CONDUCTIVITY	THICKNESS	THERMAL RESISTANCE
Liminal inner layer	-	-	0.13
Civil plaster and gypsum	0.70	0.02	0.03
Concrete blocks of pumice stone	0.20	0.25	1.25
Plaster type "Li Vigni"	0.64	0.03	0.05
Liminal outer layer	-	-	0.04
THERMAL TRASMITTANCE U		0.67 W/m²K	

The current value of the transmittance of the opaque envelope is U = 0.67 W/m²K, which happens to be a value greater than the transmittance limit imposed by the law for the climatic area "B", in which lies the city of Palermo (Italian Decree n. 192/2005) that is, instead, equal to 0.48 W/m²K.
In addition, a further verification was performed on the other characteristics of the dwelling that determine behavior in summer mode: surface mass (Ms) and periodic thermal transmittance (Yie). These results, when compared with the respective limits, require adequate interventions of opaque envelope insulation, such as to adapt their characteristics to those prescribed by current laws.

The table 2 shows the main thermal and dynamics characteristics of the opaque wall, in the current state:

Table 2: Comparison between the key thermal characteristics and with the limits established by law

Thermal and dynamic characteristics	Law requirements	Current state
Thermal transmittance U [W/m²K]	0.48	0.67
Surface mass Ms [kg/m²]	230	255
Dynamic transmittance Yie [W/m²K]	0.12	1.51

Results by adding different insulating panels

Once analyzed the current state of the dwelling envelope, and understood the low energy performance of the opaque walls, it is necessary to compare some actions that could be possible to applied as energy retrofits.

Figure 7: Scheme of application of the insulating panel from the inner face of the wall.

The most appropriate strategies, planning to act from the internal part of the walls with the application the insulating material, take into account the following panels, selected as the most common on the building market:

- Rock wool: $\lambda = 0.040$ W/m^{2}K;
- EPS (Expanded Polystyrene Sintered) with conductivity value equal to $\lambda = 0.033$ W/m^{2}K);
- Wood fiber panel ($\lambda = 0.041$ W/m^{2}K);
- Opuntia ficus-indica panel ($\lambda = 0.071$ W/m^{2}K);
- Air cavity ($\lambda = 0.026$ W/m^{2}K).

Assuming, for each case, the application of a rigid panel of insulating material of 60 mm, it is possible to get the following values, as in Table 3:

Table 3: Thermal characteristic allowed by each strategy of thermal insulation.

CHARACTERISTICS:	CURRENT STATE	AIR	ROCK WOOL PANEL	EPS PANEL	WOOD FIBER PANEL	OPUNTIA FICUS-INDICA PANEL	LIMIT VALUES FOR LAW
Wall thickness [mm]	250	250	310	310	310	310	-
Thermal trasmittance U [W/m^{2}K]	0.67	0.20	0.23	0.22	0.24	0.30	<0.48
Surface mass Ms [kg/m^2]	255	255	282	268	315	293	>230
Periodic thermal transmittance Yie [W/m^{2}K]	1,51	0,07	0,02	0,02	0,01	0,03	<0.12

The panel of Opuntia ficus-indica, as reported in the table, has met all the legal limit values for each characteristic indicative of the thermal performance of the envelope. The comparison of these results with those obtained with other typologies of insulation panels, shows how the panels have almost homogeneous requirements and how it is highly competitive with the other ones on the market.

Furthermore, also the evaluation of the dynamic parameters, fundamental in the assessment of the system answer in warmer cities, as the case of Palermo, confirms the possibility to use the new panel with good results.

Conclusions

To determine the convenience of an insulating material, as in the exsaminated case study, depends on the ability to achieve certain benefits, for a given mass in each case. However, the choice of the most suitable material strongly influences the degree of "sustainability".

For example, to determine how a material is ecological, it is necessary to take in account several factors, such as the production steps, the way from the manufacturing and all that makes the material ready for marketing: thus carrying out an energy balance of the life of the insulating material - emissions for the production, emissions for the transport, lower emissions due to the isolation of the material - could result that a material of chemical origin, such as EPS, in addition to having one of the greatest values of insulating capacity, it is more ecological of some "natural" materials requiring little energy for the production, but that may be subject to warping for thermal expansion in the process of its implementation.

Even in the case of materials of mineral origin it could be possible to present disadvantages as in the case of rock wool, for which is required a fusion of the raw material at elevated temperatures (about 1400 °C) and, if not properly applied and protected from moisture, the thermal performance is drastically reduced.

Furthermore, to obtain a certain stability of the panel shape, the fibers are mixed with the binder bakelite, a phenolic resin that releases formaldehyde.

Similarly, the wood fiber must be subjected to very onerous treatments before they can be used. It means that a cost-benefits analysis is the key strategy to assess the most suitable solution, case by case, and that a natural and innovative panel, such us the Opuntia ficus-indica, may reach very high energy performance with low cost of implementation, and the possibility to exploit a natural material, usually wasted (Figure 8).

Figure 8: Waste materials

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ZEMCH 2015, in its fourth year, is an annual global interactive forum for intellectual discussion on the problems and delights of design, manufacturing and marketing surrounding the delivery of low CO2 and ultimately, Zero Energy Houses that are customisable on a mass scale, either built or under construction in developing and developed countries.

The conference is covering topics involving **Mass Customisation and Sustainability in the Built Environment.**
This Conference Proceedings consist of many informative and comprehensive scientific abstracts and papers, which are featured as oral presentations.
Therefore, it provides a good opportunity to become familiar with the most recent research in sustainable development.

The Proceedings covers many valuable studies and 64 full-papers presented at the Parallel Sessions over the entire conference.
The Congress was attended by speakers from 35 countries from all continents together with the most representative authorities of the Apulia Region and the professional world.

It is true to say that the interest in Zero-energy homes/ buildings appears to be increasingly over the years, due to the collaboration among academics, professionals and construction industries.
In this light **ZEMCH Network** worked together with the Professional Associations (Architects P.P.C. and Engineers) but also with the representatives of the Apulian regional and provincial territory: this experimental co-organization formula was selected to reach a wider sharing and participation among all the parts involved in "governance" processes and according to ZEMCH "mission".
On behalf of the organisers, we would like to appreciate everyone who contributed to this Proceedings.

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