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Thermal insulation for a sustainable rehabilitation of traditional buildings

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ABSTRACT

Experiences and testing made in the course of 15 years at the DICAAR – Dipartimento di Ingegneria Civile, Ambientale e Architettura at the University of Cagliari, highlighted that the major interventions for the conservation and rehabilitation of traditional buildings are generally to be made on openings and roofs. Walls are, in fact, almost always in a pretty good condition, as are the horizontal timber frames between floors.
Some recent researches offered the possibility to experiment new solutions for roof and wall insulation. Starting from the need to put together natural and very performing materials, and the need to limit the transportation of building elements for economical and ecological reasons, some tests were made on new panels made with locally produced fibers, waste product from other artisanal production, and clay. Panels made with clay and straw, loofah or hemp wood have been manufactured and tested both in restoration sites and in the climatic chamber. The results obtained are very promising.

1. INTRODUCTION

In the course of the last 15 years the DICAAR of the University of Cagliari, Italy has focused its research and testing on the techniques of interventions for the conservation and rehabilitation of traditional Sardinian architecture. Results have been collected through the edition of the *Manuals for the conservation of Sardinian popular buildings*, a set of volumes focusing on the state of Sardinian ancient construction and the historical building technologies. In all cases, whether it was stone or earthen architecture, mountain or coastal buildings, results have been very comparable. Walls, even earthen walls, are in general in a very good conservation state, they show no concerning structural failure, but they almost all show external erosion, especially at the base of the wall and where plaster is missing.

More frequently common building pathologies are to be found on openings and roofs, due most frequently to lack of maintenance or original errors in the choice of the materials or the dimensioning of the building elements. In these cases windows and doors lintels are too short or thin, trusses are placed too far out on the outer walls exposing the heads to humidity, causing their deterioration.

Roofs were generally covering an upper floor that was commonly used to store food and other goods, never for residential purposes. Nevertheless, as its surface is identical to the downstairs floor, the tendency in restoration is to convert it to a residential space by raising the height of its springer (generally too low for residential purposes) and increasing the thickness of the roof in order to achieve thermal protection.

As a result, restoration interventions on ancient buildings commonly foresee the complete substitution of window sets and the complete remake of the roof.

This type of intervention is also influencing and solving a very important issue regarding the actual regulation for energy saving, which compliance is nowadays mandatory in almost all Mediterranean countries. These regulations represent quite a problem for almost all countries in the south of Europe, as they were originated in central European countries with different climate and different needs. These regulations work in fact very well for cold climates and in winter condition, but they strongly penalize historical buildings that have been conceived to comply with hot climate and long summer conditions through the year.

On the one side they oblige the use of a consistent thermal insulation even on traditional buildings if restored, but on the other side they give no indication on the characteristics that these insulation should have. More specifically, they give no indication on how to manage the danger represented by opposing no transpiring/synthetic elements (as most of the products sold on the current market) on natural supports.

Some researches projects that the DICAAR is carrying out since 2016 lead to the development and testing of new solutions for wall and especially roof insulation.

The challenge concerned several issues: the need to put together natural materials in order to better adapt the new elements to the natural supports (stone and earthen walls), the goal to obtain very performing panels for the hot local climate, the need to limit the importation of building elements for economical reasons and at the same time sustain the development of a local micro-economy in the sector. Some tests were made on new panels made with fibers produced locally, almost always waste products from other artisanal production, and earth. Three types of panels (earth and straw, earth and loofah and earth and hemp wood) have been produced and tested both in real restorations and in the climatic chamber.

These panels have been inspired by the ancient tradition of using vegetable fibers as insulation, and thanks to their hygroscopic nature, adapt well to the use on natural surfaces. In addition to this it is important to underline that, unlike other natural insulation materials produced in Sardinia, as cork and sheep wool, their production cost is much lower, as the main material used is not a prime material.

2. THE EARTH BINDER

For the three tests the soil used as binder was excavated in the area of Serrenti, 35 km away from the capital, Cagliari. The soil was empirically characterized with the methodology followed by CRATerre (Houben, Guillaud, 2006), through tests of sedimentation, mechanical resistance and absorption. The tests gave the result of a homogenous soil in granulometry, with clay content of about 25%.

Even such a little quantity of clay guaranteed a good binding action. The soil was previously sieved with a 2 mm mesh sieve, and then brought mechanically to a viscose/fluid state with the addition of 50% of water in order to reach the consistence of a fluid grout (*barbottina*).

3. STRAW-EARTH PANELS

Straw and earth have been used together as building material in many ways since ever and worldwide. The addition of straw allows creating light earth construction with different techniques: light adobe, cob, straw-earth fillings, among others. In Sardinia straw was mixed to earth only to prevent adobe and plasters from cracking. Today, its use for thermal insulation is still almost unknown. In Sardinia, due to the mild climate, thermal insulation has been historically not an issue, and houses were actually never insulated, relying on the massive earth walls for a protection against the weather. Nevertheless, it gets more and more necessary nowadays to provide an effective insulation in summer condition, as temperatures can become very high for long periods. Thermal retrofitting is furthermore obliged by law, in case of renovation with major changes also of historical building.

Straw-earth panels test samples were produced manually using local wheat straw and earth. Straw is intensively grown on the island for alimentary purposes; the resulting straw is generally sold in the livestock sector.

Wheat straw was incorporated to the grout, mixed in a basin built for this purpose and covered with more grout. Afterwards, the mix was pressed by hand into 50x50x18cm molds. The grout cover, in addition to binding the straw fibers, assures a light protection from insect and fire events.

Figure 1. Straw-clay panels

The press action was empirically measured with multiple tests in order to achieve a density of around 300 Kg/m^3. The panels were left to dry naturally during a period of one month (September) until completely exsiccated. At the end of the process each panel weighed 16 kg, had a fairly regular form and was compact enough to be safely manipulated.

In a second phase the straw panels were tested in the climatic chamber. The test was made on a panel 50 X 50 X 12 cm size. The imposed temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0,5 m/s, the external at 1,0 m/s. The test lasted 4 days.

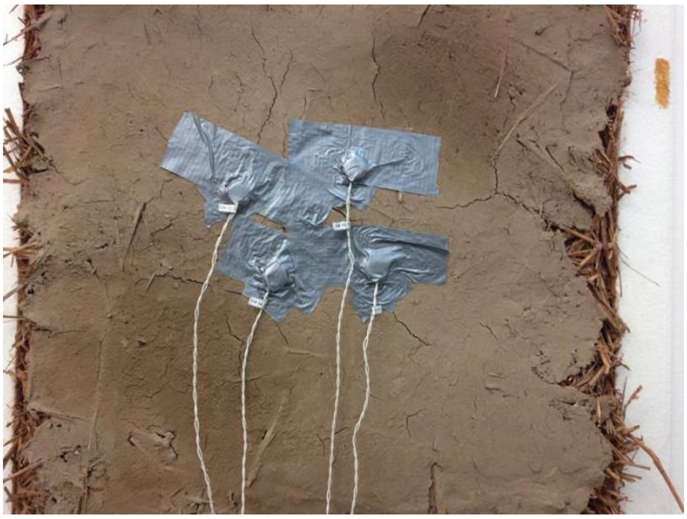

Figure 2. Straw-clay panel ready for the climatic chamber test

The result determined a thermal conductivity λ= 0,06 W/mK, which qualifies the product as a good performing insulation natural material, comparable to mineralized wood fiber and reed mats (K. Marti 2001).

Considering the cost of the raw materials used and the costs of man/working hours needed for the entire production process, the straw-earth insulation panels ultimately cost 15 €/m^2.

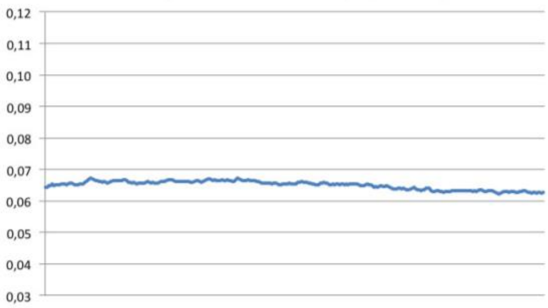

Figure 3. Thermal conductivity during the last 24h of the test

The same panels were used as thermal insulation on a ventilated roof in the restoration of a private residential building. In this case, the panels had a dimension of 50 X 25 X 18 cm and were mounted between the wooden planking and a ventilation chamber. At the bottom and on top of it a steam barrier was positioned.

The calculation to design the dimensions of the roof were made according to the instructions of the Italian Ministerial Decree D.M. 06/2015 that states that the maximal thermal transmittance for horizontal or tilted opaque structures, in winter condition for the climatic area "C" has to be equal to 0,34 W/m^2k.

In the case of the straw-earth panel tested, their thickness of 18 cm corresponds to a thermal transmittance (U-Value) U=0,29 W/m^2k.
In the calculation the building elements beyond the ventilated space have been ignored.

The periodic thermal transmittance was equal to Yie= 0,064. As for thermal transmittance in the calculation the building elements beyond the ventilated space have been ignored.

The calculated time lag, i.e. the time delay due to the thermal mass, is equal to φ=12,56 (h), the decrement factor fd= 0,216.

4. LOOFAH-EARTH PANELS

The cylindrical loofah that was used for the experiment comes from the Campidano plain.

The 2 hectares of cultivation give an annual production of about 50000 loofah used for the production of sponges for personal care. Several tens of thousands pieces are sold throughout the island of Sardinia and the Italian Peninsula yearly. "The advantage of cultivating loofah - explains the producer Marcello Mancosu – is that it does not require special terrains. It can easily grow on various types of soils".

The product is collected once it is completely exsiccated, that is when the squash has fully lost both pulp and seeds. Later it gets washed in special laundries and prepared for further processing.

With a similar procedure to the one used for the straw-earth panels, loofah panels have been produced using the same earth as a binder.

There have been many attempts to test mixtures, to find the best solution to obtain a regular and well

Figure 5. Loofah-clay panel ready for the climatic chamber test

Figure 4. Straw-clay panels mounted on the ventilated roof

resistant sample.

The loofah used was the waste material derived by the sponge production, further cut in pieces of maximum 1 cm in size. The shredded loofah becomes easy to handle and gives a smooth and regular surface to the panels once unmolded. Being the waste material of the sponge production its cost is very low, around 20 € per cubic meter.

Loofah panels offer an interesting new application for the building sector. The ease of processing the panels allows their adaptable use for different purposes: for thermal or acoustic insulation, or as filling for bearing structures. It is possible to vary the percentages of the materials mixed, in order to obtain more porous or more compact panels. It is also possible to change their size and thickness, depending on the final use. Finally it is possible to measure the compression force to get the panel to a precise density and repeat it for the entire production, to obtain a standardized product.

Panels were produced in the size 20 X 20 X 5 cm, and mounted in the climatic chamber in order to reach a module 50 X 50 X 10. The temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0,5 m/s, the external at 1,0 m/s. The test lasted 4 days.

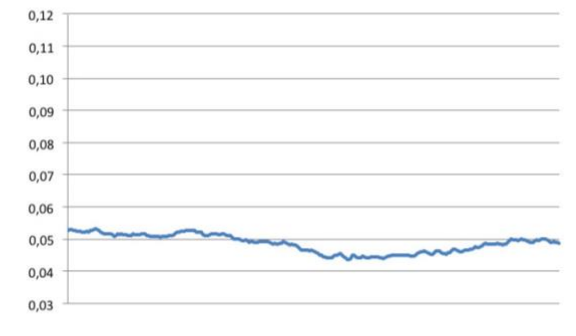

Figure 6. Thermal conductivity during the last 24h of the test

The values determined in the climatic chamber, thermal conductivity λ= 0,05 W/mK, indicate that the tested panels have insulation values comparable to other high-efficiency insulating natural materials as wood chips, cork granules, expanded perlite and cellular glass.

5. HEMP SHIVE - EARTH PANELS

The Cannabis Sativa is becoming a new business in Sardinia. The plant is easy to cultivate and does not need irrigation, herbicides or pesticides, furthermore, not containing proteins it does not get attacked by rodents and insects. The seed produced represents the prime product and is used in the food chain, for the production of flour and oil. The outside of the hemp stalk is covered with a skin (epidermis), underneath it there are bast fibres whereas in the centre of the stem there is a wood-pulp core (shive), the proportion of which is between 60 to 80% of the total mass of the stem. Hemp shive is the secondary product and is used in textile and building industry as building and insulation material. The shives and fiber obtained from the hemp stalks, with the addition of water and clay can give very regular and resistant panels. Test panels have been produced in the initial size 20 X 20 X 5 cm, but they had a little shrinkage in the exsiccation phase.

Figure 7. Hemp shive panel

Panels have been mounted in the climatic chamber in order to reach a module 50 X 50 X 12. The imposed temperature setting was 2°C for the outdoor chamber and 22°C for the indoor chamber. The relative humidity value was set at R.H. 50%. Internal Air Velocity was set at 0,5 m/s, the external at 1,0 m/s. The test lasted 5 days.

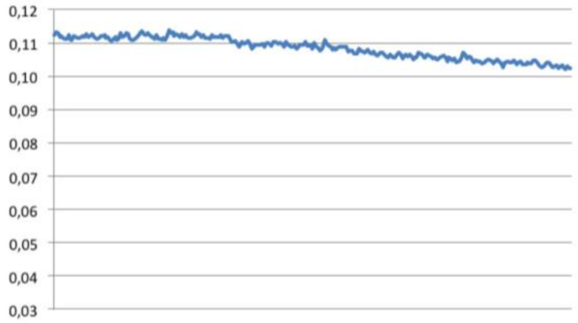

Figure 8. Thermal conductivity during the last 24h of the test

The average value determined in the climatic chamber for the thermal conductivity of hemp-earth panels is λ= 0,110 W/mK.

Compared to the straw–earth and loofah–earth panels, the thermal conductivity results fairly weaker. This can be attributed to the increased density of the material. The shives in fact present a surface offering a more difficult grip for the clay, which must be added in higher amounts, consequently increasing the specific weight of the product.

This result can certainly be improved by carrying out further tests on the percentages of the components and the quality of the binder chosen.

6. CONCLUSIONS

From the dawn of human settlements stems of fiber plants have been mixed with earth or lime to build shelters, housing and infrastructure so commonly that even today, after more than a millennium, they continue are extremely common. Vegetable fibers are revalued today for the performance they offer in the field of building insulation.

They give an exceptional contribution to sustainable building considered in terms of quality and quality / price ratio, healthiness of dwellings and the effective protection of the environment, starting with a drastic reduction of CO^2 emissions.

Their local availability, their being often waste product, the ease of transformation and use, make them an appealing resource for building purposes.

Fibers are commonly used in building generally mixed with cement or lime bonds, but they do not really represent in Italy a true alternative to commercial synthetic products, which are still more performing and cheaper.

The experimentation done by the DICAAR on the mentioned products bonded with earth aim to verify the possible use of local resources for the building sector that can support the local micro-economy, decrease the loads of waste production and introduce in the building market energy-efficient elements for the renovation of historic buildings and new sustainable construction.

The calculation made for the application of straw-earth panels on an ongoing restoration work have given very positive results, suggesting a valid contribution to the use of this kind of insulation for ancient buildings in all countries with hot Mediterranean climate.

The investigation just started will be extended in the near future towards the characterization of the materials used and their possible standardization in the thermal insulation sector, in view of a future industrial production. At a later time, other parameters of the behavior of materials, such as the acoustic insulation capacity and the durability will be verified.

7. ACKNOWLEDGEMENTS

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Alessandro Mereu elaborated the thermal calculation for the design of the ventilated roof insulated with straw-clay panels; he used the calculation sheet by Andrea Ursini Casalena, according to the Italian Standard UNI 13789/2008.

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