Sheep Wool for Sustainable Architecture

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Sheep wool for sustainable architecture

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Abstract

Sheep wool is a natural material, already used for thermal insulation of pitched roofs, in the form of soft mats. The paper presents a research project called Cartonlana, concerning a new sheep wool-based product with two main innovative features: it is a stiff panel, unlike the existing soft wool mats; it has a low environmental impact, using local recycled sheep wool, otherwise disposed as special waste. Physical and chemical properties of Cartonlana panel were determined by measurements, in order to demonstrate its effectiveness as insulation for buildings: thermal conductivity, acoustic absorption coefficient, absorption of formaldehyde, thermal transmittance of a wall.

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Keywords: sheep wool; thermal conductivity; acoustic absorption coefficient; sustainable architecture.

1. Introduction

Sustainable architecture needs natural materials with low environmental impact and physical performances which meet the requirements imposed by regulations concerning energy consumptions of buildings [1]. Sheep wool is a natural material suitable for thermal and acoustic building insulation. Taking into account the national context (Italy), the sheep wool insulation products already available in the building market can be divided into two categories:

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- soft mats made of 100% sheep wool, with thicknesses between 4 and 6 cm, mainly used for the insulation of pitched roofs;
- semi-rigid panels made of sheep wool (70-80%) and polyester fibers (20-30%), with thicknesses between 5 and 12 cm. The stiffness, obtained through the partial fusion of the polyester fibers, also allows for application in walls.

A research conducted by the Politecnico di Torino, Department of Architecture and Design (DAD), [2, 3] has evidenced some critical points concerning the economic and social aspects of the wool production-chain in the Piedmont Region, in Italy, such as:

- sheep farming is mainly geared for the production of milk and meat;
- sheep are not selected for the quality of their wool, which cannot be used by textile industry;
- wool, in most cases, is improperly disposed. It is buried or burned, with a strong impact on soil and air pollution;
- sheep wool building products are in most cases made of wool imported from foreign countries.

2. Cartonlana, an innovative building product

Starting from the critical issues analysed above, DAD, Davifil s.r.l. and ISMAC CNR carried out a research project concerning Cartonlana, a semi-rigid thermo-acoustic insulation panel obtained from Piedmont recycled wool [2, 3]. The study investigates an innovative way to produce an insulation panel with low environmental impact and high stiffness, using the low quality sheep wool collected in the Piedmont Region.

2.1. Low environmental impact

The low environmental impact of sheep wool-based building products is demonstrated in literature [2, 3, 4]. In particularly, the following wool life cycle stages must be considered: raw material supply, transport, end of life. In Cartonlana the raw material is represented by low quality wool, not suitable for the textile industry, and considered as special waste according to national regulations. Therefore, the impact of raw material supply is minimized, considering the avoided impacts of wool disposal. Concerning transport, the lack of wool collection facilities represents a huge limit to its utilisation, and pushes wool insulation producers to buy raw material from foreign countries, increasing the impact of transport on the environment. For instance, the primary energy content of transports of wool from New Zealand averages 10% per kilogram of the final product [3]. Considering the end of life stage, the compositions of the panel is important: panels with polyester fibres cannot be recycled as the 100% wool soft mat or stiff panel, which can be re-used in various innovative ways, like, for example, as a high value agricultural fertilizer [5].

Hence, Cartonlana stiff panel (Fig.1 - product C2) has been compared with other insulating wool products available on the Italian construction market: the 100% wool soft mat (Fig. 1 - product A) and the semi-rigid wool and polyester panel (Fig. 1 – product B). An environmental evaluation based on the Life Cycle Assessment methodology defined by the UNI EN ISO 14040/44 [6] has been made in order to analyse the potential environmental impact of each product. Life cycle inventory data are collected directly from the industrial partners of the research project. It has been assumed that all the three products are made of recycled sheep wool from Piedmont. Figure 1 shows a comparison between the three products in term of mega joule of non-renewable resources per kilogram. The washing process requires a large amount of energy for all the three products. Product B requires more energy than A and C2 for the raw material supply. Considering the total use of not renewables resources, C2 is similar to A, but has a higher manufactory process impact.

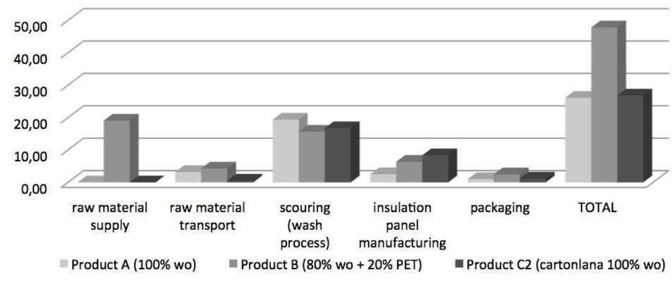

Fig. 1. Use of resources in the processing steps for manufacturing different wool insulation products (A, B, C2)

2.2. Stiff insulation panel: production and installing processes

The stiffness of Cartonlana is the result of thermal and chemical processes developed by CNR ISMAC and Davifil s.r.l [7] which partially degrade the wool fibers producing a protein glue, which adheres the remaining fibers together. The availability of a 100% sheep wool stiff panel, instead of soft mats or semi-rigid panels with polyester fibers, leads to new applications and the integration of building envelope components. Two different applications were explored:

- insulation of external walls. In this case Cartonlana is used for its thermal and acoustic insulation properties.
- internal insulation of walls or ceilings, exposed to internal environments, without any finishing layers. In this case, in addition to the insulating property (thermal and acoustic), also sound absorption and formaldehyde absorption must be considered. Referring to these applications, physical-technical measurements have been carried out in order to demonstrate their effectiveness.

3. Experimental methodology

3.1. Thermal conductivity measurement

Laboratory measurements have been performed to assess the equivalent thermal conductivity of the sheep wool samples (45 mm thickness and 600x600 mm size). A set of experimental measurements was carried out with a guarded heat flux meter apparatus, in accordance with EN ISO 12667 [8] and ASTM C518 [9] standards. The experimental apparatus consists in a single sample guarded heat flux meter device (Lasercomp FOX600), equipped with two plates containing the heat flux meters sensors above and below the sample. The instrument was calibrated with "1450b NIST SRM" calibration reference sample previously certified by NIST.

Laboratory measurements were performed on three different samples (18d, 34d and 38d) with different densities and different water content (humid sample and dry sample). For the dry tests, 34d and 38d specimens were dried to constant mass in a ventilated oven for 48 h at 60°C. The relative loss in mass and the water content was calculated comparing the samples mass before and after the drying cycle. The tests were carried out at two different mean temperatures T_{avg}: 25 and 40 °C, respectively. The measurement principle is to generate a constant temperature difference between the upper and the lower plates (20°C in order to minimize measurement uncertainty), and to measure the specific heat flux and surface temperatures in steady state conditions. The equivalent thermal conductivity λ_{eq} [W/(mK)] was then calculated using equation (1).

$$\lambda_{eq} = (s \cdot \dot{q}) / \Delta T \quad (1)$$

Where: s is the sample thickness [m], q is the specific heat flux [W/m^2] and ΔT is the temperature difference between the two faces of the plates [°C].

3.2. Thermal transmittance measurement

Besides laboratory measurements of thermal conductivity, in-situ measurements of thermal transmittance were carried out in a test box built by a drywall technology (dimension 4x2, 5x3 m) during winter time. The wall (Table 1) was insulated by a double Cartonlana panel with properties comparable to sample 34d dry (Table 2).

Table 1. Test box wall stratigraphy

Material (from internal to external side)	Thermal conductivity λ	Thickness
-	[W/(mK)]	[cm]
plasterboard	0.210	1.2
Cartonlana (double panel)	0.043	9.0
concrete board	0.350	1.5

In situ measurements were carried out according to the heat flowmeter (HFM) method described in the standard ISO 9869 [10]. The north wall of the test box was chosen in order to avoid the influence of direct solar radiation, whilst internal conditions were kept constant by an electric heating system. Surface temperature sensors and two HFM probes were placed on the internal surface considering the wall homogeneity. Besides thermal flux measurements, indoor and outdoor air temperature were measured accordingly at both sides of the tested vertical element. The data from the HFMs and the temperature sensors were acquired over a period of 5 days without interrupting the data acquisition process.

3.3. Sound absorption coefficient measurement

Sound absorption coefficient was assessed by means of a reverberation room at the National Institute of Metrological Research (INRIM – Turin - Italy). The test specimen was constituted by 12 m^2 of Cartonlana stiff panels with 50 mm of thickness and 130 kg/m^3 of density, mounted on the floor of the reverberation room with the rough side selected as the absorption surface area (Fig. 2). According to standard EN ISO 354 [11], the sound absorption coefficient by reverberation room method was obtained through two reverberation time measurement sets of the test room with and without the specimen placed in it, within the intervals of 100-5000 Hz in third-octave frequency band. The reverberation room was equipped with diffusing panels to obtain a uniform distribution of acoustic energy and random direction of sound incidence on specimen. Test measurements were conducted at an air temperature of (16 ±0.5) °C, relative humidity of (39 ±1) % and pressure of (1005 ±1) hPa.

3.4. Formaldehyde absorption measurement

The chemical composition of sheep wool is: approximately 82% keratin, 17% non keratin proteins and about 1% lipids and polysaccharides. Thanks to its high protein content, wool is able to absorb and neutralize particulate matter, heavy metals, and other hazardous gases such as nitrogen oxides, sulfur oxides and VOCs (volatile Organic Compounds) such as formaldehyde [12, 13]. The adsorption performances of Cartonlana were evaluated measuring the formaldehyde concentration in an hermetically sealed chamber (3.3 l volume at 20 °C; 65 % RH), equipped with an air circulation fan, with a Formaldemeter™ htV (PPM Technology). An aqueous solution of formaldehyde was introduced into the chamber. When a stable concentration of formaldehyde was reached in the air, the solution was removed and the concentration (6 ppm) was measured versus time, in order to assess the sealing properties of the chamber itself (Fig.4). Then, a 9 g Cartolana specimen was introduced in the sealed chamber measuring the formaldehyde concentration drop versus time.

4. Results and discussion

4.1. Thermal conductivity results

The experimental results show that samples 34d and 38d differ mainly with respect to density: sample 38d presents a higher density than sample 34d for both humid and dried samples. The thermal experimental results of the two different samples are reported in Table 2, which shows the equivalent thermal conductivity for different average temperature and different water content. Both samples demonstrate a not negligible influence of the water content on λ_{eq}. The dried samples results are lower than humid ones: about 10% for 34d at 25 and 40°C, while for 38d the λ_{eq} value is 7% and 4% lower respectively for test at 40°C and 25°C. Samples 34d and 38d in both humid and dry conditions shows a little difference in thermal conductivity in the range of measurement uncertainty (±2%). Differently sample 18d shows lower thermal conductivity around 12%-14% compared to 34d and 11% compared to 38d depending on the test set-point temperatures and independently from the water contents.

Table 2. Test specification and experimental results.

Sample	Test n°	Density	T_{avg}	Water content	$\lambda_{eq\,40°C}$	$\lambda_{eq\,25°C}$
-	-	[kg/m^3]	[°C]	[%]	[W/ (mK)]	[W/ (mK)]
18d dry	1	75.9	40	0.0%	0.037	0.034
34d humid	1	142.0	40	8.6%	0.044	0.040
34d dry	3	129.8	40	0.0%	0.043	0.039
38d humid	1	97.8	40	7.7%	0.045	0.040
38d dry	3	90.2	40	0.0%	0.042	0.039

4.2. Thermal transmittance results

Measured data through HFM probes and temperature sensors were processed using the progressive average method over the acquisition period of 5 days, according to ISO 9869 [10].

U values measured in two different point of the wall were 0.45 W/(m^{2}K) and 0.42 W/(m^{2}K) respectively and comparable to 0.41 W/(m^{2}K) of U value calculated considering the same materials of the tested wall and sample "34d humid" for Cartonlana thermal conductivity. This test has also confirmed that thermal performance of Cartonlana is comparable to other fibrous insulating materials such as fiberglass and rock mineral wool.

4.3. Sound absorption coefficient results

An overview of measured sound absorption coefficient within the frequency band of 100-5000 Hz is given in Figure 2. In accordance with standard EN ISO 11654 [14], from these results the weighted sound absorption coefficient was calculated obtaining a value of $\alpha_w = 0.55$ (MH). Since the tested Cartonlana specimen shows a good performance at medium and high frequencies typical of acoustic fibrous materials (i.e. glass and rock mineral wool with the same density), it can be considered suitable for acoustic treatments in indoor workplaces.

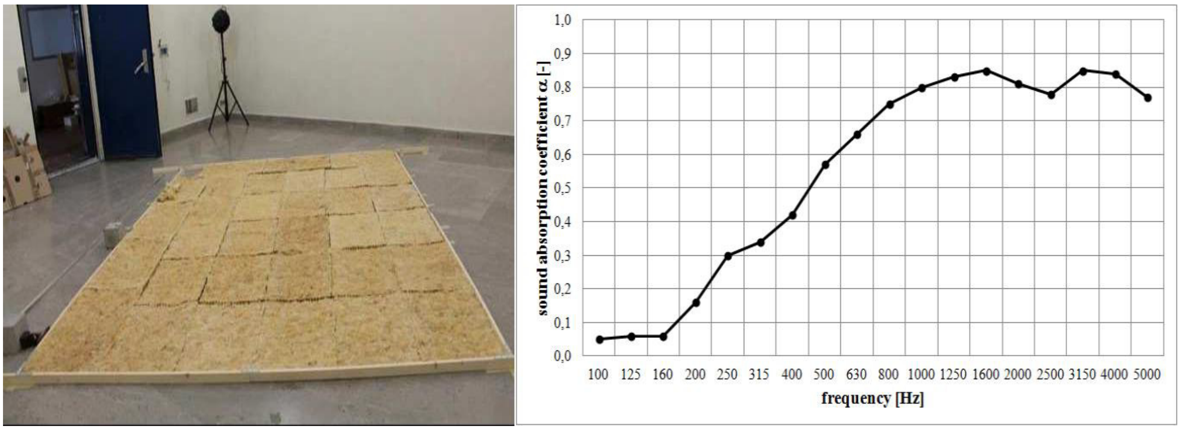

Fig. 2- (a) Cartonlana panels placed in the reverberation room; (b) Values of sound absorption coefficient α of tested panels.

4.4. Formaldehyde absorption results

It is known that formaldehyde has high reactivity towards proteins, particularly with the amino groups of lysine, arginine, glutamine and asparagine. Figure 3 b shows that Cartonlana reduces airborne formaldehyde concentration by 89,3% in less than 3 days. The effective abatement is the result of simultaneous physisorption (physical adsorption) and chemisorption (absorption by chemical reaction) of formaldehyde that occur first on the surface and then in the wool fibre bulk. This may contribute to lessen the Sick Building Syndrome due to low concentration of formaldehyde and other VOCs released from boards, furniture and paints in new buildings and renovated properties.

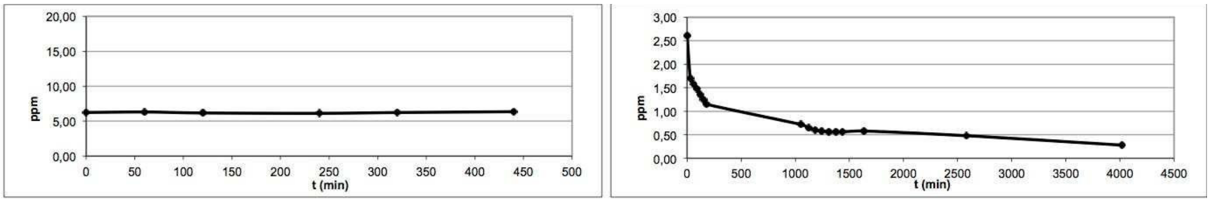

Fig. 3- (a) Formaldehyde concentration in the chamber versus time; (b) Absorption of formaldehyde by CARTONLANA versus time.

5. Conclusion

The results of the experimental measurements show that Cartonlana is competitive in terms of thermal conductivity and acoustic absorption and comparable with other insulation materials. The in situ application in an external wall, built with dry technologies, shows a good workability and thermal insulation performance. In addition, Cartonlana can be used in indoor applications for formaldehyde absorption. The main critical point for the scale-up to an industrial production is the absence of an efficient wool collections network at the regional level. Cartonlana can be considered a sustainable and innovative alternative to the waste of local low quality wools and a new opportunity for the sheep farming sector [15].

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