SHEEP WOOL - A PERFORMANT AND SUSTAINABLE ALTERNATIVE TO CONVENTIONAL BUILDING INSULATION

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REZUMAT. Utilizarea materialelor naturale de construcţie şi îmbunătăţirea eficienţei energetice constituie elemente esenţiale ale conceptului de sustenabilitate în domeniul construcţiilor. În acest context, se remarcă promovarea lânii drept material izolator ecologic, performant şi sigur pentru sănătate. Producerea de izolaţii din lână poate contribui la valorificarea deşeurilor de lână brută, în special sorturi de lână grosieră, care nu intră în ciclul productiv al industriei textile, dar care pot constitui materia primă pentru diverse aplicaţii tehnice. Scopul lucrării este acela de a trece în revistă caracteristicile fibrei de lână care susţin utilizarea sa drept izolator sustenabil pentru clădiri, precum şi tehnologiile aplicate pentru fabricarea izolatorilor de lână disponibili pe piaţă.

Cuvinte cheie: lână brută, valorificarea deşeurilor, construcţii ecologice, eficienţă energetică, sustenabilitate

ABSTRACT. Use of natural building materials and improvement of thermal efficiency are key elements of sustainability in the construction industry. In this context, sheep wool is being promoted as an environmentally friendly, effective and consumer-safe insulation material. During last decades, great amounts of raw wool, mainly of low quality grades, were rejected by the textile industry and turned into a problematic waste. Production of sheep wool insulation contributes to the valorization of raw wool waste into value-added technical applications. This paper aims to review the main wool fiber characteristics that are relevant to its use as insulator *for* sustainable building, and the manufacturing technologies for sheep wool insulation currently on the market.

Keywords: raw wool, waste valorization, green building, energy efficiency, sustainability

1. INTRODUCTION

Green or sustainable building is an actual response to societal concerns regarding the environmental impact of building materials and practices. According to UNEP [1], the building sector consumes about 40% of the global resources, 40% of the world global energy, and is also responsible of about 30% of greenhouse gas emissions (GHG) of the whole planet. Elements of green building are: energy efficiency, environmentally friendly building materials, waste and toxics reduction, indoor air quality. Energy efficiency comprises the energy yield of the facilities and the envelope energy losses. Insulation is key to increasing the energy efficiency of a structure and to minimizing noise pollution, which is becoming a health concern mainly in urban agglomerations. The demand for integration of more recycled and renewable resources into the construction industry stimulated the replacement of common insulation with natural fiber-based insulation materials.

Wool is a valuable textile fiber, mainly appreciated for its comfort and thermal properties. Though, the development of man-made fiber industry determined a continous decline of the wool textile sector. With a steady production of about 1.2 million metric tons per year and a share of about 2.5% on the global textile market, wool is currently regarded as a marginal fiber, reserved mainly for luxury clothing [2]. Great amounts of coarse or even fine grade non-marketed raw wool have turned from an income source into a waste management issue, and are thrown away, burned or landfilled. In the past years, sheep shearing was only an animal welfare activity, with no profit for the farmer. Dramatic price lowering of raw wool brought farmers to get rid of unwanted wool, sometimes by illegal practices.

With increasing demand for sustainable resources, wool was reconsidered as an underrated renewable resource. Efforts are being made to find value-added non-clothing applications of raw wool waste, through economically feasible manufacturing processes. In this context, the developments of the wool-based building insulation market have been lately noticed. The use of wool for home insulation is rising in popularity.

The aim of this paper is to shortly review the current state and perspectives of using sheep wool as insulation for green building. Main properties that qualify raw wool as a high performance alternative to common building insulation are presented. Arguments in favor of using sheep wool as a sustainable, energy efficient insulation, and current technologies for commercially available wool-based insulation products are reviewed as well.

2. PERFORMANCE OF WOOL AS INSULATION MATERIAL

Wool has been traditionally used as natural building insulator from ancient times. Nowadays, most building insulation is made up of synthetic materials, and its technical characteristics and use are regulated by standards. Sheep wool meets all the key requirements for building insulation (Fig. 1 and Table 1), and some characteristics are even superior as compared with conventional insulation materials.

Fig. 1. Key properties of wool as insulation material.

The most important aspect of an insulation material is its performance, expressed in terms of thermal coefficients:

● **Thermal conductivity** or **K-value (W/m·K)**. Natural fibers have slightly lower K-values than conventional insulation, but the figures are within the common range for performant building insulation.

● **Thermal resistance** or **R-value (m^2·K/W)** connects the thermal conductivity of a material to its thickness. The R-value of building insulation has not a standard value, because it depends on many factors: location inside the house, local climate etc. In general, minimum R-values for exterior walls insulation lies between 2.3 – 4, while ceilings require R-values of 5-10 m^2·K/W [3]. The typical woolen rolls and batts being produced offer approximately 2.6 R per 100 mm in thickness.[4] while loose fill insulation can provide a R-value of up to 2.8 per 100 mm [5].

● **Thermal transmittance** or **U-value (W/m^2·K).** Within the current regulations, the thermal transmittance is the main factor used to compare the thermal insulation of buildings. The admitted U-value for well-insulated external walls is 0.2 or lesser. Achieving the same thermal performance requires a slightly thicker wall of wool-based materials as compared with conventional insulating materials [6**].**

● with high values of **sound absorption coefficient** (**SAC**) and long service life, wool is a valid alternative to traditional soundproofing materials. As expected, with increasing the thickness of the specimens, the sound absorption coefficient increases significantly, especially in the low frequency range. The raw wool has slightly higher sound absorption coefficients than processed wool, probably for the presence of more interwoven fibers that allow an increased energy dissipation Thus, the SAC of a 10 cm thick raw wool mat is very close to 1 above 800 Hz, while a commercial wool insulator does not exceed 0.91 [7].

● **Condensation** is one of the major challenges facing the building industry today. Excess moisture has a detrimental effect on the structure of a building and is also a root cause of mold, which can have adverse effects on the inhabitants' health. Apart from its thermal properties, wool's main advantages as insulator come from its capacity to control condensation. Natural wool is hygroscopic: it can absorb over 35% of its own weight in moisture without significant changes to thermal performance, whereas the thermal performance of man-made mineral fiber insulation deteriorates when condensation is present. Breathability and air humidity buffering capacity come from its ability to absorb, store and release moisture faster than most other materials. In cold, humid air, wool absorbs water and releases condensation heat, which is not noticeable inside the building, but prevents condensation in construction cavities, by keeping the temperature above the dew-point in damp conditions. In warm and dry atmosphere, water evaporated from wool fibers absorbs heat from the inside air and keeps walls cool. Sheep wool insulation acts as a buffer between the cold damp weather outside and the warm dry environment inside your home.

● **Indoor air quality.** Apart from its insulating function, wool can improve the indoor air quality (IAQ), due to its ability to act as an effective filter and adsorbent for hazardous volatile organic com-

pounds (VOCs) such as formaldehyde and toluene, which are released from building materials, furniture and household appliances. Wool is particularly efficient in removing formaldehyde from indoor air, but its sorption capacity depends on sheep breed and processing operations: 4 g/kg of white scoured wool, 5.5 g/kg of unscoured white wool, and as much as 10 g/kg of black wool [8].

● **Fire behavior.** Of the common textile fibers, wool is widely recognized as the most flame resistant. Wool's fire resistant attributes include: high ignition temperature (570-600° C), higher levels of oxygen in the surrounding air in order to burn, low heat of combustion, self-extinguishing behavior, low levels of released smoke and toxic gas. Wool fire properties are currently exploited in technical textiles like firefighters protective equipment, but these attributes are a significant advantage when it is used as building insulation.

● **Durability.** Insulation materials are affected by shrinkage, compaction or moisture during their service life. Properly processed wool insulation has a long life span- up to 50 years according to manufacturer's [9] - mainly due to inherent wool fiber durability. Wool sheep wool is not affected by damp, while synthetic insulation needs to be kept dry in order to perform and preserve integrity. Another advantage sheep wool insulation has over other fibrous materials is that it is less affected by compression, and does not break.

Table 1. **Wool performance, compared]er common insulation materials (data from manufacturers)**

Insulation material	K value W/m·K	R value (100 mm) m^2K/W	Thickness for U-value 0.2 mm	Density kg/m^3	Embodied energy GJ/m^3	Sound absorption coefficient (500 -2000 Hz)	Water absorption % wt/wt
Sheep wool	0.034 – 0.067	2.5 – 2.6	180-200	18-23	0.11	0.77 (60 mm)	up to 35 %
Glass wool	0.032 – 0.04	2 –3	170	10-30	0.83	0.65 (100 mm)	0.2 %
Polystyrene foam	0.033 – 0.035	2.5 – 2.8	150	30-50	3.03	0.35 (50 mm)	0.03 – 0.1 %

3. SUSTAINABILITY CHARACTERISTICS OF WOOL INSULATION

There are several arguments in favor of sheep wool as a sustainable insulation material:

● It is a **natural material**, readily available as a by-product of the livestock farming process. As a sheep produces at least one fleece per year, wool can be considered a **renewable resource**.

● Man-made insulation can only be disposed of into landfills, whereas sheep's wool insulation is 100% **biodegradable** and can be recycled or composted at the end of its life.

● It has **low environmental impact**, due to **low values of embodied energy** and **GHG emissions**. Many construction materials use large amounts of energy in their production and transport. This is known as the "embodied energy" of the material. Most of this energy is produced by the burning of fossil fuels, which increases the amount of carbon dioxide (CO_2) incriminated for climate change. Wool insulation is energy efficient, using approximately 15% of the embodied energy for production that it takes to manufacture fiberglass insulation for example. A comparative Life Cycle Assessment of wool, hemp and mineral wool insulators showed that the wool-based insulator offered a net negative carbon footprint (CF) of -0.323 kg CO2-eq over its entire lifecycle, while the hemp had a CF of 0.345 kg CO2-eq, and the mineral wool had a much higher value of CF, equal to 1.2 kg CO2-eq [10].

● unlike mineral insulation, wool is **not a health hazard**, as it is naturally non-toxic, non-allergenic, resistant to mold and odorless.

● unlike other insulation products, wool insulation is **easy to install**, and the installation process does not require any protective clothing or extra safety measures.

● Sheep breeding is an important source of livelihood worldwide, mainly in mountain and arid area. The dual purpose farming - meat and wool - provides the source of income and protects farmers against prices oscillation. Lately, the dramatic decrease of demand for raw wool increased small farmers community vulnerability and put in danger their living standard and traditions. Finding profitable uses and establishing specific value chains for wool can bring **social and economic benefits to the local sheep breeders communities,** and on a larger scale, can contribute to the agrarian and textile sectors sustainability.

Objections are mainly related to:

● **the use of preservation and fire-retardant additives.** One disadvantage of sheep wool is the danger of moth infestation, which makes the protective treatment mandatory. Chemicals commonly used for this purpose are organic halogen compounds. Use of such additives with toxic effects on humans and environment is inconsistent with the requirements of "green" products, when it comes to house or commercial building. Currently, wool insulation is treated with about 4% non-toxic borax

to prevent moth infestation, fungi growth, and to enhance its fire-retardant properties.

● **potential allergenic**, due to mold growths on its surface. Recently, tests on durability and susceptibility to mold growth of different bio-based insulating materials like hemp, wool and wood fiber, showed that despite its high hygroscopicity, wool exhibited the lowest growth intensity of common mold strains [11].

● **pollution associated to cleaning and preparation processes**. In order to be produced for effective insulation, wool has to be properly cleaned and treated. These operations involve the use of toxic chemicals and the release of highly-polluted wastewater. However, cleaning and scouring, well-known for their negative environmental impact, are key operations in all production processes applied in the wool textile industry if high quality products are desired. Till now, the contribution of wet processing to the environmental impact of wool-based insulation has not been estimated.

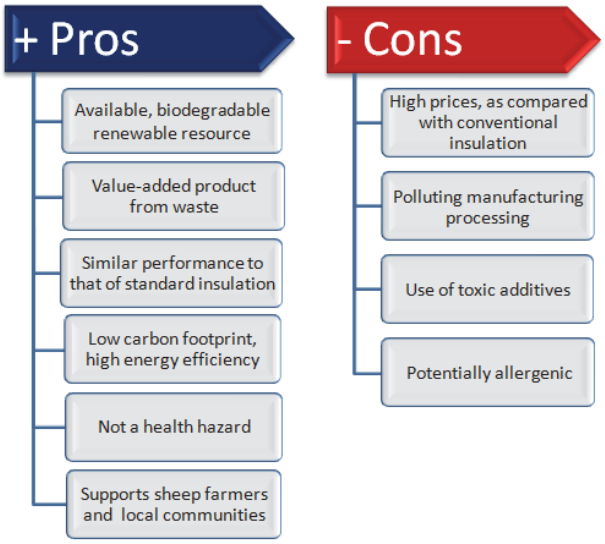

Fig. 2. Pros and cons of using sheep wool insulation.

● **high prices.** The most obvious drawback to sheep wool is the high prices. Compared to fiberglass or cellulose insulation, which are some of the cheapest in the industry, wool insulation products are about two to three times more expensive. The organic origin, the need for production facilities and availability, which is many times affected by poor wool collecting systems, is the biggest issues affecting the cost [12].

The current prices of sheep's wool insulation ranges between 11÷14 EUR per m^2 for 10 cm thick batts and can reach about 20 EUR per m^2 for premium quality products [4, 13], In contrast, the current price of fiberglass insulation ranges from 2 to 10 EUR per m^2, depending on thickness and R value. It is hoped that as increasing volumes of sheep's wool insulation enters the world market and as manufacturing capacity increases, prices will become more competitive. The higher expenditure for purchasing the insulation product is counter-balanced by lower installation costs and by its long service life.

Pros and cons of using sheep for green building insulation are given in Fig. 2.

4. FABRICATION AND APPLICATIONS OF SHEEP WOOL INSULATION

Sheep wool insulation is commercially available in different forms, from a small but increasing number of suppliers worldwide.

Wool insulation is made from sheep wool fibers that are either mechanically held together or bonded using between 5% and 15% recycled low-density polyester adhesive, to improve performance in terms of density and strength. In many cases, the wool is cleaned and have borates added in order to add fire resistance to the material. Formats of wool-based insulators provided by manufacturers are (Fig. 3):

- loose fill insulation, applied with standard insulation blowing equipment [5] in lofts, sloping ceilings, timber frame walls and timber floors.

- flexible batts and rolls, made up of 100% sheep wool or wool + recycled polyester binder, with thicknesses between 4 and 6 cm, mainly used for the insulation of pitched roofs [4,9];

- semi-rigid slabs made of sheep wool (70-80%) and polyester or polypropylene fibers (20-30%), with thicknesses between 5 and 12 cm. The stiffness, obtained through the partial fusion of the polyester fibers allows for application in walls. Recently, wool-hemp semi rigid panels were fabricated [14]. Wool fibers were treated with a soda solution in order to hydrolyze and release part of keratin protein; the solubilized wool worked like a natural glue, pasting wool and hemp fibers together.

The typical rolls and batts being produced are similar in shape to conventional mineral/glass wool insulation products.

The production line comprises a preparatory stage for wool cleaning and different forming stage based on mechanical bonding, chemical bonding or wet felting (Fig. 4).

Wool-based insulation provides excellent warming and cooling properties for walls, floors, ceiling and roofs of residences and commercial buildings. Sheep's wool insulation is ideally suited to timber frame structures as it has a natural synergy with wood. The sheep wool fibers draw out the moisture, conditioning the wood and act as a 'buffer' to protect the building fabric.

Besides the functional effectiveness, economics and manufacture-related issues must be taken into account when wool is assessed as insulation for sustainable building. In this respect, it was shown that manufacture of wool insulator on a small scale, using low cost, non-marketed raw wool, can offer small but significant benefit to sheep farmers and manufacturers as well. Use of coarse wool of lowest quality did not have a negative impact on the production process or product insulating performance [12].

Fig. 3. Wool insulation formats: a) loose fill; b) rolls; c) batts.

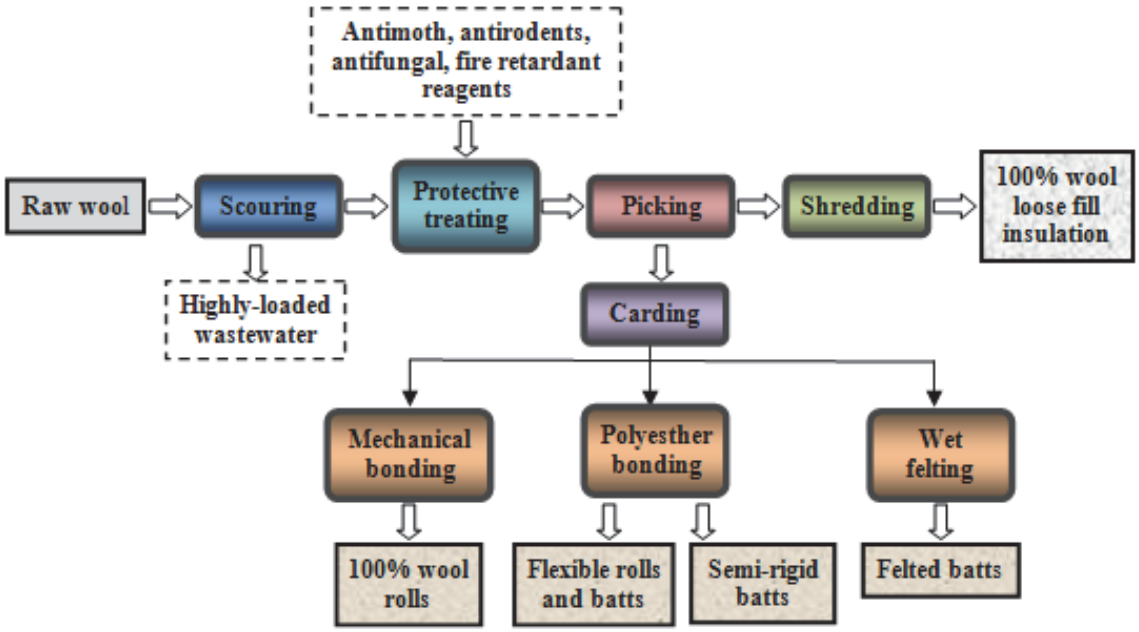

Fig. 4. General manufacturing process of sheep wool insulation.

5. CONCLUSIONS

Sheep wool has the potential to be developed as a feasible green building insulation, as it responds to all the key requirements of green building, and meets all the performance standards for building insulation at the same time.

The characteristics that make wool competitive to man-made insulation are: high values of thermal and sound proofness coefficients, fire retardance, breathability, durability, non-toxicity.

Arguments in favor of sheep wool insulation as a sustainable insulation are: it is a natural, renewable resource, with high biodegradability and re-cyclability, it has high energy efficiency and low carbon footprint.

The main objections to wool-based insulation are the danger of moth and rodents' infestation, and the high purchasing price.

The emergence of wool-based insulation materials was determined not only by the "greening" of the building sector, but also by the need to find viable solutions to the environmental and economic issues raised by increasing amounts of raw wool, rejected by the textile industry and turned into waste.

Manufacture of sheep wool insulation can provide employment and regional economic growth in rural regions, by supporting the local sheep farmers and entrepreneurs.

Sheep wool insulation is still a new and expensive product on the market, preferred by environmentally-aware and financially-potent home-

owners and builders, but with real prospects to expand its market share.

The use of natural insulation materials, particularly sheep wool, is a small but significant contribution to environmental, economic and social sustainability.

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