Energy Renovation of Building Stock in Europe: The Role of Biobased Insulation Materials in the Transition toward Carbon Neutrality and Circular Economy.

KEYWORDS

Energy retrofit, Sustainable retrofit, Residential buildings, Traditional buildings, Insulation materials, Biobased materials, Multicriteria approach, Life Cycle Analysis (LCA).

ABSTRACT (496 words)

Over the past thirty years, insulation materials have become a cornerstone of architectural design, shaped by evolving energy regulations and thermal insulation standards **[1]**. The 2018 revision of the European EPB regulations **[2]** urged member states to intensify renovation efforts and achieve substantial improvements in building energy efficiency by 2050 **[3]**. In Wallonia, as in all European regions, energy renovation represents a major challenge, given the heterogeneity of the residential building stock —both in rural and urban contexts **[4,5]** and includes a high proportion of traditional pre-war buildings that are little or no insulated and highly energy-intensive **[6-8]**. Consequently, demand for insulation materials is expected to increase significantly **[9]**. It is therefore essential that this demand be aligned with European and regional objectives for ecological and circular transition **[10-14]**.

The selection and implementation of insulation material during renovation, especially in traditional buildings, has become crucial **[15]**. Techniques commonly used in new construction are often unsuitable for old traditional buildings, which interact closely with their climatic environment and depend on the hygrothermal properties of their materials to regulate the water vapor **[16]**. Inappropriate insulation choices can severely disrupt this balance, leading to material degradation and reduced summer comfort due to diminished thermal inertia. Moreover, such interventions risk erasing the cultural and architectural identity of buildings that contribute to regional character and heritage, which must be preserved for future generations. Furthermore, non-circular insulation solutions, characterized by irreversible assemblies and limited reuse potential, exacerbate resource depletion, greenhouse gas emissions and waste production **[17-19]**.

In this context, this study investigates the advantages of biobased insulation materials from constructive, circular and environmental perspectives, with a specific focus on the energy renovation of the Walloon traditional residential building stock, built before 1920, before cavity wall systems were developed **[20]**. Adopting a multidisciplinary and comparative approach **[21]**, it highlights the pivotal role of these "balanced materials" in the transition toward carbon neutrality and a circular economy.

The study begins by refining the definition of "biobased" materials **[22, 23]** and compiling an inventory of around twenty biobased insulation products currently available in Europe. Then, based on a model representative of pre-war Walloon residential buildings **[20]**, three to five energy improvement scenarios were proposed for each type of envelope wall, varying in insulation technique and material. These scenarios are introduced in the Belgian environmental assessment tool “TOTEM” **[24]**, based on one square meter of wall over a 60-year lifespan, to measure their global environmental impact and specific contribution to Global Warming Potential, Abiotic Resources Depletion and Water Use. Finally, circularity is also evaluated through a set of criteria encompassing resource origin, assembly reversibility and the potential for effective recovery via reuse or recycling **[25]**.

The contribution first presents the methodology, followed by an overview of the materials inventory, the indicators used for comparative analysis, and the main findings. It concludes with a discussion of the potential of biobased insulation materials to enhance energy efficiency and to support ecological and circular transition of the built environment.

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