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# Acoustical properties of hemp concretes for buildings thermal insulation: Application to clay and lime binders

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## HIGHLIGHTS

- Hemp-clay and hemp-lime acoustically behave in a similar way.
- Three different acoustical behaviors are highlighted, depending on the density of hemp-based concrete.
- Hemp concentration influence the acoustical behaviour of these materials.
- A four-parameters approach is well-suited for lime-hemp and hemp-clay acoustical behavior modelling.

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## ABSTRACT

This experimental and modelling study provides a general overview of the acoustical performance of hemp-lime and hemp-clay for building thermal insulation at the material scale. It is based on statistically robust experimental results from more than 100 hemp-clay samples, together with the analysis of a large hemp-lime database.

In hemp-clay mixes, our experimental results show the concentration of hemp in a mix has a first order effect on the acoustical performance, while binder fluidity and clay type have no effect. Another conclusion of this study is that hemp-clay and hemp-lime behave acoustically in a similar way. For both materials, experimental sound absorption and transmission curves can be modelled with a physical-based four-parameters approach. The close agreement between experimental measurements and modelling highlights the good level of understanding of the physical phenomena responsible for the acoustical behavior of hemp concrete.

A classification is finally proposed in terms of density to be used as a general guideline to evaluate or optimize the acoustical performances of hemp-based concrete.



## 1. Introduction

The use of bio-based materials for thermal insulation is a solution for reducing environmental impacts of the building sector, which represents 40% of the worldwide energy use [1,2].

Different bio-based materials have different environmental impacts. For instance, most actual bio-based thermal insulation panels include about 15% of polyester in mass to tighten the fibres together. In hemp wool panels, this small amount of polyester has an environmental impact 7–8 times higher than the hemp wool production itself (in $kg_{eq.CO2}$) [3]. In addition, due to this low amount of polyester, the end of life strategy of the panel cannot be a composting like the bioresource alone. Alike conventional thermal insulation material (glass wool...), its end of life requires the organization of a recycling branch for collecting and processing operations. A raw bio-based material resulting from a simple and low energy demanding transformation process often has an additional benefit: it does not need a highly industrialized and costly plant to be produced. Thus, the economic balance point can be reached while maintaining production and commercialization at a local scale (< 100 km). This is the case of light earth.

Light earth is unfired clay lightened with renewable particles in order to improve the thermal insulation. Earths that are well-suited for construction often have a natural dry density about 1500–1800 $kg \cdot m^{-3}$. Fig. 1 shows some light earth construction techniques depending on the targeted dry density. Light earth

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above 1000 kg·m$^{-3}$, such as straw-clay blocks, is heavy and has poor thermal insulation properties (thermal conductivity $\lambda$ above 0.2 W·m$^{-1}$·K$^{-1}$ at 10 °C dry state). The particles are often fibres whose main role is to prevent drying cracks. Light earth between 500 and 1000 kg·m$^{-3}$ is not light enough to be considered as an efficient thermal insulator, with $\lambda$ within the range 0.1 to 0.2 W·m$^{-1}$·K$^{-1}$ at 10 °C dry state. A "hemp-lime or hemp-clay thermal corrector plaster" (a 6 cm light plaster applied with a trowel on an existing wall to reduce the "cold wall" effect) has a density included in this range, generally between 700 and 900 kg·m$^{-3}$. Below 500 kg·m$^{-3}$, light earth might be considered as an option for insulation purposes but the density has to be reduced to 300–400 kg·m$^{-3}$ to reach the thermal insulation material threshold $\lambda \leqslant 0.065$ W·m$^{-1}$·K$^{-1}$ (at 10 °C at dry state) defined in the standard NF P75-101 [4]. Light earth between 200 and 500 kg·m$^{-3}$ can be used for building works by shuttering techniques, spraying or casted blocks, with or without a timber frame. Light earth with density lower than 200 kg·m$^{-3}$ has a low mechanical resistance, but it can be used as a filling material in lost casing. The lowest density bound is the aggregate one, about 100 kg·m$^{-3}$ for hemp shiv.

Light earth properties and applications for building thermal insulation were first studied by German research teams. Some of their results were published in a high quality compilation [5]. Different light earth mixes were recently studied by different research teams, mostly focusing on thermal and hygrothermal properties, using straw [6], coco [7], typha [8], hemp [9], rape straw and sunflower [10]. A raw comparison between hemp-clay [9,11] and hemp-lime [12–14] shows these mixes have rather similar thermal and hygrothermal performances, but hemp-clay has a 20 times lower embodied energy.

Using clay over lime or cement has several advantages (environmental impact, economic…). Clayed earth can be found easily on a local scale: it is a widespread material in the sub-ground, and it is often available in large quantities after public works for free on a economical and environmental standpoint. The main difference between theses binders is that the setting of clay is a reservible process because only due to drying, while the setting of lime and cement is an irreversible process. The benefit is that unstabilized clay based concrete is infinitely repairable and recyclable. The drawback of the reversible setting of the clay is that, in contact to a large quantity of liquid water, clay will become mud again. Nevertheless, all insulation materials, even glass wool, suffer from liquid water which induces either compaction or degradation. The durability of a clay concrete insulation is similar to the one of traditional houses made of stones, wood and clay: it can last for several centuries, up to the point where the building is heavily exposed to liquid water (often due to a degraded roof).

Acoustical properties are usually described by two quantities, the sound absorption coefficient $\alpha$ and the transmission loss $TL$, the latter corresponding to the sound insulation. These performances can be characterized at three scales: building, wall and material scale. The methods for measurements in buildings are described in standards [15]. However, a scientific interpretation

(a) Brick with fibres (1 200 kg.m$^{-3}$).

(b) Coating with a trowel (800 - 900 kg.m$^{-3}$).

(c) Shuttering (200 - 500 kg.m$^{-3}$).

(d) Spraying (200 - 500 kg.m$^{-3}$).

(e) Lost-casing ($\leq$ 200 kg.m$^{-3}$).

**Fig. 1.** Different construction methods associated to hemp-lime or hemp-clay density. Some pictures courtesy of Vincent Corbard.