Hemp-lime – contemporary usage of traditional materials

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Abstract

Hemp-lime is a comparatively unknown building material in Estonia. Scientific interest in this material is increasing remarkably quickly around the world, yet practical competence regarding its usage is lacking in Estonia, as far as construction is concerned.

Hemp occupies an important place amongst crops that have traditionally been cultivated in Estonia, but its use has not been typically associated with the construction industry. Owing to its strong fibre, hemp has primarily been seen as raw material for the production of textile products, particularly rope, and the inner core of the plant, or 'hemp hurd', has been cast aside as a by-product. Since the porosity of hemp hurds results in relatively low thermal conductivity, hemp-lime, the composite material made by mixing hemp with lime, is suitable for insulating pre-existing building envelopes as well as for installing insulation for new buildings during construction. Lime creates an alkaline environment around hemp hurds, making it difficult for fungi and pest insects to thrive. Compared to other natural insulation materials, hemp-lime therefore has a rather good balance between durability and cost-effectiveness.

The essential feature of hemp-lime relevant to construction engineering is that the material is monolithic – any occurrences of sparsity and the resultant risk of thermal bridging in building envelopes is kept to a minimum, since the hemp-lime filling that surrounds the load-bearing structure forms a solid external surface when properly installed. Owing to its high level of air-tightness, external structures made from hemp-lime can reduce the risk both of excessive cooling and of overheating. In addition to creating a comfortable indoor climate for residents, mitigating any sharp fluctuations protects the wooden construction elements surrounded by the hemp-lime, which also reduces the risk of moisture accumulation and frost damage.

Reducing the annual energy consumption of buildings and ensuring healthy indoor air quality pose significant challenges to the construction industry, since

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Photo 1. Hemp-lime wall structure. *Photo by Silver Tõnisson*.

according to the current building code, the energy performance indicator of buildings constructed from 1st January 2021 should not exceed the limit established for nearly zero-energy buildings. In short, this calls for more efficient use of resources, including the production, transport, installation, and recycling of materials. Compared to the majority of contemporary building materials, hemp-lime is relatively eco-friendly, and its energy content is low.

Keywords: industrial hemp, lime, clay, hemp-lime,
sustainable building materials

Introduction

Sustainable development is increasingly seen as a natural part of any future strategy for a state, an enterprise or an organisation. Sustainable development is often associated with a preference for using renewable natural resources. Regarding cost effectiveness, such nature-friendly materials have a hard time resisting the onslaught of modern construction products made at an industrial scale and pace. On the other hand, the sustainable use of natural resources is rapidly developing from a simple trend into an informed and recognised way of living. In construction, the objectives of sustainable development can be found, for example, in the use of low-energy and nature-friendly materials, in designing and applying more lasting construction and engineering solutions, in a healthier and more comfortable indoor climate, and in lower operations and maintenance costs. Research carried out in different parts of the world seems to indicate that hemp-lime has a strong potential for contributing in these areas and helping to achieve the objectives of sustainable development.

Photo 2. Crushed hemp hurd. *Photo by Kerttu Kruusla*.

Although hemp-lime has successfully been applied in construction in North America, Australia and in several European countries, and its good properties for construction technology have been proven by numerous studies, the demonstration wall built as the practical portion of the author's graduation paper (Pau 2017) is the first hemp-lime wall structure made in Estonia.

Ingredients of hemp-lime and its advantages as a building material

Hemp has an important position among traditional crops in Estonia, but its use has usually not been related to construction. Due to its strong fibre, hemp has primarily been seen as a raw material for textile products, mainly for making rope, and the inner core of the plant, or the 'hemp hurd', has been cast aside as a by-product. Owing to its porosity, hemp hurd has low thermal transmittance values; when mixed with lime, the resulting composite material, or hemp-lime, is suitable for insulating walls of existing buildings as well as for filling the frames of new buildings (Sparrow, Stanwix 2014). Compared with other types of plant material used for filling, hemp hurd has a relatively high silica content (Lyons 2014), increasing its resistance to biological damage, moisture and fire. Lime creates an alkaline environment around the hemp hurd which is unfavourable for fungi and pests. In comparison with other nature-friendly insulation materials, hemp-lime has a good balance between durability and sustainability.

A good feature of hemp-lime for construction technology is its monolithic nature – instances of uneven density and the resulting potential danger of thermal bridges in external walls have been reduced to a minimum because, when correctly applied, the hemp-lime surrounds and forms a seamless outer envelope over the load-bearing frame. In this case, the wall structure is composed of a wooden frame, hemp-lime and a layer of plaster, reducing the possibility of unexpected occurrences in the thermal and moisture regime in the transition zones from one construction material to another. Kristo Anslan (2015: 30–35) briefly described such constructions based on hemp-lime in his master's thesis.

Hemp hurd is a material of rather small specific weight and with closed pores which, due to its low thermal transmittance, is well-suited for use as insulation. The composition of hemp hurd is an essential factor in the development of the properties of the mixture (Sinka et al. 2015). Arnaud and Gourlay (2012: 50–56) studied the effect of the different length of the hurd pieces on the properties of constructions made of hemp-lime and affirmed that, when the hurd was too finely crushed, the resulting denser mixture of larger specific weight will cause a noteworthy rise in thermal transmittance.

Another main factor is the choice of the binder, which has a great effect on the air and moisture transfer of the wall. Other important factors include the specific weight of the mixture and whether it is convenient to use. My experiments, which I carried out in order to get some practical experience in this field when writing my graduation paper, were focused on comparing three different types of binders and on the indication of possible bottlenecks. The specific weight of a suitable mixture with clay proved to be considerably higher than that of mixtures which were based on air-lime or on natural hydraulic lime. Pouring the lime-based mixture into the prepared casings is much easier and more convenient than working with clay-based mixtures. I also found that mould may spread on the surface of test blocks made of clay. Mould was not found on any test blocks made of hemp-lime. Consequently, the use of clay was excluded in the subsequent tests.

Construction-physical properties

Hemp-lime has good insulating qualities, and it helps to reduce fluctuations in temperature and moisture. This can be seen in the results of measurements carried out at the University of Bath, which are presented in Figures 1 and 2.

Figure 1 represents the results of measurements, carried out in the test building over the course of 11 days, which illustrate the ability of hemp-lime to lessen temperature fluctuations in indoor air. The approximate fluctuation measured in the outdoor air was 15–16 degrees Celsius, but that in the indoor air remained at about 3 degrees Celsius.

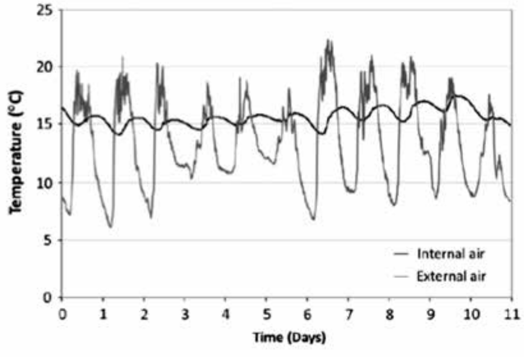

Figure 1. Results of the measurements of indoor and outdoor air temperature. *Source: Lawrence et al. 2012: 273.*

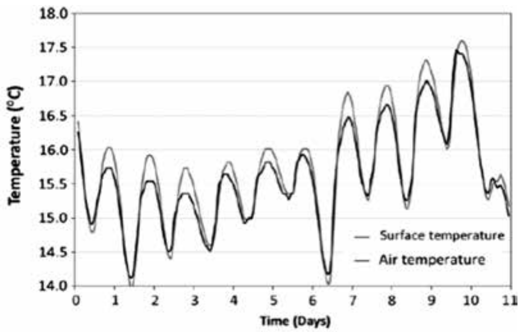

Figure 2. Fluctuations in the temperature of the indoor air and on the internal surface of walls. *Source: Lawrence et al. 2012: 273.*

The results illustrate very well how a building envelope made of hemp-lime can reduce the danger of excessive cooling or overheating due to its large air capacity. This means a more convenient indoor climate for residents, but reducing sharp fluctuations also protects the wooden construction elements surrounded by hemp-lime, thus reducing the danger of moisture accumulation and frost damage.

Besides the differences in indoor and outdoor temperatures, the study also mapped the difference between indoor temperature and the temperature of the internal surface of the building envelope made of hemp-lime. Figure 2 shows that the differences were small, remaining below 0.5 degree Celsius. It is known that, on average, the air cools by less than half a degree when in contact with the wall; therefore, there is no noteworthy danger of condensation. When the air cools by 0.5 degree, its maximum moisture content does not decrease enough to allow the superfluous amount of water to condense on the surface of the wall and damage the coating.

Berardi et al. (2016) present, based on data drawn from extensive research, several comparisons between the construction-physical properties of hemp-lime. According to their data, with the density of hemp-lime at 220–627 kg/m3, the range of specific thermal conductivity remains between 0.06–0.138 W/mK. According to data presented by Lawrence et al. (2012), the compressive strength of hemp concrete or hempcrete remains between 0.05–0.35 Mpa.

Practical testing of different materials

The purpose of the practical testing carried out by the author of this article for his graduation paper, “Introduction and testing of hemp concrete mixtures in the Estonian climate” in 2017, was to find suitable compositions of the mixture for different binders. Besides the air-lime, which is the main

Photo 3. Mixtures of hemp-lime and hemp-clay, separated by an aspen frame. *Photo by Silver Tõnisson.*

component in producing hemp-lime, test blocks were also made of natural hydraulic lime and red clay. Sample blocks of 150x150x150 mm were made using these components in different proportions to test for important differences and possible shortcomings. The objective of testing the hemp hurd mixtures with air-lime, clay and hydraulic lime in different proportions was to find the most suitable mixture recipes for each binder. The immediate purpose of testing was to find suitable mixtures for use in a model wall to be built as a practical part of the graduation paper.

Due to the specific conditions of the location of the model wall, and depending on the advice of the supervisor of the paper, the wishes of the contractor, and a rational assessment of the amount of work needed, it was not possible to build a wall which would meet all the requirements for a wall of a residential building. The frame of the model wall was made of 200x200 aspen beams, which are not appropriate to use in the walls of a building in which it is necessary to ensure the quality of the indoor climate. The main reason for using this wood was the aesthetics of the wall and the fachwerk (or half-timbered) technique used to build it. Another reason was the need for a clear separation line between the lime-based and clay-based parts of the construction to show the differences caused by different building technologies.

Due to the fact that the wall structure of residential buildings differs from that of the model wall, exactly the same solutions cannot be used in practical construction, but they give a starting point for understanding the specifics of different binders and their proportions. One of the most important conclusions is that hemp-clay mixes can develop some mould growth

Photo 4. Hemp-clay and hemp-lime model wall. *Photo by Silver Tõnisson*.

during the beginning of the drying period. This does not mean that clay is unsuitable as a binder for hemp hurd mixtures, but it can prove to be a bit more problematic under certain conditions. Moisture transfer in clay is lower than in hemp, and the clay-based test blocks needed more time to dry. Combined with the factor that, contrary to lime, clay does not form an alkaline environment, this caused the spread of mould on clay-based test blocks.

Photo 5. Mould on the test block made of clay and hemp hurd. *Photo by Markus Pau.*

The amount of mould was smaller on the blocks with less clay content, but the problem was still discernible. Such a problem did not emerge with the mixtures with air-lime and hydraulic lime, no matter how much of the binder was used. The tests showed that in the building of the model wall, the most suitable mixtures contained one part binder, one part water and four parts hemp hurd. Due to the specifics of the model wall, the assessment was made that using more diluted mixtures could have lessened the final strength of the wall. Further research in this area will focus on specifying the composition of mixtures suitable for the walls of residential buildings. The methods of the tests mentioned above are described in more detail in the graduation paper of the author (Pau 2017).

Photo 6. Test block made of air-lime and hemp hurd. *Photo by Markus Pau.*

Effect on the environment

When hemp-lime is used, carbon dioxide is first absorbed by hemp plants during their growth period, and later, by lime during the carbonisation process in the walls. Owing to this, the amount of absorbed CO_2 exceeds the amount of CO_2 emitted into the air during the production of the material. Pavia and Walker (2014: 270) give an overview of research carried out by Boutini et al., which shows that the production of 1 m^2 of the 260 mm-thick hemp-lime layer uses 370–394 MJ energy and absorbs 14–35 kg of carbon dioxide during its lifetime of 100 years. Production of a similar amount of Portland cement uses 560 MJ of energy and emits 52.3 kg of carbon dioxide. With the development of technology and by adjusting methods according to the test results, we can say that hemp-lime has the potential to reach the level of the thermal insulation standard required for zero-energy houses in most climates. It also contributes to the development of a healthier indoor climate and helps to reduce the effects of global warming (Ahlberg et al. 2014: 45).

Photo 7. The author finishing the model wall. *Photo by Silver Tõnisson.*

Future prospects

Reducing the annual energy consumption of buildings and ensuring the quality of indoor air poses an important challenge to the construction industry. In short, this means the need for more effective use of resources in the production, transport, installation and reprocessing of materials. Processing hemp-lime is relatively nature-friendly, easy and uses less energy in comparison with most modern construction materials. The life cycle of construction materials has so far been a relatively under-researched area, but it is clear that the use of resources needs to be mapped and directed in a much more effective way. In the European Union, the energy consumption of buildings accounts for 40% of the total energy consumption, and this number is growing.[1]

The author's further research will focus on testing hemp-lime mixtures in the construction of new buildings as well as in adding thermal insulation to already existing buildings. Adding thermal insulation to walls made of limestone or fieldstone by using hemp-lime seems to be one of the most interesting research subjects. A mixture of a lesser lime content than that made for walls can be used in insulating attics and ceilings. Several old timber frame buildings have been given thermal insulation made of hemp-lime in Great Britain and France, but such methods have not yet been tested in Estonia. The suitability of hemp-lime for the Estonian climate needs confirmation through further practical tests and the analysis of measurement results collected in test buildings.

1 Good practice in energy efficiency. European commission (02.09.2017).

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Photo by Silver Tõnisson.