Addressing Embodied Carbon in Building Envelope Insulation Systems with Hempcrete Bio-composite Materials

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Executive Summary

Efforts to address human contributions to climate change have included a great deal of attention brought to the built environment given the large greenhouse gas emissions associated with this segment of the economy. And while progress has been made towards improving the carbon footprint of buildings, most of the focus has been on reducing carbon emissions from building operations. This has been driven in large part through a combination of more stringent energy codes, energy efficiency initiatives, zero energy building design and construction strategies such as Passivhaus, and the addition of renewable energy generation.

Global attention is now turning to the long-ignored issue of embodied carbon in building materials. Embodied carbon is the carbon emitted in the production, transportation, installation and demolition of materials, and it accounts for 11% of annual emissions globally. With the built environment forecasted to double by 2030, building materials are moving to the forefront as part of the climate solution (UN Environment and International Energy Agency 2017).

This paper will focus on the issue of embodied carbon in buildings by illustrating the potential of an increasingly popular bio-composite insulation material called hempcrete. Hempcrete is comprised of hydraulic lime and a pozzolanic material as a binder, combined with the woody core of the hemp plant which acts a bio-aggregate. This unique and carbon negative infill insulation has the potential to replace more energy intensive materials typically used in building envelope assemblies to achieve the Passivhaus energy standard.

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Embodied Energy in Building Materials

It is generally accepted that human activities play an important role in contributing to the greenhouse gas emissions believed to be driving global temperature increases. Scientists warn that without aggressive efforts to limit and reduce carbon emissions, the world could undergo fairly dramatic and possibly dangerous climate changes such as rising sea levels, severe weather events, and food and water shortages.

No carbon emission reduction strategy would be complete without considering the built environment as it accounts for almost half of total greenhouse gas emissions, more than any other sector of the economy (Fay, 2014.) Most reduction efforts to date have focused on the operating emissions of buildings. This includes enhancements to existing building stocks for improved energy performance as well as higher energy performance standards for new construction to avoid developing long-term investments in assets that are energy inefficient. This focus on energy efficiency is illustrated by the Passivhaus goal of constructing zero or near-zero net energy buildings. The European Union, in fact, has set an ambitious goal requiring that all new buildings be nearly net zero energy buildings by the end of 2020. Publicly owned and occupied facilities were required to meet that standard by the end of 2018. (IPEEC, 2018).

While this is important progress toward a built environment that is carbon neutral, the very construction of these high performance buildings implies substantial carbon emissions. In order to achieve low operational energy consumption, a larger proportion of a building's lifecycle carbon emissions can occur with investments in increased insulation, heavier building materials and additional energy efficiency technology. (Thormark, 2001) More material means more embodied energy, defined as the "sum of the energy requirements associated, directly or indirectly, with the delivery of a good or service" (Cleveland & Morris, 2009). Combined with the construction processes involved in building assembly, the embodied carbon of a building's materials logically becomes even more relevant in low operational energy buildings as all of this substantial carbon "investment" occurs at the beginning of the building lifecycle. And while operational energy consumption can be improved over time with energy retrofits and the addition of renewable energy generation, the embodied carbon emissions of building materials are set in stone from day one of building construction.

Global building operations and construction together account for 36% of energy use and 39% of energy-related carbon dioxide (CO2) emissions. Just the material use in buildings alone is estimated to account for 28% of these emissions, or 11% of total carbon emissions related to global human activity (UN Global Status report 2017 page 8). With approximately 6 billion square feet of new building construction every year in the United States, for example, it is estimated that the embodied carbon emissions from the construction processes and materials alone has a carbon footprint of 150 million metric tons. That embodied energy content considers the lifecycle of the materials from mining, manufacturing, and construction. With 25 million metric tons of carbon emissions every year estimated from the operation of that new space, we can extrapolate that the embodied carbon content of materials represents about six years of building operations. This is before building operations emissions even begin, and is well into some of the shorter time-frame carbon reduction goals that have been set in place in more aggressive policy regimes like the European Union. (The Total Carbon Study, 2015). Working toward a future that contemplates zero-emission, fully decarbonized buildings means that the opportunity to find more sustainable practices in the building materials and construction sector is large and meaningful.

Building Envelope Systems

Building envelope systems are the key interface between the interior (conditioned) and the exterior (unconditioned) environment and are a key variable in reducing operational energy consumption. The Passivhaus focus on a high level of occupant comfort while using very little energy for heating and cooling typically results in envelope assemblies that contain highly processed and complex building materials. By extension, this implies high embodied energy. One example would be the "perfect wall" as articulated by the Building Science Corporation. This envelope detail can be applied to wall, roof and floor planes.

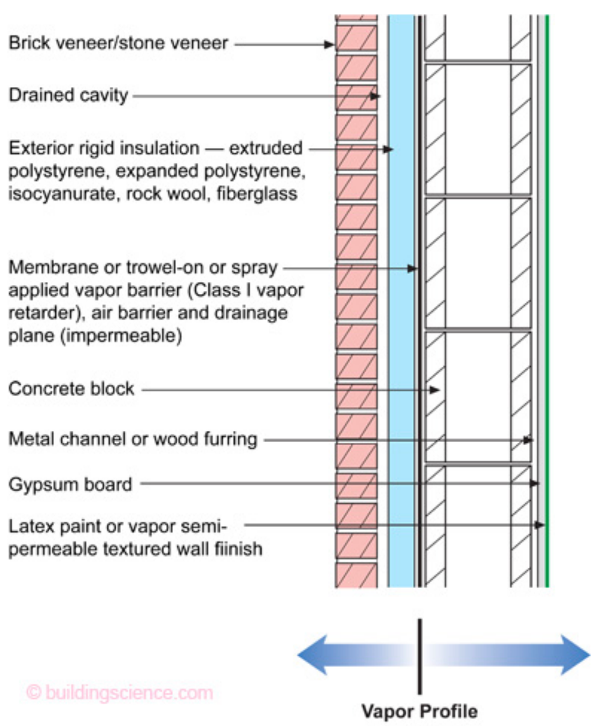


Figure 1: The Institutional Wall as detailed by the Building Science Corporation.
Cited as being the best wall they know how to construct. This approach is advocated to achieve Passivhaus performance due to its ability to manage water, air penetration, vapor transfer and thermal regulation.
Source:https://www.buildingscience.com/documents/insights/bsi-001-the-perfect-wall Joseph Lstiburek. July 15, 2010.

In addition to the carbon footprint of the materials used to create the “perfect wall,” there are serious toxicity issues associated with some of the insulation products advocated. Polystyrene, for instance, contains antioxidant additives and ignition retardants known to be environmentally toxic. Its production also results in benzene and cholorfluorocarbon emissions. Polyurethane is derived from isocyanates which are classified as potential human carcinogens (Liang & Ho 2007). Is there a more “planet-friendly” way to deliver similar performance characteristics as the “perfect wall” for Passivhaus performance while using lower embodied energy and less toxic building materials?

Bio-Composite Insulation Materials

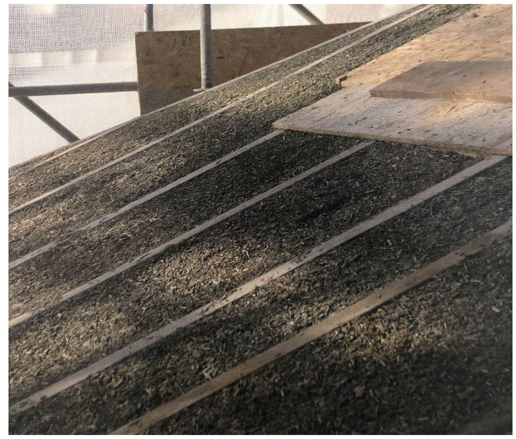
The search for lower carbon footprint and less toxic insulation materials has brought researchers to reconsider more traditional building methods like bio-composite materials. These materials come from traditional building techniques that have stood the test of time and are, by nature, less processed and have a lower carbon footprint. They are comprised generally of an inorganic binder like clay or hydraulic lime mixed with a renewable crop waste like straw, hemp or rice husks. Examples of this are high thermal mass approaches like rammed earth and adobe, and so-called light earth approaches like clay-straw and hempcrete. (Strozs M., Sahmenko G. 2011) The high thermal mass examples bring the advantage of structure and the dampening of temperature swings in one material. Light earth examples, like hempcrete, bring the advantage of the ability to optimize bulk density, and thereby thermal transfer rates, by altering the mix design. These bio-composite materials can also be more easily disposed of at the end of their lifecycle as they can be composted or simply tilled into the soil.

Hempcrete

Hempcrete is a mixture of a plant-based aggregate, hemp shiv, and a binder, typically hydraulic lime amended with a pozzolanic material. It is defined as a carbon negative building insulation material as more carbon is sequestered in the material than is released into the atmosphere through the production process. The CO2 absorbed in the growing of the hemp more than offsets the CO2 produced in the manufacture of the binder. In addition, during the life cycle of calcium hydrate (lime) a large portion of the CO2 emitted in manufacture is reabsorbed as it cures and reverts back to limestone (calcium carbonate) (Sinka & Samehnko 2013.)

Reimagining the Perfect Wall

Hempcrete can be installed in a building as infill insulation either as prefabricated blocks or panels, or cast in situ at the building site. Cast in situ installation is optimal from the perspective of Passivhaus. The mixed material is in a more plastic state and careful detailing allows for molding the material in and around structural elements. It can also fill joints between other components like doors and windows. This helps eliminate open gaps or channels in the fabric of the building where air can infiltrate. This can be applied not only to walls, but also to floor and ceiling assemblies as well, mimicking the concept of the “perfect wall’s” application to all planes of the building.

Hempcrete cast in situ in wall, floor and ceiling assemblies
Source: The Hempcrete Book. Designing and building with hemp-lime

Hempcrete and the Management of Moisture

Hempcrete is described as a breathable material as it allows the transfer of moisture through the walls. This helps to avoid condensation build up and protects the building structure from degradation. It also prevents the thermal performance of the material from being compromised. This inherent breathability of hempcrete facilitates vapor transfer and contributes to a healthier indoor air quality.

Traditional lime plaster is typically the exterior rendering applied to hempcrete. Lime plaster is also a low embodied carbon construction material. While “old-fashioned,” it is still considered state of the art for providing protection against wind-driven rain and other moisture penetration. It is also vapor permeable with excellent drying potential. Any moisture that does penetrate the exterior sheathing does not get trapped and raise the potential for mold. The fact that the hempcrete binder is lime also mitigates mold and pest risk. All of the above ensures building envelope durability, the most fundamental definition of building sustainability.

Hempcrete as an Air Control Layer

A continuous air barrier is a key performance layer of a high performance building envelope. The interface between different building elements is where the greatest opportunity for air leakage occurs. Buildings constructed using hempcrete exhibit a monolithic wall system with no cavities within and no requirements for membranes. This makes hempcrete buildings inherently air tight, and the consistency of construction details helps ensure that they remain that way without ongoing maintenance. The simplicity of hempcrete installation and the limited materials palette also means contractor errors are kept to a minimum.

Hempcrete as a Thermal Control Layer

Hempcrete's thermal insulation value is dependent on the bulk density of the mix design, the thickness of the material and the degree to which the material is compacted within the wall. Typical insulation values are, however, quite good with a 12 inch wall section exhibiting a U-value of approximately 0.2. And because the hempcrete is cast in place, it fills virtually the entire cavity in a monolithic blanket of insulation. This compares favorably with a 12 inch section of EPS insulation, for example, which has a similar U-value. Hempcrete has other performance advantages over EPS, one of the greatest being the ability to "optimize" the mix design depending on the building elevation. For instance, one may prefer a higher density mix for a southern exposure to provide thermal mass, while a lighter density mix may be more appropriate for a western exposure in a hotter climate zone. This ability to optimize a mix design for bulk density is unique to bio-composite light mixes like hempcrete. This allows the building designer to blend the best characteristics of lightweight insulation products with the advantages thermal mass brings to flattening out temperature variations. In short, hempcrete can provide both good insulation and good thermal mass.

Conclusion

Building envelope systems are a natural place to look when seeking out opportunities to both reduce embodied carbon and to improve long term building performance given the large contribution of the building sector of the economy to climate change. The ubiquitous use of high embodied content materials and the complexity of envelope assemblies in modern construction practice raises questions about long term durability against carbon cost. There are tremendous opportunities to address these issues with traditional, low-tech building systems while constructing healthy, net or near-zero energy and low embodied carbon material structures. Bio-composite materials like hempcrete offer historical techniques in a modern engineering context to provide a monolithic insulation system that is robust, carbon negative, durable and easily recycled with no negative environmental impact.

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