

Comparing Facade Materials: Traditional versus Net-Zero and Sustainable

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Abstract:

The evolution of facade materials reflects a broad shift in architectural practice, from traditional construction methods to performance-driven and environmentally responsible design. Conventional facades, often composed of brick, stone, concrete or metal, have long been valued for their durability and structural integrity. However, they typically embody high energy and carbon footprints. In contrast, emerging net-zero and sustainable facade systems integrate low carbon cladding, bio-based or recycled insulation materials and high efficiency assemblies that reduce environmental impact while enhancing thermal performance. By comparing these material strategies, it will not only reveal technical characteristics, but it also offers insight into how future facades can reconcile aesthetic tradition with the urgent demands of climate responsive architecture.

Introduction:

Our goal for this report is to compare newer facade materials (outer materials, insulation, etc.) with historically common materials in terms of thermal properties. We want to discover if these new materials meet similar thermal requirements while being more sustainable than current materials. This will include calculating thermal properties, comparing how much of a material is needed in comparison to others (ex. comparing insulation materials), and calculating the cost of materials used in carbon emissions. We will compare three facades: a traditional brick facade, a sustainable facade, and a low-carbon facade.

Methodology:

This study employs a comparative analytical methodology to evaluate traditional facade materials against net-zero and sustainable alternatives. Comparing three different facade types will give a larger insight into how impactful a newer sustainable alternative can be. While diving deeper into the costs, materials properties, and calculations of these materials, the collected data enables an understanding of how traditional materials and sustainable facade systems align with contemporary net-zero alternatives.

Important factors of facade design

According to the Building Science Corporation, these are the four main control layers needed for every wall, listed in order of importance (Lstiburek, 2010).

- a rain control layer: this layer is located on the outer-most part of the exterior wall and protects the structure from moisture, which can lead to corrosion or decay.
- an air control layer: air control is a mix of a few things – moisture, heat, and overall infiltration of the envelope. Maintaining a continuous barrier can be one of the most effective ways to prevent infiltration.
- a vapor control layer: vapor can be more concerning than regular water, as it can penetrate deeper into the building by being mixed in with the air and condensate on any surface. Vapor barriers are needed for almost every building, as vapor may be an issue from both the outside and the inside. Depending on the climate region, a vapor barrier may be placed on the inside or outside of the main wall (Lstiburek, 2009).
- a thermal control layer: thermal control is deemed the least important for durability, but it can make or break the overall energy usage within a building due to heat entering or escaping the building through various means. Adding insulation and maintaining an airtight building can greatly reduce the overall energy needed for thermal compensation within the building.

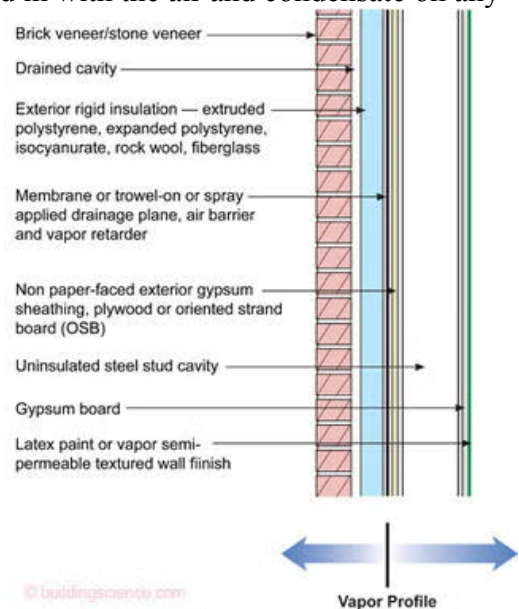


Figure 1: "The Commercial Wall" (Lstiburek)

Sustainability and embodied carbon

Operational carbon is "The total greenhouse gas emissions associated with the operation of an asset (i.e., building) during the use stage of the asset" (ASHRAE). As of right now, many sustainability efforts are already dedicated to reducing operational carbon footprints such as ASHRAE and LEED.

Embodied carbon is defined as "the total greenhouse gas emissions arising from the manufacturing, transportation, installation, maintenance, and disposal of an asset (i.e., building)" (ASHRAE). Currently, embodied carbon contributes to about 11% of all carbon emissions globally (WorldGBC). One major concern regarding embodied carbon is that it is difficult to calculate in comparison to operational carbon. This is due to many factors, including the large range of manufacturers and methods for each type of material (some may use coal while others may have access to hydroelectricity), the large variety of transportation needs that range based on distance and material size, and the overall lack of measurements in relation to harvesting materials.

Solutions for reducing embodied carbon (Tigani et al.): Material selection can have a great impact on reducing the embodied carbon, in choosing materials that require little to no extraction, low carbon such as, timber or bamboo, local materials, this offsets carbon emissions related to transport, recycled materials. While understanding these material qualities, it is important to keep in mind that some materials require a lot of carbon to reuse materials.

Other considerations include carbon offset; some materials or additions to the building can offset carbon emissions. The facade design should be considered, as architects should design more effectively with consideration towards air gaps, thermal bridges, etc. Keep into consideration the operational lifetime of the chosen materials that require less maintenance. Another option is a modular and prefab construction; these methods reduce emissions and waste.

Sustainability does not always equal low embodied carbon emissions. The use of good insulators to reach net-zero energy does not have a requirement for the types of materials used. A building can be sustainable through minimizing overall energy consumption through a variety of means, whereas a carbon-neutral building may be utilizing specific materials and may not be as efficient energy-wise. They are not always overlapping goals.

Other concerns/considerations

Not all climates require the same types of building facades; some can rely on more passive systems such as wind, sunlight, and even high quantities of snow. Some climates may have a smaller demand for higher R-values, which can overall reduce the cost of materials. There's also the consideration of the durability of the materials, as some may be more vulnerable to certain climate types. Different materials have different penetration and/or infiltration rates, which can also differ depending on the climate zone.

While some materials are more efficient than others carbon-wise, the cost might also be a considerable factor. It's important to consider when choosing materials that are in the budget range of the project. There may be a lack of suppliers in the area, raising the overall cost due to demand and transport. Not only can the materials be expensive, but there is also the cost of labor, which can vary depending on the type of assembly and the conventionality of it. If very few tradesmen know how to build a certain type of wall assembly with specific materials, the cost of the project can go up due to the demand.

Depending on the location, different building design requirements must be met. Some councils and companies may have strict guidelines, but others may be preferences, such as LEED, which has both minimum requirements and other goals to achieve certifications.

Sometimes a certain type of aesthetic goal can affect the performance of the building. This includes window-wall ratio (WWR), texture, and lighting. This can also affect the thickness of walls; it is usually assumed that thicker walls which have thicker layers of insulation would be better efficiency-wise. Although this may be the case, consideration of cost should be applied in these scenarios.

Materials also break down over time and can reduce air quality. Some materials, such as XPS, are known to off-gas toxic chemicals over time, which reduces the air quality and decreases the

R-value of the materials as the gases get replaced with air within the material composition (Pierson and Reynolds).

While there is a difference between sustainability and low carbon, there is also discourse about whether materials deemed sustainable are beneficial in the long term. Heavy timber, for example, is widely received as a sustainable and low-carbon material over other structural members, but the World Resources Institute states that the overuse of heavy timber may be detrimental to the environment, as the process of harvesting material isn't carbon-neutral and the demand would outweigh the production (Searchinger).

Sustainable materials study

Insulation: insulation is one of the biggest embodied carbon contributions, as most insulative materials utilize some sort of aeration (requires energy and/or aerosols) to maximize the effectiveness. Many traditional materials studies have shown that certain materials, such as fiberglass and spray foam insulation, are causing long-term health issues for people (Pierson and Reynolds). By comparing traditional and more sustainable insulative materials, it was found that the sustainable materials' overall R-values may be on the lower side (R-3.5), but their carbon footprint was under 25% of the traditional materials (0.2-1.5 kg CO₂e per square meter per inch of thickness) (Table 1).

There have been recent developments in sustainable insulation, many of which have been tested and proven to be safer and durable enough to last the lifespan of a building (One Community, Table 2). This shows that the overall development in sustainable insulation can replace traditional insulation and still match or surpass the standards set by these materials.

Standards for comparison

- All walls must reach an R-value of R-30. This is determined to be ideal because this is the minimum required R-value for Illinois according to 2021 Illinois Energy Conservation Code (International Code Council).
- All walls must include the base layers needed for regular functions. This includes the outermost facade, insulation, vapor barrier, and framing.
- All walls must not be thicker than 24in. Aesthetics are a key variable in architectural design, and most clients aren't willing to pay for unattractive facade envelopes.
- Walls will be calculated with a 9ft x 12ft wall area with wood 2x4s located at every 16". Framing usually varies from building to building, but, for this investigation, maintaining consistent framing allows for other, more considerable material changes to be investigated.
- Walls will be compared both with and without fenestration. This fenestration must be 6x8 in dimension. Fenestration can vary in U-values, as some are more efficient, sustainable, or lower in carbon emissions. When doing the carbon calculations, these windows will not be taken into consideration, as the information for fenestration embodied carbon is even less accurate than the materials' sources. However, it is important to note that many parts of the window will increase the embodied carbon, such as increasing the number of panes, adding coatings, tinting the glass, and what gas is filling the spaces (Saadatian et al.).

- Walls will be compared based on R-value and embodied carbon calculations. Embodied carbon will be estimated based on resources found via Table 1, Building Transparency.org, and Kaleidoscope.

Wall 1: Traditional Brick Facade

- Brick layer, double (3.5in thick, R-0.44)
- Draining cavity
- Exterior rigid insulation (3in, polyiso, R-6.5 per in)
- Moisture barrier membrane
- OSB (1/2 in, R-0.68)
- Stud cavity with blow-in insulation (2x4 at 16in, R-4.38, spray foam, R-6.5 per in)
- Gypsum board (5/8 in, R-0.57)
- Triple glazing, e = .10 on surfaces 2, 3, 4, or 5, wood frame, U-0.25

Without fenestration:

Area = 9ft*12ft = 108 sqft

$R_{tot} = 0.44 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 3\text{in} (6.5 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) + 0.68 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 4.38 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 0.09$
 $) + 3.5\text{in} (6.5 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) (0.91) + 0.57 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} = \underline{\underline{42.22 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$

Wall thickness: 12.125in

With fenestration:

Wall area = 108sqft - (6ft * 8ft) = 60 sqft => 56% total area

Fenestration area = 48 sqft => 44% total area

$R_{tot} = 42.22 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} (.56) + 1/0.25 \text{ Btu}/ \text{F}\cdot\text{h}\cdot\text{ft}^2 (.44) = \underline{\underline{25.4 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$

Carbon emissions (from Table 3):

$902.88 \text{ KgCO}_2 + 105.35175 \text{ KgCO}_2 + 324 \text{ KgCO}_2 + 65.268 \text{ KgCO}_2 + 2170.891146 \text{ KgCO}_2 + 43.848 \text{ KgCO}_2 = \underline{\underline{3612.24 \text{ KgCO}_2}}$

Wall 2: Sustainable Facade

- Terracotta rainscreen (hollow, 2 in, R-0.6)
- Aluminum support system (1 in, negligible R-value)
- Mineral Wool exterior continuous insulation (7 in, R-4 per in)
- Moisture barrier membrane
- OSB (1/2 in, R-0.68)
- Stud cavity with rigid polyiso insulation (2x4 at 16in, R-4.38, polyiso, R-6.5 per in)
- Gypsum board (5/8 in, R-0.57)
- Quadruple glazing, e = .10 on surfaces 2, 3, 4, or 5, 1/4in krypton spaces, insulated fiberglass frame, U-0.12

Without fenestration:

$$R_{\text{tot}} = 0.6 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 7 \text{ in } (4 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) + 0.68 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 4.38 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}(0.09) + 3.5 \text{ in } (6.5 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) (0.91) + 0.57 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} = \underline{\underline{46.9467 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$$

Wall thickness: 15.625in

With fenestration:

$$R_{\text{tot}} = 34.947 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} (.56) + 1/0.12 \text{ Btu}/\text{F}\cdot\text{h}\cdot\text{ft}^2 (.44) = \underline{\underline{29.957 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$$

Carbon emissions (from Table 4):

$$15.50016 \text{ KgCO}_2 + 366.12 \text{ KgCO}_2 + 1164.24 \text{ KgCO}_2 + 324 \text{ KgCO}_2 + 65.268 \text{ KgCO}_2 + 111.84844 \text{ KgCO}_2 + 43.848 \text{ KgCO}_2 = \underline{\underline{2090.8246 \text{ KgCO}_2}}$$

Wall 3: Low-Carbon Emission Facade

- Tulipwood/poplar lumber sheathing (1 in, R-1.1)
- Galvanized steel support system (1 in, negligible R-value)
- Natural Hemp insulation (10 in, R-3.5)
- Moisture barrier membrane
- OSB (1/2 in, R-0.68)
- Stud cavity with hemp insulation (2x4 at 16in, R-4.38, polyiso, R-3.5 per in)
- Gypsum board (5/8 in, R-0.57)
- Quadruple glazing, e = .10 on surfaces 2, 3, 4, or 5, 1/2in air spaces, wood frame, U-0.2

Without fenestration:

$$R_{\text{tot}} = 1.1 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 10 \text{ in } (3.5 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) + 0.68 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} + 4.38 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}(0.09) + 3.5 \text{ in } (3.5 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}) (0.91) + 0.57 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} = \underline{\underline{51.1083 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$$

Wall thickness: 16.625in

With fenestration:

$$R_{\text{tot}} = 51.1083 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu} (.56) + 1/0.2 \text{ Btu}/\text{F}\cdot\text{h}\cdot\text{ft}^2 (.44) = \underline{\underline{31.11 \text{ F}\cdot\text{h}\cdot\text{ft}^2/\text{Btu}}}$$

Carbon emissions (from Table 5):

$$-76.8096 \text{ KgCO}_2 + 28.0938 \text{ KgCO}_2 + 651.9744 \text{ KgCO}_2 + 181.44 \text{ KgCO}_2 + 36.55008 \text{ KgCO}_2 + 8.9479 \text{ KgCO}_2 + 24.55488 \text{ KgCO}_2 = \underline{\underline{854.75146 \text{ KgCO}_2}}$$

Conclusion:

The comparison of these three building materials highlights the evolving priorities of contemporary architectural practice. While conventional materials such as brick continue to offer durability, and its established construction techniques, the higher embodied carbon and limited thermal performance underscored its environmental limitations. It appears that it is possible to cut embodied carbon emissions to about a quarter of the traditional facade assembly without sacrificing too much wall thickness. However, these calculations are based on estimations from non-specific to our location sources, which will throw off the embodied carbon that is included in transporting materials to the site. Window assemblies are also going to contribute a lot to embodied carbon, as manufacturing glass and treating surfaces require quite a bit of energy.

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Appendix

Table 1: Traditional Vs Sustainable Insulation Materials (Pierson and Reynolds)

Material	R-Value (per inch)	Embodied Carbon/Carbon Footprint (kg CO ₂ e per square meter per inch of thickness)	Other info
Fiberglass	2.9-3.8	1.7-2.5	Irritating to skin and lungs during installation, degrades over time if exposed to extreme conditions
Cellulose	3.2-3.8	0.2-1.1	Prone to settling over time, important to select high density
XPS Rigid	5	3.5-5.0	Uses greenhouse gasses for production, non-recyclable, linked to off-gassing over time
EPS	3.6-4	1.5-3	Better overall than XPS, not super durable in extreme conditions, affordable
Polyiso	6.5-7	3.5-4	Durable, not biodegradable, less effective below 25F
Spray foam	6.5-7	2-6	Durable, new developments that are less bad for environment, MANY health risks associated
Rigid wood fiber	3.1-4	1-2.5	Can absorb carbon, more susceptible to water, potential contaminants when reusing wood fiber
Mineral Wool	3.7-4.2	2.5-3.8	Good overall, but more expensive
Recycled cotton	3.5	0.3-1	Renewable, biodegradable, needs moisture management, may compress over time, less available
Natural hemp	3.5	0.3-1	Renewable, biodegradable, easy to grow, slightly more expensive
Sheep's wool	3.5	0.8-1.5	Renewable, biodegradable, higher carbon footprint than plant-based

Table 2: Sustainable Insulation Materials (One Community)

Material	Make-up	R-value (per inch)	Cost (\$ per sqft per in)	Pros	Cons
ROCKWOOL Comfort Batt	Natural rock and slag	4	0.06	<ul style="list-style-type: none"> • Entirely nontoxic • Naturally mold and rot resistant • Excellent flame and smoke resistance • Made of natural and recycled materials • No known direct ecological or atmospheric impacts • Extremely flame and smoke resistant • 40% recycled materials • Production energy for wool is quite low • DIY installation easy • expected to last lifetime of the building • Excellent moisture management and good sound absorbency • GREENGUARD Gold Certified, LBC Red List Free, and contributes to LEED points 	<ul style="list-style-type: none"> • No vapor barrier, likely requiring additional installation • Customer reviews reveal main cons to be availability and cost
Sheep Wool Batt	90-100% wool	3.5-4.3	0.15-0.20	<ul style="list-style-type: none"> • Entirely nontoxic, and naturally filters out airborne toxins • No known negative environmental side effects • Easy DIY installation • Lower than average density, making it easier to transport and work with • High durability, expected to last the lifespan of the building • Good moisture management • Can help score LEED points • Good sound absorbency • Naturally mold and pest resistant 	<ul style="list-style-type: none"> • No vapor barrier, likely requiring additional installation
ROCKWOOL Comfort Board	Rock wool	4.2	0.26	<ul style="list-style-type: none"> • Entirely nontoxic • No known direct ecological or atmospheric impacts • Extremely flame and smoke resistant, it will not even ignite when exposed to direct flame • Made from 40% recycled materials • Production energy for wool is low • Batts make DIY installation easy • Highly durable, expected to last lifetime of the building • Excellent moisture management and good sound absorbency • GREENGUARD Gold Certified, LBC Red List Free, and contributes to LEED points 	<ul style="list-style-type: none"> • Very high price per sq. ft. per R-value • High density, heavier than most products • No vapor barrier, likely requiring additional installation • Customer reviews reveal availability may be a concern

DIY Aircrete	Cement, water, foam	3.9	0.05	<ul style="list-style-type: none"> • Entirely nontoxic • Extremely fire-resistant • DIY production and installation • No known adverse environmental effects • Good moisture management and sound absorbency 	<ul style="list-style-type: none"> • Likely will need to purchase some extra supplies and machinery for DIY production • Claims to be durable, but some concerns about shrinkage over time which reduces the air seal • No vapor barrier, likely requiring additional installation
HempWool Fiber Batt	92% hemp,	3.7	0.11	<ul style="list-style-type: none"> • Entirely nontoxic, and can even absorb harmful chemicals • Naturally hypoallergenic and mold resistant • Good fire resistance • A sustainable, renewable material • Acts as a carbon sink • DIY installation • Highly durable • Can help score LEED credits • Good sound absorbency 	<ul style="list-style-type: none"> • No Health and Safety Data Sheets readily provided on their website • Inferior moisture management, no claims of water resistance, instead it is vapor permeable
Thermacork	Cork, water	4.0	0.56	<ul style="list-style-type: none"> • Entirely nontoxic and VOC-free • Naturally hypoallergenic and mold resistant • Cork is renewable, requires little energy to produce, and improve soil health • Cork acts as a carbon sink • DIY installation • Nonhazardous and flexible disposal at the end of the product's life, it is recyclable and compostable • High durability, expected to last 50-60 years without loss of characteristics • Great moisture management, low water absorption 	<ul style="list-style-type: none"> • Class B Fire Rating • Most of the cork is harvested in Portugal, causing high transportation costs to get this product to the US • Very expensive per sq. ft. per R-rating • High density, making installation and transportation more difficult • Poor sound absorption • No vapor barrier, likely requiring additional installation
Hempitecture HempCrete	Limestone, hemp	2.5	N/A	<ul style="list-style-type: none"> • Entirely nontoxic, and even absorbs harmful chemicals • Naturally pest, rot, and mold resistant • Excellent fire resistance, Class A rating • Renewable resource that is sustainably grown and not energy-intensive • Acts as a carbon sink • Hemp is biodegradable • DIY installation • Highly durable due to the natural strength of hemp fibers • Good moisture management, but not ideal for very humid climates • Helps score LEED points • Good sound absorbency • Allegedly doesn't require a vapor barrier 	<ul style="list-style-type: none"> • No specific data sheet provided for this product, because you buy the ingredients and mix it yourself • Unknown cost per sq. ft. per R-rating • Will need extra supplies and machinery to mix the HempCrete yourself, also more labor-intensive than other options • Low R-value per inch, which may require thicker walls to reach sufficient insulation, which can cut into living space

Straw Bales	straw	1.5	0.01-0.05	<ul style="list-style-type: none"> • Entirely non-toxic • Good fire resistance when properly installed • Straw is a naturally occurring byproduct of other agricultural harvesting that is typically just composted or burned • Low production energy • Straw absorbs CO2 from the atmosphere • Straw is 100% biodegradable • Excellent cost per sq. ft. per R-rating • DIY installation • Good durability, can last 100 years if properly installed and maintained (but if it gets wet the lifespan is reduced) • Can help score LEED points • Good sound absorbency • Not necessary/recommended to install a vapor barrier 	<ul style="list-style-type: none"> • If the straw gets wet it becomes susceptible to mold growth • Transportation energy and costs can be high depending on proximity • Storage of bales may require extra costs and effort to keep them dry • May need additional supplies, such as chainsaw to cut bales to size and may require thicker plaster • Installation is more labor-intensive than that of other products • High density makes transportation and installation more challenging • Average moisture management, if bales absorb more than 20% of their weight they may be subject to rot and they lose insulative qualities • Cost and availability of straw bales varies widely depending on location • Only an option for new construction • not always compliant with local building codes.
Bonded Logic Ultra Touch Denim Insulation	80% denim	3.7-4	0.06	<ul style="list-style-type: none"> • No long-term toxicity dangers • Good mold, fungi, and bacteria resistance • Good fire resistance (Class A) due to being treated with boric acid • Cotton is a renewable resource • Very low manufacturing energy • Good cost per sq. ft. per R-rating • DIY installation • Low density, making transportation and installation easier • Highly durable, should last 30-50 years • LEED Certified Green building material • Good sound absorbency 	<ul style="list-style-type: none"> • Post-consumer denim could contain residues of chemically-based laundry products, which likely is not widely toxic but might be a potential problem for those who are chemically sensitive • Though cotton has a small carbon footprint, the processing of dyeing the denim results in significant emissions • Should be biodegradable when its time to dispose of, however, there are environmental concerns of various chemicals in the recycled materials • Very poor moisture management • No vapor barrier, likely requiring additional installation
Greenfiber Blended Blow-In Insulation	85% recycled newsprint (cellulose)	3.7	0.01	<ul style="list-style-type: none"> • Good fire resistance • Low manufacturing and transportation energy • No direct atmospheric effects • Excellent price per sq. ft. per R-rating • DIY Installation • Readily available at local hardware stores • Good moisture management • No need for a vapor barrier 	<ul style="list-style-type: none"> • Toxicity issues • Concerns of mold growth due to being made of cellulose • Some materials have ecotoxicity concerns, making safe disposal questionable • May need to rent a blow-in machine for installation • typical lifespan is 20-30 years • Poor sound absorbency

Table 3: Embodied carbon emissions per material (Wall 1)

Material	KgCO2 (building transparency.org and kaleidoscope)	Thickness (in)	Sqft wall	KgCO2 per wall	Sqft w/ fenestration	KgCO2 per wall w/ fenestration
Brick	8.36 per sqft	4	108	902.88	60	505.6128
Polyiso	0.4911 per sqft RSI	3	108	105.35175	60	58.99698
OSB	162 per yd ³	1/2	108	324	60	181.44
2x4 wood stud	51.8 per yd ³	3.5	9.72	65.268	5.4432	36.55008
Spray foam	0.171 per sqft RSI	3.5	98.28	2170.891146	55.0368	1215.699042
Gypsum board	0.406 per sqft	5/8	108	43.848	60	24.55488

Table 4: Embodied carbon emissions per material (Wall 2)

Material	KgCO2 (building transparency.org and kaleidoscope)	Thickness (in)	Sqft wall	KgCO2 per wall	Sqft w/ fenestration	KgCO2 per wall w/ fenestration
Hollow terracotta tile	0.14352 per sqft	2	108	15.50016	60	8.68
Aluminum support system	3.39 per sqft	1	108	366.12	60	205.0272
Mineral wool insulation	0.385 per sqft RSI	7	108	1164.24	60	651.9744
OSB	162 per yd ³	1/2	108	324	60	181.44
2x4 wood stud	51.8 per yd ³	3.5	9.72	65.268	5.4432	36.55008
Polyiso	0.4911 per sqft RSI	3.5	98.28	111.84844	55.0368	62.635
Gypsum board	0.406 per sqft	5/8	108	43.848	60	24.55488

Table 5: Embodied carbon emissions per material (Wall 3)

Material	KgCO2 (building transparency.org and kaleidoscope)	Thickness (in)	Sqft wall	KgCO2 per wall	Sqft w/ fenestration	KgCO2 per wall w/ fenestration
Tulipwood lumber sheathing	-1.27 per sqft	1	108	-137.16	60	-76.8096
Galvanized steel support system	3.01 per sqft	1	108	50.1675	60	28.0938
Hemp insulation	0.5 per square meter per in	10	108	1164.24	60	651.9744
OSB	162 per yd ³	1/2	108	324	60	181.44
2x4 wood stud	51.8 per yd ³	3.5	9.72	65.268	5.4432	36.55008

Hemp insulation	0.5 per square meter per in	3.5	98.28	15.978	55.0368	8.9479
Gypsum board	0.406 per sqft	5/8	108	43.848	60	24.55488