

**An Investigation Into the Use of Cob and/or Straw Bale Construction in Nonresidential  
Buildings**

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**University of British Columbia**

**APSC 262**

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**An Investigation Into the Use of Cob and/or Straw Bale Construction in  
Non-residential Buildings**

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## ABSTRACT

The University of British Columbia (UBC) Farm is planning on building a new Farm Centre to welcome guests and educate visitors. As part of this objective, the UBC Farm wishes to investigate straw-bale and cob as potential construction materials. With a major focus on the economic and regulatory impacts, this paper examines the effects of these non-traditional materials.

This analysis take the form of a triple-bottom line assessment; linking the economic, social and environmental impacts of the proposed materials. Two case studies were used to provide a basis for the analysis; both non-residential buildings of a similar size to the proposed UBC Farm Centre. Additionally, primary and secondary research was conducted to quantify the findings. Interviews with industry experts were used, as well as a thorough examination of academic research.

This analysis shows that while straw-bale and cob offer significant economic, social and environmental advantages, these are conditional on specific criteria. Regulatory and economic concerns suggest that neither straw-bale nor cob should be used as a load-bearing component. A timber-frame structure with traditional protective wall-siding is recommended (certain plasters could be used); using the straw-bale as the main wall material and cob as a coating on either side. This will allow the UBC Farm to take advantage of the benefits of these proposed materials while minimizing any potential for regulatory issues.

# TABLE OF CONTENTS

<b>LIST OF ILLUSTRATIONS.....</b>	<b>3</b>
<b>1.0 INTRODUCTION.....</b>	<b>5</b>
<b>2.0 CASE STUDY A - DEMMITT COMMUNITY HALL.....</b>	<b>6</b>
<b>3.0 CASE STUDY B - INSPIRE BRADFORD BUSINESS PARK.....</b>	<b>7</b>
<b>4.0 ECONOMIC ANALYSIS.....</b>	<b>9</b>
4.1 Cost of Construction	9
4.2 Lifetime Costs	10
<b>5.0 SOCIAL ANALYSIS.....</b>	<b>12</b>
5.1 UBC Developmental & Building Regulations	12
5.2 BC Building Code	12
5.2.1 Thermal Insulation [Section 9.25.2]	13
5.2.2 Air Barrier System [Section 9.25.3]	13
5.2.3 Vapour Barriers [Section 9.25.4]	14
5.3 LEED Buildings at UBC	16
<b>6.0 ENVIRONMENTAL ANALYSIS.....</b>	<b>17</b>
6.1 Carbon Impact Indicators	17
6.1.1 Sequestered Carbon	17
6.1.2 Embodied Carbon	18
6.2 Operational Indicators	19
6.2.1 Insulating Properties	19
6.2.2 Thermal Mass	20
<b>7.0 CONCLUSION.....</b>	<b>21</b>
7.1 Triple Bottom Line Assessment - Economic Analysis	21
7.2 Triple Bottom Line Assessment - Social Analysis	21
7.3 Triple Bottom Line Assessment - Environmental Analysis	21
7.1 Triple Bottom Line Assessment - Conclusion	21
<b>8.0 RECOMMENDATIONS.....</b>	<b>22</b>
8.1 Economic	22
8.2 Social	22
<b>REFERENCES.....</b>	<b>23</b>

# LIST OF ILLUSTRATIONS

Table 1 - Results of Vapour Permeance Test Results.....15-16  
Figure 1 - Total house materials CO2 emissions.....18  
Table 2 - Materials required for construction and associated embodied energies.....19

## 1.0 INTRODUCTION

The UBC Farm, as part of its organizational goals, sets high standards for environmental and social sustainability. These standards manifest themselves in the UBC Farm's proposed plan to build a new UBC Farm Centre; a building for education and social exchange. This centre will be roughly 2500 to 3000 m<sup>2</sup> and contain a variety of different spaces including classrooms, meeting spaces, eating areas and kitchens. The UBC Farm wishes to investigate the possibility of using straw-bale and cob as building materials for this new centre.

A triple bottom line assessment has been conducted in order to determine the economic, social and environmental impacts of There are well-known environmental benefits to using these non-traditional materials; as such, this analysis focuses more heavily on the economic and regulatory impacts of these construction materials. The economic analysis centers on the indicators of initial construction cost and long-term operating costs. The social aspect is based on a safety perspective and any regulatory concerns enacted by UBC's adherence to the British Columbia Building Code (BCBC). Finally, the environmental impacts are measured through the energy saved through carbon sequestration, embodied carbon and the operational energy savings from improved thermal insulation.

The main goal of this analysis is to provide a recommendation to the UBC Farm about straw-bale and cob as a construction material for the new UBC Farm Centre. Much of the information and comparisons are taken from non-residential buildings of a similar size using straw-bale and cob, as these will most closely mimic the construction and operational requirements.

## 2.0 CASE STUDY A - DEMMITT COMMUNITY HALL

For our first case study, we are going to look at the Demmitt Community Hall in Demmitt, Alberta. We decided that this would be a very relevant case study, as the building is situated in a nearby Canadian province and has a fairly large footprint. On June 10, 2010, the construction of a new community hall situated in Demmitt was announced by the department of Western Economic Diversification Canada (“Canada’s economic action”, 2010). In addition to providing short-term employment to the town of Demmitt during the construction period, the new community hall was also expected to provide long-term economic benefits to local businesses through the hosting of various events. As a part of Canada’s Economic Action plan, the federal government was set to fund half of the estimated \$1 million that was needed for the construction of the 4000 sq. ft. community hall (“Canada’s economic action”, 2010). This is a very modern building with amenities such as a kitchen, stage, dressing rooms, and a hardwood dance floor. As a public building, the Demmitt Community Hall is required to be compliant with commercial building standards such as test based engineering standards and a two hour rating for the plasters and walls (Gonzalez, H.J. (March 22, 2013).

Email interview).

From its inception, the Demmitt Community Hall was constructed with sustainability and longevity in mind. According to the President of the Demmitt Cultural Society, Peter von Tiesenhausen, the building is “built to last 100 years” and will use “local building materials and advanced sustainable practices” in the process. (“Canada’s economic action”, 2010) The basic structure of the building consists of a timber frame with straw bale walls coated in wire and stucco (Plummer & Parklander, 2011). A significant portion of the wood that was used for the timber frame was sourced from local trees that were already killed by the mountain pine beetle (Plummer & Parklander, 2011). In addition to sourcing local construction materials, solar were also used as an additional source of heating for the building. To improve the insulation of the building and reduce the cost of heating, a Structural Insulated Panel (SIP) from Greensmart Manufacturing was used. In addition to the local craftsmen and members of a regional college were hired, around 34 local volunteers were present over one long weekend to assist the construction. The Demmitt Cultral Society announced the opening of the Demmitt Community Hall on September 5, 2011 for an estimated \$1.28 million (“Canada’s economic action”, 2010).

### 3.0 CASE STUDY B - INSPIRE BRADFORD BUSINESS PARK

The Inspire Bradford Business Park is an eco-friendly business park located in Bradford, West Yorkshire, England. It was constructed using straw bale wall panels. This building was selected as a case study, for this report, as it has a similar footprint to that proposed for the UBC Farm centre. It was also constructed in adherence to the BREEAM construction standards, which is the British equivalent to the LEED (Newlands Community Association, 2012).

The Inspire Bradford Business Park demonstrates the presently uncommon, yet effective, use of straw bale in the provision of commercial property. It is comprised of 18 service offices and 14 workspaces, for small businesses and startups, and a community facility housed in two buildings covering a surface area of 2787 square metres. Construction began in April 2011, taking 36 weeks to finish. The facility opened in October 2012 (Newlands Community Association, 2012). The cost of the project was £4 million. The project received additional funding from various organizations, which include the European Union (£1.019 m), the UK government's Community Builders Fund (£1.38 m), Bradford's Newlands Community Association and Local Enterprise Growth Initiative (£990k), and additional funding was obtained through a £1m from the Charity Bank (Wainwright, 2010).

The development of the facility incorporated environmentally sound construction methods that aimed to achieve a BREEAM Excellent rating for energy efficiency. It was built using 260 thermally efficient, 48 cm thick, prefabricated straw bale wall panels developed by ModCell. A panel is composed of a wooden frame filled with spray-plastered lime straw bales (Offin, 2010). The benefits of using these wall panels is that they have a U-value of 0.13 to 0.19 - well below the UK regulatory standard of 0.35 – a fire performance of 2 hours and 15 minutes, and a sound reduction of 50 dB (ModCell, 2011). The use of prefabricated wall panels, which are constructed in controlled factory conditions and then transported to the construction site, is particularly advantageous as it alleviates the susceptibility of straw bale to moisture, which can lead to rotting, and a lack of uniformity found in traditional straw bale walls (Offin, 2010).

700 rolls of thermal and acoustic insulation, manufactured using fibers from waste denim, were used. This insulation is free of chemical irritants, such as melamine or phenolic



resins. It also meets the highest UK testing standards for fire and smoke ratings, fungi resistance and corrosiveness (Newlands Community Association, 2012). 50% of the site's electricity requirements are generated by 36 kW photovoltaic cells located on the roofs of the buildings. 50% of the water requirements are satisfied by a rainwater catchment reservoir (ModCell, 2011).

One of the major successes of the business park is sustainability in energy and water consumption. Prior to the completion of the project, preliminary calculations showed the energy usages as follows (Newlands Community Association, 2012). :

- Energy consumption: 84.25 kwh per square metre
- Fossil fuel consumption: 0
- Renewable energy generation: 14.31 kwh per square metre
- Water use: 4 cubic metres per person per year.

## 4.0 ECONOMIC ANALYSIS

In conducting an economic analysis of the proposed cob and straw New Farm building we wanted to determine the economic feasibility of a project of this scale based cost estimations. In order to do so, we decided to assess not only the costs associated with the construction of the building, but also the cost of maintaining such a building. In addition to the conducting research, we also talked to two experts in order to gain a greater into the costs involved with cob and straw bale construction. The first person that we got in contact with was Mr. Habib Gonzalez, a bale construction consultant for Sustainable Works. Our second contact was Michael Chiang, a licensed real estate agent who has been involved with residential construction projects.

### 4.1 Cost of Construction

One of the benefits of utilizing cob and straw as a building material is ability to source local materials. The benefit of doing so is that the cost of transporting building materials can be significantly reduced. Our research revealed that a local bale of straw with a height of 14", a width of 18", and a 35-40" length can be sourced for a cost of \$7.95 ("Vanderveen hay sales ltd", 2013). Based on the research done by R.H. Saxton of the University of Plymouth, typical cob mixtures consist of 30% gravel, 35% sand, 35% silt and clay with a permitted 10% deviation (Saxton, 1990). While it may be possible to use the soil within the construction site for the cob mixture, it is very likely that a small amount of the materials above will have to be purchased in order to achieve the right cob consistency. Tests will have to be conducted on the soil samples of the UBC Farm in order to assess the soil content.

In the context of our building cost analysis, basic costs include the frame of the building and straw bale walls that will be used to cover the building. Based the information provided by Mr. Gonzalez and Mr. Chiang, the basic costs of materials and design is highly dependent on the design details and complexity of the building. Mr. Gonzalez believes that local designers would give estimate of \$15 - \$20 per sq. ft. for a building with exterior bale walls and a building permit

(Gonzalez, H.J. (March 22, 2013). Email interview). Note that this figure does not include the cost of electrical wiring, sewage, the cob layer, or waterproofing costs. Possible ways of reducing the complexity of the building design would include minimizing the use of windows, or the utilization of a traditional rectangular shape for the structure. Further cost savings of course can be realized with the use of salvaged material such as wood beams or doors.

One of the most significant cost of any construction project is labour. Based on our conversation with Mr. Gonzalez, the Demmitt Community Hall project had 6 full time workers that were comprised of local tradesmen and students (Gonzalez, H.J. (March 22, 2013). Email interview). In addition to the 6 full time workers, there were also two or three volunteer workers that worked within the job site. Based on the information provided by both Mr. Gonzalez and Mr. Chiang, the amount of workers that are required for a project is highly dependent on the complexity of the project and the efficiency of the construction crew (Chiang, M. (March 31, 2013). Personal interview). With the assumption that the proposed New Farm building will have a complexity that is similar to that of the Demmitt Community hall and a footprint that is close to the Inspire Bradford Business Park, we believe that the building will require a design and construction period of around approximately 36 weeks (Newlands Community Association, 2012). Based on Mr. Chiang's previous projects, the cost of hiring a local construction worker will cost an estimated \$15 per hour with an 8 hour work day (Chiang, M. (March 31, 2013)).

## **4.2 Lifetime Costs**

While initial construction cost may be a sufficient economic indicator in most cases, the lifetime cost of maintaining a building is also a crucial factor in the triple bottom line assessment. We believe that cob and straw buildings will have an advantage in terms of lifetime costs based on their history of longevity and high level of insulation.

In certain parts of England, cob-based houses have existed for centuries with most being between 100 and 400 years old (Saxton, 1990). The Demmitt Community hall from the first case study was designed to last for 100 years ("Canada's economic action", 2010). We believe that with the use of either cob or straw bale (or a hybrid of the two materials) in the construction of

the New Farm building, existing buildings built with these materials are capable of lasting for many decades.

As we discovered during the environmental analysis of cob and straw construction, we found that straw bales do have a higher insulation efficiency value compared to both cob and traditional construction materials (Stone, 2003). According to a study conducted by Canada Mortgage and Housing Corporation (CMHC), they found that “straw bale homes used an average of 20% less heating energy” in the 11 straw bale homes that they studied (Stone, 2003). Given the expected longevity and the large footprint of the proposed building, we believe that this insulation efficiency will present long term cost savings from the decrease in energy required for heating.

## 5.0 SOCIAL ANALYSIS

The following presents a discussion into the regulatory concerns associated with cob and straw bale construction. The relevant building standards and regulations enforced by provincial legislation, and by the university, will be examined and the feasibility of the building materials to satisfy those requirements will be assessed with regards to their engineering properties.

### 5.1 UBC Developmental & Building Regulations

UBC upholds the British Columbia Building Code for all building and construction on the UBC Vancouver campus. The Leadership in Energy and Environmental Design rating system is also enforced at UBC, as UBC is a member of the Canada Green Building Council. These systems have been put into place to ensure the health, safety and protection of persons and property, and in pursuit of a campus of high-performing green buildings at the university (UBC, 2013).

### 5.2 BC Building Code

The 2012 BCBC is an objective-based code, which identifies the minimum standard within the Province of British Columbia for buildings to which this code applies. The BCBC establishes requirements to address the following five objectives:

- Safety
- Health
- Accessibility for persons with disabilities
- Fire and structural protection of buildings
- Energy and water efficiency

The BCBC should not be considered as a textbook on the design or construction of buildings and facilities, nor is it the only document regulating health and safety. It establishes the

criteria that materials, products and assemblies must meet (Office of Housing & Construction Standards, 2012).

While earthen construction methods have been in use for many centuries, presently, the challenge exists in assessing earthen building materials, such as cob and straw bale, in accordance to modern day regulations. In the BCBC, particular focus is made on the conventional construction methods using concrete, wood and metallic building materials. Unconventional methods must be able to moisture and thermal performance standards, namely the regulations pertaining to moisture and thermal performance requirements. The challenge present in this task is that cob and straw, or other earthen building materials, are not recognized by the code and it uses metrics that do not readily apply to earthen building systems. (Eco-Sense, 2011). Section 9.25 of the BC Building Code contains the standards and regulations pertaining to heat transfer, air leakage, and condensation control.

### **5.2.1 Thermal Insulation [Section 9.25.2]**

The BCBC states that: “all walls, ceilings and floors separating heated space from unheated space, the exterior air or the exterior soil shall be provided with sufficient thermal insulation to prevent moisture condensation on their room side during the winter to ensure comfortable conditions for the occupants.” (Office of Housing & Construction Standards, 2012)

The Greater Vancouver region has 2631 heating Degree days per year (The Weather Network, 2013). For framed wall assemblies in this region, walls must be a minimum of R13.06 (or 2.30 RSI, < 4000 HDD) (Office of Housing & Construction Standards, 2012). The thermal resistance of a cob wall largely depends on its assembly.

- Cob walls traditionally have an R-value of 0.60/inch, with the wall assembly being a nominal 24 inches, or 61 cm, thick. A wall of 28 inches, or 71 cm, would be required to meet the code (Eco-Sense, 2011).
- Straw-bale, at standard densities, achieves R-values of 2.40 to 2.77 per inch (Commins, 1998). A wall of above 5.50 inches is sufficient to meet the code.

### **5.2.2 Air Barrier System [Section 9.25.3]**

The BCBC stipulates that: “wall, ceiling and floor assemblies (separating conditioned

space from unconditioned space or from the ground) shall be constructed so as to include an air barrier system that will provide a continuous barrier to air leakage. From the interior of the building into wall, floor, attic or roof spaces, sufficient to prevent excessive moisture condensation in such spaces during winter (Office of Construction & Housing Standards, 2012).

Cob naturally provides a continuous air barrier due to its monolithic structure. However, this air barrier must be continued in the areas where cob meets other assemblies, namely the roof structure. It is good practice to have an earth- or lime-based plaster applied to the exterior and interior of the walls (Fratolocchi et al, 2010). For straw bale assemblies, all wet-applied monolithic plaster finishes are sufficiently air impermeable to control airflow (Straube, 2000).

### 5.2.3 Vapour Barriers [Section 9.25.4]

The BCBC asserts that: “thermally insulated wall, ceiling and floor assemblies shall be constructed with a vapour barrier so as to provide a barrier to diffusion of water vapour from the interior into the wall spaces, floor spaces or attic or roof spaces.” (Office of Housing & Construction Standards, 2012)

Based on the findings of researchers John Straube and Gernot Minke,

- cob has a permeance of 1088 ng/(Pa·s·m<sup>2</sup>),
- lime plasters have a permeance rating of 500 ng/(Pa·s·m<sup>2</sup>),
- and earthen plasters have a permeance of 1200 ng/(Pa·s·m<sup>2</sup>) (Eco-Sense, 2011).
- A 1 meter thick layer of straw bale is expected to have a vapor permeance of 50 to 100 ng/(Pa·s·m<sup>2</sup>)
- and a 450 mm thick layer of straw bale should have a permeance of approximately 110 to 220 ng/(Pa·s·m<sup>2</sup>) (Straube, 2000).

In Section 9.25.5.1 of the BCBC, it goes on to state that “... a water vapour permeance less than 60 ng/(Pa·s·m<sup>2</sup>) when measured in accordance with ASTM E 96/E 96M, ‘Water Vapor Transmission of Materials,’ using the decant method” is required (Office of Housing & Construction Standards, 2012).

It is this section of the code that presents the biggest challenge. For the case of cob, historical evidence has shown its effectiveness when combined with interior and exterior plaster

(Fratalocchi et al, 2010). It can be shown that cob excels in this aspect despite the metrics being incongruent between the code's vapour permeance standards and actual performance (Eco-Sense, 2011). However, since the BCBC is strictly enforced at UBC, it is recommended that cob be used in a wall assembly that can satisfy this requirement and where it is not the sole nor largest component of the assembly.

Straw bale, while being less permeable than cob, as previously mentioned, is still very vapour and water permeable and, thus, relies on plaster to control the entry of these sources of moisture. The ability of an exterior plaster to absorb and store moisture is critical in preventing moisture from being transported inward to the straw bales. In consequence, the vapour permeability, or permeance, should be of no practical importance since excessive moisture should not be allowed to come into contact with the straw bales (Straube, 2000). Based on the following table, it is recommended that a straw bale wall assembly should consist of plaster composed of cement bonded sand which will satisfy the vapour permeance requirement of the BCBC.

Sample	Thickness [mm]	Permeance [ng/(Pa·s·m <sup>2</sup> )]	Permeability [ng/(Pa·s·m)]
<b>Cement:Sand</b>			
datum	43.5	39	1.7
elastomeric coating	39.5	40	--
siloxane	41.0	40	1.7
<b>Cement:Lime:Sand</b>			
datum	35	295	10.3
linseed	36	223	8.0
elastomeric coating	32.5	244	--
siloxane	41	203	8.3
calcium stearate	53.5	81	4.3
calcium stearate	44	142	6.2
calcium stearate	53.5	41	2.2
latex paint	36.5	203	--



oil paint	40	41	--
<b>Cement:Lime:Sand</b>			
datum	50.5	295	14.9
linseed	50.5	259	13.1
<b>Lime:Sand</b>			
datum	33.5	565	18.9
datum	35.5	529	18.8
quicklime	32	459	14.7

Table 1: Results of Vapour Permeance Test Results (Straube, 2000)

*Results of a series of vapour permeance and water uptake tests on a range of plaster finishes that had been applied to straw bales. Samples were all lime or cement bonded.*

### 5.3 LEED Buildings at UBC

All publicly-owned new construction and major renovation projects over 600 m<sup>2</sup> in British Columbia must achieve LEED Gold certification. UBC has enacted upon the LEED rating system and has green building policies to ensure that sustainable practices are followed and implemented in-line with the university’s targets (UBC, 2013). The UBC LEED Implementation Guide for LEED Canada Building Design + Construction 2009 can be viewed for further reference.

## 6.0 ENVIRONMENTAL ANALYSIS

In order to properly assess the environmental impacts of the use of straw-bale and cob materials for construction, proper indicators must be chosen with which to evaluate these materials. By examining the differences between traditional construction materials and the proposed materials, these indicators will determine whether there is a benefit to switching. The main indicators we will use are the CO<sub>2</sub> ratings based on creation and construction, and the on-going performance of the materials. In order to quantify this, we will investigate the sequestered and embodied carbon ratings, the insulation properties and the thermal mass of the proposed materials. Sequestered carbon and embodied carbon (or embodied energy in general) are well-known measures of the initial costs and benefits for a material (Hammond & Jones, 2008), where as insulation and thermal mass provide a proxy for operational impacts.

### 6.1 Carbon Impact Indicators

#### 6.1.1 Sequestered Carbon

Sequestered carbon is a measure of the theoretical amount of CO<sub>2</sub> gas trapped in the material through its creation process. This is often quoted when speaking of wood constructions; wood captures (sequesters) carbon dioxide as a plant, effectively trapping that gas in the material. And so, sequestered carbon represents the opposite of carbon emission during formation. Straw-bale, as a plant based material, sequesters a significant amount of carbon; this is a significant benefit. Depending on the type of straw used (which plant), 29% by mass of straw-bale is sequestered carbon (Alcorn & Donn, 2010). If using a more theoretical model, carbon dioxide sequestration may be as high as 52% by mass (Sodagar et al., 2011). Accurate data for cob sequestration are not available for every soil composition, however soil from less temperate northern climates may contain 31% to 40% carbon dioxide by mass (Milutienne et al., 2007). Most non-organic materials sequester no carbon dioxide; this carbon offset is a significant change.

As seen below, the use of plant-based materials, such as timber and straw-bale, can significantly decrease the carbon impact of construction; in some cases the sequestered carbon

offsets the initial carbon costs.

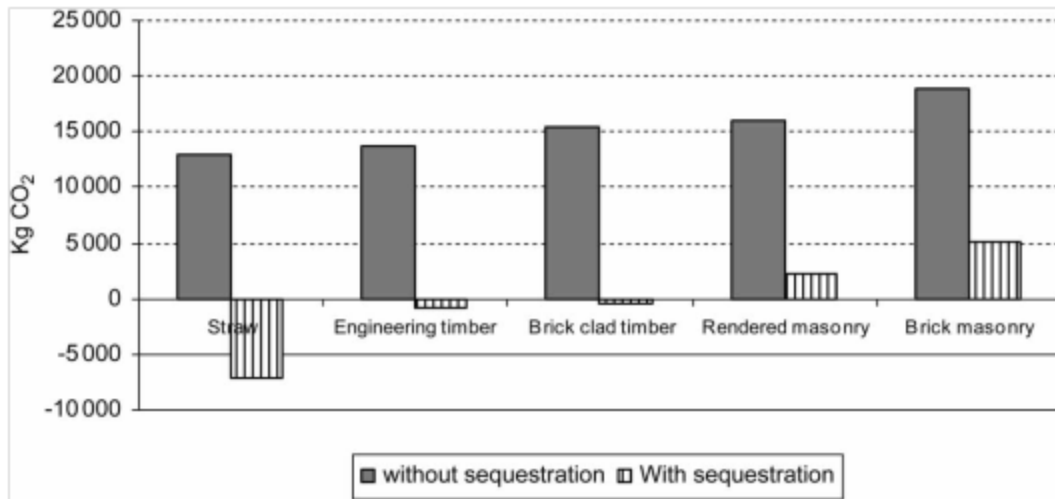


Figure 1 - Total house materials CO<sub>2</sub> emissions of one of the houses with different external walling systems (Sodagar et al., 2011)

### 6.1.2 Embodied Carbon

Similarly, embodied carbon (EC) is a more complete measure of the carbon emissions of a material, through its entire life-cycle. EC takes into account the energy required to create the material, store it, transport it and prepare it for construction, as well as any emissions or capture that occurs during the material's operational life. The major advantage of using cob as a construction material is that it is available locally – potentially on-site at the UBC Farm – meaning the transportation portion of the EC is minimal. Straw-bale, depending on the source, has an EC value of 0.91 MJ/kg, versus an EC value of 15 MJ/kg for plywood or 4.6 MJ/kg for cement (Offin, 2010). The EC value for cob is much higher than that of straw-bale, mainly because of how much more work-intensive it is; there is a significant mixing step, coupled with the possible additives (sand, gravel, clay) that are required to create the right mix (Carfrae, 2009). Values between 5.3 and 6.8 MJ/kg are common for cob (Offin, 2010).

Material	Quantity	EE per unit mass/volume	Total EE for a component of the 1X2.4m wall, MJ
38 x 88 stud (2 x 4)	8.748 board feet	2.795 MJ/board foot (Athena,2000)	24.45
Plywood	7.573 kg	15 MJ/kg (ICE, 2008)	113.6
Straw Bales	92.46 kg	10.397 MJ/kg (Athena, 2000)	78.74
Sand	144.18 kg	0.91 MJ/kg (Chapter 3)	84.14
Lime	18.015 kg	0.1MJ/kg (ICE, 2008)	14.42
Cement	22.59 kg	0.0948 MJ/kg (Athena, 2005)	13.67
1:1:6 - cement/lime/sand		5.3 MJ/kg (ICE)	95.48
		6.864 MJ/kg (Athena, 2002)	123.7
		4.6 MJ/kg (ICE, 2008)	103.9
		4.689 MJ/kg (Ath, 2005)	105.9
		{1.18 MJ/kg (ICE, 2008)}	213.8
TOTAL:			243.3
			410.9 MJ
			393.3

Table 2 - Materials required for construction of 1m x 2.4m section of exterior wall in straw bale house and embodied energies associated with them (Offin, 2010)

## 6.2 Operational Indicators

### 6.2.1 Insulating Properties

In order to evaluate the environmental impact of these construction materials post-construction, a measure of the carbon emissions of the structure is required. The main contributors to operational carbon of structures are heating and power (the power systems within the building are not relevant to this research). Thus, any change in heating efficiency of a structure will serve as a good proxy of the carbon emissions when using the proposed materials. The insulating properties of a material provide a direct correlation to the amount of energy expended in heating a building as it tracks the amount of energy lost to the environment. Often, thermal insulation is measured using the R-value of thermal resistance, where a higher value insulates better. Straw-bale provides very good thermal insulation, achieving values of R2.4 to R2.77 per inch for standard straw-bale densities (Commins, 1998). Special straw-bale packing,

with higher density, can drop the value to as low as R0.94 per inch (Stone, 2003). Cob provides poor thermal insulation, with a value of between R0.30 and R0.63 per inch, with R0.60 being the most common (Stone, 2003).

### 6.2.2 Thermal Mass

In like manner, thermal mass correlates well with heating-energy; it is a measure of the amount of heat energy a material can store per unit mass (or per unit volume). A material with a high thermal mass will store more energy, allowing excess energy to be captured and released as the temperature fluctuates. In other words, higher thermal mass allows a material to store more energy – in basic terms the material will cool the building when it is hot outside and provide heat when it is cold. Cob has a high thermal mass because of its relative density (Chalfoun, 2003), however an exact value is difficult to determine given the variety of methods used to measure thermal mass. Straw-bale, given its relatively low density, provides very little thermal mass(Chalfoun, 2003). One method of measuring the thermal mass of a material is based on its volumetric specific heat capacity. Straw-bale has a value of about 250 kJ/m<sup>3</sup>K while cob has the much higher value of 1900 kJ/m<sup>3</sup>K (Atkinson, 2008).

## 7.0 CONCLUSION

### 7.1 Triple Bottom Line Assessment - Economic Analysis

There exist significant economic benefits to using straw-bale and cob for construction of the new UBC Farm Centre. These are demonstrated by the difference of initial construction costs, as well as long-term savings associated with the reduced heating requirements. However, many of these costs are contingent on an appropriate labour force and design experience during the planning and construction phases.

### 7.2 Triple Bottom Line Assessment - Social Analysis

From a regulatory perspective, there are no direct restrictions on the use of straw-bale and cob in construction at UBC (or in BC). However, BC Building Code requires that standards for thermal insulation, air barriers and vapour barriers be met. Straw-bale will allow the construction to meet code for thermal insulation, however the vapour and air barriers must be made of a different material. There are also concerns when using straw-bale or cob as a structural (load-bearing) material.

### 7.3 Triple Bottom Line Assessment - Environmental Analysis

Straw-bale and cob present a significant environmental benefit when used. Not only do they sequester carbon, the energy involved in their creation and life-cycle is very low compared to traditional materials. Additionally, they present an operational advantage when factoring in the heating energy savings over the long-term.

### 7.1 Triple Bottom Line Assessment - Conclusion

This analysis shows that the use of straw-bale and cob as construction materials provides meaningful economic and environmental benefits. These economic benefits can be maximized with proper design considerations. However, there exist some regulatory concerns which limit their use to wall mass and other non-load-bearing roles. Overall, we recommend that straw-bale and cob be used in the construction of the new UBC Farm Centre.

## 8.0 RECOMMENDATIONS

This analysis confirms the recommendation of using straw-bale and cob in the construction of new UBC Farm Centre, with certain conditions, listed here below.

### 8.1 Economic

The economic benefits can be maximized if the design of the building is simplified as much as possible in addition to using traditional structural components (such as timber). This will minimize the design costs associated with getting an engineer to sign off on a construction with non-traditional materials. In order to minimize costs associated with length of construction, labourers or consultants experienced with straw-bale and cob use are preferred. Where possible, materials should be sourced locally; straw-bale from suppliers in the Lower Mainland, cob on-site if the soil is of the proper composition and timber from BC forests (possibly pine-beetle killed wood).

### 8.2 Social

In order to meet the specifications of the BC Building Code, we recommend that the structural components of the building be made of timber, that straw-bale and cob be used as wall material, and that plaster be used as a vapour and air barrier for the walls. A wet-applied monolithic plaster finish is necessary for the air barrier, while any cement-bonded plaster is sufficient for the vapour barrier. Given their mechanical and thermodynamic properties, straw-bale and cob are not suitable to be used as structural components for large buildings, nor as seal layers in exterior walls.

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