384060 Salford Road | Oxford County

Low Embodied Carbon Materials

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Introduction

The Oxford County Waste Management Facility & Education Centre (WMEC) is one of many examples of the County's initiative towards their 100% renewable energy goal. The Smart Energy Oxford goal aims for the county to meet all their energy demands through producing renewable energy, by the year 2050 [1]. WMEC is an example of sustainable construction and building operation. The building has rammed earth walls that contain low embodied carbon while adding a visually aesthetic exterior. It is powered by a solar photovoltaic system that produces more electricity than the building consumes to achieve net-zero energy status. The solar system does not only provide energy for the building, but also generates enough electricity to make the rest of the waste facility site net-zero (including weigh-stations, site lighting, etc.). Currently, the energy use in the building is being tracked for the mandatory period after construction in order to achieve net-zero certification from the New Building Institute (NBI) [2].

Figure 1: Oxford County Waste Management Facility and Education Centre, 384060 Salford Road, Oxford County

Background Material

Carbon Footprint of a Building

Carbon footprint is a term that is often used in discussion to determine the impact an individual, institution, system, or building has on the environment. The following definition is the most common definition used to define a carbon footprint [3]:

> *"A direct measure of greenhouse gas emissions (expressed in tons of carbon dioxide [CO_2e]) caused by a defined activity. At a minimum this measurement includes emissions resulting from activities within the control or ownership of the emitter and indirect emissions resulting from the use of purchased electricity."*

The definition only highlights operational carbon emissions. However, we know that a building's carbon footprint should also include the embodied carbon dioxide emitted during the complete lifecycle as shown in figure 2. The sum of the embodied carbon and operational carbon give a more complete picture of the life cycle carbon footprint of the building. This total carbon can then be normalized per unit area of a building; for example, it can be quantified using units of $kgCO_2e/m^2$ or $kgCO_2e/ton$ [4].

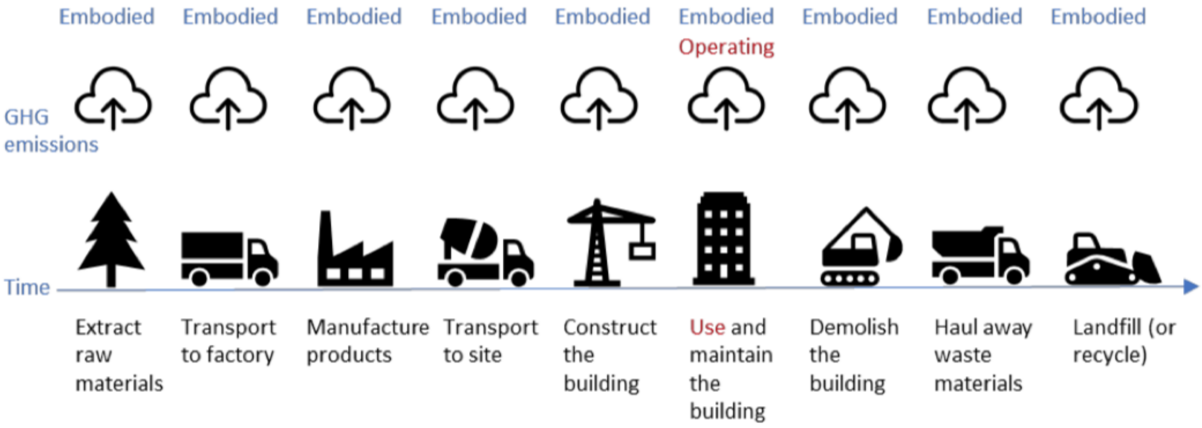

Figure 2. Carbon emissions during a buildings service life [5]

Rammed Earth

In the previous case file (Kehl Street) the two types of carbon emissions associated with buildings were introduced. The Oxford County Waste Management and Education Centre controlled both embodied and operational carbon in their design. The use of alternative materials such rammed earth as an environmentally sustainable and local material for the construction of the walls was the primary method of controlling the embodied carbon in the building. Traditionally, brick, wood or concrete are used to for wall assemblies. However, these materials contain higher embodied carbon concentrations in comparison to rammed earth. Table 1 presents an example of materials and their embodied carbon concentrations.

Table 1: Comparison of advantages and disadvantages of rammed earth [6]

Material	Embodied Carbon (kg/kg)
Rammed Earth	0.023
Polyissocyanurate	2.55
Glass	0.85
Concrete	0.34

Raw earth construction has been use for hundreds of years in Europe. Mud blocks, Cob and adobe are all different construction techniques that require the use of natural soils resulting in low embodied carbon [7]. Subsequently, rammed earth walls are created by compacting damp soil in layers between two temporary vertical forms [8]. 10 to 25 cm of the soil is layered in the framework and compacted by 50%. Even though the use of raw earth construction has been used for hundreds of years, the construction industry desired faster results with building methods thus adopting concrete and steel as primary materials [7].

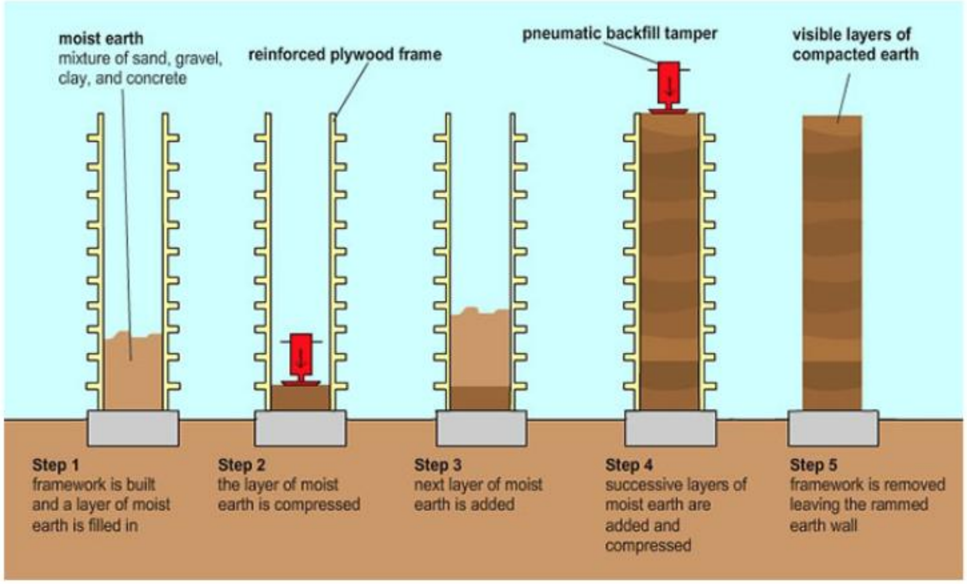

Figure 3. Composition of Rammed Earth Walls [9]

Since rammed earth is composed of earth soils, the mixtures needed must be modified to ensure its strength and durability. This is completed by adding 5-10% by weight of a chemical stabiliser that can improve the adequacy of the mixture. The most common stabiliser is cement and it is used to create cement stabilised rammed earth (CSRE) despite its high embodied carbon levels [10]. The addition of other materials such as lime and bitumen can also improve the strength and durability of rammed earth [7]. This distinguishes the difference between rammed earth (RE) and stabilized rammed earth (SRE).

One of the main challenges with using rammed earth is maintaining the original low embodied carbon concentration. The addition of stabilising materials can compromise the sustainability as they have high concentrations of embodied carbon and complicate recycling and disposal at the end of the life cycle. Additionally, carbon emitted due to transporting soils increases the embodied carbon concentration when the soil is not sourced locally [7].

RE walls also have long construction periods as a result of consistent quality control and lack of codes outlining the expectations of construction. Maintaining quality control is required during mixing and storage of the soil in addition to testing the final strength and durability to meet code standards. When RE is used on a construction site it takes up to 66% of the site operations [7].

Despite the disadvantages of RE walls their advantages are not limited to their environmental benefits. RE walls can control the humidity of the building due to their ability to store moisture in the pores of the walls then release it when the air in the room is dry. Additionally, it provides good acoustic insulation which improves occupant’s comfort and provide and astatically pleasing design [7]. If non-stabilised rammed earth is used the recycling and disposal of the materials is considered environmentally friendly.

Problem Statement

The predicted energy requirements of the Oxford County Waste Management & Education Center (WMEC) was modeled using eQuest. The report can be found in the suggested readings, and should be used to create a simpler energy model with the assistance of the tutorial provided. Additionally, quantity take-offs were completed using the architectural drawings for WMEC to estimate the total embodied carbon in the facility. An analysis should be completed highlighting the highest and lowest percentages of embodied carbon with respect to the materials used in the building.

Lesson Objectives

After the lesson, students should be able to:

- Compare the embodied carbon in rammed earth to concrete or other traditional methods of building a wall (wood, concrete and brick)
- Calculate the different percentages of embodied carbon of materials in buildings using embodied carbon factors and mass of materials used
- Input data into eQuest and analyze the data from the energy modelling output
- Know how to size and arrange solar panels to offset carbon emissions
- Identify key materials that dominate the embodied carbon of most buildings, and know the strategies to reduce EC in these elements.

Readings

*****needed to complete assignment

- *WMEC eQUEST Report
- *WMEC architectural drawings
- Article summarizing the WMEC building specifications
    - http://www.oxfordcounty.ca/Home/Newsroom/News-Details/ArticleId/14245/New-net-zero-Oxford-County-Waste-Management-Education-Centre-officially-open
- Improving rammed earth walls' sustainability through life cycle analysis (LCA)
- A review of rammed earth construction [8]
- A geotechnical perspective of raw earth building [7]

References

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384060 Salford Road | *Assignment*

Notes:

- Complete the following calculation and discussion questions.
- Always show units, and cite sources, where appropriate.
- Clearly indicate final answers.
- Minimum standards of neatness are expected.

- Calculate the embodied carbon of traditional materials (concrete, brick, wood) and compare the carbon factor to rammed earth using the Oxford County quantities
- List the benefits of using low embodied carbon materials and discuss the limitations associated with it

Calculation Questions:

1. Calculate the site EUI and the carbon emissions intensity of the 20 Mill Street residence if the total energy used in 1 year is 54 GJ, the total carbon emissions are 6.55 tonnes $C0_2e$, and the total livable square footage is 1,200 ft^2. Compare that to a typical Canadian building, and to one unit at 242 Kehl Street, where 33350 kWh per year are estimated, along with 4.52 tonnes $C0_2e$, for an average unit size of 1,116 ft^2? *Hint: Compare to the Canadian average on page 4.*

   Solution:

   20 Mill Street

$$\text{EUI} = \mathit{Yearly\ Energy\ Consumed}\ /\ \mathit{Building\ Area} = \frac{54\text{GJ}}{111.5\text{m}^2} = 0.48\ \text{GJ/m}^2$$

$$\text{CEI} = \mathit{Yearly\ Emissions}\ /\ \mathit{Building\ Area} = \frac{6.55\ \text{tonnes C}0_2\text{e}}{111.5\text{m}^2} = 58.7\ \text{kg C}0_2\text{e/m}^2$$

   242 Kehl Street

$$\text{EUI} = \mathit{Yearly\ Energy\ Consumed}\ /\ \mathit{Building\ Area} = \frac{30\text{GJ}}{103.7\text{m}^2} = 0.29\ \text{GJ/m}^2$$

$$\text{CEI} = \mathit{Yearly\ Emissions}\ /\ \mathit{Unit\ Area} = \frac{4.52\ \text{tonnes C}0_2\text{e}}{103.7\text{m}^2} = 43.6\ \text{kg C}0_2\text{e/m}^2$$

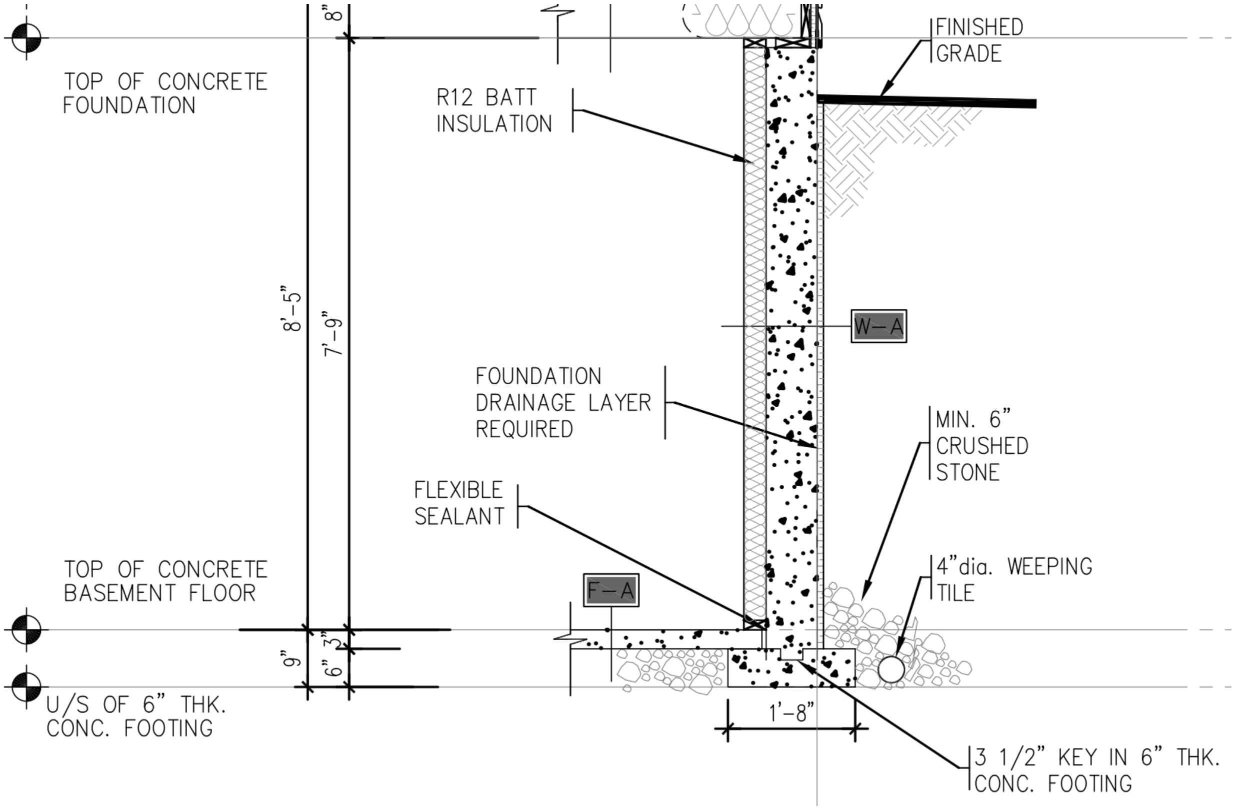
   These numbers fall well below the Canadian average of 1.0 GJ/m^2 (site EUI), however, they are for residences, and should be below. That said, they are still below the multi-unit residential figure (1.1), even after scaling up to source EUI with a factor of 1.6.

2. Comment on the algebraic sign for each embodied carbon value given (production, demolition, and recycling), for wood, as compared to brick, concrete, and steel, as shown in Table 2. Specifically, why is the production of wood associated with a negative embodied carbon value, and why is the demolition of wood products associated with such a high embodied carbon value? What is a negative embodied carbon, and why is the recycling of materials assigned a negative value?

   Solution:

   Wood has a negative EC value for production because of "carbon sequestration". By using wood in buildings, the carbon inside the wood is being stored there for many years, offsetting the carbon emissions that would occur if the tree died and *decomposed. However, at the end of the products life, the wood is typically burned or decomposed in landfills, releasing that carbon (and a significant amount of it). Negative embodied carbon arises from the recycling of materials because it saves carbon that would occur due to the extraction and manufacturing of new raw material.*

3. Add up the quantity of concrete required to make the footings, foundation walls, and basement slab of the 242 Kehl Street building. What is the total cradle to cradle embodied carbon of that concrete? How does this value compare to the carbon arising from yearly operation, if the building lasts for 50 years? 100 years?



You may assume: 3,744 linear ft. of footing/wall (shown above), and a slab area of 2,414 ft. Add a 15% allowance to the total concrete volume to account for waste from the truck, and miscellaneous other strip/spread footings. Take the unit weight of concrete to be 2,350 kg/m^3.

Solution:

Concrete	W (in)	T (in)	L (in)	m^3	kg
Footing	20	6	3,744	7	17,305
Slab	34	3	71	0	279
Wall	96	8	3,744	47	110,750
					147,584
61,013	in^3/m^3		25,089	kg CO$_2$e	
2,350	kg/m^3		25.09	tonnes CO$_2$e	

We see that just the concrete material alone gives 25 tonnes of C0$_2$e in embodied carbon (taking a factor of 0.17). This is equivalent to more than 5.5 years of operating emissions at 4.52 tonnes per year (give in Q1). Over a 50 year lifespan, this would constitute 10% of overall emissions, but *over a 100 year lifespan, it would only constitute 5%. However, if operating emissions were reduced further through better sourced electricity, the embodied carbon would be come a higher percentage of the overall emissions (and this is only considering the concrete!).*

Discussion Questions:

1. Why is the embodied carbon of aluminum so high, and what can be done to change this?

   Aluminum takes a great deal of electricity to produce. It is likely that electricity produced from greenhouse gas emitting procedures was common for the source used in Table 2 (to get a value of 8.24 kg $C0_2$e/kg Al). Better sources of electricity (hydro, wind, solar, nuclear), would change this. Case in point – Quebec Aluminum!

2. What do you think is more important to focus on between embodied carbon of materials, and operational carbon? What are the simplest strategies for reducing each?

   To reduce embodied carbon:

- Use less material!
- Make buildings that last a long time
- Find better ways to recycle material or reuse/repurpose buildings
- Use low embodied carbon materials (or substitutes, such as fly-ash)

   To reduce operational carbon:

- Create energy efficient buildings
- Minimize energy losses by producing energy on-site
- Move away from Natural Gas and Coal as a means to produce electricity

3. Where are the embodied carbon values shows in Tables 2 and 3 taken from (what source and what locale)? How important is it for every country to have their own embodied carbon estimates? What factors change from country to country that may affect the values?