Low-Carbon Housing Project

Calvin University - Engineering 333B - Thermal System Design - 2021

Project Overview

In 2020, residences used 21% of all final energy in the United States[1] and were responsible for 20% of all U.S. carbon dioxide emissions[2] (henceforth referred to as carbon emissions). Habitat for Humanity for Kent County is endeavoring to design homes that reduce energy consumption, energy expenditures, and carbon emissions. They have established a goal of a "low carbon footprint build" that will minimize energy consumption and carbon emissions, both during construction and across the lifetime of the house. To accomplish this goal, Habitat for Humanity for Kent County partnered with Calvin's ENGR 333 – Thermal System Design and asked two guiding questions for this project:

- **What is the expected carbon emissions savings of the low carbon footprint build house?**
- **If not carbon-neutral, how can carbon emissions be reduced by a further 20%?**

Preliminary Analysis

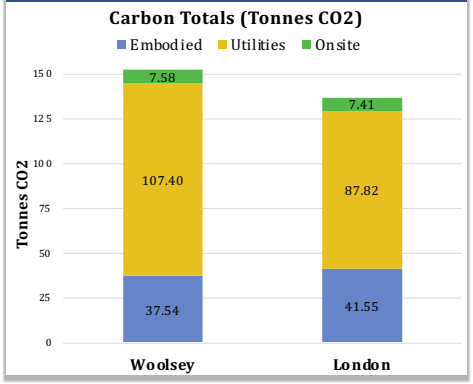
Analysis consisted of quantifying the lifetime total carbon emission of two different houses:

- **Woolsey**: a previously constructed traditional Habitat for Humanity house
- **London**: an under-construction fully electrified house that does not use natural gas

Quantification was done by three teams focused on specific sources of emissions with an additional design-oriented team.

- **On-Site**: carbon emissions associated with on-site activities during construction of the houses
- **Embodied**: carbon emissions embodied within the materials of the houses
- **Utilities**: carbon emissions associated with the primary utilities (electricity and natural gas) of the household throughout their expected lifetimes
- **Design:** focused on the questions regarding emission reductions through the generation of design options to be analyzed for carbon reduction

Preliminary Results



Design Options

Since the new carbon footprint build house (London) was not carbon neutral, work was done to reduce associated carbon emissions by 20%. This work took the form of design option and focused on relatively small changes to the house with the goal of emission reduction

- **Design Option 1: ROCKWOOL Insulation**
  Replaces DOW Foam to decrease embodied carbon
- **Design Option 2: Double Insulated Vinyl Siding**
  Replaces standard vinyl sidings to increase wall R value
- **Design Option 3: Portland Limestone Cement (PLC)**
  Replaces Portland Cement to lower embodied carbon
- **Design Option 4: 3-Pane Argon Windows**
  Replaces traditional Double Pane Vinyl Windows to decrease U value of windows (increase R value)
- **Design Option 5: Increased XPS Insulation**
  Increases the thickness of DOW Foam by 33% to increase wall R value
- **Design Option 6: Solar Panels**
  Generates electricity to reduce electricity usage
- **Design Option 7: Handifoam Wall Insulation**
  Replace blow-in-cellulose Insulation within the wall to increase wall R value
- **Design Option 8: Handifoam Roof Insulation**
  Replace blow-in-cellulose Insulation within the roof to increase roof R value

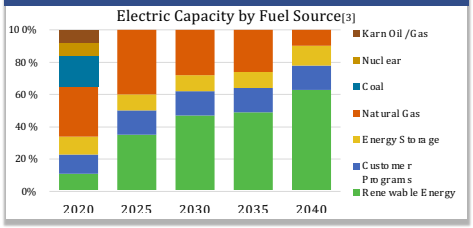
Ultimately, options 1 and 3 were not productive as the decreased embodied carbon did not counteract the increase heat loss and associated emissions.

Electricity Emissions

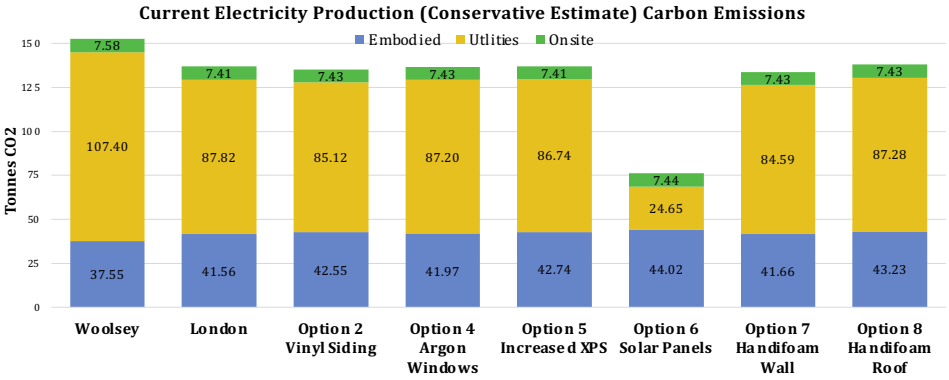
Preliminary analysis showed the importance of electricity and natural gas usage in terms of carbon emissions. This established a need to account for the changing factor of these emissions as utility companies move toward more renewable energy.

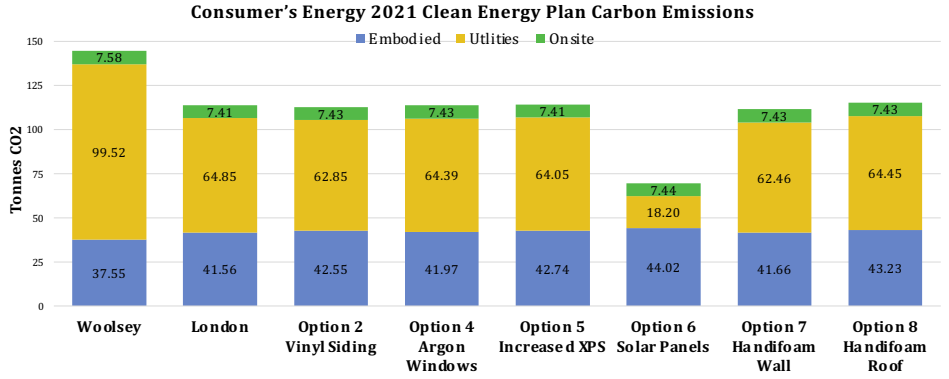
A conservative estimate was formed using 4.99×10^{4} Tonnes/kWhr based on the ratio of carbon emissions to electricity generation in the Michigan for 2021. A more optimistic estimate was found by accounting for Consumer Energy's 2021 Sustainability Plan[3] as depicted in the figure below. This analysis yielded an average factor of 3.68×10^{4} Tonnes/kWhr which is clear improvement and contributes to the goals of Habitat for Humanity.

Clean Energy Plan



Design Option Results





Conclusions

The analysis concluded that design options 5 and 8 resulted in an increased amount of carbon emissions.

In combination, the remaining design options account for a total reduction of 48.4% of net carbon emissions, exceeding the 20% goal. Ultimately, design option 4 proved to be the most beneficial, especially when using the conservative current electricity conversion model accounting for a 44.4% and 32.2% reduction for the two estimates.

Overall, the London house proved to be a successful carbon footprint house. The electrification is a success with the heat pump proving to be far more efficient than a traditional furnace. Despite this, the house, even with the possible 48.4% reduction, is far from carbon neutral and continued efforts must be made. Habitat for Humanity must continue to focus on optimizing efficiency of the heating/cooling systems and appliances, in addition to an environmentally friendly construction processes.

References

[1] *Energy Data Fact*, Residential Program Guide. Office of Energy Efficiency & Renewable Energy

[2] *Today in Energy July 26, 2021*. US Energy Information Administration

[3] *2021 Clean Energy Plan*. Consumer's Energy

Acknowledgements

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