Boxed-In: Comparative Analysis of the Environmental Performance of Recycled Shipping Container Dwellings.

ROBERT L WILLIAMS
University of Massachusetts, Amherst

Keywords: Building Performance, Embodied Carbon, Operational Energy, Shipping Containers, Housing.

In popular media, recycled shipping containers are perennially touted as low-cost solutions for providing sustainable, high-performance homes[1-4]. However, there is limited analysis of the actual performance of shipping container buildings with respect to energy efficiency and overall carbon impact[5]. This project aims to fill that gap through a comparative analysis between a small shipping container home and a similarly sized home built with conventional high-performance assemblies.

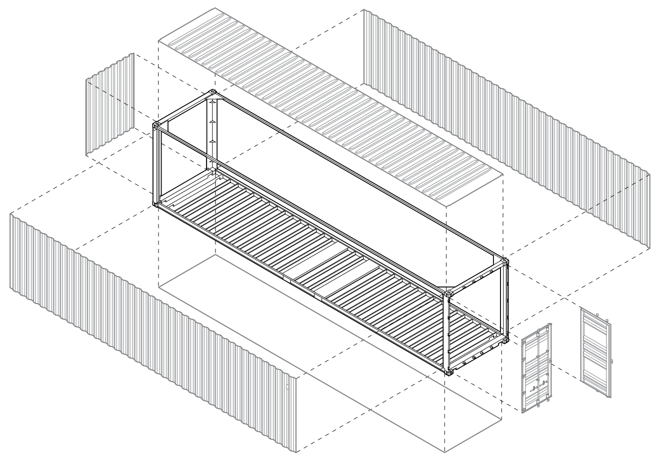

Figure 1. *40' High Cube Container.* Image by author.

DESIGNING WITH SHIPPING CONTAINERS: CHALLENGES AND BENEFITS

Despite their ready-made appearance, shipping containers present unique challenges for designing durable, high-performance dwellings. First, the dimensions of standard shipping containers – particularly the long, narrow proportions – are rather awkward for inhabitation. The standard section of a high-cube container - 8'-0" x 9'-6 - is small to begin with and is further reduced by the installation of framing, insulation, and interior finishes. Second, the solid steel exterior creates challenging hygrothermal issues that must be managed through careful detailing and construction. As a highly conductive yet air-impermeable material, the steel exterior is highly susceptible to wintertime condensation in cold climates. If insulating from the inside of the container, either air-impermeable insulation in the form of closed-cell spray foam or other foam-based rigid insulation products or a robust interior air barrier are required. Alternatively, insulation could be installed to the exterior of the container. This begs the question of why a shipping container is being used at all. Finally, construction is often more difficult, and therefore more expensive, than conventional stick-framed buildings[6]. Unique details, structural steel work, and the need for highly skilled welding to ensure water-tight welds in the envelope all contribute to the relative complexity of designing and building with containers.

Figure 2. *Interior framing over polyiso*. Photo by author.

Challenges notwithstanding, there are unique benefits to shipping container housing. There can be a significant reduction in the quantities of materials required, particularly with respect

Figure 3.*Challenging window openings.* Photo by author.

Figure 4. *Wall and floor assemblies.* Photo by author.

to exterior envelopes and cladding. The air-tight nature of the original shipping container is conducive to creating air-tight buildings. Shipping container houses are often well suited for modular construction and for designing houses that can be easily re-located. Finally, there is the distinct aesthetic character of the up-cycled shipping container itself.

SHIPPING CONTAINER HOUSING PROTOTYPE

The shipping container home being analyzed is the final product of the design phase of a design-build collaboration initiated at our University in Spring 2022[7] . Based around a single, 40' long, "high-cube" container, the student design employs best practices for implementing high-performance assemblies while also negotiating the unique challenges of designing with containers, including moisture management and dimensional limitations. The primary exterior envelope assemblies are presented in Figure 7. To evaluate the environmental impact of the proposed dwelling, embodied carbon, operational energy, and operational carbon were all modelled. Carbon modelling was completed with the BEAM estimator developed by Builders for Climate Action and energy modelling was completed with Sefaira developed by Trimble Labs.

ALTERNATIVE HIGH-PERFORMANCE HOUSING PROTOTYPE

To evaluate and contextualize the relative performance of the shipping container home, a equivalent home designed with conventional high-performance assemblies was also assessed with respect to embodied carbon, operational energy, and operational carbon. The alternative dwelling has the same interior conditioned floor area, similar massing, and similar glazing-to-façade ratios. The proportions are adjusted to avoid the awkwardness of container dwellings, while remaning within the limits of standard modular construction to allow for transport analogous to the container dwelling. Primary exterior envelope assemblies are presented in figure 8.

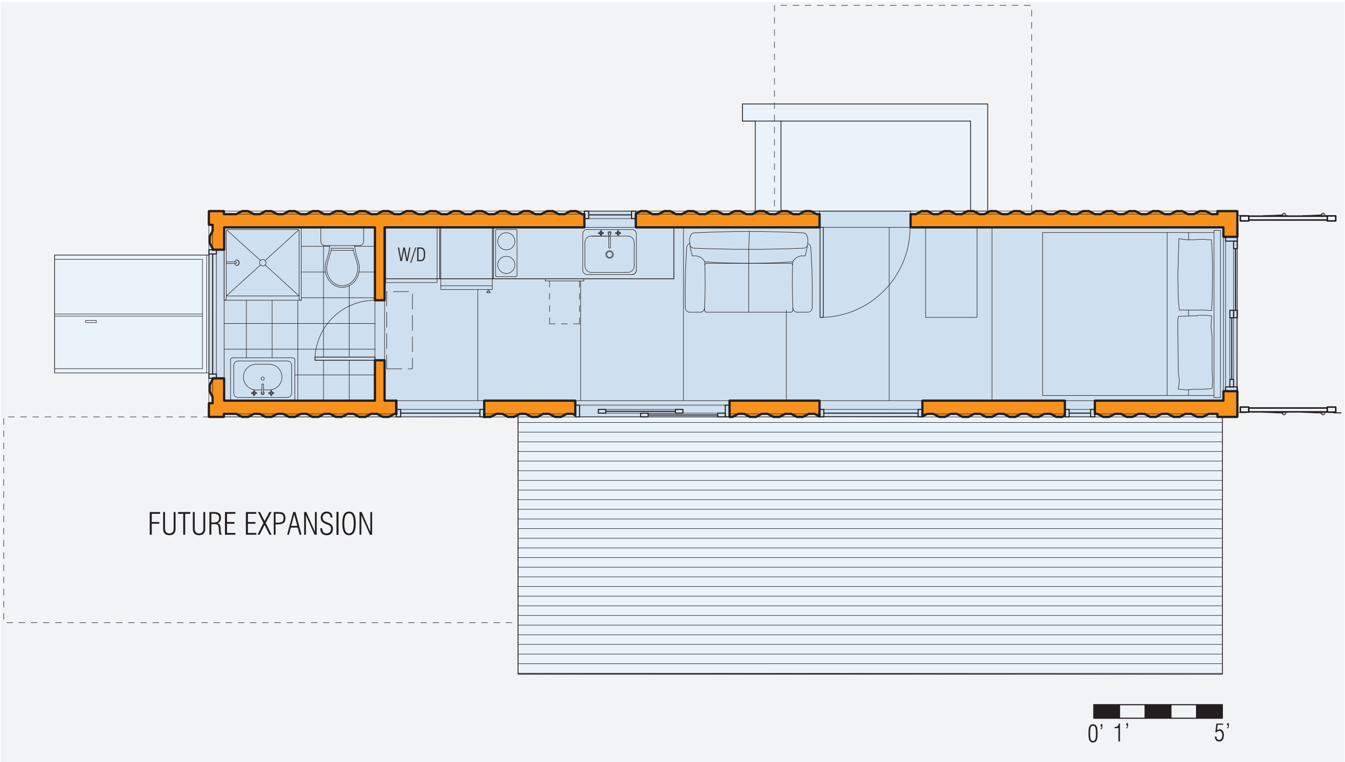

Figure 5. *Shipping container house prototype.* Image by author.

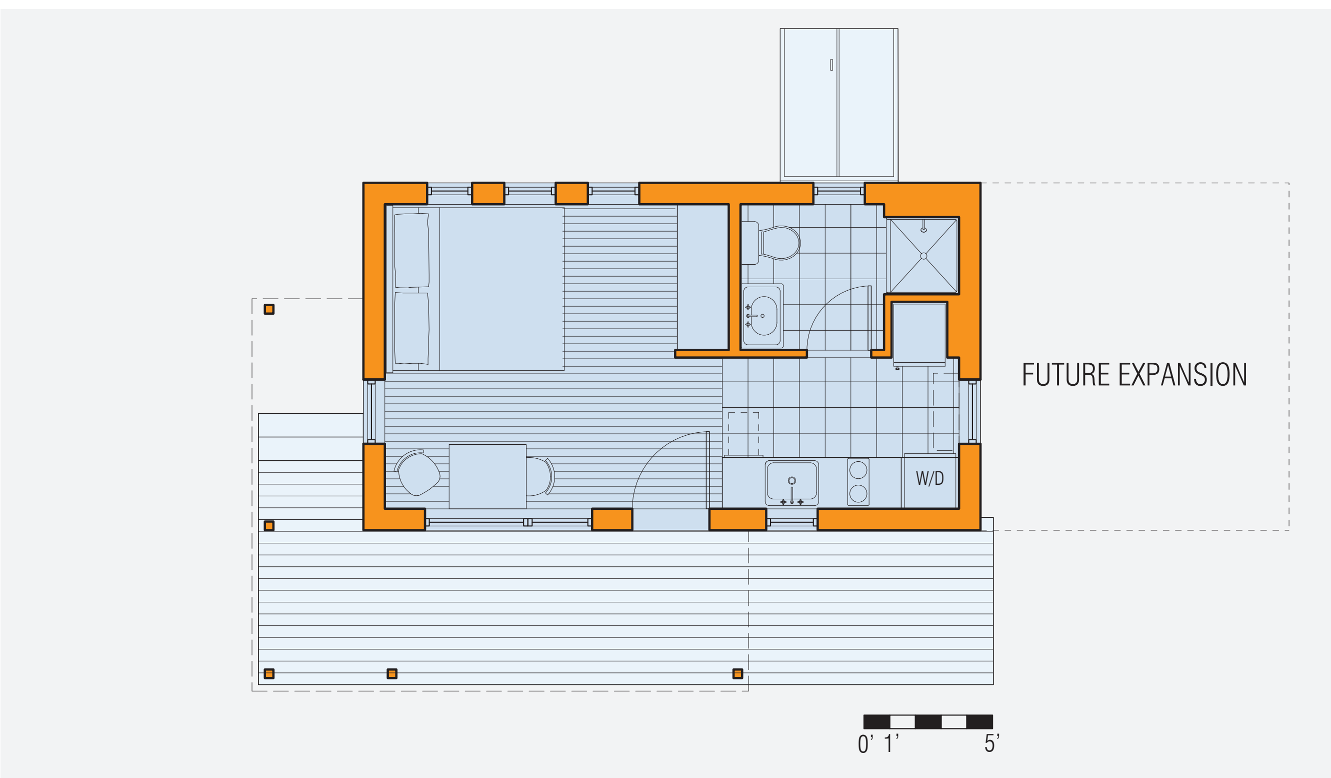

Figure 6. *Alternative high-performance home prototype*. Image by author.

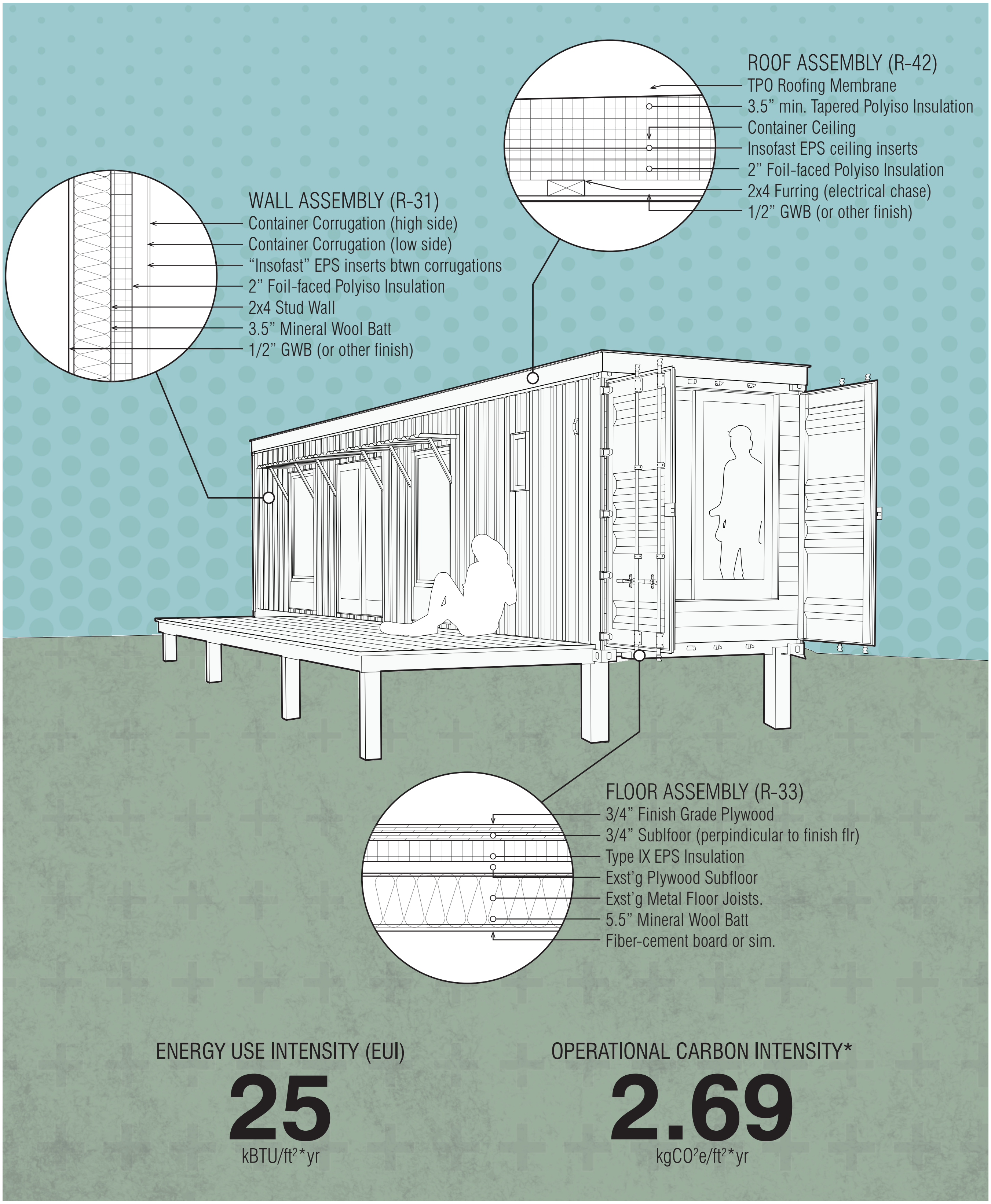

Figure 7. *Shipping container prototype: assemblies and energy use*. Image by author.

PROJECT

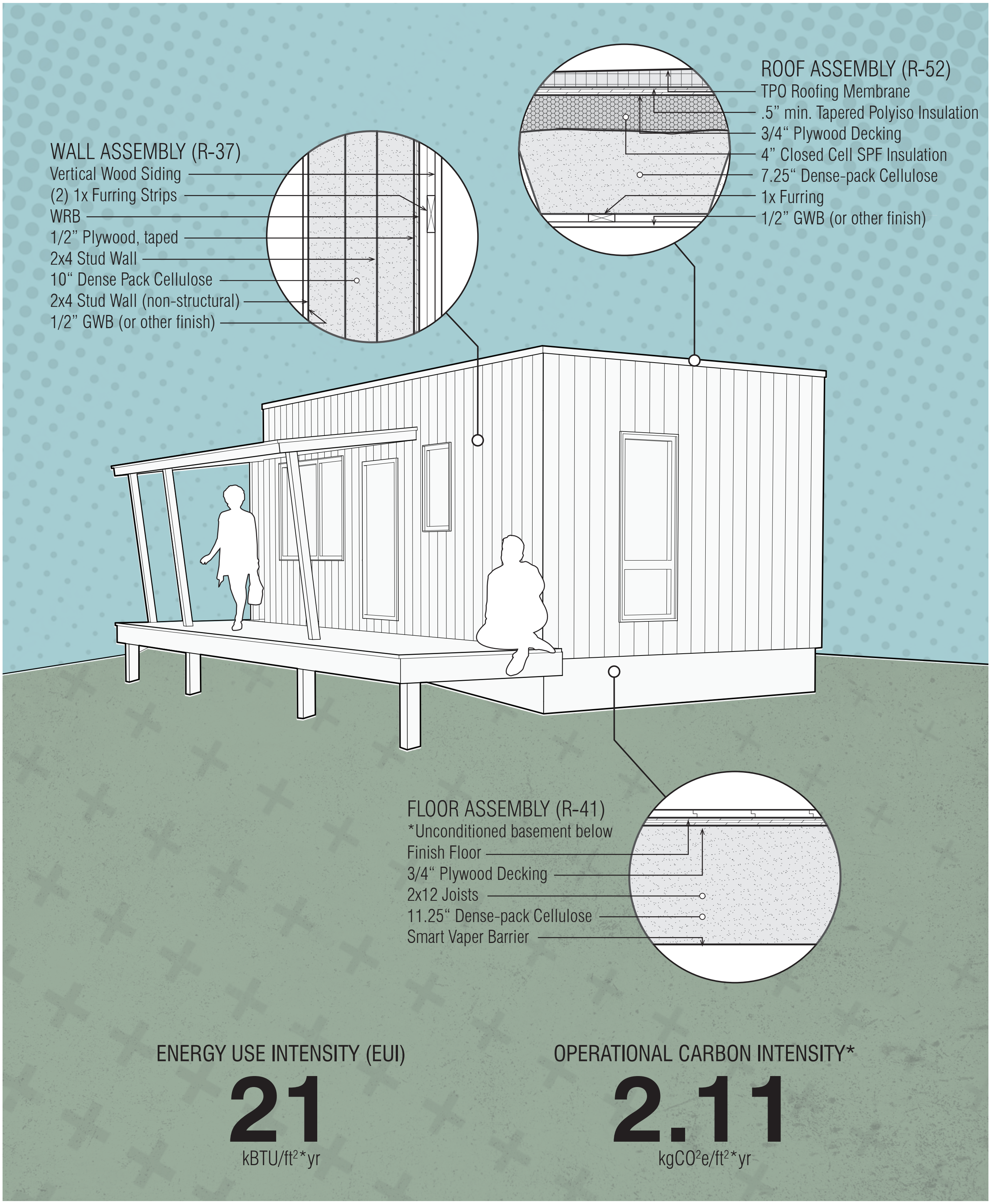

Figure 8.*High performance alternative prototype: assemblies and energy use*. Image by author..

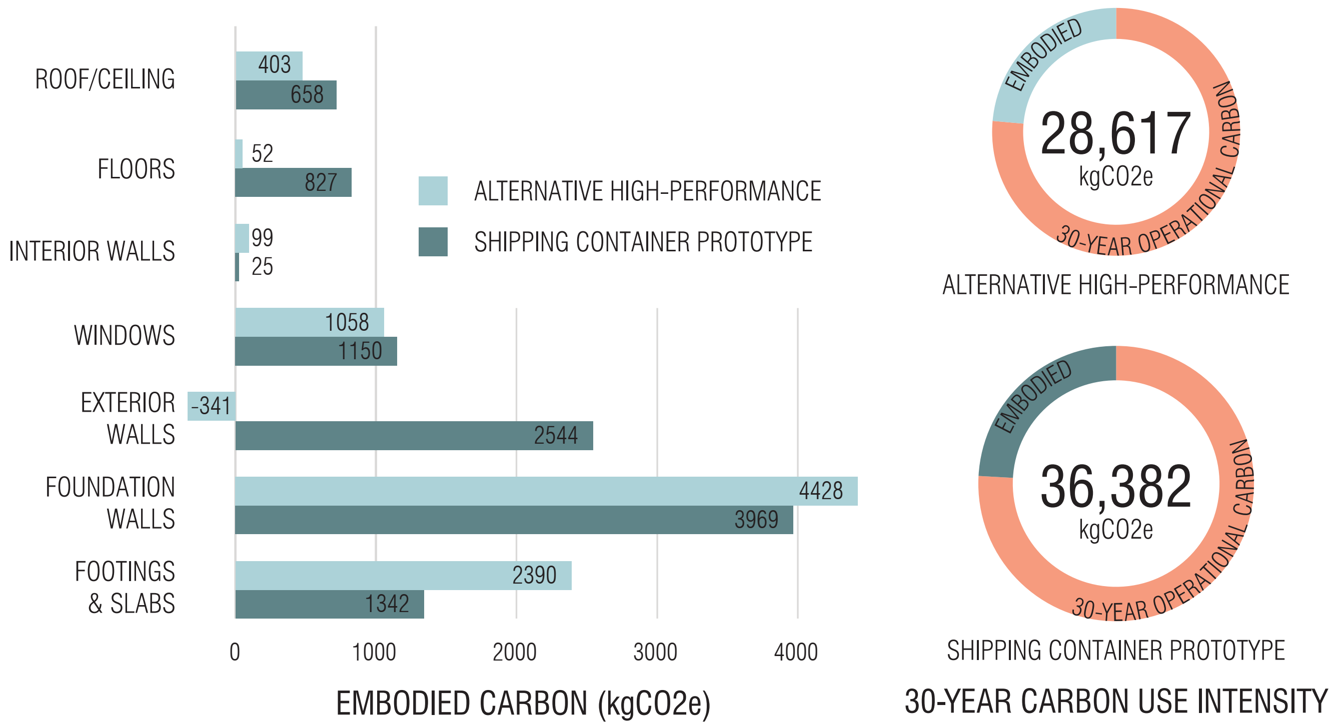

Figure 9. *Embodied carbon & carbon use intensity.* Image by author.

RESULTS & CONCLUSIONS

The modelling demonstrates that the alternative home utilizing conventional high-performance assemblies out-performs the shipping container home with respect to both upfront embodied carbon and with respect to on-going operational energy and operational carbon. The alternative has a Material Carbon Intensity (MCI) of 25 kgCO2e/ft2 compared with 33 kgCO2e/ft2 for the shipping container home. This represents an approximate 25% reduction in upfront carbon emissions. Similarly, the operational carbon intensity (OCI) of the alternative home is 2.11 kgCO2e/ft2 compared with 2.69 kgCO2e/ft2 for the shipping container. This represents an approximate ~22% reduction in operational CO2 emissions per year. Much of the carbon impact of the shipping container dwelling is driven by the need to use air-impermeable and therefore foam-based insulation products within the exterior envelope. This modelling assumes new foam products. Further research needs to be conducted on the impact of using recycled insulation products. Similarly, concrete still accounts for largest share of the overall carbon impact in both buildings. By virtue of bearing solely on corner castings at the container perimeter, shipping container dwellings could take advantage of simple pier foundation systems to further reduce concrete. This could offer a path to significant carbon reductions, but also requires further research.

Nevertheless, the current research suggests that the environmental performance of shipping container dwellings, particularly with respect to carbon emissions, is complicated at best. There are many potential advantages of building with re-purposed containers, but it should not be taken for granted that they necessarily offer improved environmental performance. Given the design constraints and technical challenges inherent to shipping container dwellings, there are likely many scenarios in which more conventional high-performance construction is preferable.

ENDNOTES

1. Kenneth R. Rosen, "Coming Home to a Shipping Container," New York Times, September 22, 2017, https://www.nytimes.com/2017/09/22/realestate/home-in-shipping-container.html.
2. Dawn Hammond, "Recycled Shipping Containers make up this Off-Grid Retreat," Inhabitat, January 31, 2022 https://inhabitat.com/recycled-shipping-containers-make-up-this-off-grid-retreat/
3. Nicole Jewell, "Squirrel Park turns shipping containers into affordable housing units," Inhabitat, November 25, 2019, https://inhabitat.com/squirrel-park-turns-shipping-containers-into-affordable-housing-units/
4. For an alternative opinion, see Richard J Williams, "The Sinister Brutality of Shipping Container Architecture," New York Times, August 14, 2019, https://www.nytimes.com/2019/08/14/opinion/shipping-container-homes.html
5. Laura Battaglia and Jeehwan Lee, "Performance Evaluation of Shipping Container Potentials for Net-Zero Residential Buildings," Journal of Green Building 15, no. 1: 139-152.
6. For more on the technical constraints of shipping containers, see Joe Lstiburek, "BSI-078: Ship Shape – The Luftwaffe, Ballast and Shipping Containers," Building Science Corporation, June 10, 2014, https://www.buildingscience.com/documents/insights/bsi078-ship-shape.
7. The project was a collaboration between the Department of Architecture at UMass Amherst and the Yestermorrow Design/Build School in Waitsfield, VT.and a well-established, independent design-build school located in the region. Architecture students at UMass designed the shipping container home during the spring semester and then a second group of students completed the construction of the shipping container home during a summer build course administered by and located at Yestermorrow.
8. Thank you to Yestermorrow Design/Build for the permission to use this project as a case study. Thank you also to the students in the design course who went above and beyond and also to Alexander McNally for his help with the graphics for this paper.