EMBODIED CARBON IN PASSIVE HOUSE PART 9 BUILDINGS

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Introduction

This study investigates strategies to minimize embodied carbon in the construction of Vancouver's single-family homes. Currently, the construction industry is responsible for 39 % of the world's carbon emissions [1]. These emissions can be broken down into two groups: operational carbon (i.e. emissions from heating, cooling, and providing electricity to a building) and embodied carbon (i.e. emissions associated with a building's construction materials). Although embodied carbon is currently responsible for only 11 % of the world's carbon emissions [1] (versus the 28 % from operational carbon), it is a particularly pressing issue since climate change is time sensitive. While both embodied and operational carbon emissions need to be reduced, carbon emissions averted today are more valuable in slowing climate change than those averted in coming years. As such, this study aims to inform building industry professionals on strategies which can be used to reduce embodied carbon in single-family homes and subsequently slow climate change.

To do so, the upfront embodied carbon of three single-family homes built to the Passive House standard was analyzed. The Passive House standard is a rigorous building standard requiring high energy efficiency [2]. Passive House buildings have reduced operational carbon as a result of their low energy demands. Unfortunately, this can come at a price; to reduce energy demand, larger amounts of insulation are required, which can increase embodied carbon [3]. Despite this, architects and builders striving to achieve Passive House certification (and therefore reducing operational carbon) are likely to be interested in reducing embodied carbon as well. Moreover, the findings of this report are applicable to all single-family residences, whether they are built to conventional building code or to Passive House standards.

To calculate the embodied carbon of a building, both construction material quantities as well as the global warming potential (GWP) associated with each material are required. The GWP, which refers to the sum of greenhouse gas emissions released throughout the lifecycle of a material, is measured in kilograms of carbon dioxide equivalents (kg CO_2 eq) and is obtained from a life cycle assessment (LCA). An LCA is a standardized method used to quantify the environmental impacts of a product, process, or service. While many other environmental impacts are considered in an LCA (such as water usage, acidification potential, etc.), only the global warming potential is used to calculate embodied carbon. By gathering the GWP of each material and performing quantity takeoffs from construction drawings, embodied carbon can be determined. To streamline this process, many software packages or calculators have been designed. In this study, two such methods were evaluated alongside manual calculations, and a comparison of results is provided. As such, this study aims not only to discuss strategies to minimize embodied carbon; it also guides building professionals towards a greater understanding of the advantages and limitations of three available methods.

Methodology

In this study, three methods were used to determine the upfront embodied carbon of each Passive House. First, material takeoffs were performed, and the total quantity of each material was multiplied by its global warming potential (as determined through environmental product declarations (EPDs)). Whenever possible, manufacturer-specific EPDs were used; however, in some cases, only general information was available (e.g. for concrete and plywood). The second method used a test version of the Excel-based *Builders for Climate Action Material Emissions Calculator*, in which the total embodied carbon was calculated once assembly quantities were inputted (e.g. X m^2 of wall area or

X m of beams) and construction materials were selected from a list of options. Lastly, the *Athena Impact Estimator for Buildings* was used to determine embodied carbon via an “assembly method”, in which the dimensions and specifications of individual assemblies (e.g. walls, floors, foundations) were inputted. The *Impact Estimator* software can provide a cradle-to-grave analysis, which considers the emissions from each stage of a product’s lifetime: from manufacturing, to transportation, usage and end of life. Unfortunately, many EPDs used in the first two methods provide a cradle-to-gate analysis, which only considers emissions associated with the raw materials and their manufacturing. As such the cradle-to-gate analysis, which can also be obtained from the *Impact Estimatorl,* was used as the basis for comparison in this study.

The scope of this study includes the effects of foundations and footings, interior and exterior walls (from exterior cladding to interior drywall), floor assemblies and floor finishes, roof and ceiling assemblies, and windows. It excludes doors, staircases, cabinets, plumbing, electrical, heating and cooling systems, gutters, paint, and secondary buildings such as garages or laneway homes.

Summary

The embodied carbon of the three single-family residences in this study ranged from 24,670 to 43,894 kg CO_2 eq, across all three methods used. While all three methods reported similar trends, both the *Builders for Climate Action Material Emissions Calculator* and the *Athena Impact Estimator for Buildings* reported embodied carbon values ~20% lower than those calculated from material takeoffs and manufacturer-specific EPDs. This can be attributed to the limited material and/or assembly choices in both calculators; in some cases, material dimensions had to be underestimated (e.g. selecting a concrete thicknesses of 100 mm when the actual thickness is 140 mm). In other cases, construction materials were unavailable, which required omitting the material or selecting another in lieu. In addition to this, the *Builders for Climate Action Material Emissions Calculator* considered the effects of biogenic carbon (i.e. carbon storage), which lowers the embodied carbon associated with plant-based materials (e.g. wood, cellulose insulation, etc.). Despite these differences, the trends between the three houses were consistent across all methods: the largest house in the study always had the highest embodied carbon.

To further understand the effects of specific assemblies, structural features and construction materials on embodied carbon, the results from the manual calculations were normalized according to gross floor area (which includes all floor spaces, measured from the edge of exterior walls). This resulted in normalized embodied carbon values ranging from 130 to 150 kg CO_2 eq/m^2. These values can be compared to a database of embodied carbon projects [4], where similarly sized buildings were found to have a normalized embodied carbon of 32 to 665 kg CO_2 eq/m^2, with an average of 193 kg CO_2 eq/m^2. It is worth noting that this data comes from 17 projects, which vary in scope (e.g. which stages of the life cycle assessment were included), analysis method (e.g. which calculator was used), and data source (e.g. which EPDs or carbon databases were referenced). Nevertheless, this provides a good basis for comparison and suggests that the Passive House buildings in this study have relatively low embodied carbon. This is encouraging for builders seeking Passive House certification since it proves that low embodied carbon can be achieved despite the thicker wall and roof assemblies that are required for high-efficiency buildings. The low embodied carbon of the houses in this study can likely be attributed to conscientious material choices: expanded polystyrene was used to insulate the foundation, while cellulose and mineral wool were used to insulate the exterior walls. These materials have a fraction of the global warming potentials associated with extruded polystyrene or most spray foam insulations, for example [5,6,7,8,9].

This study also elucidated the effects of various structural features on embodied carbon; among the three houses, certain features stood out as being more emission intensive than others. For example, higher window-to-wall ratios, concrete raft slabs with grade beams (instead of typical concrete foundations walls and slab-on-grade) and gabled roofs (instead of flat roofs) were found to increase the normalized embodied carbon of a house. Another element which accounted for a large fraction of the embodied carbon in all three houses was the presence of a basement. The below grade assemblies were responsible for approximately 50 % of each house's embodied carbon while providing only ~35 % of its floor area. Overall, these results can guide urban planners, architects and builders of both Passive House and conventional building code projects towards minimizing embodied carbon.

Conclusions & Recommendations

This study has shown that the embodied carbon of Passive House buildings can be calculated using three different methods, which yield similar results. Despite this, when using the *Builders for Climate Action Material Emissions Calculator*, or the *Athena Impact Estimator for Buildings,* users should be aware that their results may be lower than those obtained from material takeoffs and manual calculations. In cases where embodied carbon calculations cannot be performed, users can follow the general guidelines presented in this study to lower embodied carbon. Material selection (e.g. insulation), structural features (e.g. foundation type, roof type, etc.), and the presence of below-grade floor area all have significant impacts on embodied carbon. With careful consideration of these features, both Passive House and conventional building code projects can achieve low embodied carbon and contribute to slowing climate change.

References

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