Whole building life cycle assessment (WBLCA) of mass timber systems: European vs North American mass timber vs steel

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ABSTRACT: Whole Building Life Cycle Assessments (WBLCA) are helpful tools in the evaluation of the environmental impacts of all of the components in a building. Inputs (like material extraction and manufacturing) and outputs (such as carbon emissions) are measured over the entire life cycle of the building. The goal is to minimize the negative impacts on the environment over the whole life cycle of the building. In this case we performed the WBLCA for a mixed use building in San Francisco California utilizing the software Tally. We compared three different building systems, North American mass timber, Austrian mass timber, and steel. The results from our comparative analysis show that concrete is the majority of the global warming potential and embodied energy regardless of the system. This paper supports and has shown the potential of Mass Timber material being used in building industries to minimize environmental impact.

KEYWORDS: WBLCA, mass timber, embodied energy, global warming potential

INTRODUCTION

The relationship between the design and construction industry and environmental pollution is discussed closely. The UN just recently came out with the tenth addition of the Emissions Gap report, which is the latest assessment on current and estimated greenhouse gas (GHG) emissions and compares them to where they need to be. The report was bleak, "GHG emissions have risen at a rate of 1.5 per cent per year in the last decade" and "The largest contribution stems from bulk material production, such as iron and steel, cement, lime and plaster."(Environment 2019,1,24). The report states that in the last twenty years the production of materials has increased 6.5 GtCO2e (Environment 2019). Recent studies identified that buildings globally are responsible for 40-50% of greenhouse gas globally and 30-40% of the world's energy use (Environment 2019; Abd Rashid and Yusoff 2015). Massive construction is taking place all over the world to accommodate for migration of populations to urban areas, this movement is supposed to reach 60% by the end of the year 2030 (Sharma et al. 2011). Such a boom in construction will require innovation in the construction methods and design in order to save our natural resources. Understanding, analyzing and comparing the environmental impacts of building design has on global climate change is the primary motivation behind this research.

One of the main incentives of mass timber construction is the potential to help combat global warming (Tollefson 2017)**.** On a sustainability level, mass timber has the potential to carry a far lighter carbon footprint than other building methods like steel structure. The carbon emissions of a building not only affects the health of the planet and speeds up climate change but there are also profound implications on our health. A study from Yale's School of Public Health found that air pollution had a damaging effect on cognition, particularly the aging brain (Zhang, Chen, and Zhang 2018). The Veteran's Association published a study linking the deaths of 4.5 million veterans to an air pollution that was below the standards set by the US Environmental Protection Agency(Bowe et al. 2019). The effects of carbon emissions are not only harmful to the planet but to the individual health of everyone on the planet.

When the carbon emissions globally need to be reduced by 7 percent each year to limit a 2 degree Celsius increase of temperature which would have devastating effects of climate change globally (Law et al. 2018) the amount of carbon that a building's structure and systems can sequester can be used as a selling point to the client and can impact the effects of the building's global warming potential throughout its life.

The building that is the focus of this paper is Pier 70, Parcel A, a 356,000 square foot building slated to be constructed in San Francisco, California. At the time of the paper the building is through the design development stage, this paper may influence the final decision of a mass timber system. The building's architect is Hacker and the structural engineer is KPFF. Pier 70, Parcel A is a six-story building with five floors of office space, bottom floor of retail and one level of below-grade parking. There are several double height spaces that provide access to daylighting as well as visual connections within and extending out beyond the building.

This study contains multiple WBLCA results using Tally The scope of the WBLCA is the building's structural model, this includes floors, columns, beams, roofs, foundations, the core, and required fireproofing. It does not include the enclosure or interior non-structural partitions. The scope also excluded metal connections such as nails, bolts, and screws) as well as finishes. The system boundary of the WBLCA study was cradle to gate, considering a 75-year building lifetime. The system boundary included extraction and production of raw materials, transportation of raw materials, manufacturing, transport to building site, transport to waste processing and end of life.

In this paper, our goal is to test three different structural systems life cycle analysis got their global warming potential and the carbon sequestration of each system. The three systems are North American mass timber (sourced from D.R. Johnson located in Riddle Oregon, primarily source from Douglas fir), European mass timber (sourced from Binderholz located in Austria, primarily sourced from northern spruce wood), and conventional steel system (including concrete slabs, gypsum and fireproofing, assuming that the steel would be sourced from China). Our goal was to identify the differences in the embodied carbon and global warming potential impacts within these three systems and identify places where each system could be improved. Within this research paper, our main goal was to look at both the operational and the embodied impacts of each structural system throughout the lifecycle of the building. Our first hypothesis for this research projects was that North American mass timber will have the lowest global warming potential and embodied carbon. Our second hypothesis is that steel will have the highest global warming potential and embodied carbon.

METHODOLOGY

In this research project the software program Tally is used to generate whole building life cycle assessment (WBLCA) reports. Tally is an Autodesk Revit Plug-in, we were gifted free educational trials of the software for use in this study. The quantities of Revit materials are translated into volumes and areas which are computed into their own LCI database(Zuo et al. 2017). The bill of materials that was user specified within Tally is listed in a table in Addendum 1. The scope of Tally does not cover the impacts from construction or operation of the building. Tally allows designers to quantify the environmental impact of building materials for whole-building analysis, in the case of this research project Tally will provide data to analyze the different options in the structural system. Tally produces a range of data that compares the environmental impacts in different categories such as global warming potential, acidification, eutrophication, smog formation, and embodied energy. For this project, we are going to just focus on the global warming potential and the embodied energy of these different systems.

For this research project, we were presented with the structural model of Pier 70 with the North American Mass Timber system modeled in Revit by KPFF. The North American mass timber system was already modeled in Revit.

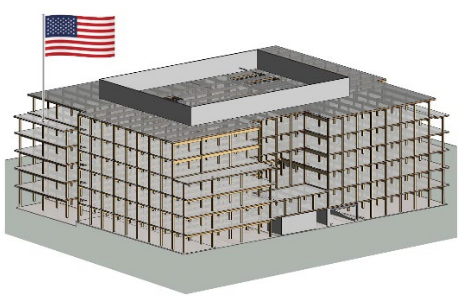

Figure 1 : North American Mass Timber Model

In order to perform comparison of the three alternative design scenarios for Pier 30, it was necessary to remodel the case study for Austrian mass timber and redesign the case study with steel structure. With the Austrian mass timber structure, we were able to perform direct material substitution for metric member sizes. The structural calculations were already completed by the structural engineers at KPFF for use to use in the substitutions. None of the structural layout was changed, just the substitution of members.

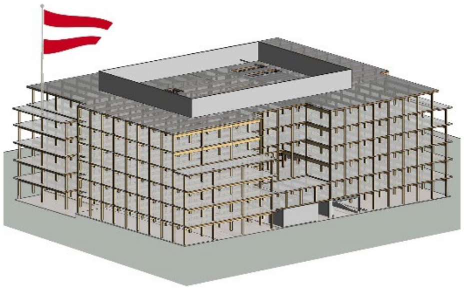

Figure 2: Austrian Mass Timber Model

In the case of the steel structural system, we redesigned the mass timber building, the structural grid that was in place for the mass timber buildings would not suffice. The goal for the steel structure was not to perform a material replacement but to redesign a functionally equivalent structural system. In this redesign, the floor to floor heights as well as the building dimensions did not change. Since the spans can be much greater with the steel system, the building cores had to be shifted as well as the grid. For the steel structural system, the CLT deck was switched out for metal deck topped with lightweight concrete. Using the model of the original building, a redesigned functionally equivalent steel structure was designed. As well, since the mass timber systems have inherent fire resisting structure (Barber 2018) there was no need to model any additional fireproofing or finishes on either of the mass timber systems. However, in the steel system, we modeled the required fireproofing such as cementitious spray and gypsum board to meet the California Fire Code standards, the same as the mass timber systems. The standards that each building must achieve is a fire resistance rating required by ASTM E119 (American Society for Testing and Materials 2016) or UL 263 (UL 263 2018).

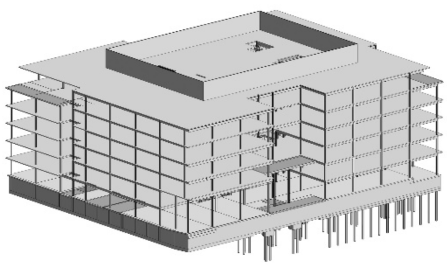

Figure 3: Steel Model

After the structural designs were completed and equivalent structural capacity was verified, the WBLCA in Tally will be done multiple times to check the data for reasonableness. When calculating the WBLCA only the direct inputs and associated outputs are considered. For example, the impacts associated with a ton of steel will not include the emissions of the machinery from manufacturing (Robertson, Lam, and Cole 2012). In order to include those impacts an economic input-output (EIO) analysis of the entire economy would be necessary. It would be expected that absolute values of a WBLCA would be lower than an EIO methodology, however the comparative results remain the same regardless of methodological approach (Lenzen and Treloar 2002). To develop appropriate simulation information, we will be factoring in the transportation of the materials to the site. Manufacturers of the mass timber were contacted to gain information on typical transportation methods and how they approach transportation.

Reducing the carbon footprint of the building industries is an important step to contribute to reaching global warming. Therefore, it is critical impact that biogenic carbon flows are assessed in the WBLCA and product carbon footprint (PCF) tools. Biogenic carbon is the carbon that is sequestered and stored in all wood products which is released in the manufacturing of these wood products but also released throughout its life. Biogenic carbon gives a boost to the carbon emissions produced by mass timber, as it takes away some of the carbon that is sequestered from the trees and minuses it from the total carbon from the whole life of the product. With the increase of using harvested wood in our buildings, the addition of calculating the WBLCA with biogenic carbon could help in the global effort to cut carbon emissions (Straka and Layton 2010).

RESULTS

After a few revisions to our models, we got the total global warming potential as well as the breakdown by material type for each of the three building systems. In summary of the performance of each of the systems, the North American sourced mass timber resulted in 11,045,124 kgCO_2eg of global warming potential. The Austrian sourced mass timber resulted in 12,820, 725 kgCO_2eg of global warming potential and finally the steel resulted in 12,013,958 kgCO_2eg of global warming potential.

System	**Total GWP ($kgCO_2eg$)**	Mass Timber GWP ($kgCO_2eg$)	Concrete GWP ($kgCO_2eg$)	Steel GWP ($kgCO_2eg$)	Fireproofing GWP ($kgCO_2eg$)
North American Mass Timber	**11,045,124**	1,731,652	6,194,827	3,117,824	-
Austrian Mass Timber	**12,820,725**	3,507,776	6,194,827	3,117,300	-
Steel	**12,013,958**	-	6,030,968	5,476,880	506,110

Table 1: Breakdown of Global Warming Potential by System and Material

The North American mass timber system resulted in 11,045,124 $kgCO_2eg$. Breakdown by materials are as follows, mass timber global warming potential 1,731,652 $kgCO_2eg$, concrete global warming potential 6,194,827 $kgCO_2eg$ and steel's global warming potential is 3,117,824 $kgCO_2eg$. The GWP of the concrete makes up for half of the emissions of the building. Even though the concrete is not a primary structural member, there is still a substantial amount of concrete in the building with 4" topping slabs and concrete foundations. The effects of transportation on the emission in the mass timber are lessened because of the short travel distance; 437 miles from Riddle, Oregon.

The Austrian mass timber system resulted in 12,820,725 $kgCO_2eg$. These emissions are over 1.7 million more than the North American mass timber systems. Breakdown by materials are as follows, mass timber global warming potential 3,507,776 $kgCO_2eg$, concrete global warming potential 6,194,827 $kgCO_2eg$ and steel's global warming potential is 3,117,300 $kgCO_2eg$. The concrete and steel emissions are very similar to the North American system, the extra 1.7 million comes from the mass timber. One potential for the explanation could be from the long transportation from Austria to Italy by truck, and then Italy to San Francisco by boat. It does not seem that the larger members affected the decreasing the emissions, however, it could be negligent with the transportation emissions.

The Steel system resulted in 12,013,958 $kgCO_2eg$. The emissions of the steel system is just under 800,000 than the Austrian mass timber systems. Breakdown by materials are as follows, concrete global warming potential is 6,030,968 $kgCO_2eg$, steel's global warming potential is 5,476,880 $kgCO_2eg$, and the fireproofing finishes global warming potential is 506,110 $kgCO_2eg$. Even though the steel is sourced from China, the transportation distance effects of the Austrian mass timber are larger than the steel transportation emissions. The effects of the fireproofing finishes is much less than originally thought, only four percent of the total global warming emissions of the building systems.

DISCUSSION

The results of the Tally analysis were initially surprising. Our hypothesis was partially correct. The North American mass timber system did have the lowest global warming potential. The steel building system however had the second highest global warming potential, which was an 8 percent increase from the North American mass timber system. The Austrian Mass Timber system had the highest global warming potential, increasing 16 percent from the North American mass timber system.

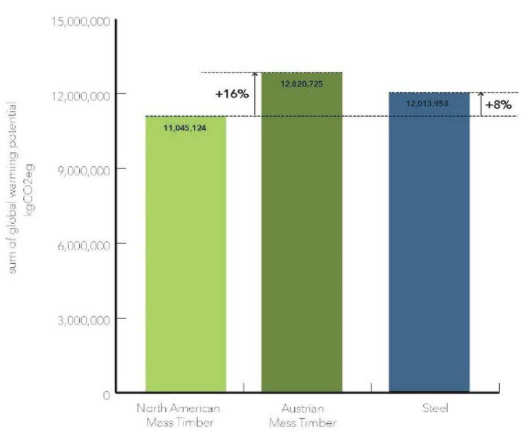

Figure 4: Comparison of the Three total GWP's

In Figure 5 the breakdown of global warming potential by material group is outlined for each building system. One of the key outcomes of this graph is that regardless of the building system, concrete is the majority of the emissions in the building. In each building system, the concrete emissions make up almost or more than half of the total global warming potential. Design lessons that could be learned from these initial findings is to lessen the amount of concrete in any building. By lessening the amount of concrete with topping slabs, and even the foundations could dramatically decrease the global warming potential. In the two mass timber systems, the global warming potential of the mass timber nearly doubles in the Austrian system. It doesn't seem feasible that transportation is the only differing impact between the two systems. It could be possible that the larger members of the Austrian system increased the emissions as well as the extra travel distance by boat.

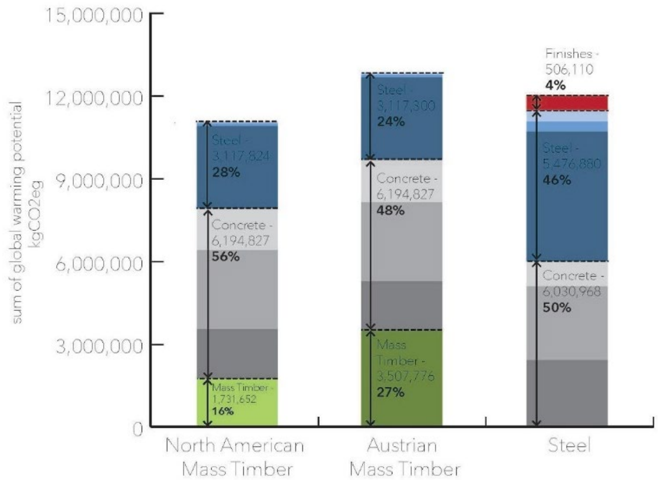

Figure 5: Material results for building systems

Initially we had thought that the fireproofing finishes would have more of an impact on the global warming potential of the building, however in the findings, the fireproofing only accounted for four percent of the total emissions. However, the global warming potential is large for the relative weight and volume of the fireproofing material in relation to the other building materials.

CONCLUSION

This research looked at three different building systems for their environmental impacts, our hypothesis that the North American mass timber system would have the lowest global warming impacts was proven to be accurate. While there is only a difference of just over 1,700,000 $kgCO_2eg$, our second hypothesis was proved to be inaccurate, the largest global warming impacts were from the Austrian mass timber building rather than the steel building system.

One of the major conclusions of this research is that concrete plays a significant role in the global warming potential of a building system. In each of the building systems the concrete made up at least half of the total emissions of the building. We need to find either an alternative to concrete that does not affect the structural capacity, or just learn how to lessen the amount of concrete that is in our buildings. Research can be done to look at new mass timber floor assemblies to eliminate the concrete. Historically, the topping slab of concrete is necessary in order to achieve the acoustic standards of the local jurisdiction. In order to see the dramatic lowering to global warming potential of the mass timber building systems, there will need to be a dramatic decrease or elimination of all concrete in the system. Alternatives that could help lessen the impacts of concrete emissions are changing the add ins away from fly ash which is a large source of emissions and researching innovative add ins such as natural byproducts of other materials like sawdust, steel dust or even high aggregate gravel. Another alternative that would require more research to verify the effects is to recycle the concrete, reducing the emission-intensive process of creating the primary materials, this is one strategy that is stated in the UN Emissions Gap Report(Environment 2019).

The current state of WBLCA software's and transparency with industry is not adequate to fully research these mass timber systems. At the time of this research paper there were no published life cycle inventory information or environmental product declarations (EPD) for any North American mass timber manufacturers. The software Tally had published EPDs for the Austrian mass timber, but for the North American was left with generic. This results in incomplete analysis when there is no published information to conduct these comparative analyses with. There will need to be transparency within the engineered wood industry to gather this information. Our assumption is that there still would be no significant changes to the global warming potential of the three building systems. A shortcoming of the WBLCA software Tally is that there is no accountability for dynamic models of forest management in any of the software's bioproducts. Dynamic modeling adds the impacts of forest management, forest rotation cycles of the set manufacturers, which would result in a much more complete analysis. The emissions that come from forest management are major and should be factored into the WBLCA of these engineered wood products. Once again this would require much more transparency from the timber industry. The forest rotation cycles are crucial to the amount of carbon the trees are sequestering and holding throughout their life, if harvest cycles were lengthened on private lands in Oregon to 80 years from the typical 40-year rotation cycles, Oregon's statewide carbon stock would increase 17 percent (Law et al. 2018). These shortened rotation cycles are having a negative impact on the carbon sequestered by trees, which could be leading to an inflation in the benefits of wood building products in these life cycle analyses.

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ADDENDUM

Addendum#1: Pier 70, Full Building Summary

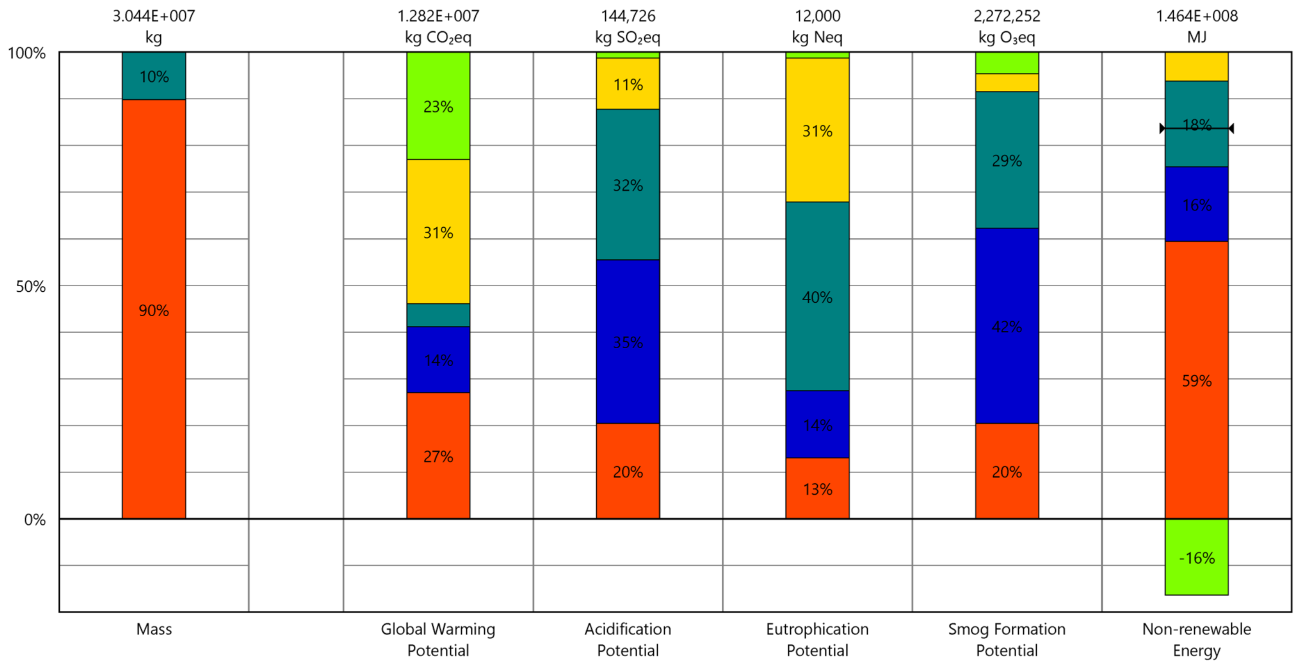
This will include all of the raw data collected from Tally, including the bill of materials for each building system.

PIER 70
FULL BUILDING SUMMARY

Project	PIER 70
Location	PIER 70 PARCEL A
Gross Area	350,000 ft²
Building Life	75 years
Boundaries	Cradle to grave, inclusive of biogenic carbon; see appendix for a full list of materials and processes

PIER 70
FULL BUILDING SUMMARY

Results per Life Cycle Stage



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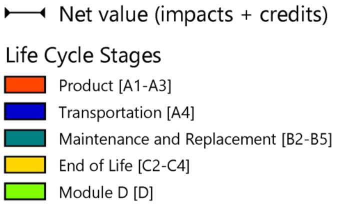
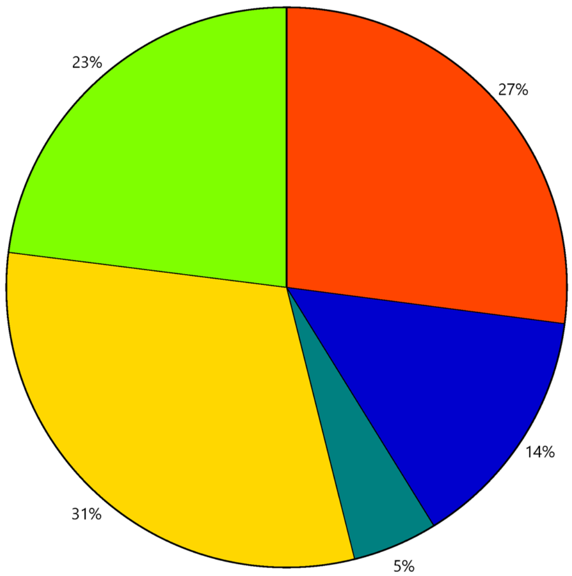
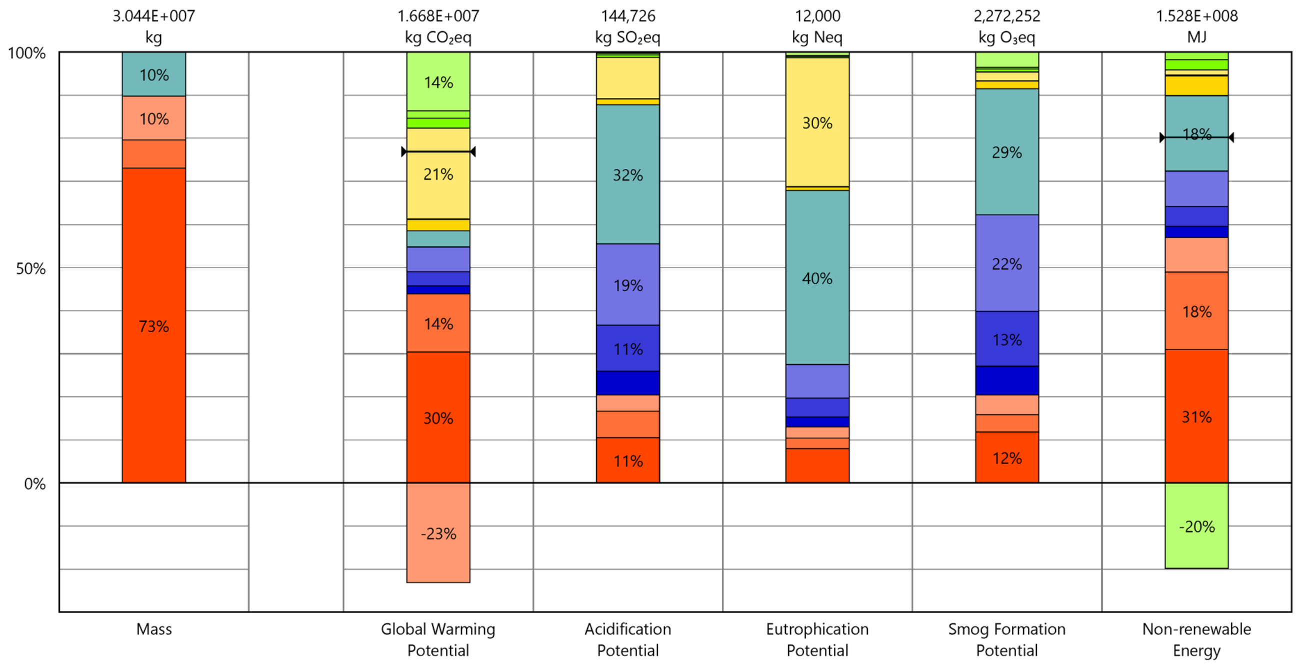




Global Warming Potential

PIER 70
FULL BUILDING SUMMARY

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Product [A1-A3]

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Transportation [A4]

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Maintenance and Replacement [B2-B5]

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

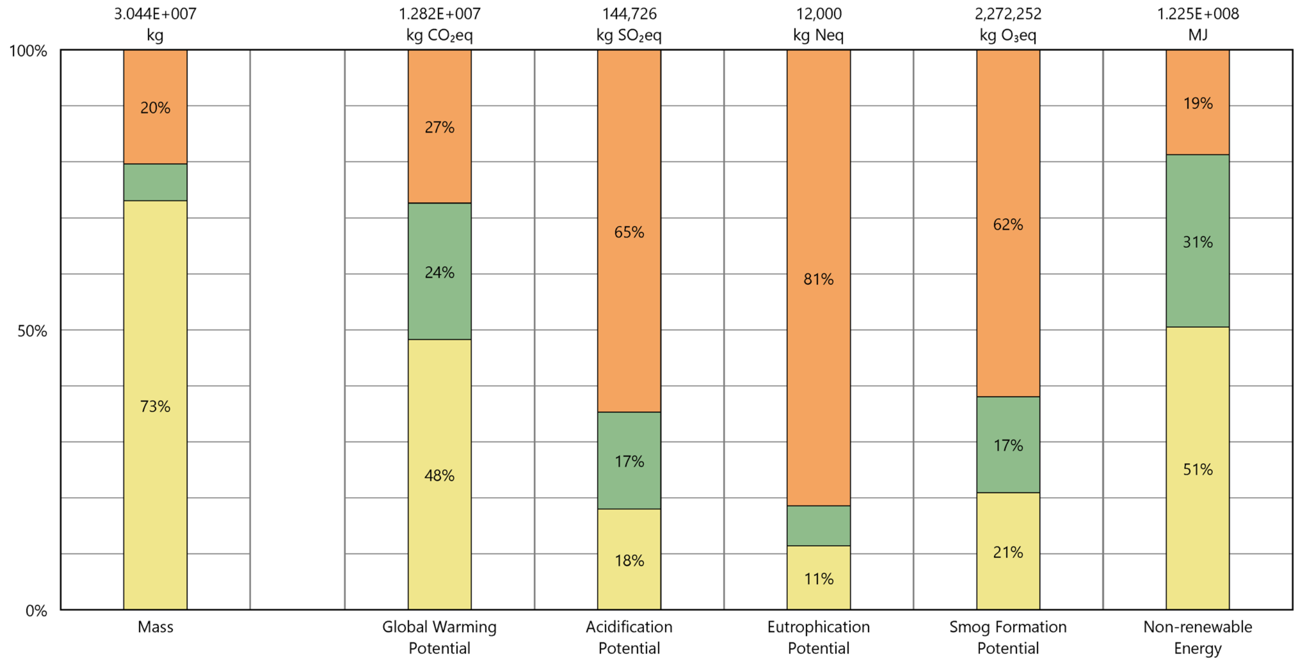
End of Life [C2-C4]

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Module D [D]

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Results per Division



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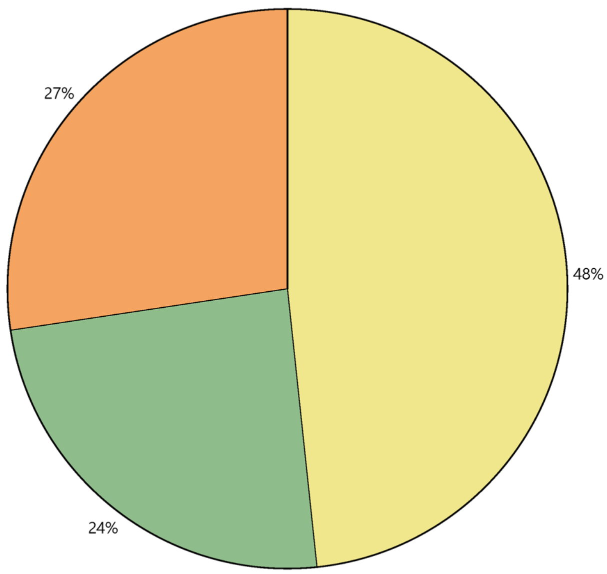
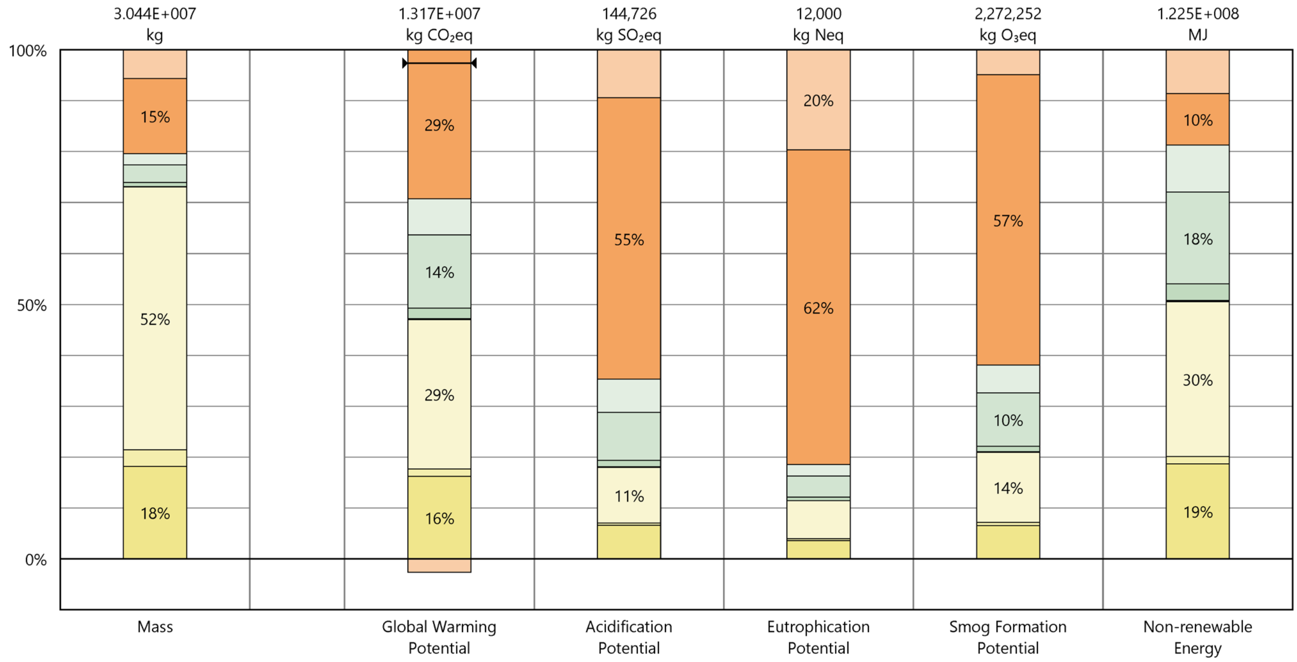
Divisions

- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes



Global Warming Potential

Results per Division, itemized by Tally Entry



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Net value (impacts + credits)

03 - Concrete

- Cast-in-place concrete, lightweight structural concrete, 2501-3000 psi
- Cast-in-place concrete, structural concrete, 2501-3000 psi
- Cast-in-place concrete, structural concrete, 3001-4000 psi

05 - Metals

- Steel, C-stud metal framing
- Steel, C-stud metal framing with insulation
- Steel, deck
- Steel, HSS section
- Steel, rod
- Steel, W section (wide flange shape)

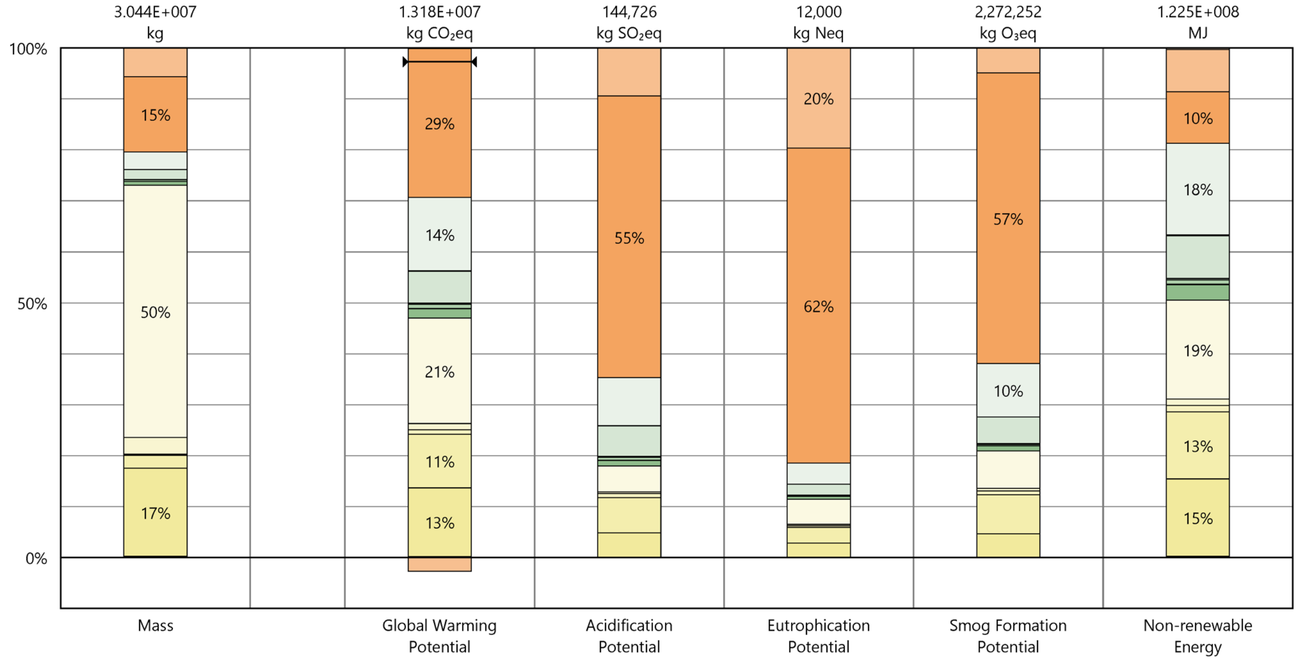
06 - Wood/Plastics/Composites

- Cross laminated timber (CLT)
- Glue laminated timber (Glulam)

09 - Finishes

- Wall board, gypsum

Results per Division, itemized by Material



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Net value (impacts + credits)

03 - Concrete

- Lightweight concrete, 2501-3000 psi, 20-29% fly ash
- Lightweight concrete, 2501-3000 psi, 30-39% slag
- Steel, concrete reinforcing steel, CMC - EPD
- Steel, reinforcing rod
- Structural concrete, 2501-3000 psi, 30-39% fly ash
- Structural concrete, 3001-4000 psi, 30-39% fly ash

05 - Metals

- Cold formed structural steel
- Fiberglass blanket insulation, paper faced
- Fireproofing, cementitious
- Fireproofing, cementitious, by area
- Fireproofing, intumescent paint, by area
- Galvanized steel
- Galvanized steel decking
- Hot rolled structural steel, AISC - EPD
- Powder coating, metal stock
- Steel, concrete reinforcing steel, CMC - EPD

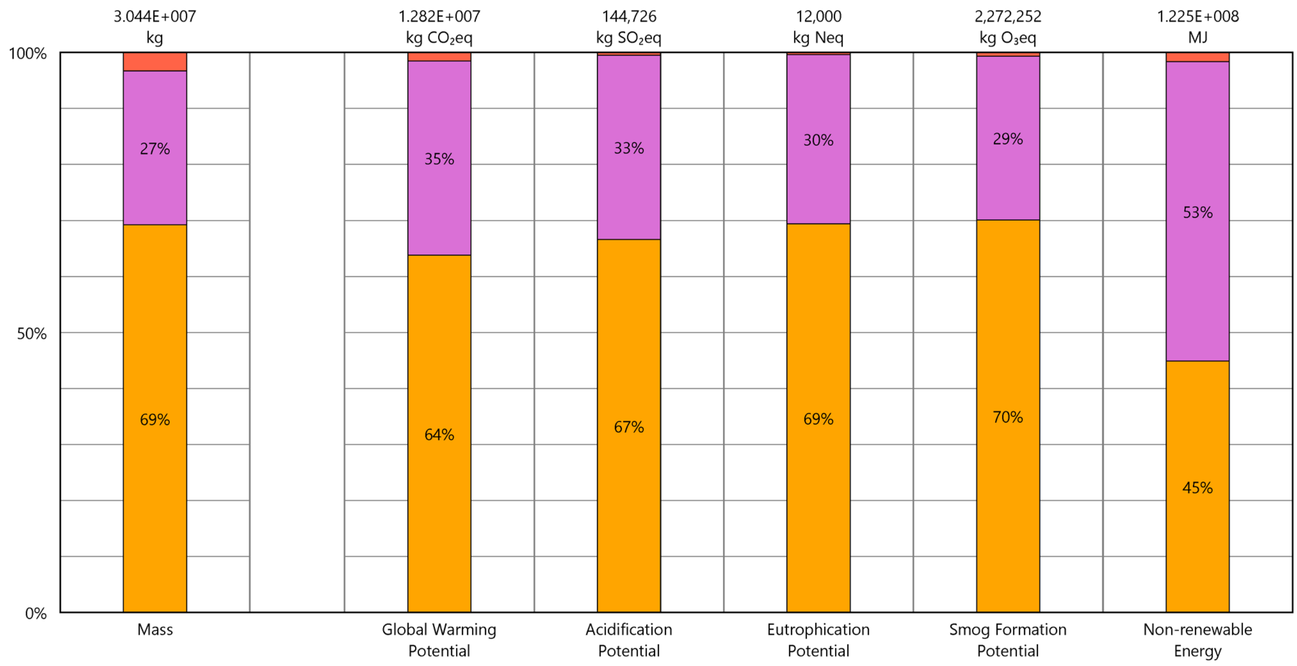
06 - Wood/Plastics/Composites

- CLT, KLH Massivholz, KLH Solid Timber Panels, 320 mm - EPD
- Glue laminated timber (Glulam), AWC - EPD
- Wood stain, water based

09 - Finishes

- Paint, interior acrylic latex
- Wall board, gypsum, fire-resistant (Type X)

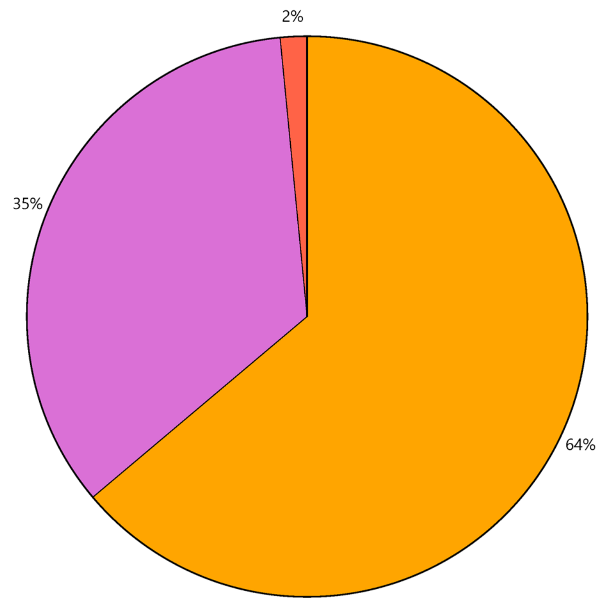
Results per Revit Category



Legend

Revit Categories

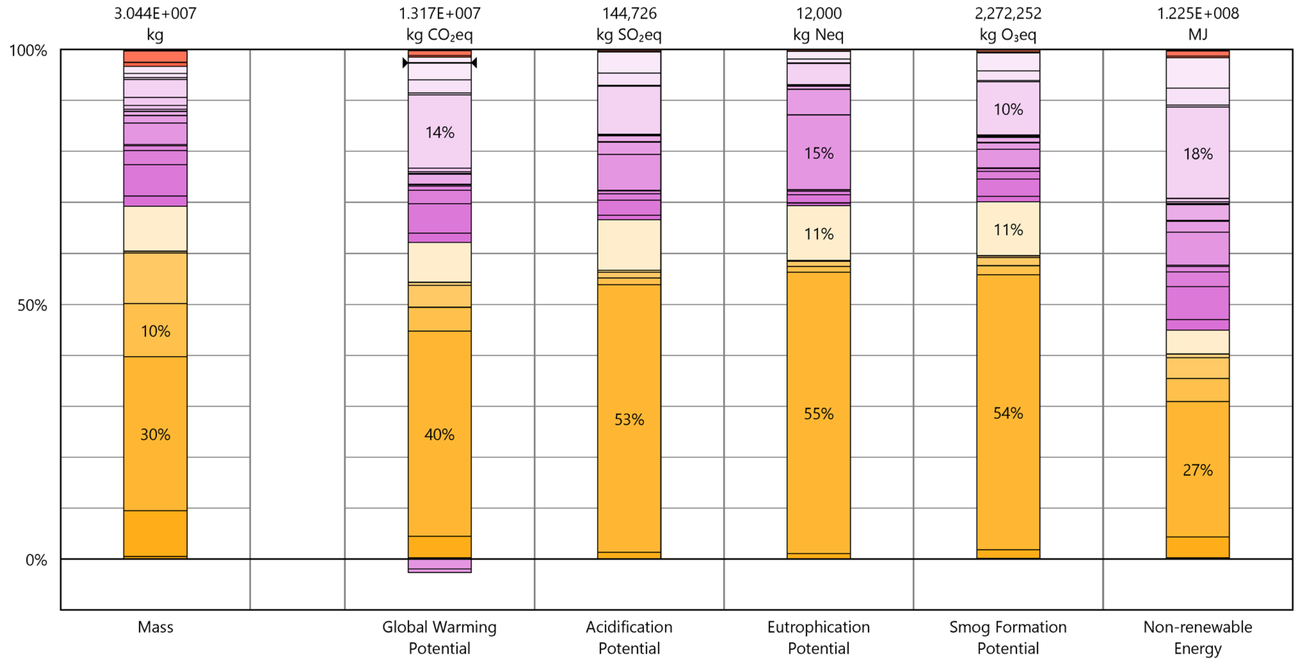
- Floors
- Structure
- Walls



Global Warming Potential

PIER 70
FULL BUILDING SUMMARY

Results per Revit Category, itemized by Family



Legend

⟼ Net value (impacts + credits)

Floors

- 10" Concrete
- 10" PT SLAB
- 11" CLT w/topping slab
- 18" Concrete
- 2'-6" Concrete
- 3" LW Concrete on 3" Composite Metal Deck
- 4" TOPPING SLAB
- 6" Concrete
- CLT + 8" Roofing Material

Structure

- 4'-0" Foundation Slab
- 5'-0" Foundation Slab
- Concrete-Rectangular Beam
- Concrete-Rectangular-Column
- Concrete-Round-Column
- Glulam-Western Species
- Glulam-Western Species-Column
- HSS Rectangular
- HSS Square
- Pile Cap-2 Pile
- Pile Cap-3 Pile
- Pile Cap-4 Pile
- Pile Cap-5 Pile
- Pile-Steel Pipe
- Retaining Footing - 48" x 18" x 18"
- W Shapes
- W Shapes-Column

Walls

- 10" Concrete
- 12" Concrete
- 5" Metal Stud
- 6" GENERIC
- 6" Metal Stud
- 8" Concret
- 8" Concrete
- 8" SCREEN WALL
- M3.4

PIER 70
FULL BUILDING SUMMARY

Report Summary

Environmental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq)	3,470,652	1,811,089	628,528	3,961,023	2,949,434
Acidification (kg SO_2eq)	29,609	50,722	46,628	15,927	1,839
Eutrophication (kg Neq)	1,564	1,735	4,840	3,703	157.4
Smog Formation (kg O_3eq)	464,932	950,513	663,413	88,231	105,163
Ozone Depletion (kg CFC-11eq)	0.09718	5.066E-008	0.0881	1.123E-007	-0.009416
Primary Energy (MJ)	1.541E+008	2.353E+007	8.903E+007	9,738,360	-3.708E+007
Non-renewable Energy (MJ)	8.711E+007	2.333E+007	2.689E+007	9,115,458	-2.397E+007
Renewable Energy (MJ)	6.686E+007	157,269	6.201E+007	630,401	-1.323E+007

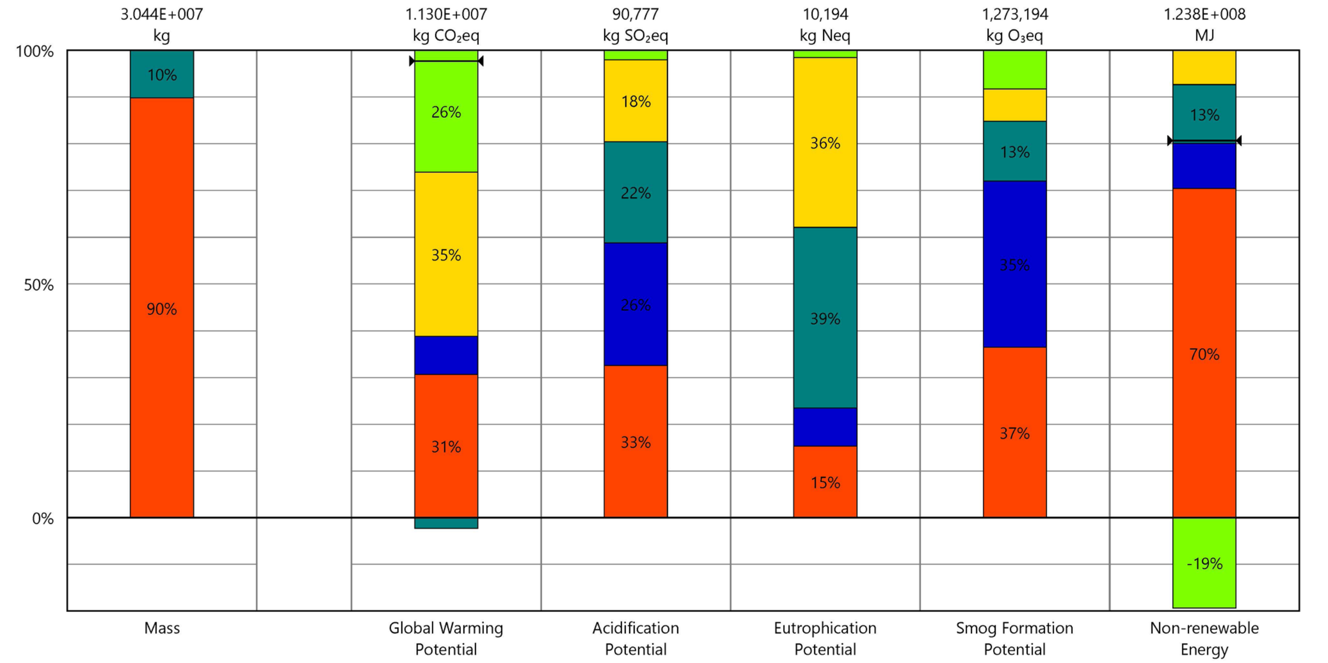
Environmental Impacts / Area	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq/m^2)	106.7	55.70	19.33	121.8	90.71
Acidification (kg SO_2eq/m^2)	0.9106	1.560	1.434	0.4898	0.05657
Eutrophication (kg Neq/m^2)	0.0481	0.05335	0.1489	0.1139	0.004841
Smog Formation (kg O_3eq/m^2)	14.30	29.23	20.40	2.713	3.234
Ozone Depletion (kg CFC-11eq/m^2)	2.989E-006	1.558E-012	2.709E-006	3.455E-012	-2.896E-007
Primary Energy (MJ/m^2)	4,738	723.6	2,738	299.5	-1,140
Non-renewable Energy (MJ/m^2)	2,679	717.6	826.9	280.3	-737
Renewable Energy (MJ/m^2)	2,056	4.837	1,907	19.39	-407

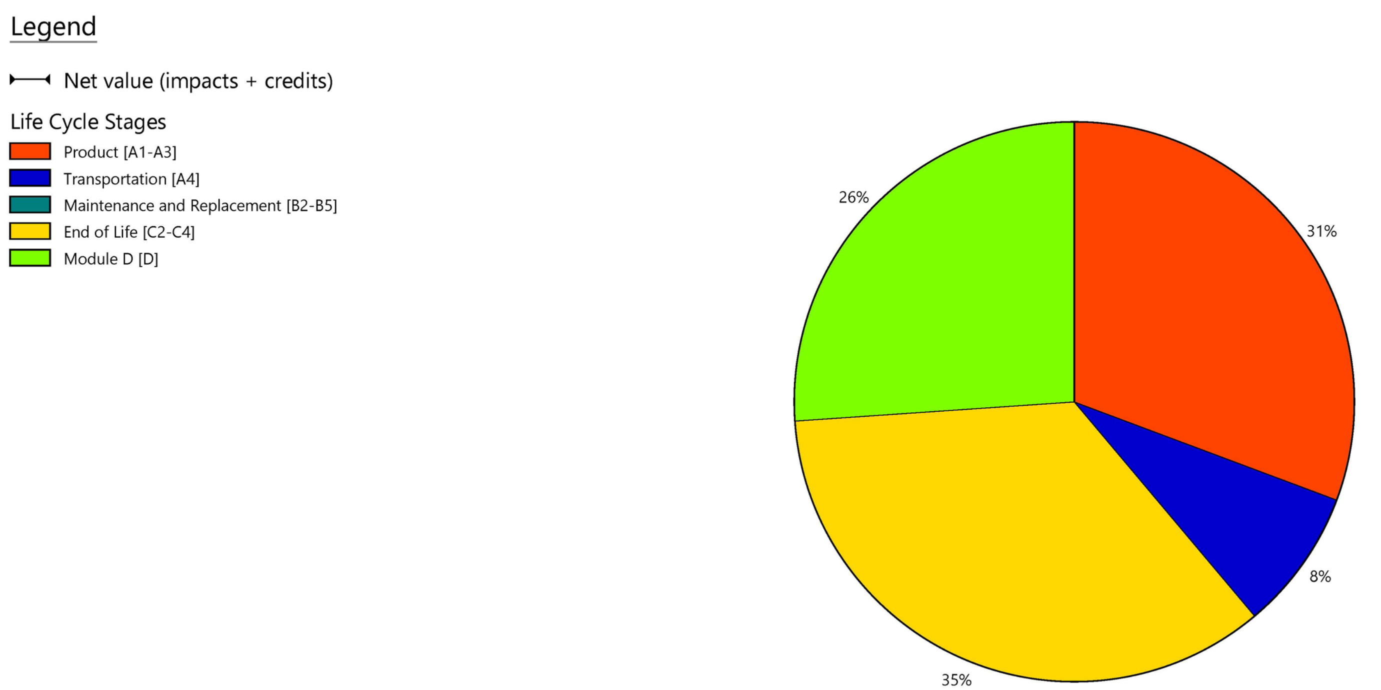
PIER 70
FULL BUILDING SUMMARY

Revit material	Tally Assumption	amount
Wood/Plastics/Composites	CLT, KLH Massivholz, KLH Solid Timber Panels, 320 mm - EPD	4,485,162.5 kg
	Glue laminated timber (Glulam), AWC - EPD	1,716,077.03
	Wood stain, water based	10,198.08
	Total	**6,211,437.65**
Finishes	Paint, interior acrylic latex	324.49
	Total	**324.49**
Metals	Cold formed structural steel	226,696.23
	Fiberglass blanket insulation, paper faced	1,832.49
	Fireproofing, cementitious	3,787.39
	Fireproofing, cementitious, by area	90,808.10
	Fireproofing, intumescent paint, by area	610.12
	Galvanized steel	8,466.08
	Galvanized steel decking	2,019.94
	Hot rolled structural steel, AISC - EPD	592,961.33
	Powder coating, metal stock	1,065.92
	Steel, concrete reinforcing steel, CMC - EPD	1,060,320.00
	Total	**1,988,567.61**
Concrete	Lightweight concrete, 2501-3000 psi, 20-29% fly ash	69,727.90
	Lightweight concrete, 2501-3000 psi, 30-39% slag	5,268,164.85
	Steel, concrete reinforcing steel, CMC - EPD	777,541.99
	Steel, reinforcing rod	69,501.27
	Structural concrete, 2501-3000 psi, 30-39% fly ash	986,815.67
	Structural concrete, 3001-4000 psi, 30-39% fly ash	15,070,294.47
	Total	**22,242,046.15**

PIER 70
FULL BUILDING SUMMARY

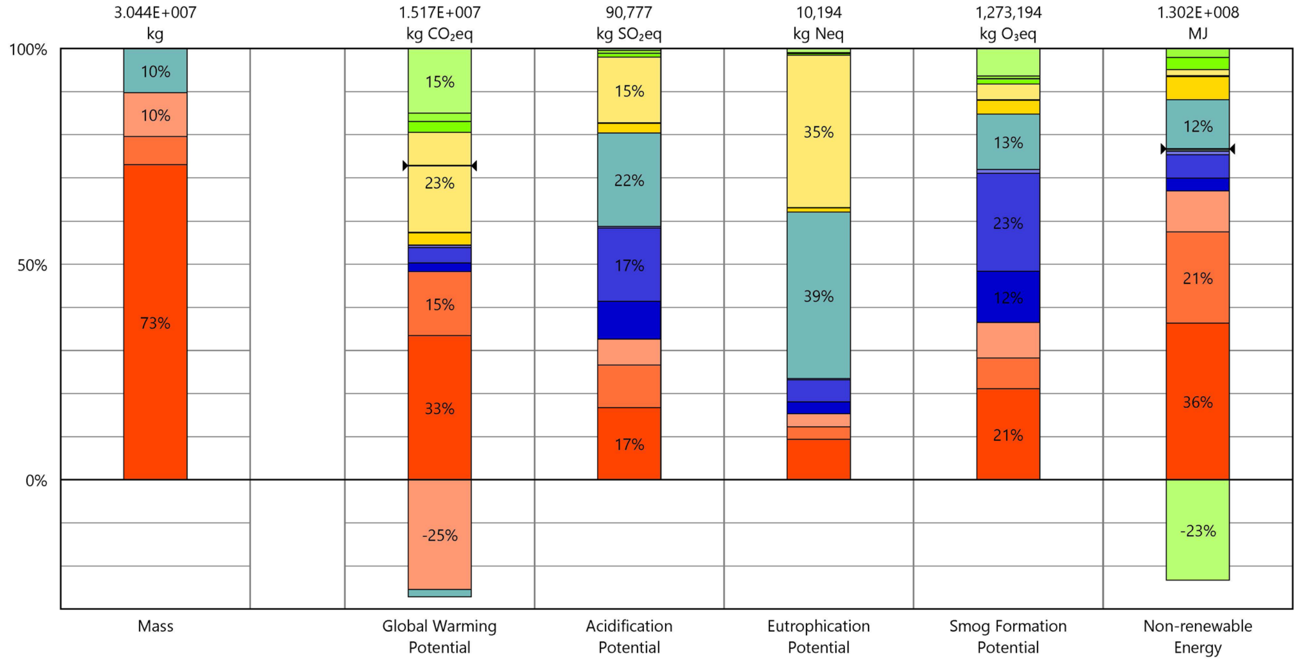
Results per Life Cycle Stage





Global Warming Potential

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Product [A1-A3]
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Transportation [A4]
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

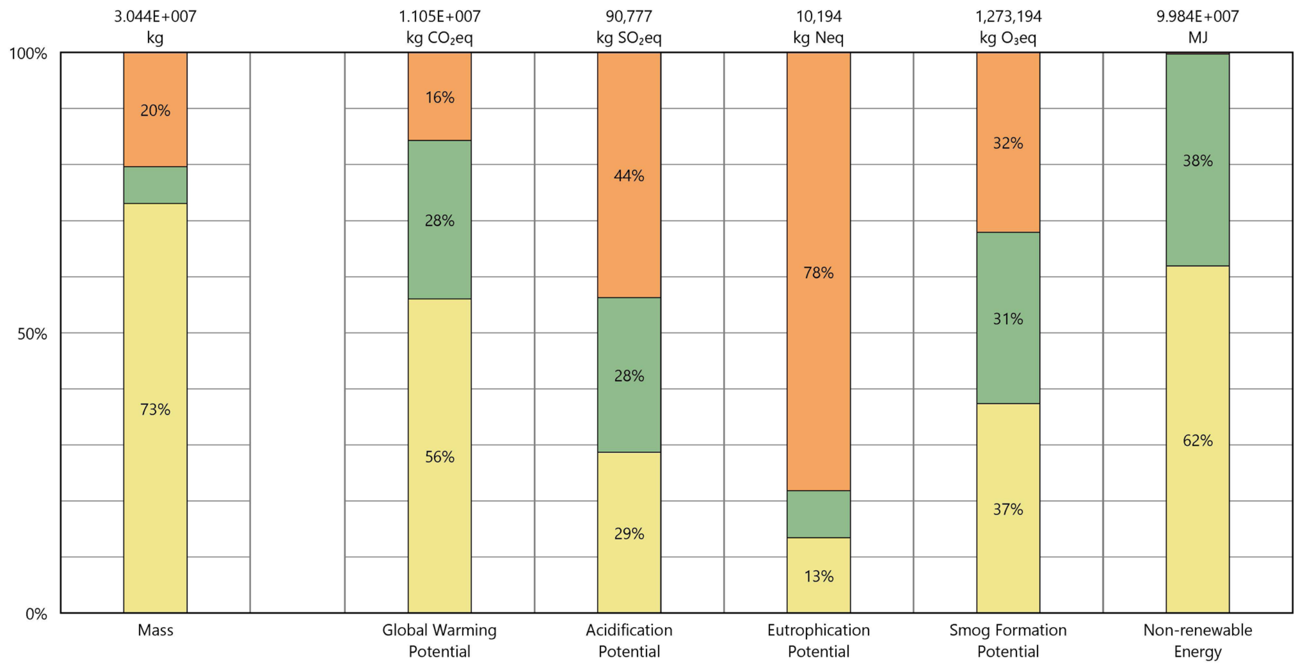
Maintenance and Replacement [B2-B5]
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

End of Life [C2-C4]
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

Module D [D]
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes

PIER 70
FULL BUILDING SUMMARY

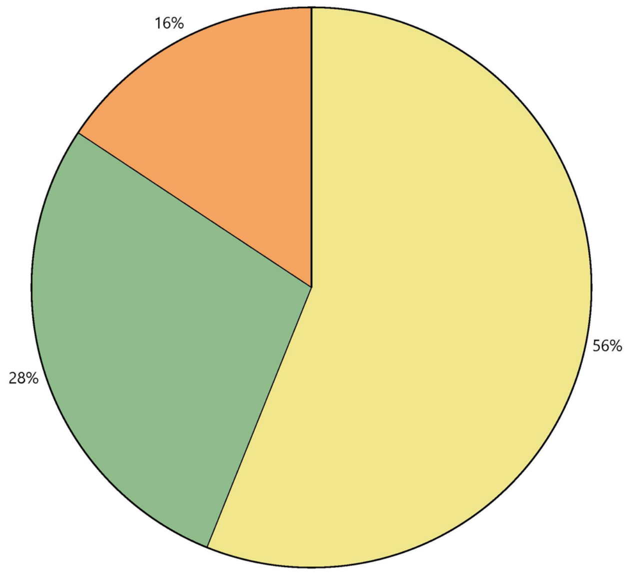
Results per Division



Legend

Divisions

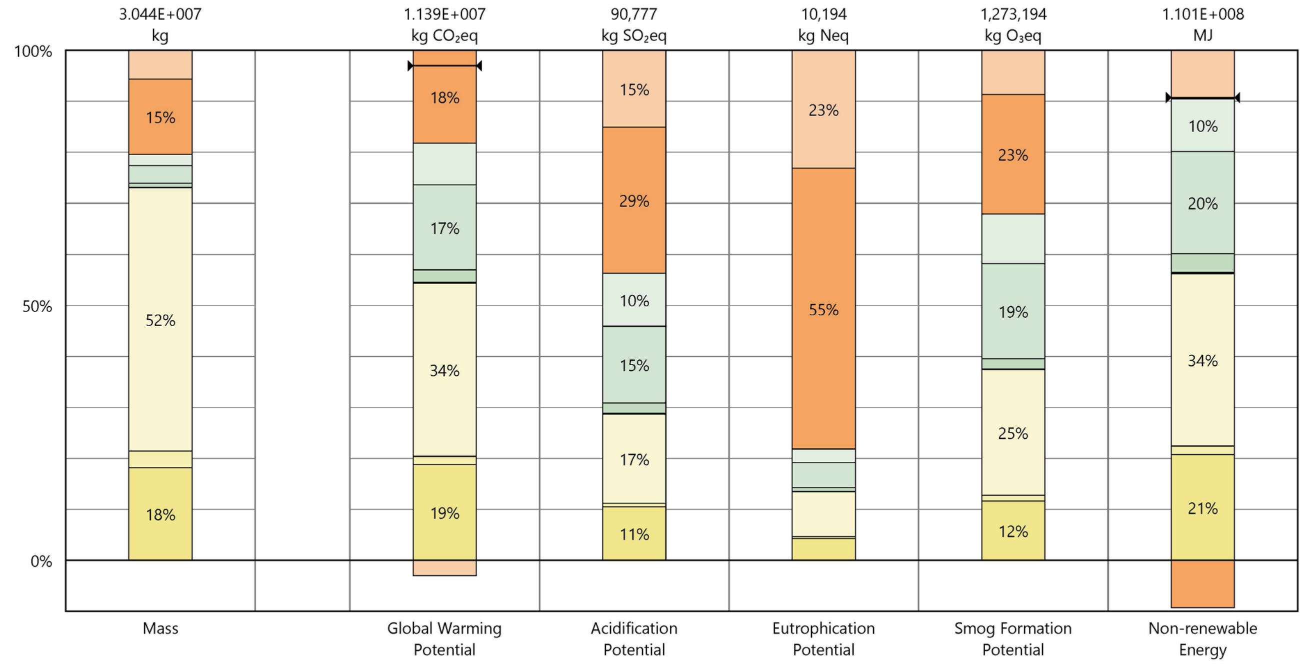
- 03 - Concrete
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 09 - Finishes



Global Warming Potential

PIER 70
FULL BUILDING SUMMARY

Results per Division, itemized by Tally Entry



Legend

Net value (impacts + credits)

03 - Concrete

- Cast-in-place concrete, lightweight structural concrete, 2501-3000 psi
- Cast-in-place concrete, structural concrete, 2501-3000 psi
- Cast-in-place concrete, structural concrete, 3001-4000 psi

05 - Metals

- Steel, C-stud metal framing
- Steel, C-stud metal framing with insulation
- Steel, deck
- Steel, HSS section
- Steel, rod
- Steel, W section (wide flange shape)

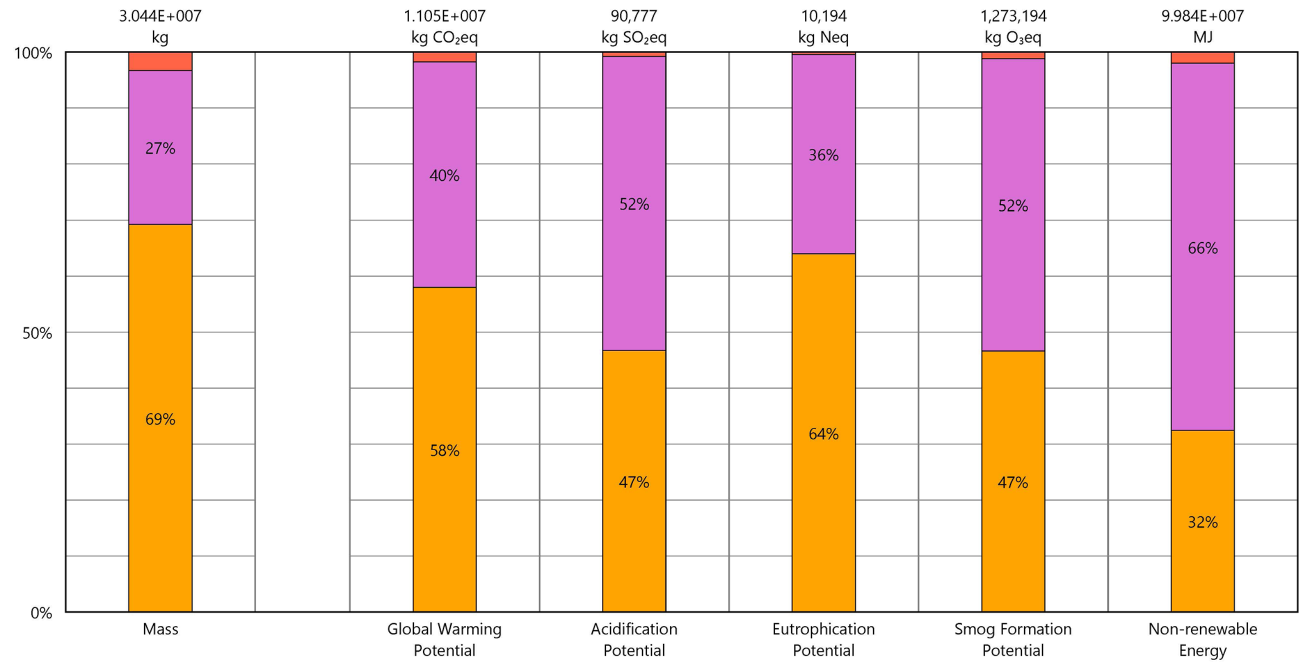
06 - Wood/Plastics/Composites

- Cross laminated timber (CLT)
- Glue laminated timber (Glulam)

09 - Finishes

- Wall board, gypsum

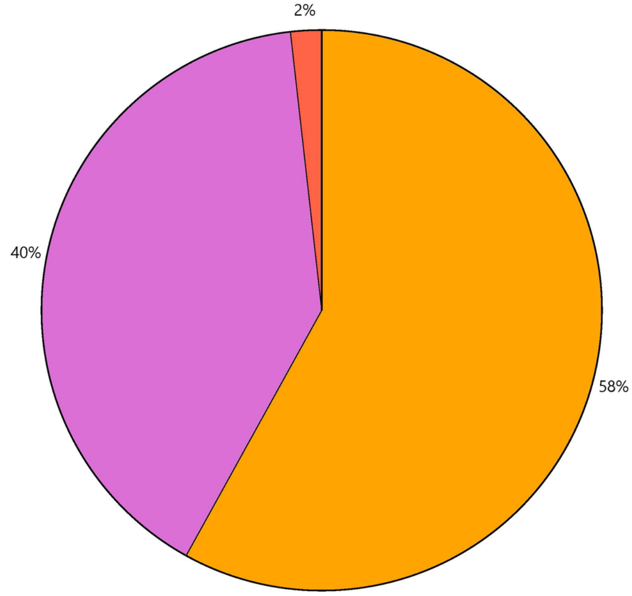
Results per Revit Category



Legend

Revit Categories

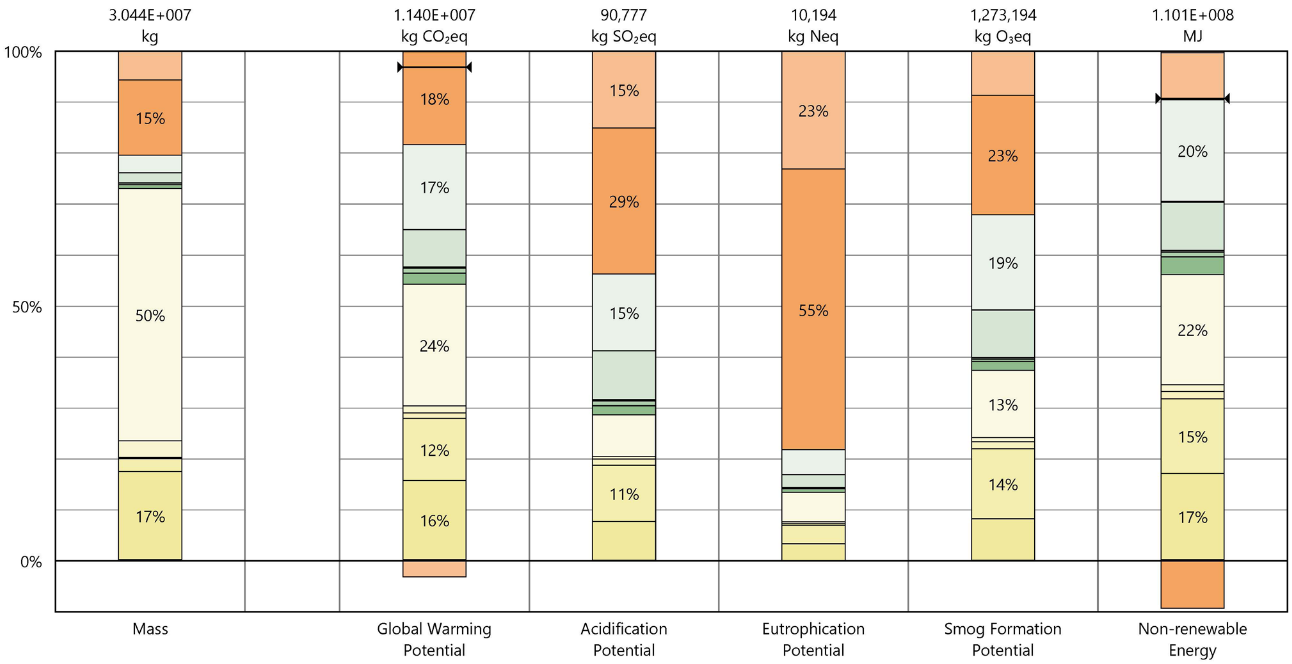
- Floors
- Structure
- Walls



Global Warming Potential

PIER 70
FULL BUILDING SUMMARY

Results per Division, itemized by Material



Legend

Net value (impacts + credits)

03 - Concrete

- Lightweight concrete, 2501-3000 psi, 20-29% fly ash
- Lightweight concrete, 2501-3000 psi, 30-39% slag
- Steel, concrete reinforcing steel, CMC - EPD
- Steel, reinforcing rod
- Structural concrete, 2501-3000 psi, 30-39% fly ash
- Structural concrete, 3001-4000 psi, 30-39% fly ash

05 - Metals

- Cold formed structural steel
- Fiberglass blanket insulation, paper faced
- Fireproofing, cementitious
- Fireproofing, cementitious, by area
- Fireproofing, intumescent paint, by area
- Galvanized steel
- Galvanized steel decking
- Hot rolled structural steel, AISC - EPD
- Powder coating, metal stock
- Steel, concrete reinforcing steel, CMC - EPD

06 - Wood/Plastics/Composites

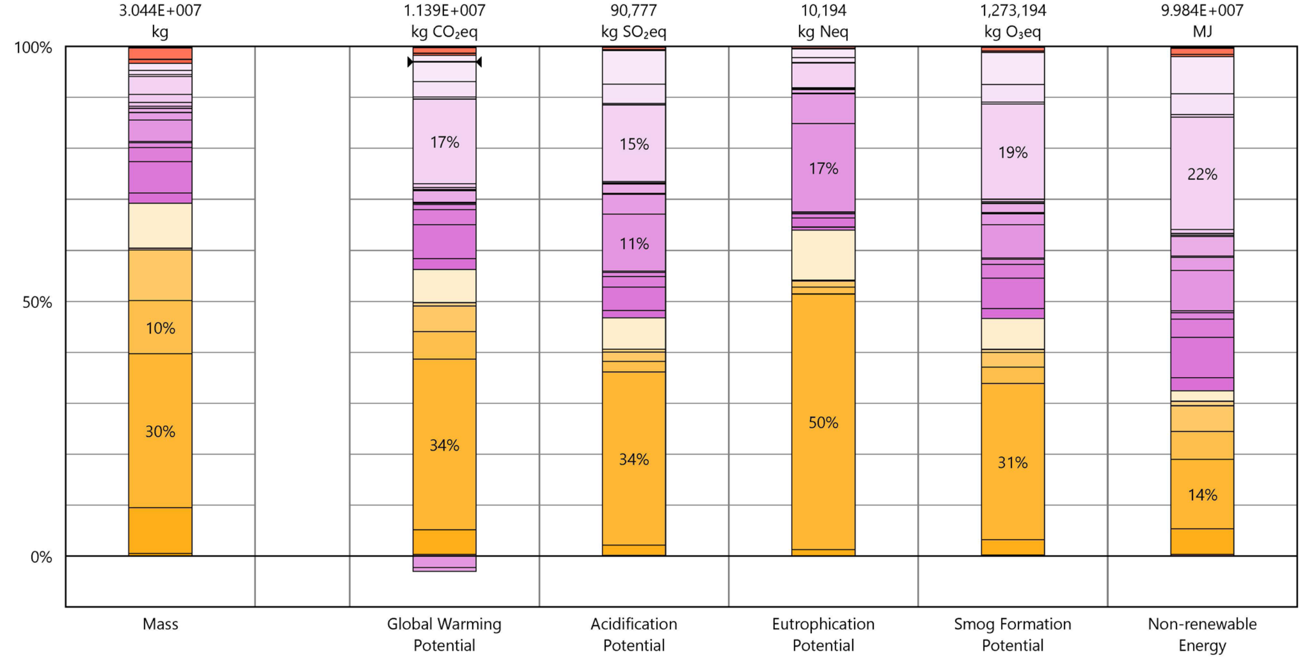
- CLT, KLH Massivholz, KLH Solid Timber Panels, 320 mm - EPD
- Glue laminated timber (Glulam), AWC - EPD
- Wood stain, water based

09 - Finishes

- Paint, interior acrylic latex
- Wall board, gypsum, fire-resistant (Type X)

PIER 70
FULL BUILDING SUMMARY

Results per Revit Category, itemized by Family



Legend

Net value (impacts + credits)

Floors
- 10" Concrete
- 10" PT SLAB
- 11" CLT w/topping slab
- 18" Concrete
- 2'-6" Concrete
- 3" LW Concrete on 3" Composite Metal Deck
- 4" TOPPING SLAB
- 6" Concrete
- CLT + 8" Roofing Material

Structure
- 4'-0" Foundation Slab
- 5'-0" Foundation Slab
- Concrete-Rectangular Beam
- Concrete-Rectangular-Column
- Concrete-Round-Column
- Glulam-Western Species
- Glulam-Western Species-Column
- HSS Rectangular
- HSS Square
- Pile Cap-2 Pile
- Pile Cap-3 Pile
- Pile Cap-4 Pile
- Pile Cap-5 Pile
- Pile-Steel Pipe
- Retaining Footing - 48" x 18" x 18"
- W Shapes
- W Shapes-Column

Walls
- 10" Concrete
- 12" Concrete
- 5" Metal Stud
- 6" GENERIC
- 6" Metal Stud
- 8" Concret
- 8" Concrete
- 8" SCREEN WALL
- M3.4

Report Summary

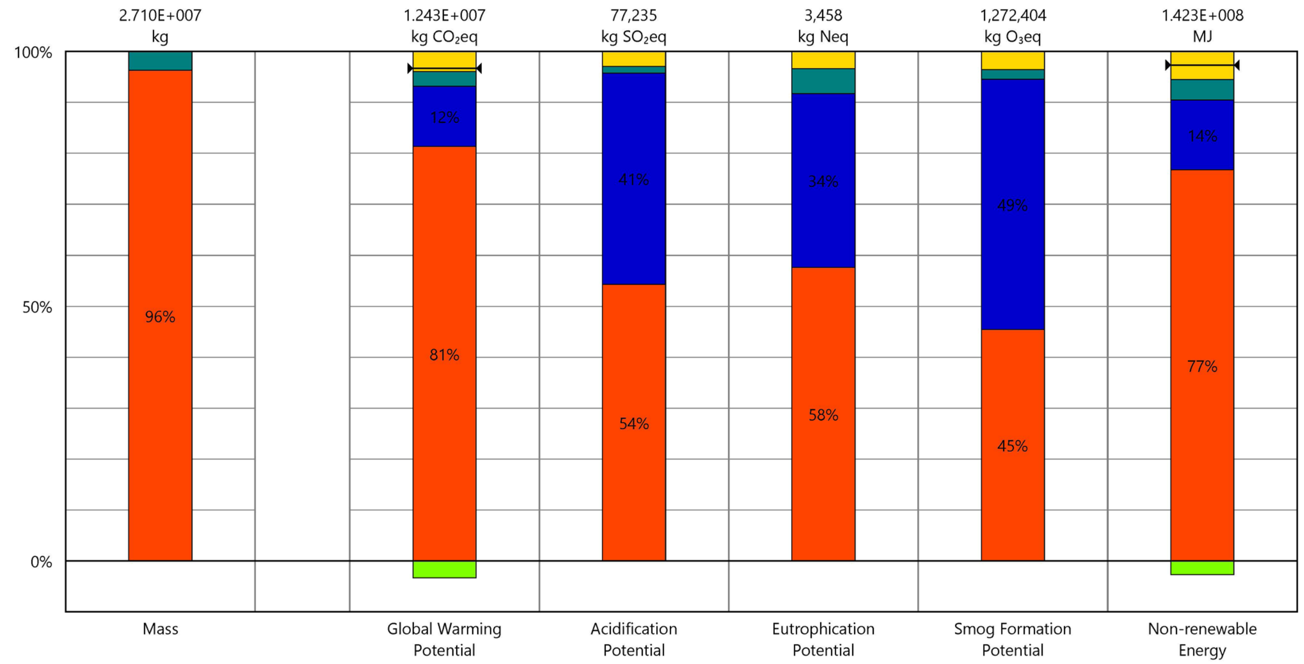
Environmental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq)	3,470,937	923,028	-259,300	3,961,026	2,949,434
Acidification (kg SO_2eq)	29,610	23,747	19,653	15,927	1,839
Eutrophication (kg Neq)	1,564	831.9	3,938	3,703	157.4
Smog Formation (kg O_3eq)	464,939	450,978	163,882	88,231	105,163
Ozone Depletion (kg CFC-11eq)	0.09718	2.638E-008	0.0881	1.123E-007	-0.009416
Primary Energy (MJ)	1.541E+008	1.213E+007	7.763E+007	9,738,411	-3.708E+007
Non-renewable Energy (MJ)	8.712E+007	1.201E+007	1.557E+007	9,115,506	-2.397E+007
Renewable Energy (MJ)	6.686E+007	103,985	6.195E+007	630,404	-1.323E+007

Environmental Impacts / Area	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq/m^2)	106.7	28.39	-7.97	121.8	90.71
Acidification (kg SO_2eq/m^2)	0.9106	0.7303	0.6044	0.4898	0.05657
Eutrophication (kg Neq/m^2)	0.0481	0.02558	0.1211	0.1139	0.004841
Smog Formation (kg O_3eq/m^2)	14.30	13.87	5.040	2.713	3.234
Ozone Depletion (kg CFC-11eq/m^2)	2.989E-006	8.114E-013	2.709E-006	3.455E-012	-2.896E-007
Primary Energy (MJ/m^2)	4,738	373.1	2,388	299.5	-1,140
Non-renewable Energy (MJ/m^2)	2,679	369.3	478.8	280.3	-737
Renewable Energy (MJ/m^2)	2,056	3.198	1,905	19.39	-407

Revit material	Tally Assumption	amount
Wood/Plastics/Composites	CLT, KLH Massivholz, KLH Solid Timber Panels, 320 mm - EPD	4,485,162.5 kg
	Glue laminated timber (Glulam), AWC - EPD	1,716,077.03
	Wood stain, water based	10,198.08
	Total	**6,211,437.65**
Finishes	Paint, interior acrylic latex	324.49
	Total	**324.49**
Metals	Cold formed structural steel	226,696.23
	Fiberglass blanket insulation, paper faced	1,832.49
	Fireproofing, cementitious	3,787.39
	Fireproofing, cementitious, by area	90,808.10
	Fireproofing, intumescent paint, by area	610.12
	Galvanized steel	8,466.08
	Galvanized steel decking	2,019.94
	Hot rolled structural steel, AISC - EPD	592,961.33
	Powder coating, metal stock	1,065.92
	Steel, concrete reinforcing steel, CMC - EPD	1,060,320.00
	Total	**1,988,567.61**
Concrete	Lightweight concrete, 2501-3000 psi, 20-29% fly ash	69,727.90
	Lightweight concrete, 2501-3000 psi, 30-39% slag	5,268,164.85
	Steel, concrete reinforcing steel, CMC - EPD	777,541.99
	Steel, reinforcing rod	69,501.27
	Structural concrete, 2501-3000 psi, 30-39% fly ash	986,815.67
	Structural concrete, 3001-4000 psi, 30-39% fly ash	15,070,294.47
	Total	**22,242,046.15**

PIER 70
FULL BUILDING SUMMARY

Results per Life Cycle Stage

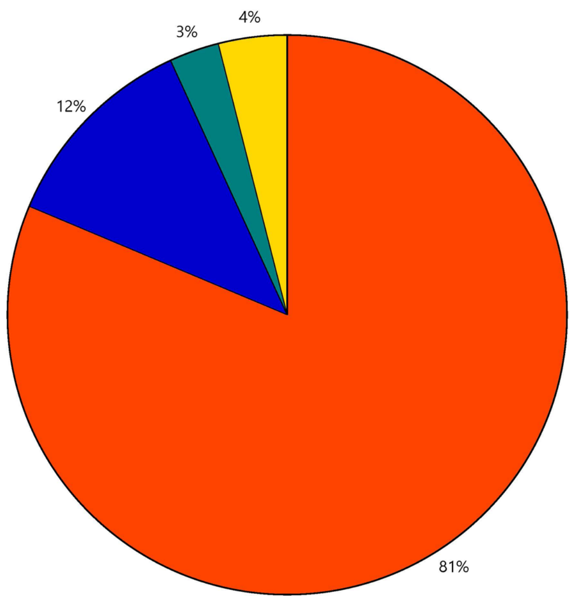


Legend

Net value (impacts + credits)

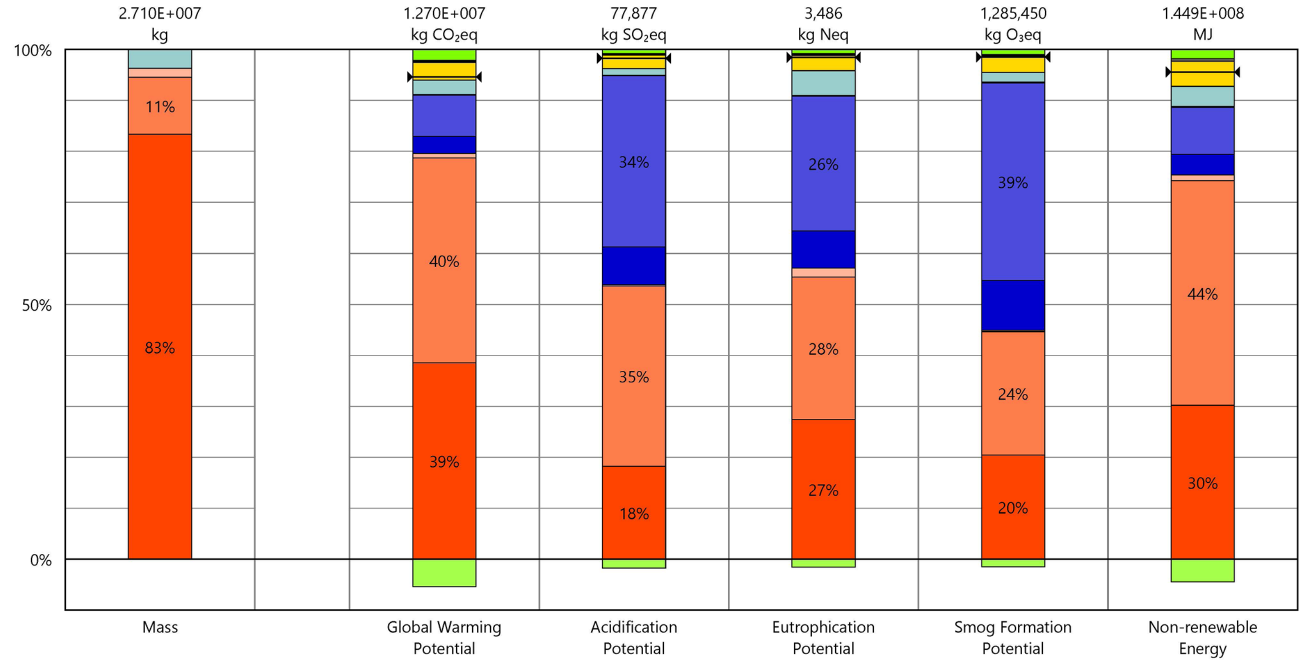
Life Cycle Stages

- Product [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B5]
- End of Life [C2-C4]
- Module D [D]



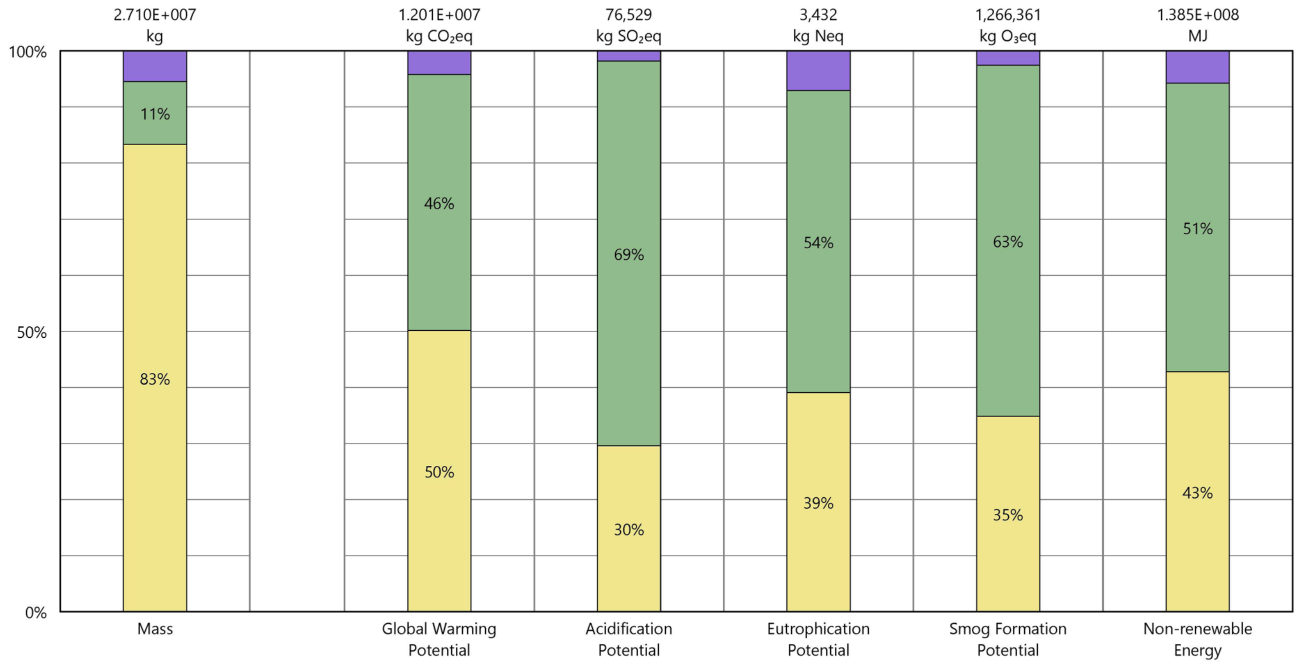
Global Warming Potential

Results per Life Cycle Stage, itemized by Division



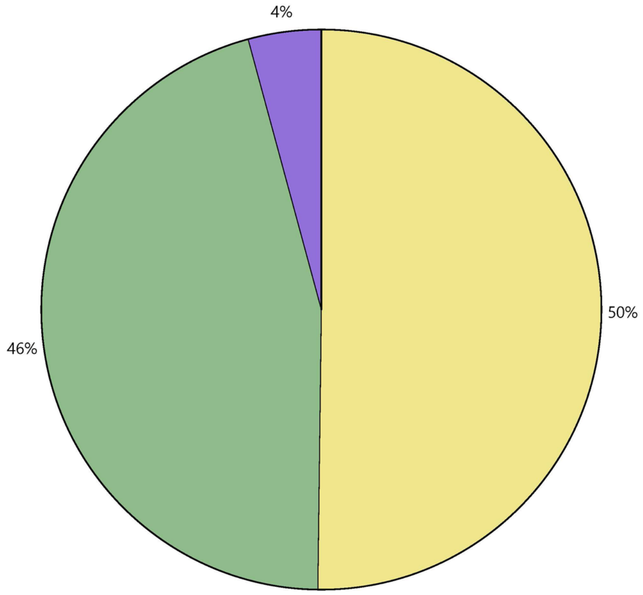
Legend

Results per Division



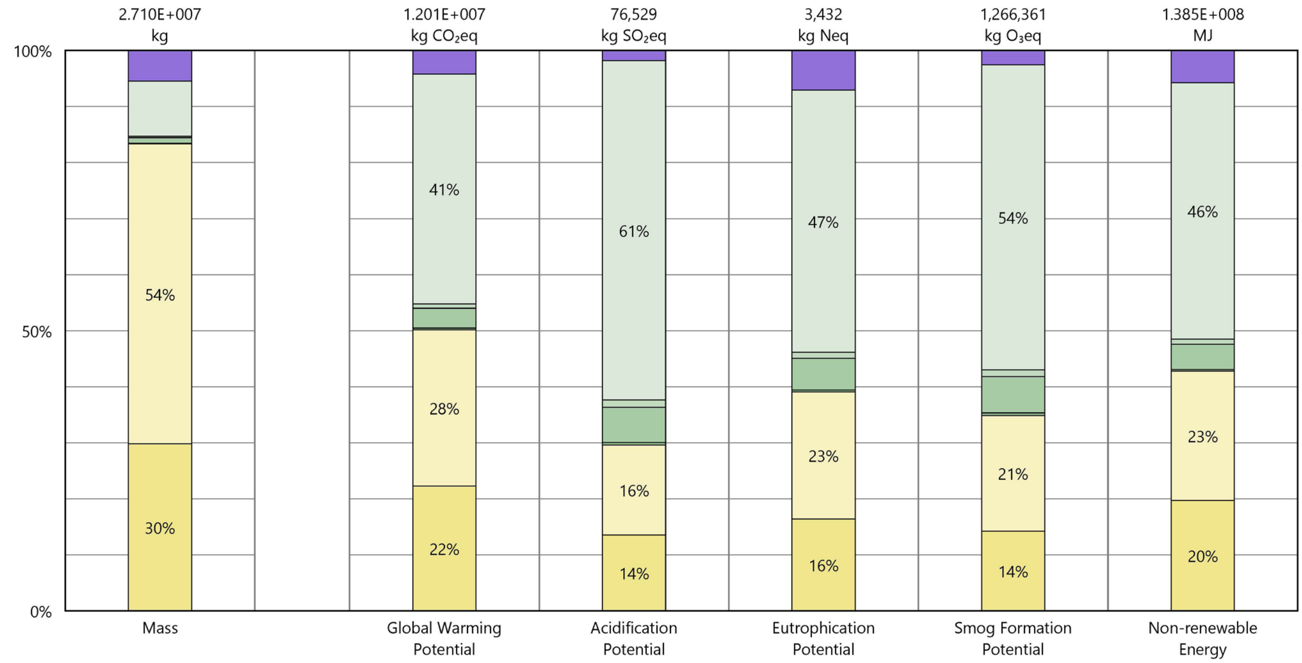
Legend

Divisions
- 03 - Concrete
- 05 - Metals
- 09 - Finishes



Global Warming Potential

Results per Division, itemized by Tally Entry



Legend

03 - Concrete

- Cast-in-place concrete, lightweight structural concrete, 3001-4000 psi
- Cast-in-place concrete, structural concrete, 3001-4000 psi

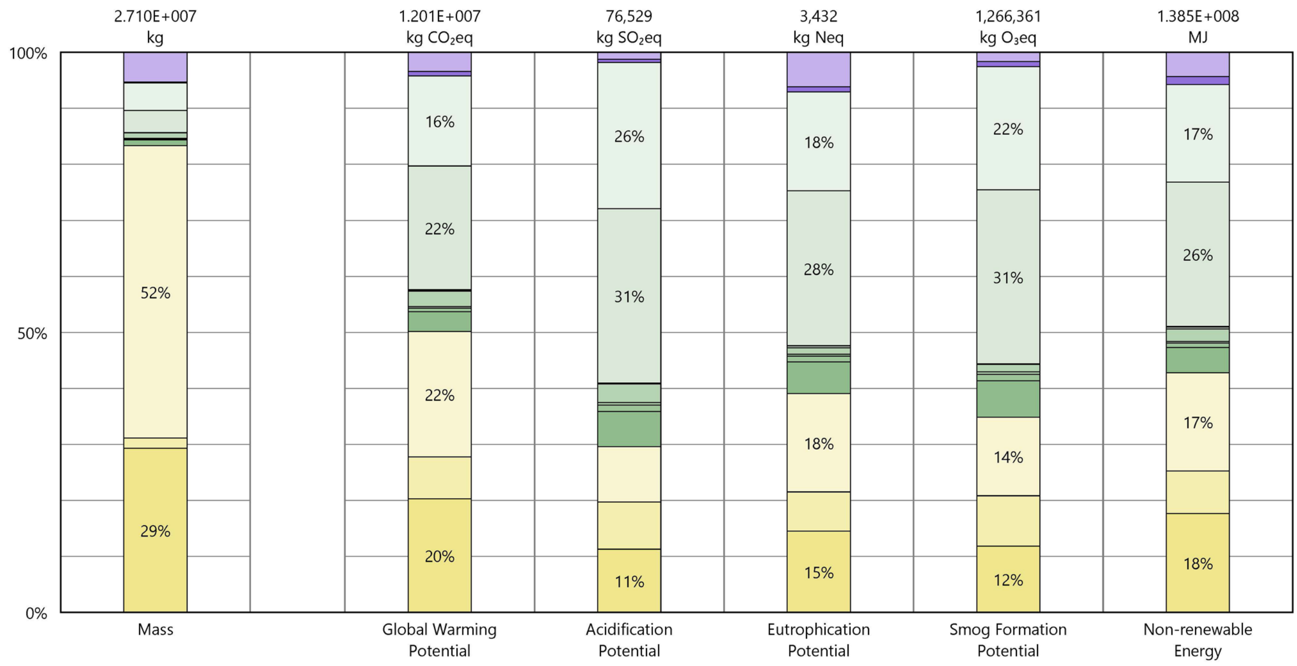
05 - Metals

- Steel, C-stud metal framing
- Steel, deck
- Steel, HSS section
- Steel, W section (wide flange shape)

09 - Finishes

- Wall board, gypsum

Results per Division, itemized by Material



Legend

03 - Concrete

- Lightweight concrete, 3001-4000 psi, 30-39% fly ash
- Steel, concrete reinforcing steel, CMC - EPD
- Structural concrete, 3001-4000 psi, 30-39% fly ash

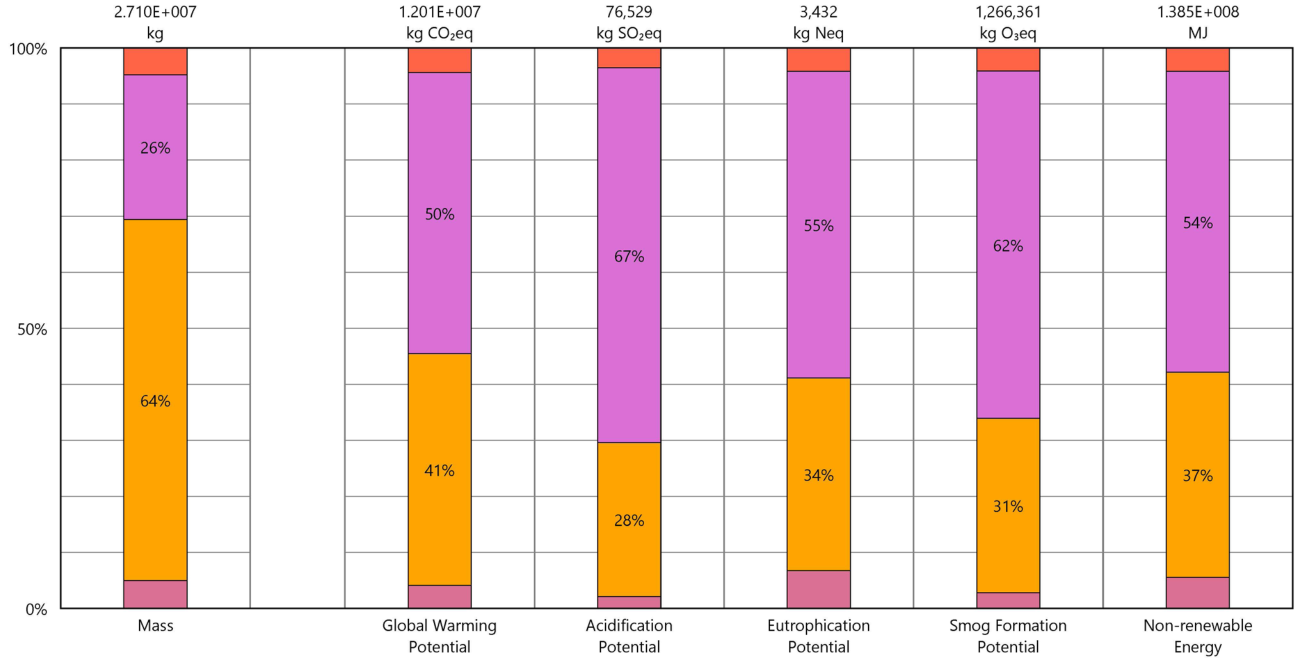
05 - Metals

- Coated steel deck, SDI - EPD
- Cold formed structural steel
- Contruction steel, light structural shapes, CMC - EPD
- Fireproofing, cementitious, by area
- Fireproofing, intumescent paint, by area
- Fluoropolymer coating, metal stock
- Galvanized steel
- Hot rolled structural steel, AISC - EPD

09 - Finishes

- Paint, exterior acrylic latex
- Wall board, gypsum, fire-resistant (Type X)

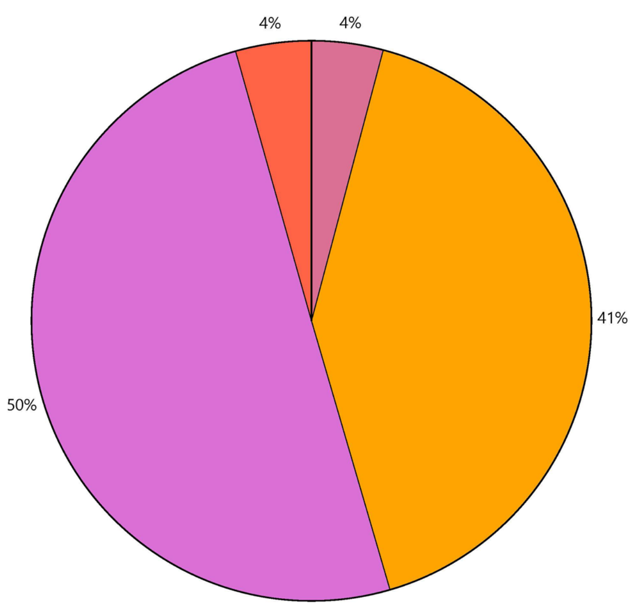
Results per Revit Category



Legend

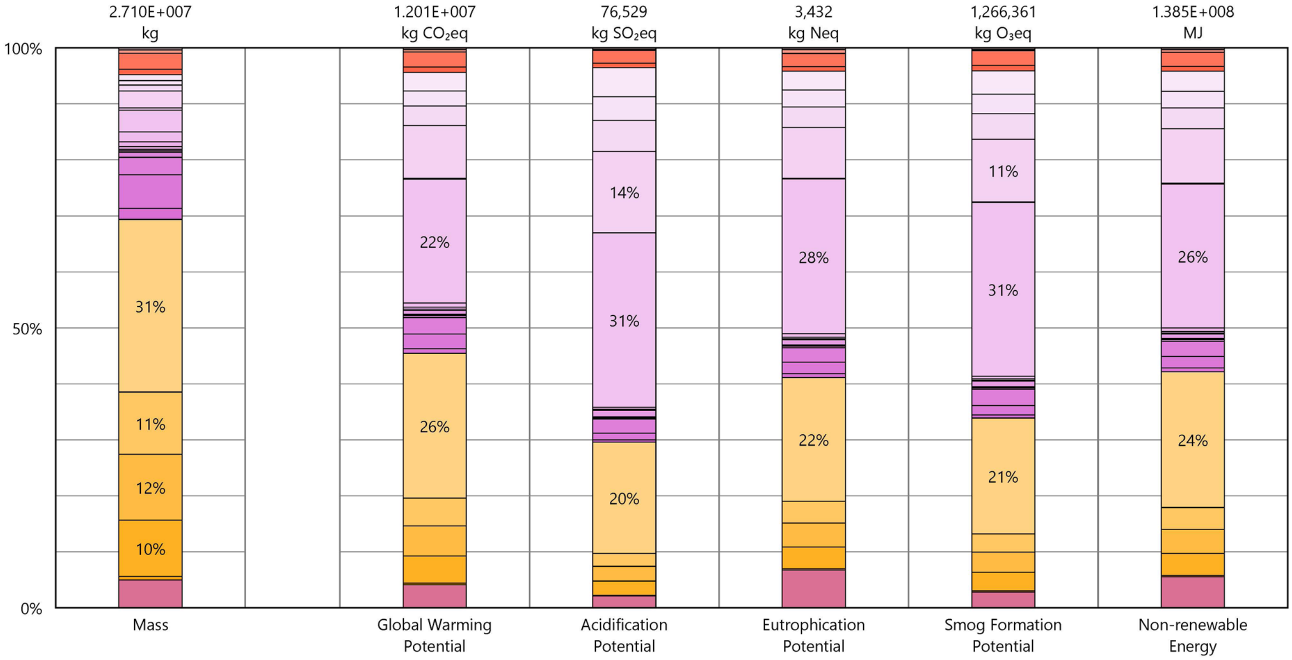
Revit Categories

- Ceilings
- Floors
- Structure
- Walls



Global Warming Potential

Results per Revit Category, itemized by Family



Legend

Ceilings
- GWB on Mtl Stud

Floors
- 10" Concrete
- 10" PT SLAB
- 18" Concrete
- 2'-6" Concrete
- 3" LW Concrete on 3" Composite Metal Deck
- 4" TOPPING SLAB
- 6" Concrete

Structure
- 4'-0" Foundation Slab
- 5'-0" Foundation Slab
- Concrete-Rectangular Beam
- Concrete-Rectangular-Column
- Concrete-Round-Column
- HSS Rectangular
- HSS Square
- Pile Cap-2 Pile
- Pile Cap-3 Pile
- Pile Cap-4 Pile
- Pile Cap-5 Pile
- Pile-Steel Pipe
- Retaining Footing - 48" x 18" x 18"
- W Shapes
- W Shapes-Column
- W-Wide Flange
- W-Wide Flange-Column

Walls
- 10" Concrete
- 12" Concrete
- 5" Metal Stud
- 5/8" gypsum 2
- 6" Metal Stud
- 8" Concret
- 8" Concrete
- 8" SCREEN WALL

Report Summary

Environmental Impact Totals	Product Stage [A1-A3]	Construction Stage [A4]	Use Stage [B2-B5]	End of Life Stage [C2-C4]	Module D [D]
Global Warming (kg CO_2eq)	1.011E+007	1,468,890	357,640	493,014	-413,182
Acidification (kg SO_2eq)	41,966	31,973	1,015	2,281	-705
Eutrophication (kg Neq)	1,992	1,179	169.0	117.0	-26.3
Smog Formation (kg O_3eq)	578,120	625,147	23,825	45,312	-6,043
Ozone Depletion (kg CFC-11eq)	0.08578	4.355E-008	9.568E-008	9.064E-008	0.003062
Primary Energy (MJ)	1.159E+008	1.969E+007	6,770,726	8,441,596	-3,606,768
Non-renewable Energy (MJ)	1.092E+008	1.944E+007	5,709,396	7,893,158	-3,819,642
Renewable Energy (MJ)	6,662,670	231,400	1,058,558	557,643	204,339
Environmental Impacts / Area					
Global Warming (kg CO_2eq/m^2)	305.5	44.39	10.81	14.90	-12.5
Acidification (kg SO_2eq/m^2)	1.268	0.9663	0.03067	0.06894	-0.02132
Eutrophication (kg Neq/m^2)	0.06022	0.03564	0.005109	0.003537	-7.939E-004
Smog Formation (kg O_3eq/m^2)	17.47	18.89	0.72	1.369	-0.1826
Ozone Depletion (kg CFC-11eq/m^2)	2.593E-006	1.316E-012	2.892E-012	2.739E-012	9.255E-008
Primary Energy (MJ/m^2)	3,502	595.1	204.6	255.1	-109
Non-renewable Energy (MJ/m^2)	3,302	587.4	172.5	238.5	-115
Renewable Energy (MJ/m^2)	201.4	6.993	31.99	16.85	6.176

Revit material	Tally Assumption	amount
Finishes	Paint, exterior acrylic latex	47,861.23
	Wall board, gypsum, fire-resistant (Type X)	1,434,280.32
	Total	1,482,141.54
Metals	Cold formed structural steel	226,696.23
	Fiberglass blanket insulation, paper faced	1,832.49
	Fireproofing, cementitious	3,787.39
	Fireproofing, cementitious, by area	90,808.10
	Fireproofing, intumescent paint, by area	610.12
	Galvanized steel	8,466.08
	Galvanized steel decking	2,019.94
	Hot rolled structural steel, AISC - EPD	592,961.33
	Powder coating, metal stock	1,065.92
	Steel, concrete reinforcing steel, CMC - EPD	1,060,320.00
	Total	3,033,632.88
Concrete	Lightweight concrete, 3001-4000 psi, 30-39% fly ash	7,952,609.38
	Steel, concrete reinforcing steel, CMC - EPD	492,034.53
	Structural concrete, 3001-4000 psi, 30-39% fly ash	14,141,862.25
	Total	22,586,506.16

Below is the calculation methodology that Tally assumed for each system for their WBLCA. We could not change any of this information.

Calculation Methodology

LIFE CYCLE ASSESSMENT METHODS

The following provides a description of terms and methods associated with the use of Tally to conduct life cycle assessment for construction works and construction products. Tally methodology is consistent with LCA standards ISO 14040-14044, ISO 21930:2017, ISO 21931:2010, EN 15804:2012, and EN 15978:2011. For more information about LCA, please refer to these standards or visit www.choosetally.com.

Studied objects

The life cycle assessment (LCA) results reported represent an analysis of a single building, multiple buildings, or a comparative analysis of two or more building design options. The assessment may represent the complete architectural, structural, and finish systems of the building(s) or a subset of those systems. This may be used to compare the relative environmental impacts associated with building components or for comparative study with one or more reference buildings. Design options may represent a full or partial building across various stages of the design process, or they may represent multiple schemes of a full or partial building that are being compared to one another across a range of evaluation criteria.

Functional unit and reference unit

A functional unit is the quantified performance of a product, building, or system that defines the object of the study. The functional unit of a single building should include the building type (e.g. office, factory), relevant technical and functional requirements (e.g. regulatory requirements, energy performance), pattern of use (e.g. occupancy, usable floor area), and the required service life. For a design option comparison of a partial building, the functional unit is the complete set of building systems or products that perform a given function. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the modeler.

The reference unit is the full collection of processes and materials required to produce a building or portion thereof and is quantified according to the given goal and scope of the assessment over the full life of the building. If construction impacts are included in the assessment, the reference unit also includes the energy, water, and fuel consumed on the building site during construction. If operational energy is included in the assessment, the reference unit includes the electrical and thermal energy consumed on site over the life of the building.

Data source

Tally utilizes a custom designed LCA database that combines material attributes, assembly details, and architectural specifications with environmental impact data resulting from the collaboration between KieranTimberlake and thinkstep. LCA modeling was conducted in GaBi 8.5 using GaBi 2018 databases and in accordance with GaBi databases and modeling principles.

The data used are intended to represent the US and the year 2017. Where representative data were unavailable, proxy data were used. The datasets used, their geographic region, and year of reference are listed for each entry. An effort was made to choose proxy datasets that are technologically consistent with the relevant entry.

Data quality and uncertainty

Uncertainty in results can stem from both the data used and their application. Data quality is judged by: its measured, calculated, or estimated precision; its completeness, such as unreported emissions; its consistency, or degree of uniformity of the methodology applied on a study serving as a data source; and geographical, temporal, and technological representativeness. The GaBi LCI databases have been used in LCA models worldwide in both industrial and scientific applications. These LCI databases have additionally been used both as internal and critically reviewed and published studies. Uncertainty introduced by the use of proxy data is reduced by using technologically, geographically, and/or temporally similar data. It is the responsibility of the modeler to appropriately apply the predefined material entries to the building under study.

System boundaries and delimitations

The analysis accounts for the full cradle to grave life cycle of the design options studied across all life cycle stages, including material manufacturing, maintenance and replacement, and eventual end of life. Optionally, the construction impacts and operational energy of the building can be included within the scope. Product stage impacts are excluded for materials and components indicated as existing or salvaged by the modeler. The modeler defines whether the boundary includes or excludes the flow of biogenic carbon, which is the carbon absorbed and generated by biological sources (e.g. trees, algae) rather than from fossil resources.

Architectural materials and assemblies include all materials required for the product's manufacturing and use including hardware, sealants, adhesives, coatings, and finishing. The materials are included up to a 1% cut-off factor by mass except for known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

Calculation Methodology

LIFE CYCLE STAGES

The following describes the scope and system boudaries used to define each stage of the life cycle of a building or building product, from raw material acquisition to final disposal. For products listed in Tally as Environmental Product Declarations (EPD), the full life cycle impacts are included, even if the published EPD only includes the Product stage [A1-A3].

Product [EN 15978 A1 - A3]

This encompasses the full manufacturing stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The product stage scope is listed for each entry, detailing any specific inclusions or exclusions that fall outside of the cradle to gate scope. Infrastructure (buildings and machinery) required for the manufacturing and assembly of building materials are not included and are considered outside the scope of assessment.

Transportation [EN 15978 A4]

This counts transportation from the manufacturer to the building site during the construction stage and can be modified by the modeler.

Construction Installation [EN 15978 A5] (Optional)

This includes the anticipated or measured energy and water consumed on-site during the construction installation process, as specified by the modeler.

Maintenance and Replacement [EN 15978 B2-B5]

This encompasses the replacement of materials in accordance with their expected service life. This includes the end of life treatment of the existing products as well as the cradle to gate manufacturing and transportation to site of the replacement products. The service life is specified separately for each product. Refurbishment of materials marked as existing or salvaged by the modeler is also included.

Operational Energy [EN 15978 B6] (Optional)

This is based on the anticipated or measured energy and natural gas consumed at the building site over the lifetime of the building, as indicated by the modeler.

End of Life [EN 15978 C2-C4]

This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Stage C2 encompasses the transport from the construction site to end-of-life treatment based on national averages. Stages C3-C4 account for waste processing and disposal, i.e., impacts associated with landfilling or incineration.

Module D [EN 15978 D]

This accounts for reuse potentials that fall beyond the system boundary, such as energy recovery and recycling of materials. Along with processing requirements, the recycling of materials is modeled using an avoided burden approach, where the burden of primary material production is allocated to the subsequent life cycle based on the quantity of recovered secondary material. Incineration of materials includes credit for average US energy recovery rates.

PRODUCT	CONSTRUCTION	USE	END-OF-LIFE	MODULE D
A1. Extraction **A2. Transport (to factory)** **A3. Manufacturing**	**A4. Transport (to site)** ***A5. Construction Installation***	B1. Use **B2. Maintenance** **B3. Repair** **B4. Replacement** **B5. Refurbishment** ***B6. Operational energy*** B7. Operational water	C1. Demolition **C2. Transport (to disposal)** **C3. Waste processing** **C4. Disposal**	**D. Benefits and loads beyond the system boundary from:** **1. Reuse** **2. Recycling** **3. Energy recovery**

Life-Cycle Stages as defined by EN 15978. Processes included in Tally modeling scope are shown in bold. Italics indicate optional processes.

Calculation Methodology

ENVIRONMENTAL IMPACT CATEGORIES

A characterization scheme translates all emissions and fuel use associated with the reference flow into quantities of categorized environmental impact. As the degree that the emissions will result in environmental harm depends on regional ecosystem conditions and the location in which they occur, the results are reported as impact potential. Potential impacts are reported in kilograms of equivalent relative contribution (eq) of an emission commonly associated with that form of environmental impact (e.g. kg CO_2eq).

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme, the environmental impact model developed by the US EPA to quantify environmental impact risk associated with emissions to the environment in the United States. TRACI is the standard environmental impact reporting format for LCA in North America. Impacts associated with land use change and fresh water depletion are not included in TRACI 2.1. For more information on TRACI 2.1, reference Bare 2010, EPA 2012, and Guinée 2001. For further description of measurement of environmental impacts in LCA, see Simonen 2014.

Acidification Potential (AP) kg SO_2eq

A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials.

Eutrophication Potential (EP) kg Neq

A measure of the impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels caused by the additional consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP) kg CO_2eq

A measure of greenhouse gas emissions, such as carbon dioxide and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. This may, in turn, have adverse impacts on ecosystem health, human health, and material welfare.

Ozone Depletion Potential (ODP) kg CFC-11eq

A measure of air emissions that contribute to the depletion of the stratospheric ozone layer. Depletion of the ozone leads to higher levels of UVB ultraviolet rays reaching the earth's surface with detrimental effects on humans and plants. As these impacts tend to be very small, ODP impacts can be difficult to calculate and are prone to a larger margin of error than the other impact categories.

Smog Formation Potential (SFP) kg O_3eq

A measure of ground level ozone, caused by various chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in sunlight. Human health effects can result in a variety of respiratory issues, including increasing symptoms of bronchitis, asthma, and emphysema. Permanent lung damage may result from prolonged exposure to ozone. Ecological impacts include damage to various ecosystems and crop damage.

Primary Energy Demand (PED) MJ (lower heating value)

A measure of the total amount of primary energy extracted from the earth. PED tracks energy resource use, not the environmental impacts associated with the resource use. PED is expressed in energy demand from non-renewable resources and from renewable resources. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Non-Renewable Energy Demand MJ (lower heating value)

A measure of the energy extracted from non-renewable resources (e.g. petroleum, natural gas, etc.) contributing to the PED. Non-renewable resources are those that cannot be regenerated within a human time scale. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

Renewable Energy Demand MJ (lower heating value)

A measure of the energy extracted from renewable resources (e.g. hydropower, wind energy, solar power, etc.) contributing to the PED. Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account when calculating this result.

LCI Data

END-OF-LIFE [C2-C4]

A Life Cycle Inventory(LCI) is a compilation and quantification of inputs and outputs for the reference unit.The following LCI provides a summary of all energy, construction, transportation, and material inputs present in the study. Materials are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur, along with any notes and system boundaries accompanying their database entries.Each entry lists the detailed scope for the LCI data sources used from the GaBi LCI database and identifies the LCI data source.

For LCI data sourced from an Environmental Product Declaration (EPD), the product manufacturer, EPD identification number, and Program Operator are listed. Where the LCI source does not provide data for all life cycle stages, default North American average values are used. This is of particular importance for European EPD sources, as EPD data are generally only provided for the product stage, and North American average values are used for the remaining life cycle stages.

Where specific quantities are associated with a data entry, such as user inputs, energy values, or material mass, the quantity is listed on the same line as the title of the entry.

TRANSPORTATION [A4]

Default transportation values are based on the three-digit material commodity code in the 2012 Commodity Flow Survey by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation is not available.

Transportation by Barge

Scope:

The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by barge.

LCI Source:

GLO: Average ship, 1500t payload capacity/ canal ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Container Ship

Scope:

The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by container ship.

LCI Source:

GLO: Container ship, 27500 dwt payload capacity, ocean going ts (2017)
US: Heavy fuel oil at refinery (0.3wt.% S) ts (2014)

Transportation by Rail

Scope:

The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by cargo rail.

LCI Source:

GLO: Rail transport cargo - Diesel, average train, gross tonne weight 1000t / 726t payload capacity ts (2017)
US: Diesel mix at filling station ts (2014)

Transportation by Truck

Scope:

The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by diesel truck.

LCI Source:

US: Truck - Trailer, basic enclosed / 45,000 lb payload - 8b ts (2017)
US: Diesel mix at filling station ts (2014)

LCI Data (continued)

END-OF-LIFE [C2-C4]

Specific end-of-life scenarios are detailed for each entry based on the US construction and demolition waste treatment methods and rates in the 2016 WARM Model by the US Environmental Protection Agency except where otherwise specified. Heterogeneous assemblies are modeled using the appropriate methodologies for the component materials.

End-of-Life Landfill

Scope:

Materials for which no recycling or incineration rates are known, no recycling occurs within the US at a commercial scale, or which are unable to be recycled are landfilled. This includes glass, drywall, insulation, and plastics. The solids contents of coatings, sealants, and paints are assumed to go to landfill, while the solvents or water evaporate during installation. Where the landfill contains biodegradable material, the energy recovered from landfill gas utilization is reflected as a credit in Module D.

LCI Source:

US: Glass/inert on landfill ts (2017)
US: Biodegradable waste on landfill, post-consumer ts (2017)
US: Plastic waste on landfill, post-consumer ts (2017)

Concrete End-of-Life

Scope:

Concrete (or other masonry products) are recycled into aggregate or general fill material or they are landfilled. It is assumed that 55% of the concrete is recycled. Module D accounts for both the credit associated with off-setting the production aggregate and the burden of the grinding energy required for processing.

LCI Source:

US: Diesel mix at refinery ts (2014)
GLO: Fork lifter (diesel consumption) ts (2016)
EU - 28 Gravel 2/32 ts (2017)
US: Glass/inert on landfill ts (2017)

Metals End-of-Life

Scope:

Metal products are modeled using the avoided burden approach. The recycling rate at end of life is used to determine how much secondary metal can be recovered after having subtracted any scrap input into manufacturing (net scrap). Net scrap results in an environmental credit in Module D for the corresponding share of the primary burden that can be allocated to the subsequent product system using secondary material as an input. If the value in Module D reflects an environmental burden, then the original product (A1-A3) contains more secondary material than is recovered.

LCI Source:

Aluminum - RNA: Primary Aluminum Ingot AA/ts (2010)
Aluminum - RNA: Secondary Aluminum Ingot AA/ts (2010)
Brass - GLO: Zinc mix ts (2012)
Brass - GLO: Copper (99.99% cathode) ICA (2013)
Brass - EU-28: Brass (CuZn20) ts (2017)
Copper - DE: Recycling potential copper sheet ts (2016)
Steel - GLO: Value of scrap worldsteel (2014)
Zinc - GLO: Special high grade zinc IZA (2012)

Wood End-of-Life

Scope:

End of Life waste treatment methods and rates for wood are based on the 2014 Municipal Solid Waste and Construction Demolition Wood Waste Generation and Recovery in the United States report by Dovetail Partners, Inc. It is assumed that 65.5% of wood is sent to landfill, 17.5% to incineration, and 17.5% to recovery.

LCI Source:

US: Untreated wood in waste incineration plant ts (2017)
US: Wood product (OSB, particle board) waste in waste incineration plant ts (2017)
US: Wood products (OSB, particle board) on landfill, post-consumer ts (2017)
US: Untreated wood on landfill, post-consumer ts (2017)
RNA: Softwood lumber CORRIM (2011)

Addendum #2: Combined results for WBLCA.

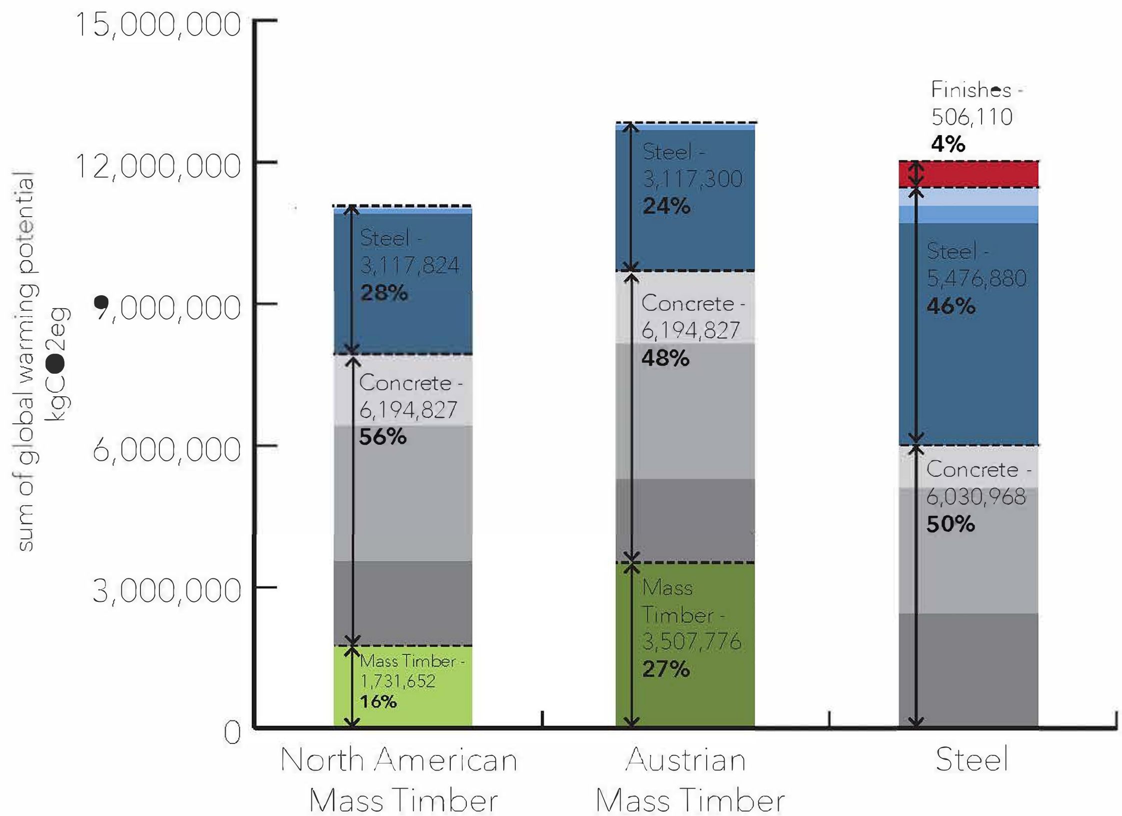


FIGURE 1: This graph is a combined results of GWP broken down by each material group per building system. It is apparent through this graph that concrete is a major factor in the GWP regardless of the building system.

Addendum #2 Cont. Combined results for WBLCA.

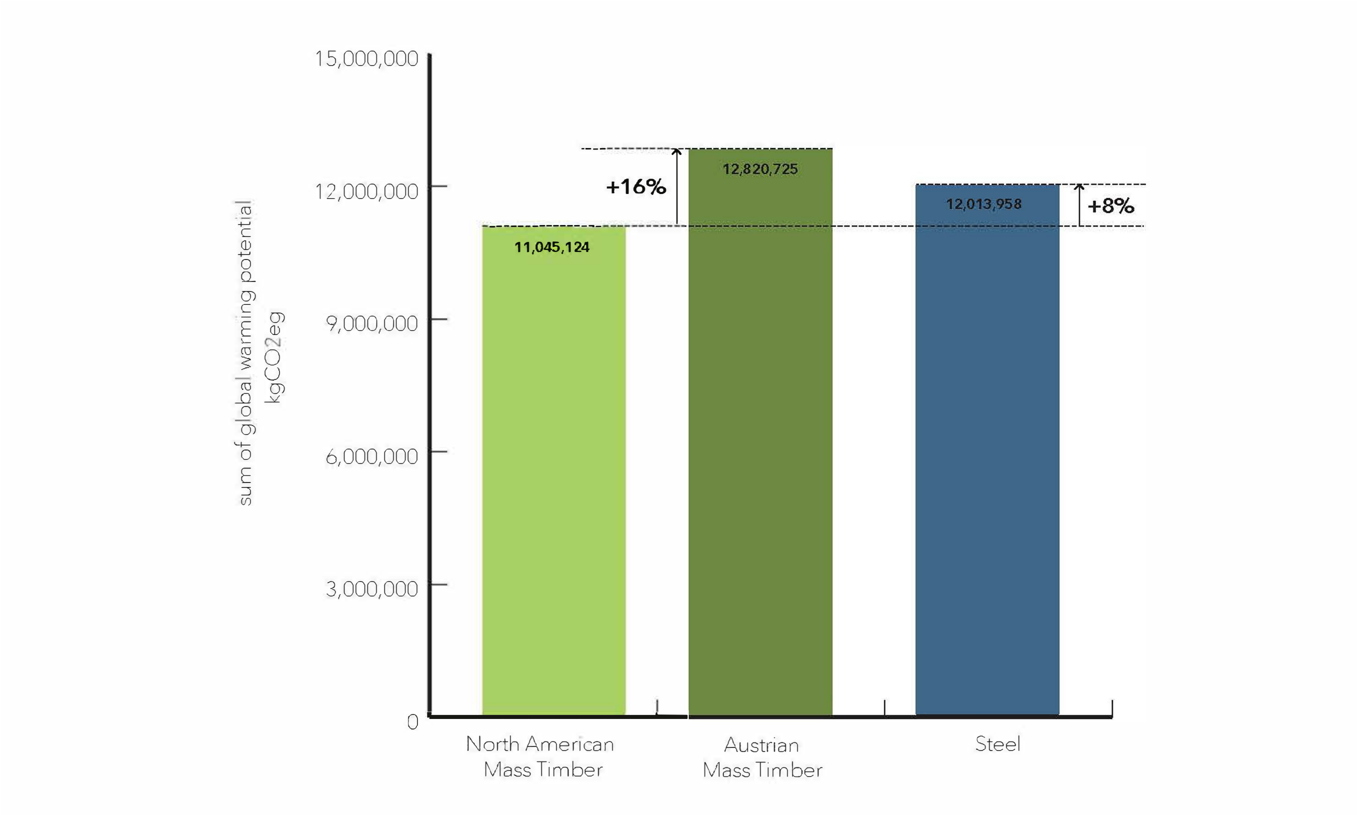


FIGURE 2: This graph is a combined results of GWP comparatively ranked against each other.

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Case Study - Grading Rubric

Research Visual Presentation (15 points)

		Points Total	Points Received
Clearly introduce audience to the background and context of study		1	1
Hypothesis illustrated		1	1
Method illustrated		1	1
Terms used properly		1	1
Data is visually compelling		2	2
Analysis shows understanding of data		2	2
Conclusions are relevant and translated into design lessons		2	2
References accurately cited		1	1
Those who helped faciltate study are acknowledged (firms, firm coordinator, building managers)		1	1
Presentation has overall engaging design with graphic quality demonstrating hierarchy of information. Use of color appropriate. Clarity of organization appropriate. Spelling, grammar, clarity of thought, quality of images and graphics are appropriate.		3	3
		15	15

Case Study - Grading Rubric

Pecha Kucha Oral Presentation (10 points)

		Points Total	Points Received
Presentation is rehearsed and meets the timing of the 20 second/slide Pecha Kucha format.		5	5
Presenters maintain eye contact with audience		1	1
Delivery is clear and succinctly describes project and relevant design lessons learned		2	2
Presenters clearly articulate how project synthesizes issues of health and energy		2	2
		10	10

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Case Study - Grading Rubric

Research Paper (30 Points)

Nicely Done!

		Points Total	Points Received
Abstract concisely summarizes study including context, research questions, setting, background information, hypothesis, methodology, highlights of findings		3	3
Introduction connects issues of human/planetary health and energy-use to the relevance of the investigation and design implications.		5	5
Assertions in introduction are properly cited (you can use Chicago or APA, just keep entire document consistent) with at least 10 relevant and credible sources developed from literature review.		3	3
Hypothesis is suitable in scope and context, testable and well-framed (not general and vague), significant and design linked.		2	2
Methodology is innovative in field/simulation methods, appropriate approach and repeatabile.		2	2
Data analysis is a credible explanation of findings.		5	5
Conclusion discusses whether hypothesis(es) was/were proven and clearly demonstrates an understanding of the complexities and variables of the project that may have affected the outcome. What were the shortcomings of the study, what can be learned and applied, what is important for future study and how would you change future study design/methods (or not)?		5	5
Design lessons learned relate the study to future design, suggestions for future studies.		2	2
Presentation quality		3	3
		30	30