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Designing for Embodied Energy:
An Examination of BIM integrated LCA using Residential Architecture in Rochester, NY

by

Thomas Shreve

A Thesis Submitted in Partial Fulfillment of the requirements for the Degree of
Master of Architecture

Department of Architecture
Golisano Institute for Sustainability

Rochester Institute of Technology
Rochester, NY
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Abstract:

The energy consumed by a building can be divided into two types. Operational energy (use phase) and embodied energy (energy consumed during the production, construction and replacement of building components). Typically, overshadowed by operational energy, embodied energy has slowly increased for a variety of reasons. A major reason for the increase in embodied energy is the surge in the Low-Energy and Net Zero Energy Building movement.

One of the primary tools used to measure embodied energy in buildings is through whole building Life Cycle Assessment (LCA). LCA modeling in architecture is a complex and time-consuming process, that presents a variety of challenges. Typically used in conjunction with green building certification, LCA modeling typically occurs in that late stages of the design process where changes can become costly and time consuming. Whereas design decisions made during the early stages of the design process can have the greatest impacts in terms of reducing embodied impacts.

This thesis will examine the existing and future housing stock within the City of Rochester, NY through the lens of embodied energy. Utilizing data gathered through a housing stock analysis, in conjunction with the most recent residential energy code, a typical housing unit will be developed as a baseline. Using design strategies aimed at reducing embodied, the opportunities presented by BIM integrated LCA will be examined through the development of a prototype housing unit. Whole building LCA and material analyses will examine the effectiveness of integrating LCA into the early stages of the design process.

Acknowledgements:

This thesis represents the culmination of 4 years of work towards a goal that I have been working towards since high school. From Eastern North Carolina to Western New York, the experiences and knowledge gained will be invaluable in the next step in my career. The completion this thesis would not have been possible without the aid of many people.

I would like to thank Nana-Yaw Andoh, Jules Chiavaroli, and Dr. Tom Trabold for serving on my thesis committee. Thank you for your guidance and patience throughout the thesis process.

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<u>Table of Contents:</u>

List of Tables:

List of Figures:

List of Definitions:

Acidification Potential: 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 ion the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, and the deterioration of building materials[1].

Architectural Materials and Assemblies: includes 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 with the exception of known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was[2] implemented by impact.

Building Information Modeling: An intelligent 3d model-based process that gives architecture, engineering, and construction (AEC) professionals the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure[3].

Construction: (EN 15804 A4) is based on the anticipated or measured energy and water consumed during the construction of the building.

Cradle-to-Cradle: a specific kind of cradle-to-grave assessment where the end-of-life disposal step for the product is a recycling process. From the recycling process originate new, identical products or different product. Due to the work of William McDonough, the term cradle-to-cradle often implies that the product under analysis is substantially recycled, thus reducing the impact of using the product in the first place[4].

Cradle-to-Gate: an assessment of a partial product life cycle from manufacture, "cradle," to the factory gate, i.e., before it is transported to the consumer. Cradle-to-gate assessments are sometimes the basis for Environmental Product Declarations (EPDs). Used for buildings, this would only include the manufacturing and perhaps, depending on how the LCA was carried out, the construction stage. For building LCA tools based on assemblies, the starting point for the assessment might be a collection of cradle-to-gate LCAs completed on major building systems, for example, curtainwall, roof systems, load bearing frames, etc., which are then assembled into a complete cradle-to-grave assessment of the building[5].

Cradle-to-Grave: the full life cycle assessment from manufacture of "cradle" to use phase and disposal phase, "grave." An example would be to use process based LCA to capture the impact of cellulose insulation[6]

[1] KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[2] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.
[3] Autodesk, "What Is BIM | Building Information Modeling | Autodesk," Autodesk 2D and 3D Design and Engineering Software, , accessed August 05, 2018, https://www.autodesk.com/solutions/bim
[4] Charlene Bayer et al., *AIA Guide to Building Life Cycle Assessment in Practice*, report (Washington D.C.: American Institute of Architects, 2010), 947
[5] Ibid., 47
[6] Ibid., 47

Embodied Energy: The sum of energy input during the material manufacturing and construction phase of a building (See Primary Energy Demand)[7]

End-of-life: (EN 15804 C2-C4) based on average US construction and demolition waste treatment methods and rates. This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfill rates. 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 base on the quantity of recovered secondary materials, incineration of materials includes credit for average US energy recovery rates. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Specific end-of-life scenarios are detailed for each entry[8]

Environmental Product Declaration (EPD): Type III declarations under the ISO 14020:2000 standard and provide detailed process-based LCA data for a specific product which is verified by a third party and determined based on a consistent methodology (Product Category Rule) which makes the result of the LCA comparable[9].

Eutrophication Potential: Eutrophication covers potential 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 may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition[10].

Functional Unit: the unit of comparison that assures that the products being compared provide and equivalent level of function or service[11].

Gate-to-Gate: A partial LCA that examines only one value-added process in the entire production chain, for example evaluating the environmental impact due to the construction stage of a building[12]

Global Warming Potential: 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.

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[7] Ibid., 182.
[8] KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[9] Farshid Shadram et al., "An Integrated BIM-based Framework for Minimizing Embodied Energy during Building Design," Energy and Buildings 128 (July 16, 2016): 2, doi:10.1016/j.enbuild.2016.07.007
[10] KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[11] Charlene Bayer et al., *AIA Guide to Building Life Cycle Assessment in Practice*, report (Washington D.C.: American Institute of Architects, 2010), 183
[12] Ibid., 183.

Life Cycle Assessment: A cradle-to-grave approach for assessing industrial systems that evaluates all stages of a product's life. It provides a comprehensive view of the environmental aspects of the product or process[13]

Maintenance and Replacement: (EN 15804 B2-B5) encompasses the replacement of materials in accordance with the expected service life. This includes the end-of-life treatment of the existing products (EN 15804 C2-C4), transportation to site, and cradle-to-gate manufacturing of the replacement products. The service life is specified separately for each product[14].

Manufacturing: (EN 15804 A1-A3) includes processes wherever possible. This includes raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The manufacturing scope is listed for each entry, detailing and 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 the assessment[15].

Operational Energy:
(a) Energy used in buildings during their operational phase, including energy consumption due to HVAC systems, lighting, service hot water, etc.[16]
(b) (EN 15804 B6) based on the anticipated energy consumed at the building site over the lifetime of the building. Each associated dataset includes relevant upstream impacts associated with extraction of energy resources (such as coal or crude oil), including refining, combustion, transmission, losses, and other associated factors[17].

Ozone Depletion Potential: 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 ray reaching the earth's surface with detrimental effects on humans and plants[18].

Primary Energy Demand (PED): A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, stream, etc.) are taken into account[19].

Product Category Rule (PCR): defined in ISO 14025 as a set of specific rules, requirements, and guidelines for developing environmental product declarations for one or more products that

[13] Mary Ann. Curran, *Life-cycle Assessment: Principles and Practice* (Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 2006), 1.
[14] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.
[15] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.
[16] Charlene Bayer et al., *AIA Guide to Building Life Cycle Assessment in Practice,* report (Washington D.C.: American Institute of Architects, 2010), 184.
[17] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.
[18] KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[19] KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

can fulfill equivalent functions. PCR determine what information should be gathered and how that information should be evaluated for an environmental declaration[20].

R-Value: A measure of resistance to the flow of heat through a given thickness of a material (such as insulation) with higher numbers indicating better insulating properties[21]

Transportation: (EN 15804 A4) between the manufacturer and building site is included separately and can be modified by the practitioner. Transportation at the product's end-of-life is excluded from this study[22].

U-Value: A measure of the heat transmission through a building part (such as a wall or window) or a given thickness of material (such as insulation) with lower numbers indicating better insulating properties[23].

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[20] ASTM International - Standards Worldwide, accessed May 04, 2018, https://www.astm.org/CERTIFICATION/filtrexx40.cgi?-P PROG 7 cert_detail.frm.

[21] "R-value," Merriam-Webster, 2018, , accessed August 05, 2018, https://www.merriam-webster.com/dictionary/R-value.

[22] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.

[23] "U-value," Merriam-Webster, 2018, , accessed August 05, 2018, https://www.merriam-webster.com/dictionary/U-value.

Introduction:

As concerns about issues such as climate change and resource depletion garner more awareness, many industries and professions are looking to adapt to a new way of thinking. In the building industry, the push to design more environmentally friendly buildings has led to the development of new buildings methods and green building rating systems. These trends are making buildings more efficient, and goals like “zero-energy” buildings are becoming more attainable.

The building sector is the largest energy consumer throughout the world, accounting for approximately 40% of energy consumption worldwide[1]. The building sectors also plays a significant role in resource consumption (approx. 50%) and greenhouse gas emissions (approx. 1/3rd or 38%)[2]. The significant contribution of the building industry to energy consumption and the associated negative environmental impacts has placed the building industry and architects in the spotlight when it comes to addressing climate change.

The issue of energy consumption became apparent during the energy crises of the 1970s, causing governments to respond through the implementation of regulatory guidelines[3]. Regulations, and goals such as the Architecture 2030 initiative have begun to address the issue of energy consumption but focus mainly on energy consumption resulting from the use and operation of a building.

The energy consumed by buildings can be divided into two categories, operational and embodied energy. Operational energy represents the energy consumed through the use and

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[1] Alexander Hollberg and Jürgen Ruth, "LCA in Architectural Design—a Parametric Approach," The International Journal of Life Cycle Assessment 21, no. 7 (February 24, 2016): 944, doi:10.1007/s11367-016-1065-1.
[2] Ibid., 944.
[3] Ibid., 944.

operation of a building. Whereas, embodied energy represents the production, construction, and replacement of building materials and assemblies[4]. Typically overshadowed by operational energy, embodied energy has slowly increased for a variety of reasons. One of the most prominent reasons for the change in balance is the trend of low-energy and zero-energy building.

This shift caused by the emergence of more efficient buildings has created a need for architects to examine the embodied energy buildings as a component of the design process. This imbalance can be addressed using tools such a Life Cycle Assessment (LCA). Currently, the practice within the field of architecture is to complete an LCA analysis late in the design process for "green building" certifications like Leadership in Energy and Environmental Design (LEED). However, with the emergence of Building Information Modeling (BIM) and modeling software like Revit, the implementation of LCA can be done earlier in the design process, allowing architects to actively consider embodied energy throughout the design process.

This thesis examined the existing and future housing stock within Rochester, NY through the lens of embodied energy. Utilizing data gathered through a housing stock analysis, in conjunction with the most recent residential building code, a baseline housing unit will be developed. Examining modern building technologies and design strategies aimed at reducing embodied energy, a prototype housing unit was developed. Comparing the baseline to the prototype housing unit provided insight into the integration of embodied energy and LCA modeling into the design process, as well as identified strategies that can be implemented to guide sustainable housing in the future.

[4] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 944.

Energy Consumption in the Building Sector:

A key concern regarding the future of architecture is energy use. Total energy consumption has increased worldwide since the 1980s, and with this increase has come a greater awareness of the associated negative environmental impacts. From 1984 to 2004 primary energy consumption has increased by an estimated 49%, growing at an annual rate of around 2% per year[5]. An alarming trend that has occurred during this time is the growth experienced in emerging economies like South America, Southeast Asia, Africa, and the Middle East[6]. Many of the emerging countries in the regions listed above are projected to outpace developed countries by the year 2020, with energy consumption growing at a rate of 3.2% annually[7]. One of the emerging economies that is experiencing this rapid growth is China, it is estimated that in the past 2 decades, energy consumption in the country has doubled growing at an average rate of 3.2%[8].

The building sector is one of the largest consumers of energy. Consuming approximately 20-40% of all energy produced[9]. The large amount of energy consumed, and the growth trend can be attributed to a variety of causes or trends. The most significant trends are: population growth, modernization of building services, higher comfort levels, and increased time indoors. Another key factor that determines the energy use in a building is the building typology or programming. Dividing buildings by their use provides a greater insight into how energy is used, giving designers an opportunity to address the cause of the increased energy consumption. In the United States, energy consumption in commercial buildings has increased from 11% to

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[5] Luis Pérez-Lombard, José Ortiz, and Christine Pout, "A Review on Buildings Energy Consumption Information," Energy and Buildings 40, no. 3 (2008): 394, doi:10.1016/j.enbuild.2007.03.007.
[6] Ibid., 394
[7] Ibid., 394
[8] Ibid., 394
[9] Ibid., 395

18% since the 1950s[10]. The United Kingdom for comparison reported commercial buildings account for 11% of the country's energy consumption[11].

Residential buildings in the United States on the other hand consume 22% of primary energy, compared to 26% in the European Union and 28% in the UK[12]. This increase in energy consumption between commercial buildings and residential buildings can be attributed to factors including: size, location, weather and climate, architectural design, energy systems, and economic characteristics of the occupants[13]. Examining the energy consumption via residential buildings in the United Kingdom and Spain shows how the factors listed above can affect energy consumption. Residential energy consumption in the United Kingdom is approximately 28% of total energy consumption, whereas in Spain, residential architecture accounts for 15% of energy consumption[14]. This difference in energy consumption can partially be attributed to the climate and size of housing. The climate in the UK is much harsher than that of the Spanish climate, and the typical housing typology in Spain are housing blocks, whereas in the UK, single family or independent housing units are used[15].

Table 1 represents data collected by the United State Energy Information Administration (EIA), Eurostat, and Building Research Establishment (BRE) showing a weighted breakdown of energy consumption by buildings[16]. The information shown represents energy consumption for the United States, United Kingdom, European Union, Spain, and the world. The data shows that

[10] Ibid., 395
[11] Ibid., 396
[12] Pérez-Lombard, Ortiz, and Pout, "A Review on Buildings Energy Consumption Information," 396.
[13] Ibid., 396.
[14] Ibid., 396
[15] Ibid. 396
[16] Ibid., 396

for all regions, residential buildings account for the majority of the energy consumed within the building sector.

Table 1: Weight of building energy consumption (2004)

Final Energy consumption (%)	Commercial	Residential	Total
United States	18	22	40
United Kingdom	11	28	39
European Union	11	26	37
Spain	8	15	23
World	7	16	24

Source: Luis Pérez-Lombard, José Ortiz, and Christine Pout, "A Review on Buildings Energy Consumption Information," Energy and Buildings 40, no. 3 (2008): 394, doi:10.1016/j.enbuild.2007.03.007.

The EIA provides data on energy consumption in the International Energy Outlook. The most recent publication was in 2017 and contains data collected and projections for future energy consumption. According to the IEO 2017, the building sector accounts for approximately 21% of the world's delivered energy consumption in 2015, and this figure is projected to remain the same through the year 2040[17]. This plateau of energy consumption can be deceiving, because the same publication reports energy use in buildings is projected to increase by 32% between the years 2015 and 2040[18]. Most of this increase is projected to occur in countries and regions where the population is shifting from rural areas to urban developed areas.

Examining the Annual Energy Outlook, a clearer picture of energy consumption in the United States can be examined. The Annual Energy Outlook for 2018 projects energy delivered to the building sector to increase around 0.3% per year from 2017 to 2050, accounting for 27% of total U.S. energy delivered in 2017 and 26% in 2050[19]. Despite the projected growth, efficiency gains, changes in distribution methods, and the population shift from rural to urban

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[17] "International Energy Outlook 2017," EIA - International Energy Outlook 2017, September 14, 2017, 94, https://www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf.
[18] Ibid., 94.
[19] "Annual Energy Outlook 2018," EIA - Annual Energy Outlook 2018, February 6, 2018, 122, accessed April 23, 2018, https://www.eia.gov/outlooks/aeo/.

helps to partially offset population growth, number of households, and commercial floor space[20]. While total energy consumption is projected to grow, the energy used by households is projected to decrease. The AEO projects a decrease in the electricity use in households despite an increase in the number of homes and house sizes[21].

The data presented by Perez-Lombard et al. and the EIA shows that energy consumption in the building sector is rising and will continue to rise. The data shown above however does not show the entire picture. Many of the agencies that collect and publish energy consumption data do not take into consideration the embodied energy, and only present data regarding the operational energy because it is easy to track, and information is readily accessible.

The tracking and monitoring of energy consumption on a large scale like the data published by the EIA comes because of a variety of concerns, but the most significant is the concern of resource consumption and the ability to produce enough energy. These concerns can largely be traced back to the 1970s energy crisis.

1970s Energy Crisis and Government Regulations:

The awareness towards energy consumption came into the limelight in the 1970s during the energy crisis that took place during this time. The crisis was triggered by fluctuations in the supply of oil and resulted in massive increases in the cost of oil[22]. Most of the industrialized countries reacted by instituting government regulations attempting to reign in the energy use within the building sector. The first regulation implemented was the German Thermal Insulation Ordinance in 1977 and since then, the regulations and requirements designed to improve the

[20] Ibid., 122.
[21] "Annual Energy Outlook 2018," EIA - Annual Energy Outlook 2018, February 6, 2018, 122, accessed April 23, 2018, https://www.eia.gov/outlooks/aeo/.
[22] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 944.

energy performance of buildings have become stricter[23]. Other form of incentives implemented to regulate or control the energy consumption of buildings is through financial incentives or even green building certification.

An example of financial incentives being used to promote energy efficient design is in Germany where a government owned bank provides subsidies for projects that exceed the German Energy Saving Ordinance (ENEV 2014)[24]. In the United States, green building certification has become increasing popular. The United States Green Building Council established the Leadership in Energy and Environmental Design (LEED) Green Building Certification in March 2000, and since then it has become the most popular green building certification in the world[25].

The growth rate for the LEED certification program has been tremendous. Many institutions and government facilities have made LEED certification mandatory for new construction. In the period of 2000 - 2006 the USGBC granted LEED certification to 715 projects, approximately 11 projects a month. This surged over the next two years as 1,500 projects were certified, a rate of approximately 63 projects per month in 2008[26]. As of 2016, 80,000 projects have been registered, and 32,500 have received LEED certification across 162 Countries[27].

While LEED has brought “green design” into the limelight and has made the implementation of sustainable building techniques popular practice, many architects and

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[2323] Ibid., 944.
[24] Ibid., 944.
[25] "USGBC History," History | U.S. Green Building Council, 2018, , accessed May 01, 2018, https://stg.usgbc.org/about/history.
[26] Cecilia Shutters and Robb Tufts, "LEED by the Numbers: 16 Years of Steady Growth," U.S. Green Building Council, May 27, 2016, accessed May 01, 2018, https://www.usgbc.org/articles/leed-numbers-16-years-steady-growth.
[27] Ibid.

designers have criticized LEED for not doing enough. These criticisms have led to the development of stricter certifications standards and has even led to some designers taking the practice of sustainable design into their own hands. Despite their motivations, many architects, designers, and clients are employing state of the art materials and systems. Some of the strategies employed to address the issue of energy consumption in buildings include increased insulation R-values, insulated thermal windows, and mechanical ventilation[28]. These innovations are aimed at reducing energy consumption and increase efficiency, but many architects ignore the energy and resources required for the production and installation of the high-tech systems and components.

Embodied Energy vs. Operational energy:

When examining the energy consumed by buildings most of the focus is given to the energy consumed during the use phase of the building. In recent years many architects and designers have focused intently on the amount of energy used by lighting, heating, and cooling systems of a building. Both passive and active measures have been taken to increase the efficiency of building systems and structures. Yet the energy consumed during this phase does not describe the total energy used by a building.

The energy consumption of buildings can be divided into two categories, operational and embodied energy. Operational energy consumption occurs during the use phase of the building and is defined as the energy used in heating, cooling, and lighting a building[29]. Embodied energy on the other hand, represents the energy consumed in production, construction, and end-of-life stages of a building’s life cycle. In the book *Embodied Energy and Design*, David

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[28] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 944.
[29] David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives* (New York, NY: Columbia University GSAPP, 2017), 13.

Johnson defines embodied energy as the sum of all energy required to extract raw materials, and then manufacture, transport, and assemble the materials into a building[30].

In the past operational energy has overshadowed embodied energy because it accounted for a larger percentage of the primary energy consumed. It is estimated that the embodied energy of a building accounted for 2-38% of the primary energy consumed in buildings[31]. However, over the past 50 years this ratio has shifted because of a variety of reasons including increased efficiency during the use phase. Not only has the amount of energy consumed been reduced, the embodied energy has increased using high tech materials and insulations. Both voluntary and mandatory programs have contributed to this shift in energy consumption. Programs like LEED, Passive House, and the 2030 Challenge have created incentives to reduce the amount of operational energy consumed but have done little to address embodied energy. At the same time, energy codes have increased their required R-values[32]. According to Bates et al. the International Energy Conservation Code has increased their standards by 14% while ASHRAE Standard 90.1 has increased by 29% between the years 1975 and 2005[33]. Even since 2004 the IECC has been changed again, the current requirements for building envelope R-Values and U-Values can be found in Table 9: Insulation and Fenestration Requirements by Components.

The ratio between embodied and operational energy continues to shift with the increase in popularity of net zero energy buildings (NZEB) and positive energy buildings. In these

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[30] Ibid., 13.
[31] Roderick Bates et al., "Quantifying the Embodied Environmental Impact of Building Materials During Design: A Building Information Modeling Based Methodology," in Sustainable Architecture for a Renewable Future, proceedings of Passive and Low Energy Architecture 2013, Munich.
[32] Roderick Bates et al., "Quantifying the Embodied Environmental Impact of Building Materials During Design: A Building Information Modeling Based Methodology," in Sustainable Architecture for a Renewable Future, proceedings of Passive and Low Energy Architecture 2013, Munich.
[33] Ibid.

projects where the operational energy consumption is equal to or less than the energy produced, the embodied energy accounts for 100% of the primary energy. As the push for more efficient buildings continues to reduce the operational energy of buildings, there needs to be a greater consideration for the embodied effects. The most effective way of understanding the embodied environmental impacts of a building is to examine its life cycle.

Life Cycle Assessment is a tool that has been implemented in other industries to examine and address the environmental impacts of a product or process. In recent years the process of completing an LCA has been introduced into the field of architecture, and certifications like LEED have begun to require and life cycle assessment as a part of the certification process. As the practice of examining the life cycles of building becomes more prevalent in the practice of architecture the question now becomes: How can it be integrated into the design process?

Literature Review:

Using a holistic – long range view of architecture has allowed architects to improve the performance of buildings by examining not only cost but also through the examination of energy consumption and environmental impacts[34]. The need for energy analysis as part of the design process is well established, and a greater degree of urgency is needed when it comes to examining embodied energy. According to David Benjamin the shift in the energy consumption ratio demands that architects consider the embodied environmental impacts within the design process[35]. Through an examination of the embodied energy of a building, it allows architects to not only design the lifecycle of the materials, but to design the lifecycle of the building, examining the life of the building from the construction phase to the end of life phase[36].

The most common tool utilized to examine the lifecycle of a product or process is through Life Cycle Assessment. While the process of completing an LCA has been established in other industries, the field of architecture has just begun applying it to buildings. The LCA process has not been extensively applied in the field of architecture because the process can be complex and difficult to complete[37]. To examine the embodied energy of housing in Rochester, a greater understanding of the LCA process, and its integration into the field of architecture is needed.

[34] Jennifer O'connor and Matt Bowick, "Advancing Sustainable Design with Life Cycle Assessment," SAB Magazine, 2014, 27.
[35] David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives* (New York, NY: Columbia University GSAPP, 2017), 13.
[36] Ibid., 10.
[37] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 943.

<u>What is Life Cycle Assessment:</u>

New technologies in the field of architecture have allowed designers to become increasingly sophisticated in the way buildings are designed. Modern technologies like building information modeling, and energy modeling have allowed architects to think about the way buildings are designed and constructed in a new light. New strategies like energy performance modeling have changed the way architects design. This shift in the design process has made buildings more efficient by allowing architects to take a more holistic long-term view of the buildings they design[38]. Another emerging technology in the field of architecture allows designers to look at the embodied impacts of the building design, further expanding the understanding of the environmental impacts of buildings.

While the process of completing a life cycle assessment is a relatively new concept for the field of architecture, the practice has been successfully implemented in other industries. The national Risk Management Laboratory defines the term life cycle assessment as "a cradle-to-grave approach for assessing industrial systems that evaluates all stages of a product's life. It provides a comprehensive view of the environmental aspects of the product or process[39]." In this case, the product or process is replaced by a building, and the analysis examines the environmental impacts associated with building materials from the production phase to the end of life phase.

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[38] Jennifer O'connor and Matt Bowick, "Advancing Sustainable Design with Life Cycle Assessment," SAB Magazine, 2014, 27.

[39] Mary Ann. Curran, *Life-cycle Assessment: Principles and Practice* (Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 2006), 1.

While still representing a new practice in the field of architecture, LCA has stable foundation of work to build upon. The process of conducting a LCA began in the 1960s during a period when concerns over resource and energy consumption were high[40]. Intended as a tool for tracking energy use and to plan future resource use and supply, the first publication of a LCA style report was at the 1963 World Energy Conference[41]. The first instance of LCA style report being utilized by a large company came in 1969 when the Coca-Cola Company compared different containers to compare the environmental impacts of each container type[42]. This study serves as the foundation for LCAs in the United States and spurred the use of LCA as an environmental impact assessment tool in both the United States and Europe. The prominence of LCA has waned throughout the years with peaks during the 1970s energy crises and in 1988 when solid waste became a prominent issue[43]. One key concern that plagued the process of life cycle assessment was the lack of a clear standard. In 1991 11 state attorney generals denounced the use of LCA to promote products because of a lack of a clear standard guiding the development of LCA reports[44]. Because of the denouncement, environmental organizations came together to establish a clear standard that guides the process of conduction a LCA. The International Standards Organization (ISO) 14000 series serves as the guiding standard for life cycle assessments, defining the scopes and creating a uniform methodology[45].

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[40] Mary Ann. Curran, *Life-cycle Assessment: Principles and Practice* (Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 2006), 4.
[41] Written by Harold Smith, the report detailed the cumulative energy requirements to produce chemical intermediates and products. Ibid., 4.
[42] The Coca-Cola Company's analysis examined the raw materials, fuel consumption, and environmental impacts associated with the new containers. Ibid., 4.
[43] Ibid., 5.
[44] Products were promoted as having used LCA analysis to examine their impacts, and as result deceived consumers. Ibid., 5.
[45] Ibid., 5.

An LCA examines the entire life-cycle of a product, from raw material extraction to end-of-life. This approach commonly referred to as cradle-to-grave allows for the examination of the environmental impacts through each life cycle stage. At each stage inputs including raw materials and energy are utilized to estimate the expected environmental outputs[46]. The life stages commonly used in LCA include: raw materials acquisition, manufacturing, use/reuse/maintenance, and recycle/ waste managements[47]. The most commonly reported incomes include global warming potential (carbon footprint), acidification (acid rain), eutrophication (algal bloom), photochemical oxidant creation (smog formation potential) and ozone depletion[48]. Also, commonly examined and the core of this research is embodied energy also known as primary energy demand. Defined as "a measure of the total amount of primary energy extracted from the earth, PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.)[49]." The division by life cycle stage and the outputs generated by the LCA lends itself to aiding in the identification of hotspots within a process.

[46] Mary Ann. Curran, *Life-cycle Assessment: Principles and Practice* (Cincinnati, OH: National Risk Management Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 2006), 1.
[47] The life cycle stages use for industrial products of processes, the life cycle stages used in architecture differ slightly. Ibid., 1.
[48] Definitions for the commonly examined metrics can be found in the appendix. Ibid., 3.
[49] Tally definition for Primary Energy Demand. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

It should be noted that while a life cycle assessment provides insight into the environmental impacts, it does not deliver precise predictions on the impacts associated with a product or process, especially when applied to the field of architecture. The Athena Sustainable Materials Institute makes the clear distinction that LCA is an environmental evaluation tool and not a triple bottom line sustainability tool[50]. Life cycle assessments have proven to be a valuable tool for estimating environmental impacts in the industrial sector and is beginning to make strides within the fields or architecture and engineering.

LCA in Architecture:

Traditionally, the design process relied on knowledge-based decisions to inform the design of a building. However, with the development of BIM and other modeling technologies, architects are increasingly using new modeling technologies to make design decisions based on quantifiable data. LCA provides a method by which architects and engineers can examine design decision through a process that quantifies the embodied impacts, while validating “green” design decisions[51].

[50] Jennifer O'Connor et al., *LCA in Construction: Status, Impact, and Limitations*, report, July 2012, 3, http://www.athenasmi.org/wp-content/uploads/2012/08/ASMI_PE_INTL_White_Paper_LCA-in-Construction_status_impact_and_limitations.pdf.
[51] Jennifer O'connor and Matt Bowick, "Advancing Sustainable Design with Life Cycle Assessment," SAB Magazine, 2014, 27.

The most common form of LCA in architecture is a "whole-building LCA" where an entire building is examined over all stages of a buildings life cycle. Another form utilized by building material manufacturers examines an individual product or material, the results of these analyses are published in documents called environmental product declarations (EPDs). In a whole building LCA, the material and energy flows between the building and nature are examined including resources consumed, waste, and emissions to the air, water, and land are considered[52].

While much of the process is similar to the LCA used in industry, there are some major differences between the two processes. One major difference between the two processes is the scale and scope of the analysis. A whole building LCA examines an entire building and all its constituent parts, examining many materials flows associated with a wide range of products and materials, whereas in an industrial setting a LCA may examines only a few processes or products. Another key difference are the stages examined in the process, during a whole building LCA the analysis examines the following stages: Product, Construction, Use Stage, and end-of-life[53]. Table 2 shows a breakdown of the life cycle stages commonly utilized in a whole building LCA as well as the modules contained in each stage.

Table 2: Whole Building LCA Life Cycle Stages and Modules

Product	*Construction*	*Use*	*End of Life*
A1 Raw Materials Supply	A4 Transport	B1 Use	C1 Demolition
A2 Transport	A5 Construction	B2 Maintenance	C2 Transport
A3 Manufacturing		B3 Repair	C3 Waste Processing
		B4 Replacement	C4 Disposal
		B5 Refurbishment	
		B6 Operational Energy Use	
		B7 Operation Water Use	

Source: LCA in Architectural Design – A Parametric Approach (page 950)

[52] Jennifer O'connor and Matt Bowick, "Advancing Sustainable Design with Life Cycle Assessment," SAB Magazine, 2014, 27.
[53] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 950.

The lifespan of a building is also another key difference between the two processes. Building are designed to last decades, making the collection of data in the use and end of life phase impractical and time consuming. This along with the complexities of buildings are a couple of the barriers blocking widespread adoption of LCA in the profession.

Despite the hurdles faced by the LCA practice it has slowly gained prominence in the practice of architecture, due in part to its adoption in building rating systems. Many of the champions of the sustainable building movement have been champions for the practice of LCA in architecture, and this influence can be seen in the development of green building rating systems[54]. In 2002 Ed Mazria launched the 2030 Challenge, this served as a call to arms of sorts for the green building movement, and front and center to this idea was the implementation LCA as a design tool[55]. In 2010 the American Institute of Architects Committee on the Environment published a guide for the implementation of LCA into the design process in the “AIA Guide to Building Life Cycle Assessment in Practice”[56]. In this guide, the AIA outlines what an LCA is, as well as providing architects guidelines and suggestions on conducting an LCA. The AIA recognizes the role that LCA can play in architecture stating that “the greatest incentive for the use of LCA in the design process is the ability of an architect to show the client that the use of LCA will improve and demonstrate the “green-ness” of the project and help significantly in increasing long-term paybacks by better decisions making[57].”

[54] Jennifer O'Connor et al., *LCA in Construction: Status, Impact, and Limitations*, 3.
[55] This need for LCA in Architecture was further solidified with the publishing of the 2030 Challenge for Products in 2011. Ibid., 3.
[56] Ibid., 3.
[57] Charlene Bayer et al., *AIA Guide to Building Life Cycle Assessment in Practice*, report (Washington D.C.: American Institute of Architects, 2010), 9

The first commercial building rating system to integrate the LCA process into its requirements was Green Globes – NC, which was introduced in 2005 in the United States[58]. Other building rating systems also introduced LCA into their certification systems, the most well know of which is Leadership in Energy and Environmental Design (LEED). The earliest appearance of LCA in the LEED rating system occurred in pilot credits, appearing in 2007, with credits for whole building LCA being included into the newest version (LEED v.4)[59]. In recent years some building codes have implemented optional requirements for the completion of LCA during the design process. In 2009 ASHRAE adopted a standard that provides both a prescriptive path and a performance path for the selection of materials[60]. Along with the ASHRAE Standard, the State of California and the International Code Council have both developed sections regarding the implementation of LCA into the design and construction processes.

[58] Jennifer O'Connor et al., *LCA in Construction: Status, Impact, and Limitations*, 3.
[59] Ibid., 4.
[60] The Standard is ANSI/ASHRAE/USGBC/IES Standard 189.1. Ibid., 4.

The adoption of the standards listed above are all indications of the growing influence LCA will have on the field of architecture. Despite the continued growth and development of standards and guidelines to simplify the process, the scale of a whole building LCA can be daunting to those who are unfamiliar. There are several issues that prevent the widespread adoption of LCA in the practice of architecture. The first concern is the complexity of buildings[61]. The adoption of LCA in the industrial sector has taken hold because there is more control over the life cycle of a single product of process. Buildings on the other hand are an amalgamation of a variety of products and building materials, creating the need to track numerous energy and material flows.

The second issue is the lifespan of buildings[62]. Buildings are designed to be utilized for many years, some lasting hundreds of years. Unlike the development of a product or process, the collection of data beyond the construction phase in whole building LCA is impractical. This is where the estimation of environmental impacts becomes invaluable. Through the estimation of the impacts that can occur during the use and end-of-life stages architects can utilize the information and help make design decisions that will extend beyond the design stage and will influence the maintenance and demolition of a building.

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[61] Quantifying the sum of materials in a building can be a difficult and time-consuming task. Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945.
[62] Buildings are designed to last making the collection of data for the later life cycle stages impossible. Ibid., 945.

The third issue is the uncertainty that occurs because of the extended life spans of buildings[63]. Through the course of a buildings lifespan, the use of a building may change. The practice of adaptive re-use has become increasingly popular in city centers around the world. The question becomes how this change in programming and use can be considered. Some designers have taken this trend of re-using buildings into account within their design process by designing with the future in mind, making buildings more adaptable.

The fourth key concern revolves around the end-of-life stage of a building life cycle[64]. Typically, architects are involved in the life of a building primarily though the course of the design and construction stages, and the status of a building in the use and end-of-life phase can be difficult to plan. As with the idea of designing buildings to be adaptable, the idea of a building for its end-of-life is becoming an increasingly popular trend in the design process. Life cycle assessment can aid in this endeavor allowing architects to engage this phase early in the design process.

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[63] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945.
[64] Ibid., 945.

While the concerns listed above represent hurdles to the application of LCA in architecture they do not limit its potential. The biggest hurdles in conducting a whole building LCA is the availability of data and the knowledge needed to complete the process. Many architects do not have the knowledge or experience to conduct a life cycle assessment[65]. While many organizations have attempted to clarify the process of conducting a LCA, many professionals do not have the time or capabilities to conduct such an intensive collection of data, which can be problematic. Many researchers have noted that the data available regarding building materials can be inaccurate and can be variable between manufacturers due to inconsistent methodologies[66] . The development and standardization of EPDs has alleviated this issue, but many manufacturers still have not published reports of this nature. As the process of conducting whole building LCA expands throughout the profession, the availability and quality of data available will improve.

Applying LCA Modeling in the Design Process:

The application of LCA modeling in the design process would present designers with a dramatic shift in thinking. In the book *Embodied Energy and Design* David Benjamin discusses the shift in thinking that would occur as the result of considering embodied energy in the design process. Amale Andraos writes “there is an incredible creativity and innovation necessary to balance the objective and subjective, the quantitative and qualitative, especially when each is backed by thorough study and observations of the natural world. Any rigorous attempt to design with embodied energy demands that architecture be simultaneously an art and a science[67]. In thinking about embodied energy in the design process, architects can connect the smallest part of

[65] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945.
[66] Farshid Shadram et al., "An Integrated BIM-based Framework for Minimizing Embodied Energy during Building Design," Energy and Buildings 128 (July 16, 2016): 593, doi:10.1016/j.enbuild.2016.07.007
[67]David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives*, 8.

a building with its extraction, transportation, and manufacture. This connection removes the notion of architecture as an autonomous object, connecting it with the material and energy flows[68]. Blaine Brownwell argues that designing with embodied energy invites architects to think of buildings as a temporary suspension of materials[69].

The adoption of LCA into the design process allows architects to create a stronger framework for measuring energy efficiency. Measuring the performance via LCA examines the effectiveness not only in terms of short term performance but also in terms of long term durability, transformation, and entropy[70]. It also provides designers the opportunity to examine a building on a variety of scales and through many materials and energy flows[71]. Life cycle assessments provides opportunities to examine the material and energy flows via a whole building analysis to the examination of a single material, allowing architects to make decisions on both the macro and micro scale.

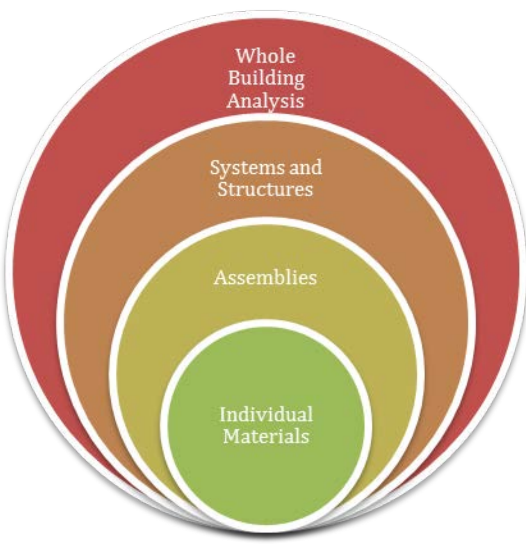

Figure 1: LCA analyses and Designing with embodied energy allows for architects to design on variety of scales.

[68] Embodied energy can be thought of on a variety of scales and changes the way buildings can be viewed in terms of energy and material flows. David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives*, 8.
[69] Ibid., 9.
[70] Ibid., 9.
[71] Ibid., 9.

The implementation of LCA within the context of the design process can be difficult. Most design processes typically contain six stages ranging from pre-design or preliminary studies to the closeout or use phase. The first of the six stages focus on the gathering of preliminary information required to begin the design process. Analysis of the site, feasibility studies and programming all occur within this stage of the design process[72]. The second stage is the schematic design or conceptual design stage. This stage represents the beginning of a series of design decisions, fundamental decisions that affect the form and orientation are made during this stage of the process[73]. The third stage is where the design is refined and developed. While basic material selections are made during this stage there are still many unknowns associated with the design of the building[74]. The fourth stage is where the development of construction details occurs[75]. This stage consists of the development of construction documents and specifications. The final stage consists of the construction and closeout processes, this stage represents the transition between the construction and use phase of a building's life cycle[76].

Figure 2: The implementation within the context of the design process can be difficult, but the stage at which it is implemented determines the effectiveness of the analysis. Reproduced from LCA in Architectural Design - A Parametric Approach by Alexander Hollberg and Jürgen Ruth.

[72] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945.
[73] Ibid., 945.
[74] Ibid., 945.
[75] Ibid., 945.
[76] Ibid., 945.

The nature of the design process creates a dilemma as to when designers can implement a LCA. To quantify the embodied impacts a bill of materials is needed to determine the quantities of materials. The exact bill of quantities, as it is referred to by Hollberg and Ruth is only available towards the end of the design process, typically during the construction documentation phase[77]. Due to a lack of data in the early design stages, the act of performing a whole building LCA is typically reserved for project pursuing green building certification[78]. Basbagill et al. noted that performing a life cycle assessment earlier in the design process has the potential to optimize impact reduction stating" the earlier decisions are made in the design process and the fewer changes to these decisions at later stages, the greater is the potential for reducing the building's environmental impact[79]. This idea of implementing LCA early in the design process is supported by Hollberg and Ruth who suggest implementing the LCA process during the schematic design phase (they refer to it as concept design) because substantial design changes made after this stage become costly and time consuming to correct[80].

To successfully implement the use of LCA in the early stages of the design process, two key hurdles need to be addressed. The first issue is time, conducting a whole building LCA can be a time-consuming process, and this issue can be further compounded if multiple design variants are being considered. To adapt LCA to the design process, a simplified approach needs to be developed, allowing to the efficient examination of design variants and options[81]. The simplification of the LCA process will allow architects without a background in LCA to quickly

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[77] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945.
[78] Ibid., 946.
[79] J. Basbagill et al., "Application of Life-cycle Assessment to Early Stage Building Design for Reduced Embodied Environmental Impacts," Building and Environment 60 (November 19, 2012): 82, doi:10.1016/j.buildenv.2012.11.009.
[80] This is a sentiment backed by many supports of early stage LCA in the design process. Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 945-946.
[81] Ibid., 945.

understand and adopt the practice[82]. According to Hollberg and Ruth, “the method must be able to proceed with missing information and make adequate assumptions to fill in the gaps[83].” The second hurdle is the availability of information during the early design stages. At the beginning stages of design, there are many unknowns within a design. In a typical design process the unknowns are flushed out as the design progresses through the design process. An LCA utilized in the early stages of design should be able to proceed without all the information, filling in the gaps with appropriate assumptions[84]. Hollberg and Ruth suggest that during the course of the traditional design processes, design decisions are made using educated guesses, and that the application of LCA in the early stages will provide architects with the opportunity to make informed data driven design decisions[85].

Types of LCA tools:

As the need for whole building LCAs continue to grow, the tools capable of conducting these analyses are becoming more sophisticated. Computer aided programs facilitate the completion of a while building LCA taking some of the burden off the architects, but not all tools integrate smoothly into the design process. In their research Hollberg and Ruth identified 4 basic types of LCA tools, cataloging software based on this categorization and their functionality[86].

The first of the four categories are the “generic LCA tools”, examples of which include Gabi, Simapro, or Open LCA. These tools typically utilize a tabular format for inputting and interpreting data, Hollberg and Ruth state that these tools are not practical and do not integrate

[82] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 948.
[83] Ibid., 948.
[84] Ibid., 948.
[85] Ibid., 949.
[86] Ibid., 946.

into the design process like some of the tools describe in other categories[87]. The second category "Spreadsheet-based calculations" as the name suggests utilizes spreadsheets as the main tool for the input and interpretation of data. Most of the software that fall into this category utilized a bill of materials to calculate the environmental impacts. The embodied impacts of a material are determined by multiplying the mass by the environmental data, typically retrieved through EPDs. The process of inputting the bill of materials into a tabular format can be time consuming and error prone, furthermore if there are multiple design variants architects may not fully explore the impacts to make an efficient design decision[88].

The Third category "Building Component Catalogues" focuses on the development of building material databases. Like the spreadsheet-based tools, these databases are represented in a tabular format and feature pre-defined components that allow architects to change the parameters of the design quickly[89]. These tools like the spreadsheet-based tools require significant labor, and any changes made during the process require a feedback loop to recalculate the impacts.

The fourth and final categories are known as "CAD integrated tools" and integrate into the commonly utilized drafting programs like AutoCAD and Revit. In this instance a bill of materials is generated though the course of the modeling process rather than at the end of the design process. Hollberg and Ruth argue that the key issues with this method of calculating embodied impacts revolve around the application of Building Information Modeling into the early stages of design[90]. Bates et al states that a key disconnect between LCA and BIM occurs in the translation of languages between the two processes. Typically, LCAs utilize the weight and

[87] Ibid., 946.
[88] Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 947.
[89] Ibid. 947.
[90] Ibid. 947.

volumes of materials as well as the chemical and waste outputs where CAD and BIM programs utilize assemblies that are expressed through linear feet or square feet[91]. Despite the difficulties associated with the implementation of BIM integrated LCA in the field of architecture, this represents the greatest opportunity for streamlining the whole building LCA process. Table 3 represents the software available to designers and the categories they fall under as well as their functionality[92].

[91] Roderick Bates et al., "Quantifying the Embodied Environmental Impact of Building Materials During Design: A Building Information Modeling Based Methodology," in Sustainable Architecture for a Renewable Future, proceedings of Passive and Low Energy Architecture 2013, Munich.
[92] Table 3 reproduced from: Hollberg and Ruth, "LCA in Architectural Design—a Parametric Approach," 947.

Table 3: Present computer-aided LCA tools

Type	Name	3D Model	Energy Demand calculation	Embodied Impact Calculation	Optimization	Online/Offline	Country
Generic LCA Tools	Gabi			●		Off	Germany
	SimaPro			●		Off	Netherlands
	OpenLCA			●		Off	Germany
	Umberto			●		Off	Germany
Spreadsheet-based tools	Envest 2*			●	○	On	UK
	SBS Building Sustainability		○	●		On	Germany
	Ökobilanz Bau		○	●		On	Germany
	eTOOL		○	●		On	Australia
	Athena Impact Estimator		○	●		Off	Canada
	Legep		●	●	○	Off	Germany
	Elodie		●	●		Off	France
	GreenCalc+			●		Off	Netherlands
Component Catalogues	EcoSoft			●		On	Austria
	Bauteilkatalog			●		On	Switzerland
	eLCA		○	●		On	Germany
	BEES			●		On	US
CAD Integrated	Impact	●	○	●		On	UK
	Cocon-BIM	○	●	●		Off	France
	Lesoai	○	●	●		Off	Switzerland
	360optimi	●	●	●		Off	Finland
	Tally	●	○	●		Off	US

● *Full Functionality*
○ *Partial Functionality*

Source: LCA in Architectural Design – a parametric approach

While some have their reservations regarding BIM integrated LCA, others recognize the role it can play making buildings more efficient. Programs like Revit and other BIM software have become common place in the practice of architecture throughout the world. By integrating the process of LCA into the modeling process of building modeling would streamline and facilitate the LCA process. Marios and Kristoffer believe that "the integration of projects' LCA studies in BIM will not only make LCA faster but by using the graphical interface of BIM tools, the results from the LCA will be communicated better among the different engineering disciplines and architects[93]."

<u>LCA Modeling and Building Information Modeling:</u>

Through the integration of LCA and BIM architects will create an environment in which LCA is compatible with the design process creating a design tool that will allow for the examination of a variety of design variants. The information sharing properties that are integrated into the practice of BIM will prove to be useful when assessing sustainability issues according to Shadram et al. The opportunities presented by BIM has the potential to achieve significant time and costs savings compared to traditional LCA processes[94].

The integration of the LCA process and BIM methodologies has become an increasingly important area of research. Basbagill et al. examined research focused on the integration of BIM software and life cycle assessment including the integration of LCA in to the design process. The studies identified in the article represent a wide range of applications for LCA, however prior research has not examined an LCA focused on the impacts of building materials or the

[93] Marios Tsikos and Kristoffer Negendahl, "Sustainable Design with Respect to LCA Using Parametric Design and BIM Tools," proceedings of World Sustainable Built Environment Conference, Hong Kong, 2, http://orbit.dtu.dk/files/133787517/Sustainable_Design_with_Respect_to_LCA_Using_Parametric_Design_and_BIM_Tools.pdf.

[94] Farshid Shadram et al., "An Integrated BIM-based Framework for Minimizing Embodied Energy during Building Design," Energy and Buildings 128 (July 16, 2016): 593, doi:10.1016/j.enbuild.2016.07.007

comparisons of design variants[95]. Marios and Kristoffer provide the best example for how LCA can be integrated with LCA using visual programming language (VPL).

In their research, Marios and Kristoffer examined the implications of integrating LCA analysis with Revit though dynamo, a VPL add in designed for Revit. The idea behind this model is to create a permanent link between Revit Materials and a Life Cycle Inventory database requiring zero input from designers to complete the LCA process[96]. By linking the materials in the LCI database to the materials in Revit, the calculations required for completing an LCA can be conducted during the modeling process. This allows designers to model a building once and perform energy analysis without having to create additional models. In the modeling process used, known as an Integrated Dynamic Model, the bridge between Revit and the LCI database performs the functions of the LCA software, and generates tabular and graphical outputs[97]. Of all the BIM integrated LCA processes, the utilization of visual programming language provides the most flexibility. However, the software used as an intermediary requires a knowledge of basic programming concepts and can be time consuming to learn. Despite this Marios and Kristoffer state that "the IDM's strongest advantage though, is the fact that it is a tool that can be easily modified by the user to meet any specific requirement[98].

While much of the research examined either discusses the benefits of BIM integrated LCA or the hurdles associated, only one examines the pros and cons. In their study *Integration of LCA and BIM for Sustainable Construction* Alvarez Anton and Diaz performed a SWOT

[95] J. Basbagill et al., "Application of Life-cycle Assessment to Early Stage Building Design for Reduced Embodied Environmental Impacts," Building and Environment 60 (November 19, 2012): 82.
[96] Marios Tsikos and Kristoffer Negendahl, "Sustainable Design with Respect to LCA Using Parametric Design and BIM Tools," proceedings of World Sustainable Built Environment Conference, Hong Kong, 3.
[97] Ibid., 3.
[98] If given the opportunity, the use if Dynamo as a tool for the completion of a LCA analysis provides the most flexibility in developing a solution for implementation in the early stages of the design process. However, through the course of learning the program, much of the work involves tinkering with the program to get the desired results, something that can become time consuming. Ibid., 7.

analysis examining the strengths and weaknesses of BIM integrated life cycle assessment. By examining the strengths and weaknesses of integrating LCA with BIM, a greater understanding of its potential and limitation as well as areas which can be improved can be achieved. Table 4 outlines the results of this analysis, identifying the strengths, weaknesses, opportunities, and threats that can come because of the integration of LCA and BIM methodologies[99].

[99] Joaquín Díaz and Laura Álvarez Antön, "Sustainable Construction Approach through Integration of LCA and BIM Tools," *Computing in Civil and Building Engineering (2014)* 8, no. 5 (2014): 2-3, doi:10.1061/9780784413616.036

Table 4: SWOT Analysis of LCA integration with BIM[100]

Strengths	• Higher capacity for accommodating the three pillars of sustainability • More extended use of environmental criteria by various stakeholders • Increased efficiency with regard to environmental assessment, making this task easier and less time consuming • Avoidance of manual data re-entry • More information available about the project during early phases, leading to greater benefits in general • Higher effectiveness of environmental assessment due to its being performed in early design stages • Possibility to compare predicted environmental performance with real performance and chance to learn from experience
Weaknesses	• Different stakeholders involved in the construction industry must be trained to include environmental criteria in their assessments • LCA process and way of presenting data are not standardized • Lack of environmental data for carrying out LCA • Assumptions have to be made for LCA calculation, thus increasing uncertainty of the assessment
Opportunities	• It is becoming compulsory in the construction sector to consider environmental criteria. Various initiatives are being launched by different governments and the European Union for this purpose • There is increased demand for sustainable constructions in the market • These tools already exist. It is just a matter of integrating them to generate synergies • There is a real need of a tool with such features in the market • There is a direct need to change the way of working in the construction industry, and as such an integrated tool and its application in the early design phases could contribute to this change • BIM is already becoming more widely accepted in the construction industry. If LCA is integrated in the BIM framework, this will make it even more acceptable for the stakeholders.
Threats	• Sometimes construction industry stakeholders are not aware of the importance of considering environmental aspects among project criteria at an early stage. • Some stakeholders may refuse to implement this step due to the effort required for integrating the tool in the early design phases. • There is a lack of research and development in the construction industry • There is a wide variety of stakeholders with different characteristics involved in the construction industry. This hinders standardization in the industry and makes it more difficult to implement change • There is a lack of interoperability between different software systems

Source: Integration of LCA and BIM for Sustainable Construction (Page 2-3)

[100] Joaquín Díaz and Laura Álvarez Antön, "Sustainable Construction Approach through Integration of LCA and BIM Tools," *Computing in Civil and Building Engineering (2014)* 8, no. 5 (2014): 2-3, doi:10.1061/9780784413616.036

Based on the analysis above, the opportunities and strengths that the integration of LCA into BIM practices bring to the practice of architecture shows the importance of the examination of embodied environmental impacts. The two key hurdles that were represented in the SWOT analysis are the involvement of the stakeholders and the lack of data and research regarding LCA integrated with BIM, these issues however do not present themselves as permanent issues, rather these issues will be resolved as the practice of conducting whole building LCA gains momentum.

As previously mentioned, implementing LCA early into the design process is important to maximizing its effectiveness. This will cause a shift in the design process, reducing the amount of knowledge-based design decisions and gradually replacing them with data driven design decisions. Kristoffer Negendahl proposes a process that integrates the two decision making processes in which, the earliest stages of the design process would rely on knowledge-based decisions and, as the process progresses, the data provided by the LCA will provide the information needed to make decisions. This progression will continue as the model transitions from the early design stages to the later stages where the building is better defined[101]. According to Negendahl the current design processes is a series of decisions affected by intuition and experience, the adoption of LCA provides the opportunity to address this and further strengthens the “green” design decisions made. Figure 3 represents the process that Negendahl details, the transition from knowledge-based design decisions to data-based decisions provides a clear foundation for the decision-making process.

[101] Kristoffer Negendahl, "Building Performance Simulation in the Early Design Stage: An Introduction to Integrated Dynamic Models," *Automation in Construction* 54 (March 27, 2015): 49, doi:10.1016/j.autcon.2015.03.002.

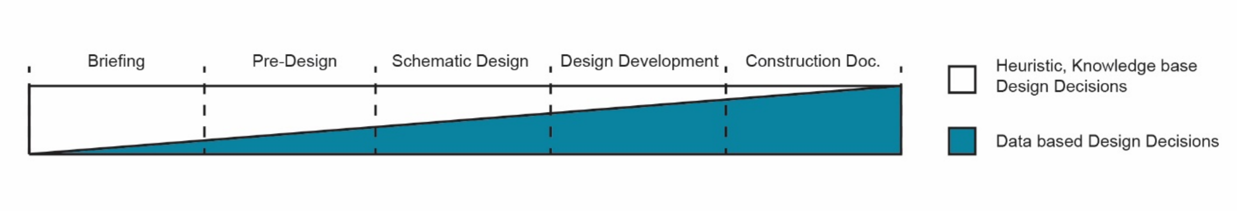

Figure 3: Utilizing a design process that transitions from heuristic knowledge-based decisions to data-based decisions will make the implementation of BIM integrated LCA more impactful. Reproduced from Building Performance simulation in the early design stage: an introduction to integrated dynamic models.

The need for the integration of life cycle assessment into the design process is clear. Through its integration with building information modeling, architects can create a streamlined process that not only makes the design of buildings more efficient but can create the foundation for stronger design decisions. The examination of embodied energy in the early stages of the design process allows architects to answer *where is all this embodied energy? What are the forces involved? What is left out of the equation? How is embodied energy actionable?* And *how might architects design with it?*[102]

[102] David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives,* 13.

Methods:

Now that a basic understanding of the LCA process and its role in the field of architecture is defined, an exploration of how it can be implemented is necessary. BIM integrated LCA can prove to be an invaluable design tool if utilized in an appropriate manner. The goal of the methodology outlined below is show the opportunities that BIM integrated LCA provides within the early stages of the design process. Utilizing the city of Rochester as a basis, a housing analysis will examine the housing stock allowing for the development of a baseline which will allow for comparison with a proposed alternative or variant.

The baseline will be representative of a "typical" housing unit within the city of Rochester and will be designed to meet the current building code (International Building Code 2015). Once developed, the baseline will be modeled in Revit and will serve as the basis for an alternative that utilizes a similar programming. Using Tally for Revit, both models will be examined for their embodied impacts, specifically examining the embodied energy of each variant.

Finally, with the information gained from the LCA analysis additional analyses will be conducted to examine "hot spots" within the prototype. These analyses will allow for the examination of individual building materials and design variants allowing for the comparison of multiple variants at once.

Developing a Baseline:

To estimate the impacts of implementing LCA and Embodied Energy modeling into the design process, a point of comparison needs to be made. In this case, a baseline will be developed that is representative of housing in the City of Rochester, NY. To develop the baseline, three important criteria needs to be examined. These criteria include housing typology, programming, and building performance. The first criteria will be explored using a housing stock analysis for a neighborhood in Rochester. Secondly, a program will need to be developed that details a “typical” residential unit within the city of Rochester.   Finally, the current building code will be consulted to determine the required building performance in terms of thermal envelope. This final stage will allow us to examine the housing being built currently and examine opportunities for reducing the environmental footprint for future housing in the city of Rochester.

Housing Typology:

To determine the housing typology to be researched, a housing stock analysis will need to be conducted. This analysis will be conducted in two stages, with the first stage focusing on identifying the most common typology of housing within the community. Using the American Community Survey as a data source provides insight into the housing of Rochester on both macro and micro levels. This stage of the analysis will focus on the CONEA (Coalition of North East Associations) neighborhood located northeast of downtown Rochester.

According to Neighborhood Data Map available through, the City of Rochester the CONEA neighborhood has an estimated 3,868 housing units within the approximately 1.17 square mile community[103]. The housing is spread across a range of typologies and densities ranging from single family detached to multi-family housing. The following table shows the distribution of housing by the # of units.

[103] Data retrieved from Rochester Neighborhood Data Map. The online mapping tool used no longer available. "Neighborhood Data Map," City of Rochester, 2014, accessed May 03, 2018, http://www.cityofrochester.gov/neighborhooddatamap/.

Table 5: Housing Units by # of Units in Structure (Source: 2011-2015 ACS Survey)

Tract #	# of Units	1 Unit, Det.	1 Unit, Att.	2 Units	3-4 Units	5-9 Units	10+ Units	Other
7	898.00	397.00	18.00	177.00	156.00	4.00	146.00	0.00
13	714.00	30.00	39.00	32.00	295.00	182.00	136.00	0.00
15	443.00	153.00	5.00	187.00	98.00	0.00	0.00	0.00
50	765.00	281.00	0.00	275.00	88.00	27.00	81.00	13.00
92	686.00	85.00	19.00	90.00	33.00	144.00	315.00	0.00
93	1105.00	171.00	78.00	408.00	230.00	103.00	115.00	0.00
Total	4611.00	1117.00	159.00	1169.00	900.00	460.00	793.00	13.00
%	-	24.22%	3.45%	25.35%	19.52%	9.98%	17.20%	0.28%

Source: 2011-2015 American Community Survey 5-year Estimates

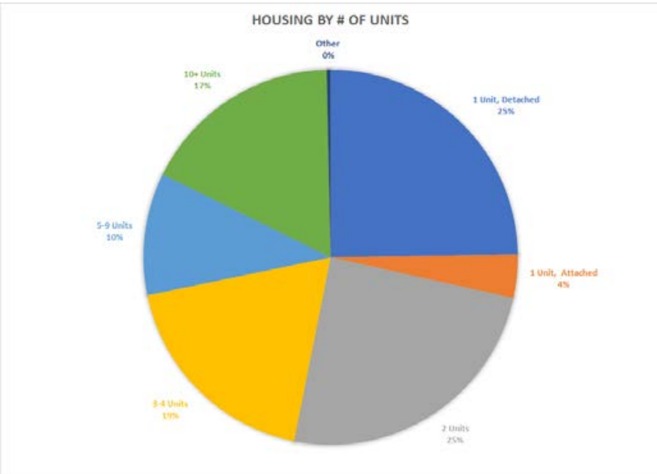

Figure 4: Housing by number of Units

Based on the data above, most of the housing within the CONEA neighborhood consists of 1-unit detached housing or 2-unit housing, each category accounts for approximately 25% of housing units within the community[104]. While most of housing in this community falls into these two categories, the focus for this exploration will be on 1-unit detached housing which accounts for 24.22% of housing in the CONEA neighborhood[105]. In order to clarify what constitutes 1-unit attached and a 2-unit housing, the definitions for the housing typology were consulted. The definition for the 1-Unit detached housing is as follows:

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[104] U.S. Census Bureau. 2011-2015 American Community Survey 5-year Estimates, Table DP04. Generated by Thomas Shreve using American FactFinder. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_14_5YR_DP04&prodType=table

[105] Ibid.

"This is a 1-unit structure detached from any other house; that is, with open space on all four sides. Such structures are considered detached even if they have and adjoining shed or garage. A one-family house that contains a business is considered detached as long as the building has open space on all four sides. Mobile homes or trailers to which one or more permanent rooms have been added or built also are included.[106]" Having identified the housing typology, the next step in developing a baseline is to develop the program.

Programming:

To determine the building typology to be examined, a micro scale was used to examine a single community within Rochester. However, to determine the programming, both micro and macro scales need to be utilized. This shift in scales is due in part to the data available. Information like number of units and rooms in a building are available for the majority of census blocks, but the information needed to develop a comprehensive program is available only for the city of Rochester.

One of the driving factors for residential architecture, is the number of bedrooms. The following table shows the distribution of housing units by the number of bedrooms in the unit. Examining the data in the following table, 65.65% of housing within the CONEA neighborhood consists of 2 to 3-bedroom housing units[107].

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[106] United States Census Bureau, "American Community Survey and Puerto Rico Community Survey 2016 Subject Definitions," Tech Docs, 2016, accessed May 3, 2018, https://www2.census.gov/programs-surveys/acs/tech_docs/subject_definitions/2016_ACSSubjectDefinitions.pdf

[107] U.S. Census Bureau. 2011-2015 American Community Survey 5-year Estimates, Table DP04. Generated by Thomas Shreve using American FactFinder. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_14_5YR_DP04&prodType=table

Table 6: Housing Units by # of Bedrooms (Source: 2011-2015 ACS Survey)				
Tract #	No Bedroom	1 Bedroom	2 or 3 Bedroom	4+ Bedroom
7	5.83	158.92	411.88	152.36
13	5.18	100.29	498.84	42.70
15	6.85	25.03	219.92	45.89
50	13.78	112.99	436.82	124.71
92	29.75	15.07	353.74	41.876
93	66.78	138.33	618.20	130.70
Total	128.17	618.19	2539.41	538.24
%	3.31%	17.08%	65.65%	13.92%

Source: 2011-2015 American Community Survey 5-year Estimates

Now that the type of housing and the number of bedrooms to be examined have been determined, the remainder of the program needs to be identified. To complete this, housing data on the city of Rochester needs to be examined. Using the 2013 American Housing Survey, the remainder of the program can be established.

The data for the city of Rochester is similar in that the majority of housing units within the city consist of 2-3 bedrooms, but this data set clarifies that the majority at 41.9% consists of three-bedroom housing. Along with further clarification on the number of bedrooms, the American Housing Survey also provides information necessary to create a baseline for the city of Rochester and the CONEA neighborhood. The following table outlines the remaining program elements that can be discerned from the associated data.

Table 7: Programming Elements and Associated Data (Source: 2013 AHS)		
Element	Quantity/ Characteristic	Housing Units (%)
Rooms	6	102.8 (22.5%)
Complete Bathrooms	1	184.4 (40.38%)
Square Footage	1,500 ft^2 (Median = 1586 ft^2)	
Selected Amenities	Porch, Deck, or Balcony	354.1 (77.54%)
Vehicle Parking	Garage or Carport Included	291.4 (63.81%)

Source: 2013 American Housing Survey

While the data above does not paint the whole picture, it gives a better understanding of the spaces that exist, and it also provides an area in which the remaining program can be filled in. The data shows that the typical house in Rochester has six rooms (22.5%) including bedrooms, as well as 1 complete bathroom (40.38%)[108]. The reported average square footage is 1,500 ft^2 with the median area being 1,586 ft^2. Along with area and number of rooms, the survey also provides information on the amenities associated with housing. One key consideration, especially in the Rochester climate, is vehicle parking. The data collected shows that 63.81% of housing in Rochester has an adjoining garage or carport. This is important to consider because even though the garage is not a key living space within a residence, it still consumes energy, and needs to be considered.

With the data collected above, the program can be interpreted and developed in more detail. The "typical" Rochester house contains 6 rooms, three of which are bedrooms. The other three rooms will be represented by a dining room, living room, and kitchen. These three functions were chosen because they represent the basic needs of a house or home. In addition to the rooms listed above, the baseline house will feature 1 complete bathroom and a garage. The following table represents the program outlined above.

[108] U.S. Census Bureau. 2013 American Housing Survey, Table C-01-AH-M. Generated by Thomas Shreve using American FactFinder. https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=AHS_2013_C01AHM&prodType=table

Table 8: Proposed Program for Baseline House		
Element	Quantity/ Characteristic	Housing Units %
Area	Less than 1,500 ft^2	
Rooms	6	22.5%
Dining Room		-
Living Room		-
Kitchen		-
3 Bedrooms		41.98%
1 Bathroom		40.38%
Garage or Carport		77.5%

The final step in creating the baseline is to examine the required building code to examine the thermal performance requirements of housing within Rochester.

Building Code Analysis:

A key consideration that needs to be made when examining embodied energy is thermal performance. Many of the insulations utilized involve energy intensive processes to make and/or install. To determine the requirements for building envelope performance, the 2015 International Residential code was examined. The requirements for envelope performance is based upon building components, and the thermal performance is based on the Climate zone where the building is located. According to Section C301 Climate Zones of the 2015 Energy Conservation Code, Monroe County is in zone 5A[109]. The following figure shows the climate zones across the United States, the star represents the location of Monroe County, NY.

[109] "Chapter 3 General Requirements," 2015 International Energy Conservation Code, May 2015, accessed May 03, 2018, https://codes.iccsafe.org/public/document/IECC2015NY-1/chapter-3-ce-general-requirements.

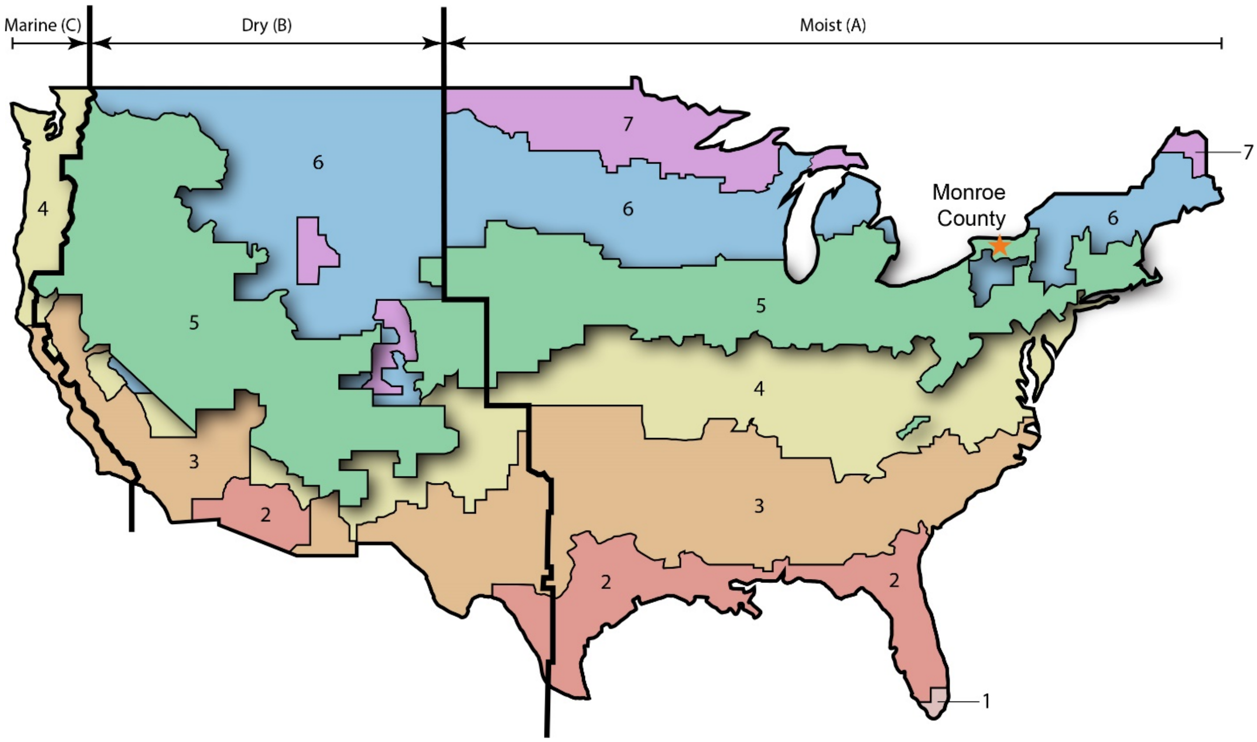

Figure 5: The thermal performance in the IBC 2015 is based on climate zones. Monroe County and the City of Rochester are in Zone 5A.

The required thermal performance of building components can be found in Table N1102.1.2 Insulation and Fenestration Requirements by Component (Table R402.1.2 in the Residential Building Code. The table has been recreated below with the pertinent information highlighted. The information in the table below guides the design of the assemblies outlined within the table. While some of the requirements are straight forward, like R-49 for ceilings, some assemblies are provided two paths for achieving code compliance. In the case where the code calls for "20 or 13+5", designers can choose between R-20 insulation in the wall cavity or R-13 in the cavity with R-5 continuous insulation[110]. The second instance where the code gives designers the option is where it calls for "15/19" in this instance, the code is requiring with R-15

[110] Table 9 note h. "Part IV - Energy Conservation," 2015 International Residential Code, January 2016, accessed May 03, 2018, https://codes.iccsafe.org/public/document/IRC2015NY-1/part-iv-energy-conservation.

insulation on the exterior of the foundation wall or R-19 insulation on the interior of the same wall[111].

Understanding the requirements for thermal performance is necessary, by accurately identifying the amounts of insulation and type of insulation in building assemblies, architects can examine variety of design criteria including the comparison of thermal performance with embodied impacts. Based on the information below, it can be determined that the wall assemblies need to be R-20 or R-13+5, the ceiling needs to be R-49, and basement walls need to be R-15 (exterior) and R-19 (interior). The slab in the basement does not require insulation because the slab will be located greater than 2' below grade.

With the information gathered from the housing stock analysis as well as an analysis of the Residential Building Code, a baseline can be developed which will serve as the control in this examination of BIM integrated LCA analysis. The baseline model utilized in this research was based on an existing house within the city of Rochester. Utilizing an existing building not only expedited the research process, but also allowed the form of the baseline to remain true to the character of housing in Rochester.

[111] Table 9 note f. "Part IV - Energy Conservation," 2015 International Residential Code, January 2016, accessed May 03, 2018, https://codes.iccsafe.org/public/document/IRC2015NY-1/part-iv-energy-conservation.

Table 9: Insulation and Fenestration Requirements by Component[a] (Table N1102.1.2 (R402.1.2))										
Climate Zone	Fenestration U-Factor[b]	Skylight[b] U-Factor	Glazed Fenestration SHGC[b,e]	Ceiling R-Value	Wood Frame Wall R-Value	Mass Wall R-Value[i]	Floor R-Value	Basement[c] Wall R-Value	Slab[d] R-Value & Depth	Crawl Space[c] Wall R-Value
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13+5[h]	8/13	19	5/13[f]	0	5/13
4 Except Marine	0.35	0.55	0.40	49	20 or 13+5	8/13	19	10/13	10, 2 ft.	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13+5[h]	13/17	30[g]	15/19	10, 2 ft.	15/19
6	0.32	0.55	NR	49	20+5 or 13+10[h]	15/20	30[g]	15/19	10, 4 ft.	15/19
7 and 8	0.32	0.55	NR	49	20+5 or 13+10[h]	19/21	38[g]	15/19	10, 4 ft.	15/19
Source: International Energy Conservation Code[112]										

[a]: R-values are minimums. U-factors and SHGC are maximums. When Insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed R-value of the insulation shall not be less than the R-value specified in the table.
[b]: The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration. Exception: Skylights may be excluded from glazed fenestration SHGC requirements in climate zones 1 through 3 where the SHGC for such skylights does not exceed 0.30
[c]: “15/19” means R-15 continuous insulation on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. “15/19” shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. “10/13” means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement walls.
[d]: R-5 shall be added to the required slab edge R-values for heated slabs, Insulation depth shall be the depth of the footing or 2 feet, whichever is less in Climate Zones 1 through 3 for heated slabs.
[e]: there are no SHGC requirements in the Marine Zone
[f]: Basement wall insulation is not required in warm-humid location as defined by Figure R301.1 and Table R301.1
[g]: Or insulation sufficient to fill the framing cavity, R-19 Minimum
[h]: The first value is cavity insulation, the second value is continuous insulation, so “13+5” means R-13 cavity insulation plus R-5 continuous insulation.
[i]: the second R-value when more than half the insulation is on the interior of the mass wall.

[112] Reproduced from "Part IV - Energy Conservation," 2015 International Residential Code, January 2016, accessed May 03, 2018, https://codes.iccsafe.org/public/document/IRC2015NY-1/part-iv-energy-conservation.

Tally LCA Impact Estimator:

To determine the embodied impacts of the baseline and prototype residential units, a Revit add-in will be implemented that utilizes the Revit geometry to complete the LCA process. According to the software's website "Tally facilitates the quantification of a life cycle assessment of building materials for whole building analysis as well as comparative analyses of design options[113]." Like many other LCA tools, the software utilizes a functional unit to facilitate the comparisons of the embodied impacts. In this case Tally draws upon the Revit model and utilizes the area of the building as the functional unit. For whole building LCA, the software examines the energy and materials flows that occur throughout the entire life-cycle of the building where as in the comparative analyses, the user is required to define the scope[114].

Utilizing a cradle-to-grave approach based on ISO 14040-14044 the software includes all stages of the life-cycle from material manufacturing to end-of-life processes, also providing the additional functionality of including the construction impacts and operational building of a design[115]. The definitions Tally utilizes to describe the individual life cycle stages can be found in the definitions section of this thesis. Tally implements the use of a LCA database that was developed through cooperation between KT Innovations and Thinkstep. The process of the LCA within the Tally framework utilizes GaBi 6 and the GaBi database to calculate the embodied impacts of building materials[116].

[113] KT Innovations, "Methods," Tally, 2016, accessed May 03, 2018, http://choosetally.com/methods/.
[114] Ibid.
[115] Ibid.
[116] Tally was developed by the architectural firm Kieran Timberlake. The tool successfully integrates the BIM software with the complex modeling processes associated with LCA analysis tools like GaBI 6. Ibid.

The benefit that arises from utilizing Tally within the BIM environment is that unlike other building performance simulators, it relies on the Revit model for the completion of its analysis. Tally pulls information regarding families from the Revit model including materials and quantities. The software then defines these materials in the Tally interface where the quantities are connected to the impacts via the LCA database. Finally, Tally generates reports that allow for the interpretation of data efficiently. The figure below shows the workflow of the Tall software from Revit model to Tally Report.

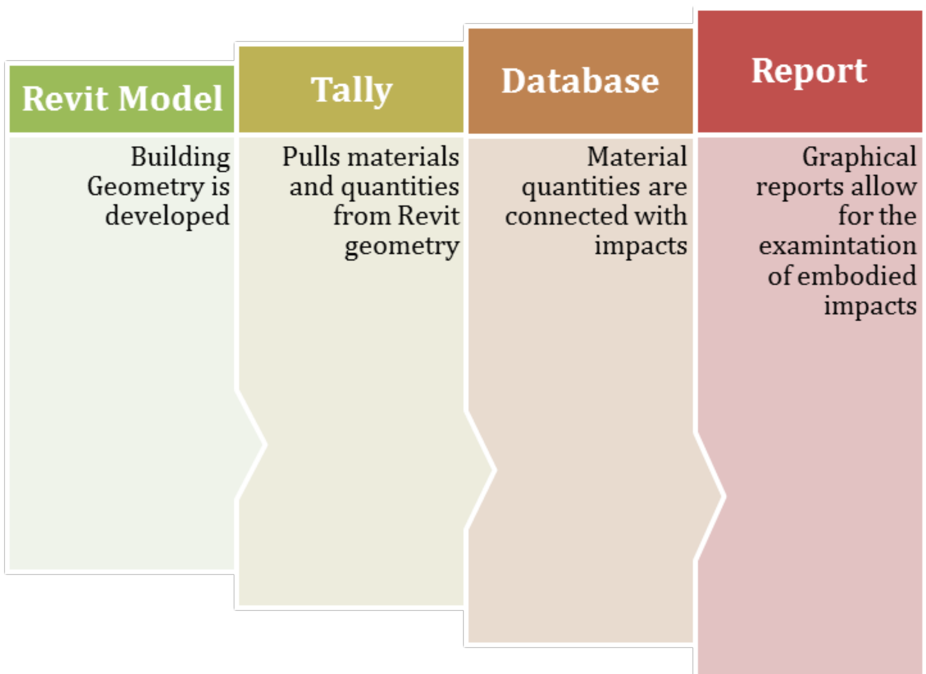

Figure 6: represent the tally workflow from the development of the Revit model through the creation of LCA reports. The process streamlines the LCA process and simplifies into a form that is easily approachable by Architects.

Using an example of a wall assembly, the following section will detail the process of completing the LCA process in Tally. The first step required is the development of the Revit geometry. In the case of a whole building LCA, the entire building needs to be modeled, the level of detail of the model is determined by the stage in which LCA is introduced in the design process. Once the modeling is complete, tally draws upon the families and assemblies created within the context of Revit, creating a catalogue of the assemblies and the materials used within

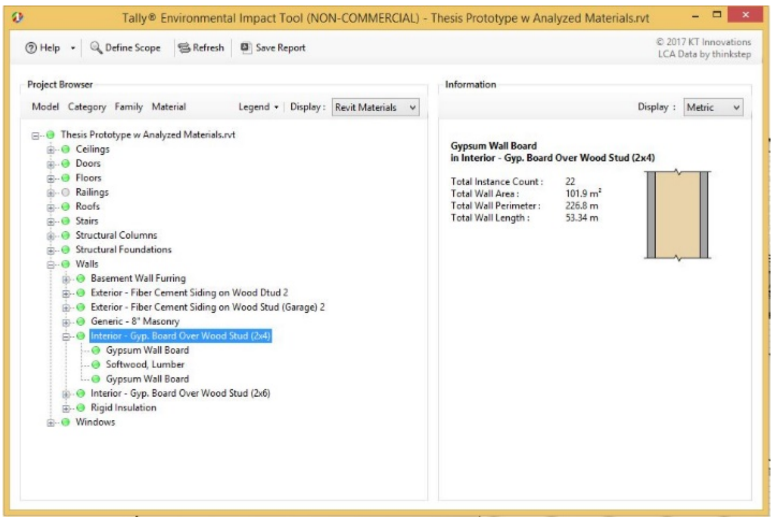

Figure 7: The Tally interface breaks down the Revit model by Category, then Family, and then Material. The green dots mean that the material has been defined in Tally and the embodied impacts can be estimated.

each family. The image below shows the Tally interface displaying the assemblies and families modeled within Revit. In this window, the user defines the materials utilized in the Revit model connecting them with the LCA database. Many materials in the Tally database require further information to better determine their impacts. Many of these materials feature a finish or adhesive that are not modeled. This allows tally to fully determine the impact of materials like painted gypsum board or stained hardwood floors, the image below shows and example of this window.

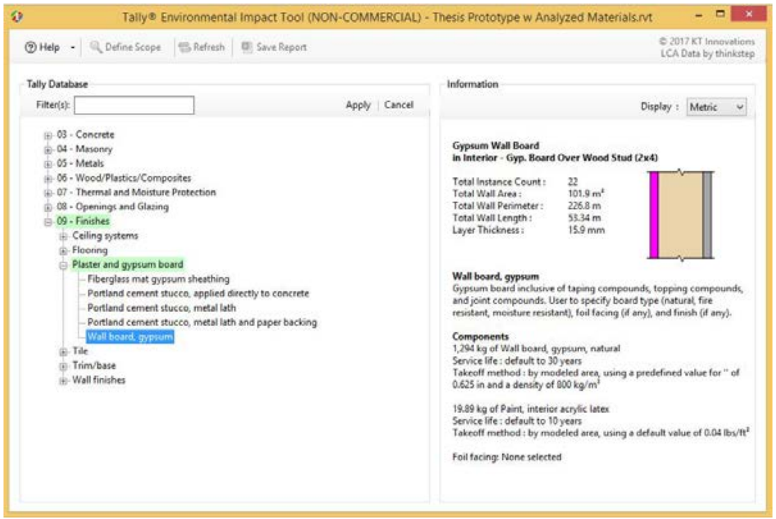

Figure 8: This window is where users connect the Revit Materials with their Tally counterparts.

Using tally in conjunction with design strategies aimed at reducing the embodied energy of a building, the baseline and prototype models will be compared in three ways. Whole building LCA will be implemented for both the baseline and prototypes. This will allow for the detailed examination of the embodied impacts and allow for the identification of "hotspots." After the hotspots have been identified, material analyses will be conducted on common residential building materials to determine their impacts on the embodied energy of a house. Finally, considering the material analyses, the prototype home will be examined using the traditional materials implemented in the baseline compared to the materials examined. This will allow for the side by side comparison of the two design options.

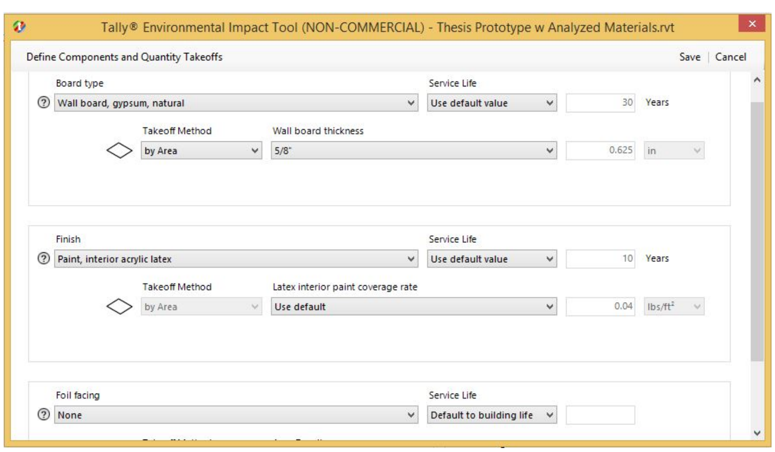

Figure 9: This window allows Tally users to define the information that is material specific. In this window, designers can identify adhesives, finishes, and other pertinent information that may not be modeled in Revit.

Results and Discussion:

To examine the potential provided by BIM integrated LCA, a point of comparison is needed to be developed. The baseline developed via the data gathered by the housing stock analysis will serve as the base point for this analysis.

Baseline Analysis:

Based on the housing stock analysis, it was determined that most of housing in the City of Rochester consists of single family unit accounting for approximately 25% of housing within the neighborhood analyzed. Table 7 outlined the program that was developed using data from the 2013 American Housing survey. To accelerate the process and to retain the character of the housing in Rochester, an existing building was selected to serve as the baseline. The design of the house was preserved except for thermal performance. The envelope of the baseline building was updated to the current building code to allow for the comparison of the baseline and prototype.

The building utilized for the baseline model was chosen because of its similarity to the program outlined by the housing stock analysis. Table 10 shows the spaces and programming of the residence utilized for the baseline model.

Table 10: Baseline Model Room Schedule

Name	Area (ft^2)
Basement	
Basement	534
Ground Floor	
Family Room	235
Garage	218
Kitchen	122
Dining Room	117
Foyer	38
Rear Foyer	11
Closet	8
Pantry	5
Second Floor	
Bedroom	150
Bedroom	140
Bedroom	125
Landing	68
Bathroom	45
Closet	20
Closet	17
Closet	11
Closet	5
Gross Building Area	2,159
Livable Area	1,272

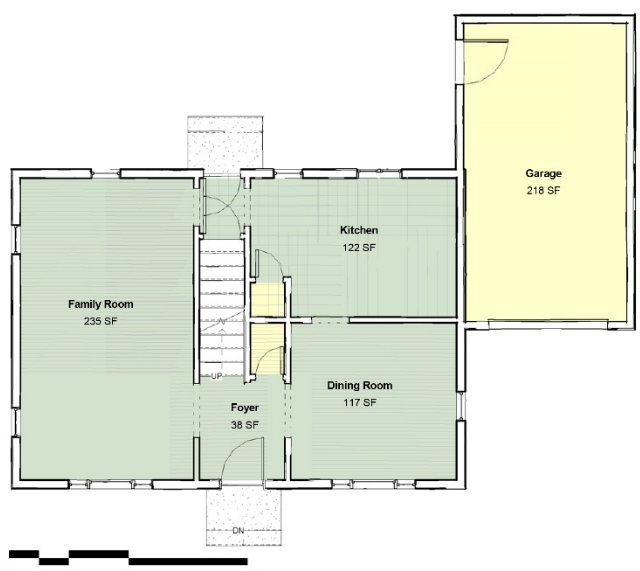

Figure 10: The first-floor plan for the baseline house contains the family room, dining room and kitchen.

The total built area or gross area of the structure is over 2,000 ft^2, but the livable area is under the average size for the city of Rochester (approximately 1,500 ft^2). The plan of the house utilizes a traditional layout, with walls dividing both common and private areas of the house. The first and second floor plans are displayed in figures 6 and 7. The areas highlighted in green represent public areas within the house, blue represents private areas, and yellow represents the utility spaces. The house was measured utilizing a Laser tape measure and input into Revit. As previously mentioned, the only changes made to the design of the house was to update the envelope to meet the modern building code. The materials selected for both interior and exterior finishes are representative of the existing materials utilized within the building. A set of drawings of both the bassline and prototype will be included in the appendix and will provide more information in terms of building construction and assemblies.

Figure 11: The second-floor of the baseline house features the three bedrooms and the house's only bathroom.

Once the process of modeling the baseline was completed, Tally was employed to determine the embodied energy of the structure. The reports generated through the Tally software show a variety of embodied impacts ranging from Acidification Potential to Global Warming Potential, but for the purposes of this research embodied energy or primary energy demand will be the primary focus. Another benefit of Tally is the way the LCA data is organized and presented. Tally categorizes and presents the data of the analysis in three ways: by life-cycle stage, by division, and by Revit category. For the purposes of identifying hotspots within the buildings, the categorization by Revit families will be utilized as the main comparison between baseline and prototype.

According to tally, the total primary energy demand for the baseline house is 701,670.45 Megajoules (MJ). This value equates to approximately y 6,000 MJ/m^2 of livable space[117]. Through further examination, the impacts associated with individual Revit categories can provide further information as to distribution of embodied energy throughout the house. Figure 12 shows the distribution of embodied energy by Revit category within the baseline house along with a distribution of embodied energy by Revit Families.

[117] Tally report generated using Revit models by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

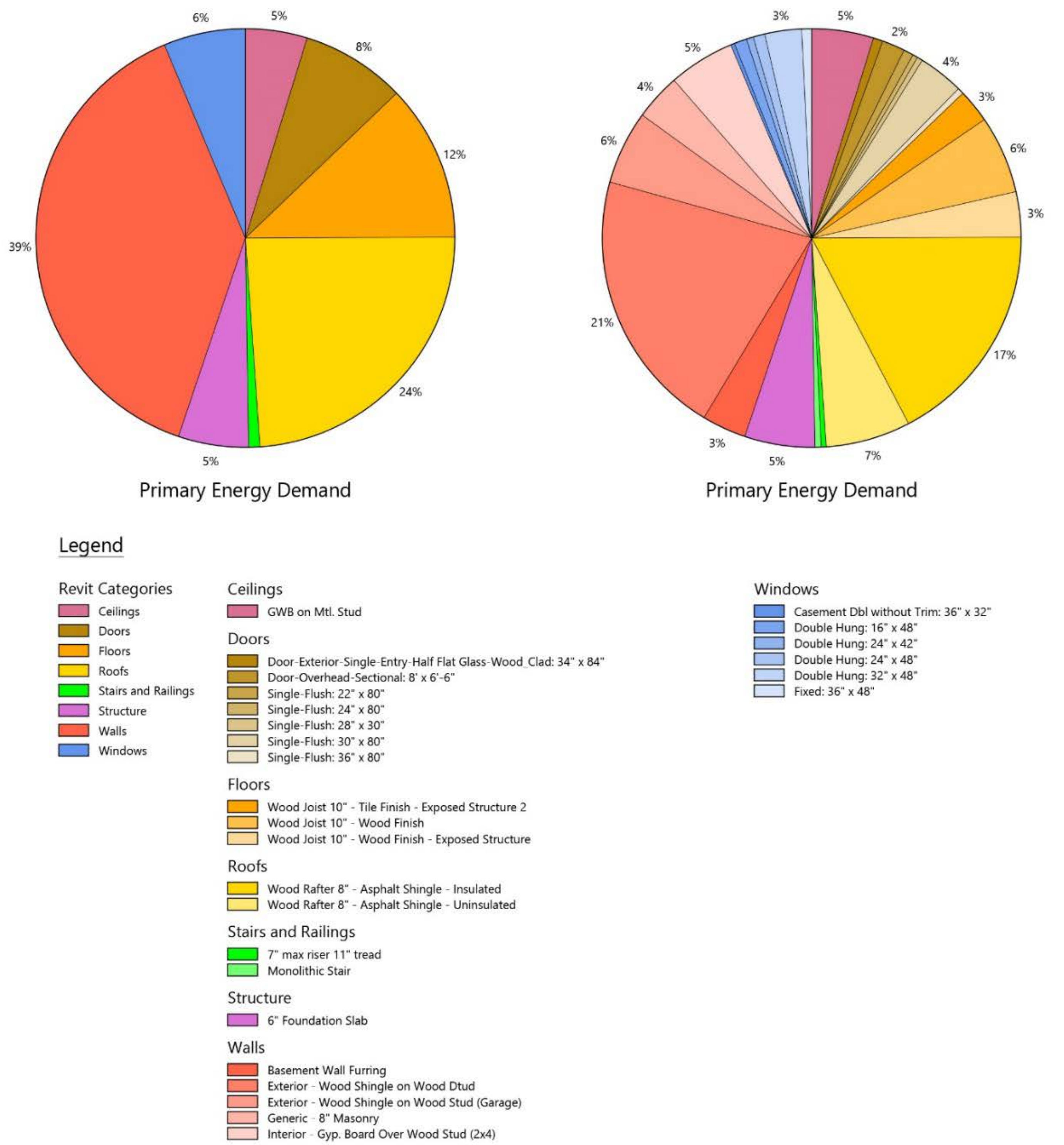

Figure 12: The graphs above show the embodied or primary energy of the baseline house. The graph on the left shows the distribution of embodied energy by Revit category, and the right shows the same information broken down by family.

Table 11 outlines the impacts of the individual Revit categories showing their impacts in terms of primary energy demand, non-renewable energy demand, renewable energy demand, and mass.

Table 11: Baseline House Embodied Energy by Revit Category

Category	Primary Energy Demand (MJ)	Non-Renewable Energy Demand (MJ)	Renewable Energy Demand (MJ)	Mass (kg)
Ceilings	33,463.69	28,342.19	5,125.05	2,396.68
Doors	56,643.79	32,747.43	23,947.98	1,236.53
Floors	84,872.83	42,530.91	42,366.72	7,315.11
Roofs	168,026.18	144,853.52	23,181.66	4,896.92
Stairs and Railing	6,092.07	3,384.59	2,708.34	1,608.53
Structure	38,657	37,463.51	1,179.34	16,419.38
Walls	270.203.48	132,727.33	137,539.25	38,404.95
Windows	44,313.57	28,908.25	15,410.55	900.42
Total	702,272.69	450,957.72	251,477.56	73,178.52

Source: Tally Report generated based on Revit model by Thomas Shreve

The data shown above, along with the graphs on the previous page allows for the identification of hot spots within the building. Based on the data, the three largest consumers of energy are the walls (39%), roofs (24%), and floors (12%[118]). A more detailed examination shows the energy consumption of the Revit categories in terms of total energy demand (primary energy demand), non-renewable energy demand, and renewable energy demand. The table above shows that over 250,000 MJ (35.83%) of the embodied energy came from renewable resources.

An interesting statistic regarding the embodied energy in the proportion of renewable energy to non-renewable energy in the walls of the baseline house. The renewable energy used in the life cycle of the wall assemblies accounts for 50.9% of the embodied energy[119]. This shows the depth at which embodied energy analyses can occur. Using the data above, architects can make design decisions focused on several criteria such as maximizing the energy demand from renewable resources within a project.

[118] Tally report generated using Revit model by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[119] Ibid.

With the completion of the life cycle assessment, a greater understanding of the embodied energy has been achieved. Using this data, as well as other design factors, a prototype house can be developed that looks to address some of the issues identified in the baseline house. In examining the program and layout of the house strengths, and weaknesses can be identified. The plan as it is provides a functional layout that does not require excessive circulation and the bedrooms on the second floor provide ample space. A key weakness to the layout is the lack of a secondary bathroom. The LCA revealed three key areas of concerns or “hot spots”. The walls, floors, and roofs all represent large consumers of energy and will be examined in future analyses. With the strengths and weakness of the baseline house identified, as well as areas of concerns in terms of embodied energy, a prototype house was developed that sought to reduce the embodied impacts of housing. The proposed prototype utilized design strategies that were aimed at reducing embodied energy, while maintaining the traditional form and architectural character that is indicative to the city of Rochester.

Design Strategies:

In the article *Design strategies for low embodied carbon and low embodied energy buildings: principle and examples*, Lupíšek et al. identifies key strategies that can be implemented to reduce the embodied energy of a building. These strategies were identified based on an analysis conducted by Annex 57 of the International Energy Agency’s Energy in Buildings and communities Program. According to Lupíšek et al, Annex 57’s purpose is to collect existing research results concerning embodied energy due to the construction of buildings, developing guidelines for the evaluation of embodied energy due to building construction, and finally to develop guidelines for the implementation of design strategies aimed at lowering the embodied impacts of buildings[120]. Through the gathering of data, Annex 57 identified three main strategies that can be implemented to reduce the embodied energy of a building. These strategies include:

1. reduction of amount of needed materials through the building life-cycle,
2. substitution of traditional building materials for alternatives with lower environmental impacts, and
3. reduction of construction stage impact[121].

Through their research, Lupíšek et al identified subcategories or design strategies for two of the strategies listed above. Table 12 identifies the subcategories and their associated strategy; these subcategories will represent that strategies implemented within the prototype house.

Table 12: Design strategies for reduction of embodied energy

Strategy	Sub-strategy
Reduction of required building materials	• Optimization of layout plan • Optimization of structural system • Low-maintenance design • Flexible and adaptable design • Component's service life optimization
Substitution of Traditional Materials	• Reuse of building parts and elements • Utilization of recycled materials • Substitution for bio-based and raw materials • Use of innovative materials with lower environmental impacts • Design for deconstruction • Use of recyclable materials

Source: Design strategies for low embodied carbon and low embodied energy buildings: principles and practices (148)

To examine the potential for BIM integrated LCA, strategies one and two will be utilized in designing the prototype.

[120] Antonín Lupíšek et al., "Design Strategies for Low Embodied Carbon and Low Embodied Energy Buildings: Principles and Examples," *Energy Procedia* 83 (2015): 148, accessed 2015, doi:10.1016/j.egypro.2015.12.205.
[121] Antonín Lupíšek et al., "Design Strategies for Low Embodied Carbon and Low Embodied Energy Buildings: Principles and Examples," *Energy Procedia* 83 (2015): 148, accessed 2015, doi:10.1016/j.egypro.2015.12.205.

The first strategy implemented is the reduction of building materials. The baseline plan featured a traditional layout with the living areas divided by walls. By implementing an open plan concept, the prototype house will seek to reduce the embodied impacts associated within the wall assemblies. Per the analysis of the baseline house, the wall assemblies accounted for 39% of the embodied energy, by reducing the materials required to construct the walls and improvement in the energy load for this Revit category should be reduced. The design of the prototype house will utilize the design strategy described in the literature review, and the beginning stages will utilize a knowledge-based design incorporating the open design concept as well as addressing the weaknesses of the baseline house discussed previously.

The second strategy will examine traditional building materials found in the baseline house and will compare them to alternatives. The materials selected will represent a mixture of the sub categories defined in Table 12 but will all represent common building materials that can be readily found. To compare the impacts of the materials, each material will be modeled on a 100 ft^2 assembly utilizing the same structure and underlayment in each option. This will allow for a quick comparison of each material and their embodied impacts.

Once both strategies have been implemented and a final prototype is developed, a final whole building LCA will be conducting to examine the overall impact of the design decisions made because of the implementation of the design strategies discussed above.

Design and Analysis of Prototype House:

The design of the prototype house draws upon the programming of the baseline yet seeks to address any of the weaknesses present within in the existing plan. The size of the prototype was increased to accommodate slight changes within the programming but was designed to stay within the parameters outlined within the housing stock analysis.

The additional programming elements added into the design of the prototype house includes the addition of a half bathroom, and the development of a master bedroom on the second floor. One of the bedrooms has been moved to the ground floor and can be utilized in a variety of ways. Table 13 outline the programming for the prototype house as well as the area of the proposed residence.

Table 13: Prototype Model Room Schedule

Name	Area (ft^2)
Basement	
Basement	542
Ground Floor	
Garage	296
Family Room	227
Kitchen	124
Dining Room	112
Bedroom	110
½ Bath	24
Laundry	21
Closet	13
Second Floor	
Master Bedroom	177
Bedroom	153
Bathroom	53
Walk in Closet	43
Closet	6
Gross Building Area	2,401
Livable Area	1,428

With the addition of the new programming, the prototype house represents a 12% increase in livable area yet remains within the parameters of the housing stock analysis. Figures 9 and 10 display the first and second floor plans for the prototype house, the first floor like the baseline contains most the living spaces (i.e. kitchen, living room, and dining room) with the addition of a flexible room that can be used for multiple purposes (i.e. bedroom or office). The second floor features the two-remaining bedroom and the full bathroom.

Once the prototype has been modeled, the embodied energy was compared to the data retrieved from the baseline. With the added floor area as well as other design changes an increase in total embodied energy is expected, the true test of the success for this design intervention will come through the comparison of embodied energy by Revit category. Table 14 provides a comparison of the embodied energy for the life-cycle stages examined in the LCA process, as well as the percent change for each category.

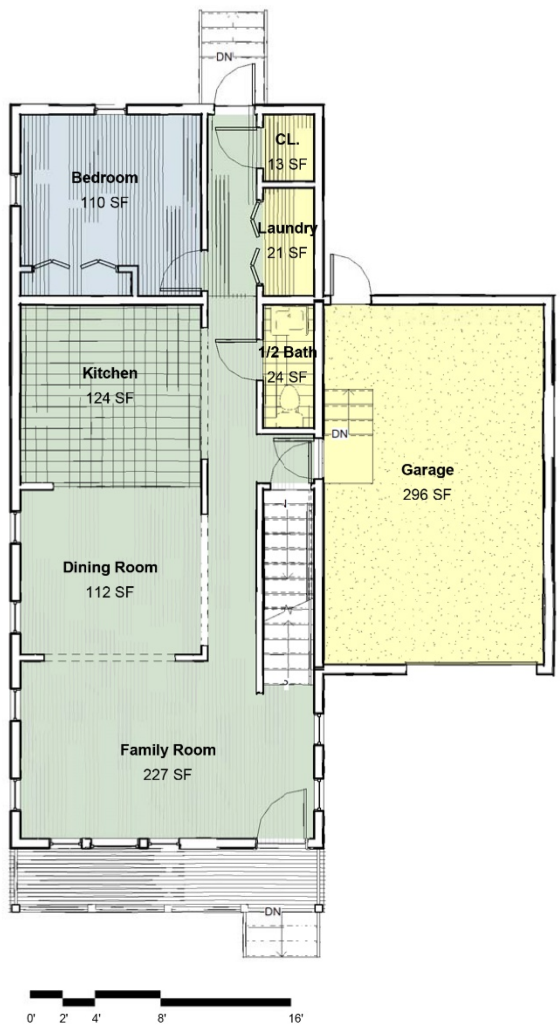

Figure 13: The first-floor plan of the prototype house featuring the living spaces as well as the third bedroom.

Figure 14: The second floor contains the remaining two bedrooms as well as the full bathroom.

Table 14: Comparison of Embodied Energy by Life-Cycle Stage[a]			
Stage	Baseline (MJ)	Prototype (MJ)	% Change
Product Stage (A1-A3)	432,080	567,824	31.42%
Construction Stage (A4-A5)	12,001	15,131	26.08%
Use Stage (B2-B4, B6)	298,990	381,669	27.65%
End of Life Stage (C2-C4, D)	-14,400	-51,916	260.53%
Total Embodied Energy	728,671	912,708	25.26%
Gross Building Area	2,159 ft^2	2,401 ft^2	11.21%
Livable Area	1,272 ft	1,428 ft^2	12.26%
Embodied Energy per ft^2	572.85 (MJ/ft^2)[b]	639.15 (MJ/ft^2)[b]	11.57%

[a] Data utilized represents the entire lifecycle of the baseline and prototypes.
[b] MJ/ft^2 calculated using Livable area
Source: Tally reports generated using Baseline and Prototype Revit model generated by Thomas Shreve

The data above represents the embodied energy for both buildings over the entirety of the life cycles. An interesting aspect of the data is the while the area of the building increases by approximately 12%, the embodied energy of the building increases on a case by case basis. For instance, according to the data above, the embodied energy consumed during the production stage increases by 37% while the total embodied energy for the prototype house increase by approximately 25%[122]. This increase in embodied energy between the baseline and prototype is in part due to the change in size and other design changes that impacts the amount of material required to construct the building. With an understanding of the total embodied energy, the effectiveness of the design intervention can be examined.

The implementation of an open plan layout was intended to reduce the impacts associated of walls within the design. Figure 11 shows a comparison between the baseline and the prototype, comparing the distribution of embodied energy by Revit category.

[122]Tally Report generated using Revit model y Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

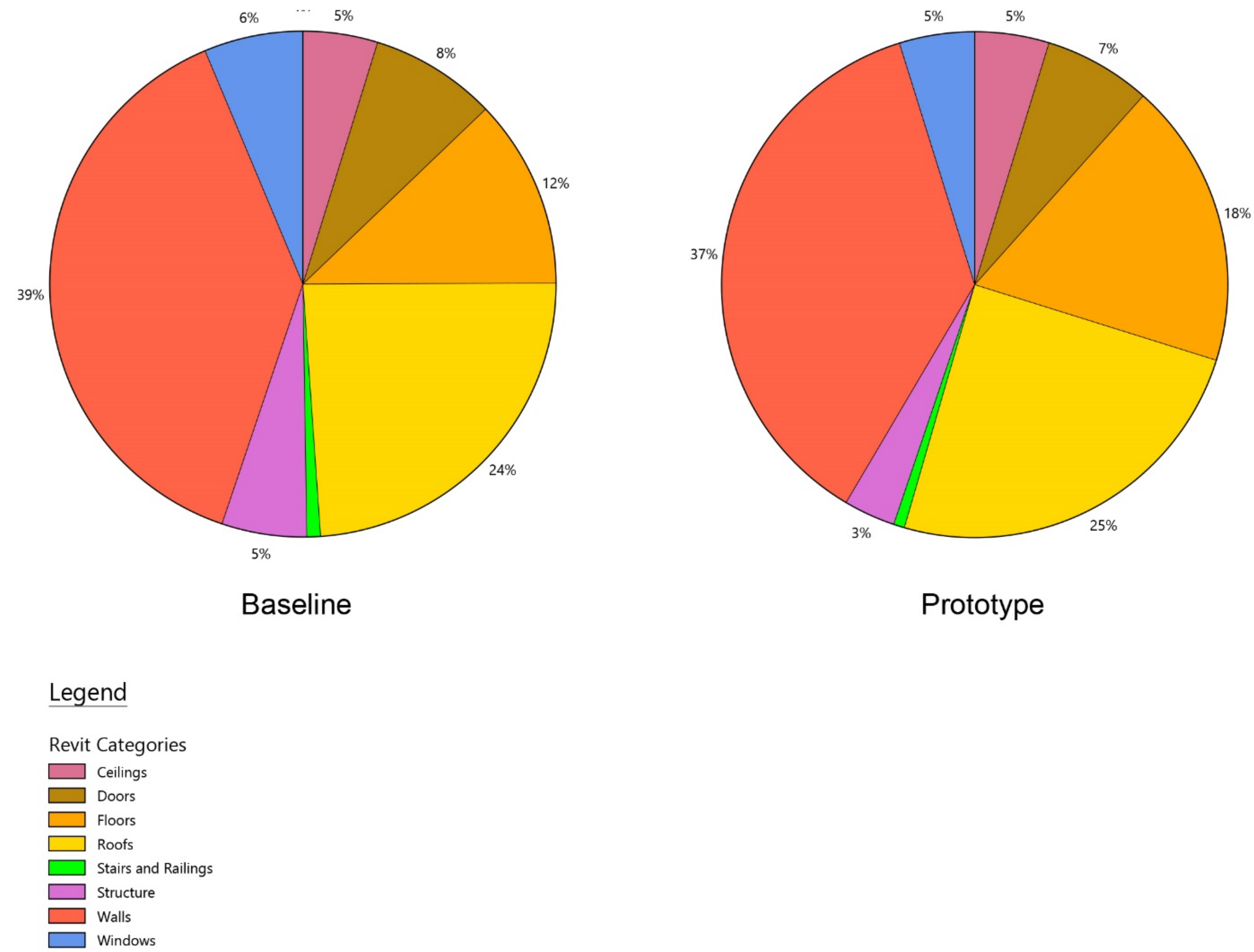

Figure 15: A side by side comparison of embodied energy by Revit category. Most of the categories increased because of the size increase between the two models. Despite this though the walls accounted for a smaller percentage of the embodied energy for the prototype.

The graphs above show that the impacts associated with the walls represent a smaller proportion of the embodied energy for the prototype building. While this does not directly translate into a reduced impact in terms of MJ, it shows that optimizing building plans and materials usage can have an impact with the goal of reducing embodied energy. Examining the empirical data produced by the Tally software provided greater insight into the impacts of adopting an open plan concept. Table 15 outlines the impacts of the baseline and prototypes by primary energy demand and examines the changes that occurred because of the design changes made.

Table 15: Embodied Energy of Baseline and Prototype by Revit Category

Revit Category	Baseline (MJ)	Prototype (MJ)	% change
Ceilings	33,463.69	43,283.75	29.35%
Doors	56,643.79	62,474.99	10.30%
Floors	84,872.83	166,538.70	96.22%
Roofs	168,026.18	224,814.91	33.78%
Stairs and Railings	6,092.07	6,370.95	4.58%
Structure	38,657.07	30,121.81	-20%
Walls	270,203.48	325,626.32	20.51 %
Windows	44,313.57	43,889.91	-1%
Total	702,272.64	903,121.34	28.60%

Source: Tally Reports generated using baseline and prototype models

Examining the model in terms of embodied energy by Revit category shows that most of the categories increased by 20 to 30 % except for a few outliers. The data above shows that the optimization of the floor plan may have been counteracted by the growth of the building. Examining the model based on individual families can provide more information regarding the effective ness of this design intervention.

The wall category is representative of all walls located within the project. This includes both interior and exterior walls. To filter the embodied impacts by wall type, a distribution of embodied energy by family will need to be examined. Table 16 shows the embodied impacts of the individual wall families in both the prototypes and baseline models. This examination further aides in analyzing the impacts of implementing an open concept, while also providing greater insight into how the different wall assemblies can impact a project.

Table 16: Embodied Energy of Baseline and Prototype by Wall Type

Wall Type	Baseline (MJ)	Prototype (MJ)
Basement Furred Wall	23,974.48	21,211.35
Exterior – Wood Shingle on Wood Stud	145,379.92	175,148.83
Exterior – Garage Wall	39,883.63	38,311.25
8” Masonry Wall	25,186.75	37,728.97
Interior – 2x4 Stud w/ Gyp. Board	35,778.70	36,576.96
Interior – 2x6 Stud w/ Gyp. Board	N/A	4191.84
Foundation Insulation	N/A	12,456.84

Source: Tally Reports generated using baseline and prototype models

The table above shows clearly the impact that implementing an open plan concept can have. The Interior – 2x4 Stud w/ Gyp. Board family represents the wall type utilized throughout the house for interior walls. While the other wall types were scaled up (except for the basement furred wall), the embodied energy impacts for the interior wall type remained relatively the same, increasing by 798.26 MJ or a 2.23% increase. While the impacts of the increased material use in the other walls types negated the effects of implementing an open plan, it shows that building form and layout can have an impact of reducing embodied energy and should be considered as part of the deign process.

While the implementation of an open floor plan did not translate into a clear reduction of embodied energy, it helps to mitigate the impact of other assemblies within the building. The implementation of an open plan concept or other floor plan optimization strategies should be integrated with other design strategies to further reduce the embodied impacts of a building. The next step in the analysis of BIM integrated LCA involves analyzing the impacts of common building materials.

Building Materials Analysis:

To further investigate the opportunities for reducing embodied energy in buildings, an examination of common building materials was conducted, creating the potential to further reduce the embodied energy of the proposed prototype. These material analyses will be examining common building materials with the goal of selecting alternatives to the materials utilized in the baseline. Figure 12 shows the distribution of embodied energy by Revit category. This graphic clearly identifies the areas of the building's design that needs further examination. The three assemblies to be examined include the walls, roofs, and floors.

The largest concentration of embodied energy is in the wall assemblies. In the base line model, wall assemblies accounted for 39% of the embodied energy and 37% of the embodied energy in the prototype model. To understand where this embodied energy comes from, an examination of the wall materials needs to be examined. Figure 12 shows the distribution of embodied energy for the prototype model by Revit category, but is further broken down by materials within each category. The graph shows that the largest consumer of embodied energy in the walls category is the wood siding, accounting for 155,207.41 MJ (approximately 17.75 MJ/kg)[123]. Examining alternatives to the typical wood siding could provide the opportunity to reduce the embodied energy associated with the building cladding. An unexpected outcome of this examination of the wall materials shows that the framing accounts for only 2,127.40 MJ of energy or less than 1% of the embodied energy associated with the wall assemblies in the prototype[124].

[123] Tally reports generated using Revit model by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[124] Tally reports generated using Revit model by Thomas Shreve. Ibid.

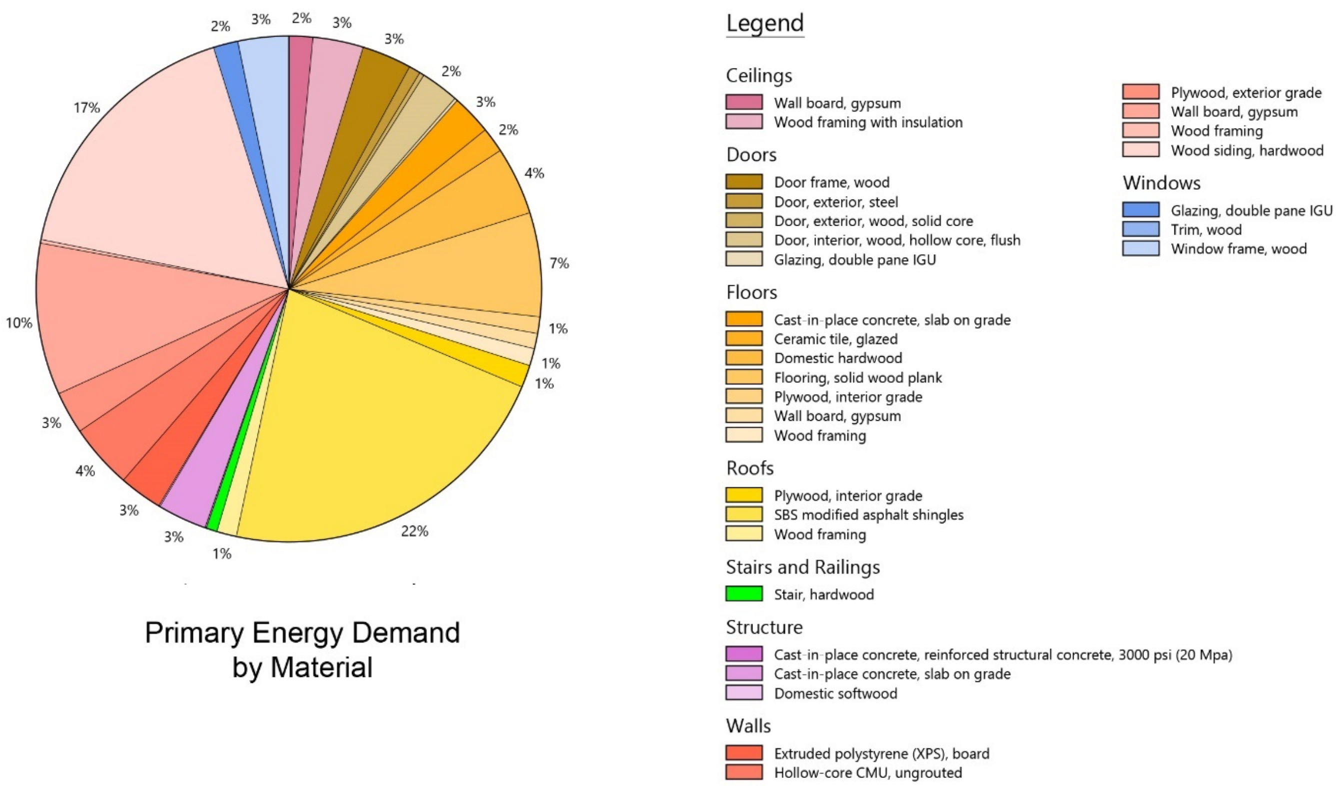

Figure 16: Displays the distribution of embodied energy by Revit category, but is further broken-down by the materials present in each category.

The analysis of exterior cladding materials compared 5 materials including the wood siding to determine the embodied energy of common cladding materials. The materials examined included: wood plank siding, fiber cement siding, vinyl siding, wood rain screen, and metal siding. Each material was examined using a 100 ft^2 wall assembly with the same structure, sheathing, and insulation values.

Tally allows for the comparison of design option within a Revit model, this functionality was utilized to compare the embodied energy of the materials listed above. Table 17 shows each option's total embodied energy, as well as the mass of the material.

Table 17: Embodied Energy of Cladding Materials

Material	Embodied Energy (MJ)	Mass (kg)
Wood Siding	4,273.70	232.35
Fiber Cement Siding	1,429.60	113.39
Vinyl Siding	1,808.24	21.51
Wood Rainscreen	6,530.55	329.11
Metal Siding	2,702.68	133.13

Source: Tally Report generated using Revit model generated by Thomas Shreve

Based on the information above, the material that performs the best in terms of embodied energy is the fiber cement siding contributing only 12.6 MJ/kg to the overall embodied energy of the building. This is surprising because like vinyl siding and metal siding, fiber cement siding is a produced via manufacturing processes, whereas the traditional wood siding is a natural material. The increase between the traditional wood siding and the wood rain screen comes because of the additional furring required to create a drainage plane with in the assembly. Figure 13 shows a graphical breakdown of embodied energy for the five materials examined by life cycle stage. Utilizing the information in the graphic below can provide a plethora of information on which architects can make decisions that reflect the goals of a project. In this case, it will allow for the examinations of the life-cycle stages for the materials analyzed and see where the embodied energy comes from. In the graphic below, the red is representative of the manufacturing stage (A1-A3), blue is the transportation stage (A4), dark green is the maintenance and replacement stages (B2-B4), and lime green is the end-of-life stage (C2-C4, D)[125]. Examining the impacts associated with the life-cycle stages of cladding options show that vinyl and fiber cement siding provided the greatest reduction in embodied energy because of the manufacturing and maintenance and replacement stages represent the lowest of the 5 materials examined.

[125] Tally Report generated using Revit model generated by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

Through this examination, it can be determined that the implementation of fiber cement siding can significantly reduce the embodied impact within the prototype. The next assembly that was examined is the roof assembly, which according to figure 11 accounts for 25% of the embodied energy within the prototype house.

The next step in the material analysis is to examine the roofing materials. Examination of figure 12 will show that the roofing material with the greatest impacts is the asphalt shingles.

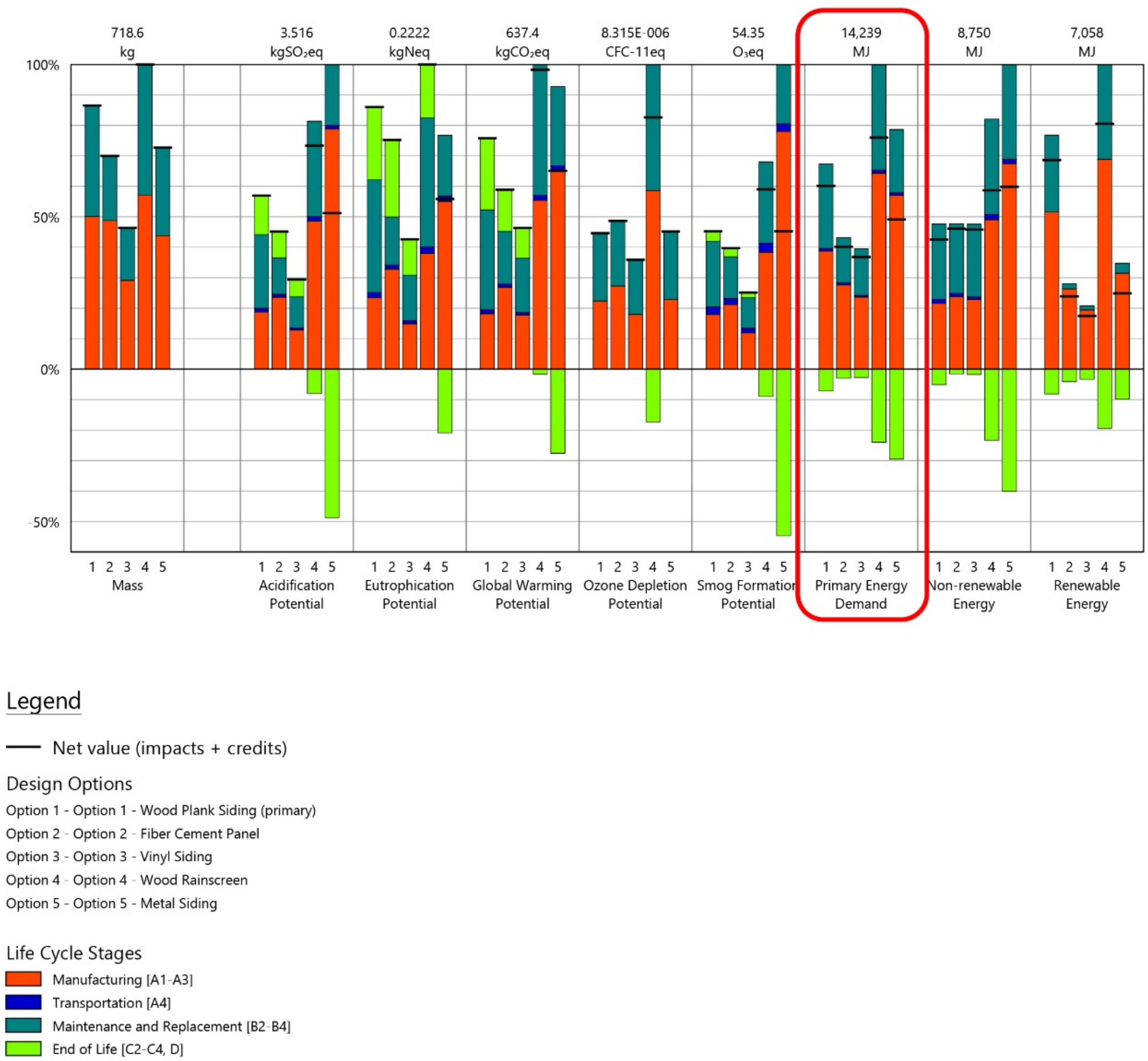

Figure 17: Shows the comparison of the 5 cladding materials broken down by Life cycle stage. The red rectangle represents the embodied energy of the cladding materials.

The materials being compared in this analysis include: asphalt shingles, slate shingles, cedar shingle, and metal roofing panels. Table 18 shows the embodied energy for each material along with its mass.

Table 18: Embodied Energy of Roof Materials

Material	Embodied Energy (MJ)	Mass (kg)
Asphalt Shingles	11,748.39	253.16
Slate Shingles	379.51	257.09
Cedar Shingles	11,092.60	608.73
Metal Roofing Panels	1,915.05	64.25

Source: Tally report generated using Revit Model generated by Thomas Shreve

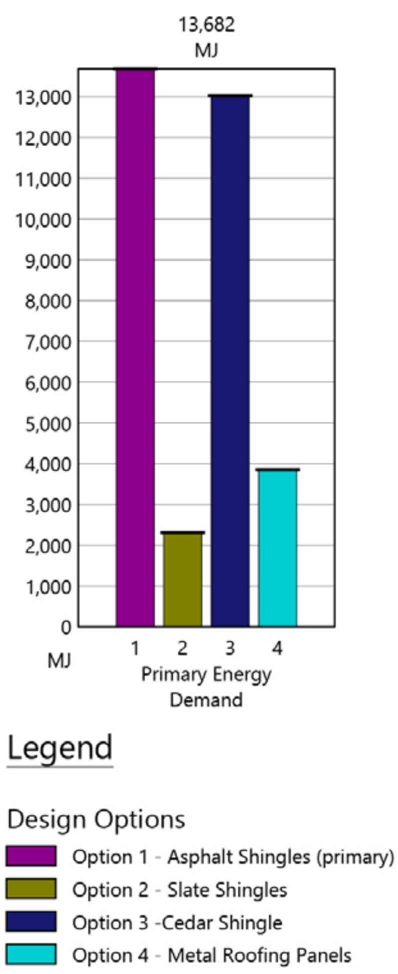

Figure 19: Shows a side by side comparison of the roofing materials. Both asphalt and cedar shingles dwarf the impacts of the two other materials analyzed.

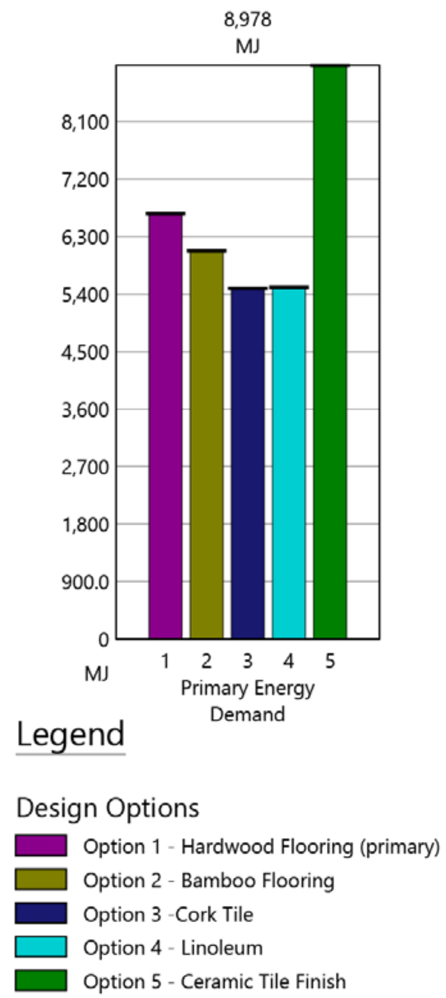

Figure 18: Shows the embodied energy for each of the flooring materials examined side by side. Source: Tally Report generated using Revit models by Thomas Shreve

The data above shows a shocking difference between the embodied energy of common roofing materials. Asphalt shingles, one of the most common building materials used in residential architecture accounts for 441.1 MJ/kg of embodied energy. Comparing this to the best performing material, slate shingles at 1.5 MJ/kg, shows a reduction in embodied energy of approximately 11,000 MJ or about 97%[126]. Figure 14 shows the embodied energy for each option compared side by side. An examination of the materials shows where this difference in impact may come from. The metadata provided in the back of the Tally reports provides information regarding the inputs required to produce building materials, as well as the outputs that come because of the end-of-life stage. This data shows that asphalt shingle (as Tally defines them) are comprised of glass fibers (5%), asphalt (45%), SBS polymer (10%), plastic chips (15%), and limestone filler (25%). Slate shingles for comparison are 100% slate in the tally definition[127].

Other information that can be gleaned from the metadata includes the outputs for the materials the end-of-life stage. In the case of the asphalt shingles, 5% will be recycled into Bitumen while the remaining 95% will be landfilled. The slate shingle will be split 50-50 with half of the material being recycled into coarse aggregate and the other being landfilled. Based on the information gathered by analyzing the roofing material selected, not only will the implementation of slate shingle significantly reduce the embodied energy of the prototype building, it will also divert more material from landfills.

[126] Tally Report generated using Revit model generated by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[127] Tally Report generated using Revit model generated by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.

The final material analysis conducted examined the embodied energy of the flooring materials. The floors in the initial prototype model accounted for 25% of the embodied energy. The embodied impacts of the flooring are more evenly distributed throughout all the constituent materials; however, hardwood flooring is the greatest source of embodied energy and will represent the focus of the final material analysis.

For the flooring analysis, hardwood flooring will be compared with bamboo flooring, cork tile, linoleum, and ceramic tile (also present in the initial prototype model). Table 19 displays the embodied energy for the five materials to be compared as well as the mass.

Table 19: Embodied Energy of Flooring Materials

Material	Embodied Energy (MJ)	Mass (kg)
Hardwood Flooring	4,649.41	187.87
Bamboo Flooring	4,065.21	128.87
Cork Tile	3,482.07	98.12
Linoleum	3,498.06	63.04
Ceramic Tiles	6,969.26	1,277.59

Source: Tally Report generated using Revit models generated by Thomas Shreve

Examining the information above, the two materials with the lowest overall embodied energy also have the highest embodied energy per kg of mass. This information shows that while a material may have a lower overall impact, the amount of energy used to produce that material can be proportionally higher. Cork tiles and linoleum flooring consume a higher amount of energy based on their mass, yet in the onsite applications these materials are less massive than the alternatives. Figure 15 shows the embodied energy for each of the examined flooring materials for a side by side comparison. The embodied energy of both the cork tiles and linoleum flooring are around the same, because of this both materials will be implemented in the prototype house.

Having examined the hot spots of the prototype house, changes to the design can be made that integrates the analyses discussed above. The data collected via the LCA shows that the materials utilized in the baseline can be substituted with alternative materials with the goal of reducing embodied energy. Table 20 outlines the materials examined, as well as the alternatives that will be incorporated into the prototype house.

Table 20: List of Substituted Materials

Original Material	Alternative
Wood Siding	Fiber Cement Siding
Asphalt Shingle	Slate Shingles
Hardwood Flooring	Cork Tile Flooring
Ceramic Tile	Linoleum Flooring

With the alternative materials replacing the original materials, a second whole building LCA will be performed using the Revit model of the prototype house. Analyzing the changes in the materials as well as the implementation of an open plane concept will further solidify the importance of integrating the LCA process into the early design stages.

Final Analysis of Prototype House:

Using the information gathered from the materials analysis, a second whole building LCA was conducted. This analysis will examine the final prototype house, incorporating the material changes above. The embodied energy of the final prototype will be examined in two ways, the first will examine the improvement between the initial prototype and the final version, and the other comparison will be between the final prototype and the baseline.

The first comparison made examined the impacts made through the changes that came because of the building materials analyses. These materials were incorporated into the design of the prototype house with the goal of reducing the embodied energy of the building. Table 21 shows the embodied energy for both the initial and final prototypes broken down by Revit category.

Table 21: Embodied Energy of Initial and Final Prototypes

Category	Initial Prototype (MJ)	Final Prototype (MJ)	% Change
Ceilings	43,283.75	43,283.75	0%
Doors	62,474.99	62,474.99	0%
Floors	166,500.58	158,156.02	-5.00%
Roofs	225,020.52	31,043.22	-86.20%
Stairs and Railings	6,370.95	6,370.95	0%
Structure	30,121.81	30,121.81	0%
Walls	335,046.37	214,262.52	-36.05%
Windows	43,889.91	43,889.91	0%
Total	884,151.61	561,045.91	-36.54%

Source: Tally reports generated using Revit models by Thomas Shreve

The table above shows that by implementing the materials selected through the LCA process all had impacts in terms of reducing the embodied energy of their associated Revit categories. The most significant changes came in the roofing category where by implementing slate shingles instead of asphalt shingles represented an 86.20% reduction in the embodied energy associated with the roof category[128]. While all the categories did not have as significant a reduction in embodied energy, they all contributed and resulted in a reduction of embodied energy by 36.54%[129]. Figure 16 shows the breakdown of the Revit categories by the Tally entry, allowing for a side by side comparison of the two design variants. Utilizing the design option functionality in Tally provides the opportunity to compare the impacts of the two variants, providing architects with a powerful tool that facilitates data-based design decisions like those made through the course of this analysis.

[128] Tally Report generated using Revit model by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[129] Tally Report generated using Revit model by Thomas Shreve. Ibid.

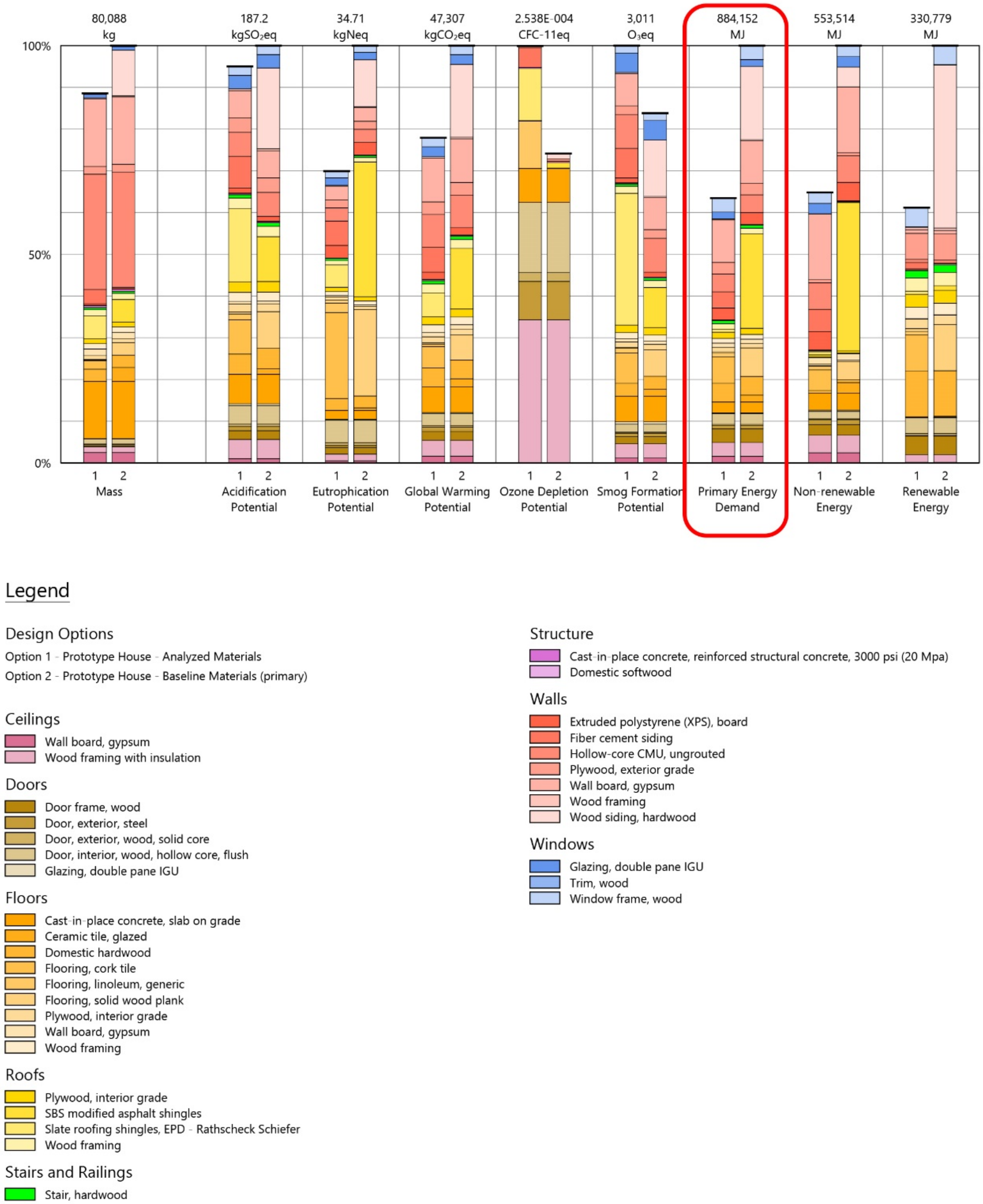

Figure 20: Shows a side by comparison of the embodied energy within the initial and final prototypes. Source: Tally reports generate using Revit models by Thomas Shreve

The final step in the examination of how BIM integrated LCA can be implemented in the design process is to compare the final prototype with the original baseline. Table 22 shows a comparison of the base and final prototype by Revit category.

Tables 22: Embodied Energy of Baseline and Final Prototype

Category	Baseline (MJ)	Final Prototype (MJ)	% Change
Ceilings	33,463.69	43,283.75	29.35%
Doors	56,643.79	62,474.99	10.30%
Floors	84,872.83	158,156.02	86.35%
Roofs	168,026.18	31,043.22	-81.53%
Stairs and Railings	6,092.07	6,370.95	4.58%
Structure	38,054.83	30,121.81	-20%
Walls	270,203.48	214,262.52	-20.70%
Windows	44,313.57	43,889.91	-.95%
Total	702,272.69	589,603.18	-16.04%

Source: Tally reports generated using Revit model by Thomas Shreve

Based on the data above, the changes implemented to reduce the embodied energy of the prototype were successful, resulting in a 16% reduction in the overall embodied energy. A key decision made was the change of roofing materials. By adopting slate shingles over asphalt shingles, the impacts associated with the roof was decreased by 136,982.96 MJ or a reduction of approximately 82%. While most of the other categories saw an increase in embodied energy, the three assemblies improved overall and made a significant impact in achieving the goal of this analysis. While some of the interventions examined were more successful than others, each strategy played a role in the reduction of embodied energy and shows the benefit of using BIM integrated LCA in the early design stages of a project.

A benefit of the LCA tool is the ability to examine a building at each individual stages of a building's lifecycle. Comparing the baseline house with the final prototype, at each stage of the life cycle reveals how the design changes made affected the overall embodied energy of the design. Based on the data gathered from Tally. Examining the baseline and final prototype, the whole building LCA shows that the largest contributor to the embodied energy of both design is the manufacturing stage. Representing 432,572.65 MJ (58%) in the baseline and 392,789.98 MJ (64%) the manufacturing stage is a key factor to consider when designing for embodied energy. Following the manufacturing stage is the maintenance and repair/replacement stage of the life cycle. This stage is the other key factor to consider, accounting for 40% of the baseline and 34% of the final prototype. The final stage that has an impact in terms of embodied energy is the transportation stage which accounted for 3% or less in both the baseline and final prototype. For both designs the end-of-life stage represented a positive value for embodied energy. Further examination show that two of the three design changes made as a result of the building material analysis aided in the reduction of the manufacturing and maintenance and repair stage. The embodied energy for both the walls and roofs Revit categories saw a reduction in embodied energy in both categories. As previously discussed, the embodied energy associated with the roof assembly saw a large reduction in embodied energy by changing the roofing material from asphalt shingles to slate shingles. Examining the impact by life cycle stage shows a 64,643.18 MJ reduction in the manufacturing stage, but the largest reduction is in the maintenance stage. Based on the data collected from the whole building LCA, the embodied energy associated with the repair and maintenance of the slate shingles is 0 MJ. This is important because it shows the impact of adopting a durable material vs. the traditional material used.

Comparing the baseline to the final prototype shows a reduction of approximately 112,000 MJ, but this figure alone does not provide a clear enough picture to gauge the reduction in embodied energy. To get a clearer picture of the significance of the embodied energy of the baseline, prototype, and final prototype, they will be compared to the energy in a barrel of oil, and to gallons of gas. According to the Energy Information Administration, a barrel of oil contains 6,031.75 MJ and a gallon of gas contains 127 MJ[130]. Using this information, a comparison can be made showing the embodied energy of a single family with gasoline, one of the most commonly used fuel sources. Table 23 shows the embodied energy of the baseline, prototype, final prototype, and the reduction of embodied energy between the baseline and final prototype compared to their equivalent in both barrels of oil and gallons of gasoline.

Table 23: Comparison of Embodied Energy

	Embodied Energy (MJ)	Barrels of Oil	Gallons of Gas
Baseline	702,272.69	116.5	5,529
Prototype	903,121.34	150	7,111
Final Prototype	589,603.18	97.75	4,642.5
Final Reduction	112,669.21	18.5	887

The information above shows how the embodied energy of a house stacks up to a regularly used fuels source such as gasoline. Based on the information above, the changes made as a result of the building material analysis resulted in a decrease of 110,000 MJ which is the energy in 887 gallons of gasoline. This not only aids in showing the magnitude of the decrease in embodied energy, but it also shows the significance of embodied energy that is attributed to a single-family home. Figures 21 and 22 shows the graphical comparison between the embodied energy of the baseline and prototypes house and the energy in gasoline.

[130] "Energy Conversion Calculators," Energy Conversion Calculators Explained, , accessed July 17, 2018, https://www.eia.gov/energyexplained/index.php?page=about_energy_conversion_calculator.

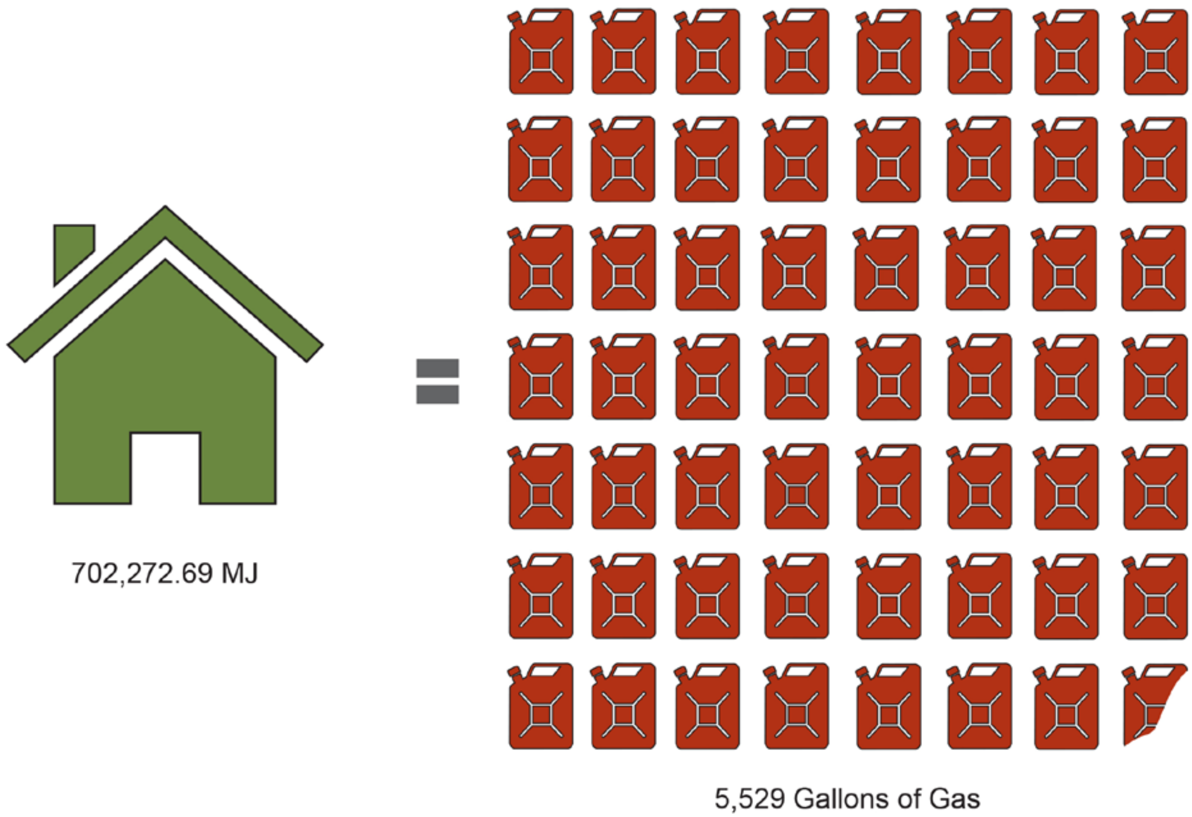

Figure 21: Shows a comparison of the embodied energy of the baseline house compared to the energy contained in a common fuel source. The baseline house's 700,000 MJ of embodied energy is equal to the energy contained within approximately 5,500 gallons of gasoline.

Each gas can above is equal to 100 gallons of gasoline. Using the data gained from the EIA, the prototype house shown above equates to 5,529 gallons of gasoline. The prototype house on the other hand is equal to 4,642.5 gallons of gas. The approximately 100,000 MJ difference between the baseline and the prototype equates to approximately 880 gallons of gasoline.

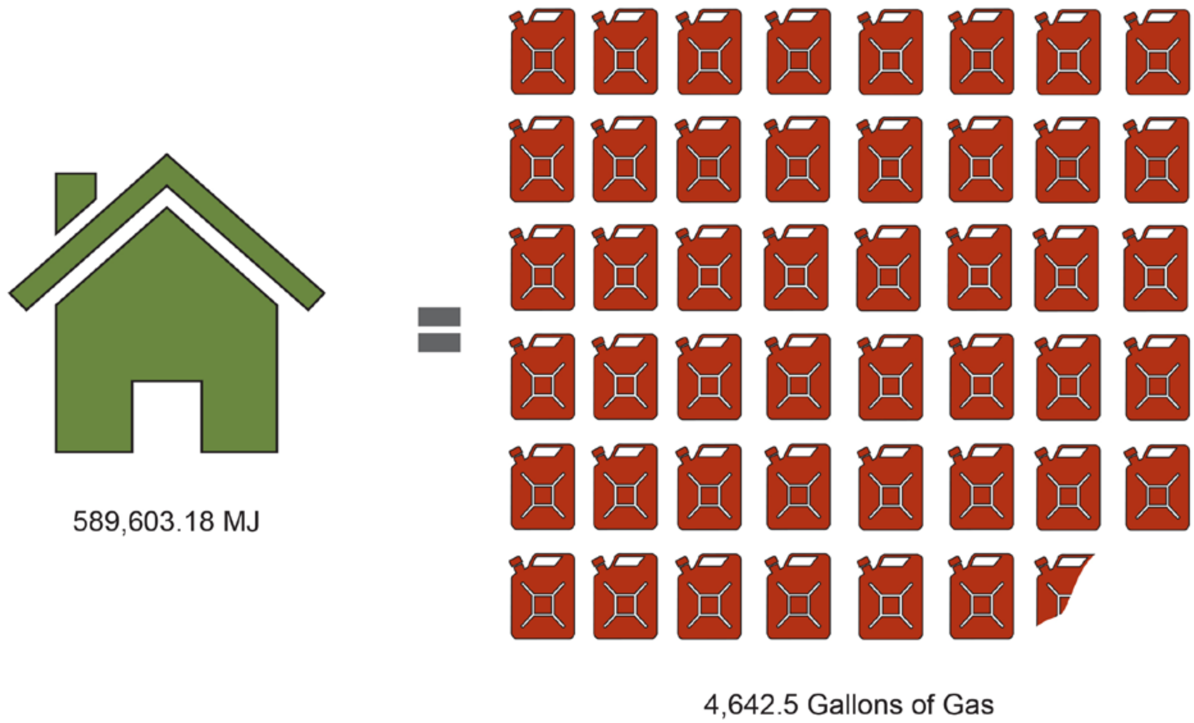

Figure 22: Shows a comparison of the embodied energy of the baseline house compared to the energy contained in a common fuel source. The baseline house's 700,000 MJ of embodied energy is equal to the energy contained within approximately 5,500 gallons of gasoline.

The design interventions implemented and the data collected via the whole building life cycle assessment show that the embodied energy of a building can and should be considered in the course of the design process. The development of BIM integrated LCA has made the process of completing an LCA more approachable in the field of architecture. As the practice of completing LCA as part of the design of a building continues to grow, the design interventions implemented will become more advanced and will provide a greater reduction in impact, while at the same time allowing architects to better understand the life-cycle of the buildings they design.

Conclusion:

The analyses conducted show that the implementation of BIM integrated LCA in the early stages of the design process can prove beneficial in guiding design decisions. The data provided by BIM integrated LCA allows architects to examine the embodied impacts of a building on a variety of scales. In this research alone, analyses were conducted on the scales of whole building analyses, as well as individual material analyses. This flexibility in the scope of the analysis provides architects and engineers the opportunity to examine all aspects of a building from a single material to structural systems and beyond to the entire building.

The goal to reduce energy consumption in the field of architecture has pushed the practice into new ideologies and technologies. Architects continually push to make buildings more efficient. Modern technologies have pushed the limit in building design to the point where net zero energy buildings and positive energy buildings are a possibility. Modeling techniques focused on the reduction of operational energy have become common place in sustainable design practices. Despite this conscious effort to reduce the energy impact of buildings, little has been done to address embodied energy.

Operational energy has remained at the forefront of the sustainability movement because of its tangibility. The ratio between operational and embodied energy has been typically dominated by operational energy. The push for increased efficiency in design has shifted the balance of the ratio, bringing embodied energy into the limelight. New standards and modern techniques have also played a role in this shift. Increasing thermal performance has required an increase in the insulation used. This in conjunction to the increase in efficiency in terms of operational energy demand has flipped the ratio. The development of net zero energy buildings and positive energy buildings has further exacerbated the issue. In buildings where the operational energy demand is zero, embodied energy represents 100% of energy consumed by the building.

To address the change in the energy ratio, architects need to be able to utilize a tool that is aimed at reducing the embodied impacts of a building. The best tool for analyzing embodied energy and other embodied environmental impacts is through life cycle assessment. Having been developed in the industrial sector, the process of LCA in the field of architecture is a relatively new concept. Current LCA practices implement the process late in the design process at a point where the information gained can have little to no effect on the design of the building. By implementing the process earlier in the early stages of the design process can maximize its benefits and provide architects with a design tool that adds depth to the design decision.

Integrating LCA into existing BIM practices will provide architects with a streamlined process that can be easily integrated with the early stages of the design process. The two largest hurdles that are presented to this idea is the lack of data, and lack of stakeholder support. Both issues can be resolved overtime, as the use of BIM integrated LCAs are proven to be successful.

By integrating within the framework of BIM, the process of conducting an LCA can become more approachable and will allow for the comparison of multiple design variants, a functionality which was difficult to complete with a traditional LCA tool. Software like Dynamo and other Visual Programming Language provides architects and architecture firms the opportunity to create a custom process that serves as a translator between the LCA and BIM Languages. Other tools like Tally can be integrated directly into the Revit software, allowing the LCA impact estimator to read the Revit geometry and generate the embodied impacts.

Tools like Tally not only provide the opportunities to examine the embodied impacts on a building scale but can also examine the impacts of individual materials on micro scale. This flexibility in scales provides the opportunity to perform multiple LCA in a short period of time. This allows architects to focus on the design of a building, using the LCA process as a design tool.

The analyses above show that the application of LCA in the framework of the design process can have positive effects. Using whole building LCA and material analysis, the embodied energy of the prototype building was reduced below that of the baseline despite an increase in building area. The analyses conducted above show the benefits that can be gained using BIM integrated LCA. Despite the impacts the design strategies discussed had on the prototype house, the use of BIM integrated LCA can go beyond the examination of embodied energy. Figure 17 shows a graph generate by Tally displaying all the impacts examined during an life cycle assessment.

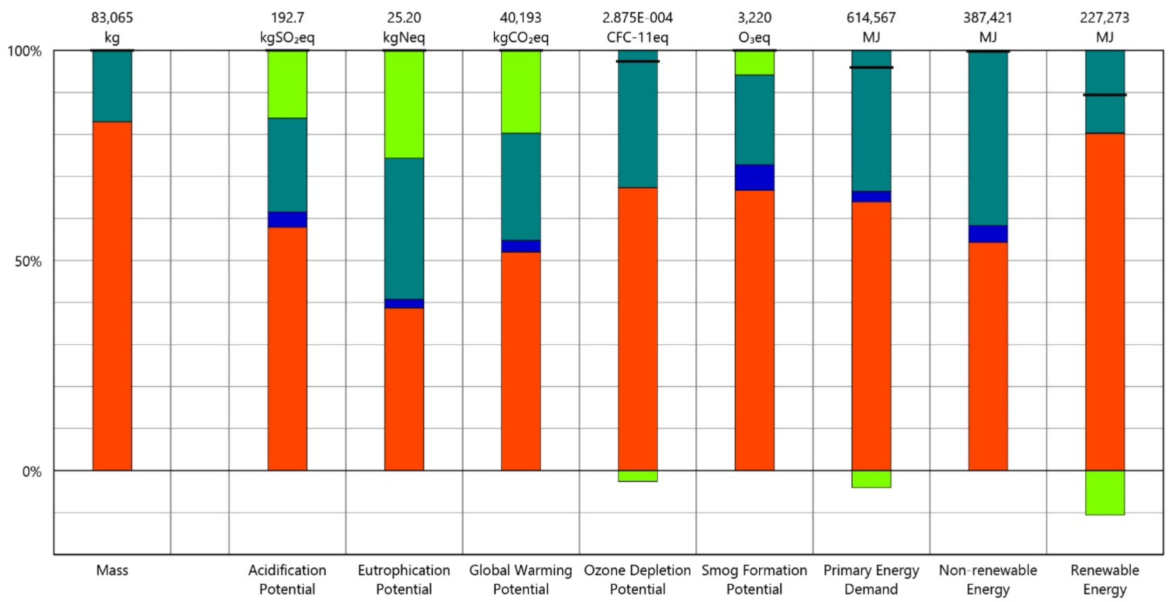

Figure 22: Shows a graph from a Tally report showing the embodied impacts examined through the course of an LCA analysis.

The opportunities that BIM integrated LCA provides to the field of architecture extend beyond the examination of embodied energy. For the purposes of this research, embodied energy was exclusively examined, however the examination of all categories can be taken into consideration. Many design decisions made using LCA come in the form of a tradeoff. While a material analyzed may present itself as having a low embodied energy, the global warming potential of the same material may be exponentially higher.

As the use of BIM integrated LCA becomes more widespread within the practice of architecture, more research into its potential applications will be conducted. The analyses conducted above only examined a small portion of the design process. Along with expanding the examination through more of the design process, further study can be conducted on the implementation of the design strategies discussed. Further examination into the design strategies that can be adopted with the goal of reducing embodied impacts will give architects and designers a clear starting point at which they can begin to make buildings more sustainable. The application of BIM integrated LCA tools can expand beyond the design process as well. The implementation of LCA into the field of architecture can be applied to a variety of projects. Both new construction and rehabilitation projects can benefit from the use of LCA analyses.

A key consideration that will need to be adopted as the use of BIM integrated LCA spreads is life cycle cost analysis. This will not only allow architects to examine the impacts of design decisions in terms of their environmental impacts, but in terms of financial impacts as well. Examining the analysis conducted on roofing materials shows why asphalt shingles are popular. The cost per square foot of material for Asphalt Shingles is approximately \$2.04 per ft^2, compared to the cost of the slate shingles at \$8.40 per square foot[131]. Table 24 shows the cost per square of each material examined.

Table 24: Cost of Analyzed Roofing Materials

Material	Cost per ft^2 (\$)	Construction Cost (\$)
Asphalt Shingles	2.04	3,480.67
Metal Roofing	6.47	11,039.18
Cedar Shingles	5.27	8991.73
Slate Shingles	8.40	14,332.164

Source: RSMeans Square Foot Costs

The total cost of the materials was calculated by multiplying the cost per square foot of material with the area of the prototype models roof (1706.21 ft^2). This equates to a range of \$2.43 - \$10.00 per square foot of livable area in the prototype house. While the cost of the material may be more expensive, other considerations need to be considered.

[131] Marilyn Phelan et al., eds., RSMeans Square Foot Costs 2013, 34th ed. (Norwell, MA: R.S. Means, 2012), 335.

Examining the project life span of the examined building materials show that while the cost of an asphalt shingle roof may be less than the cost of a slate shingle roof, the life span is significantly different. According to the metadata in the tally reports, asphalt shingles have a projected life span of 30 years vs. the 60-year projection for slate shingles[132]. This difference in life span means that the asphalt shingle roof will most likely need to be replaced at least one time during the life span of a building, whereas the slate roof is estimated to last for the entirety of the building's use phase. This dilemma between cost and embodied impacts shows the tradeoffs that can be involved in making design decisions and shows why life cycle cost analysis needs to be considered in future research.

To understand the embodied energy of buildings, David Benjamin asked 5 questions about embodied energy and its role in architecture: *Where is all this embodied energy? What are the forces involved? What is left out of the equation? How is embodied energy actionable?* and *how might architects design with it?*[133]. BIM integrated LCA allows designers to examine building on a variety of different scales, allowing for both macro and micro analyses of a building embodied impacts. This range in scales allows for the examination of the whole building, but also allows designers to identify "hot spots" in their design and understanding how the embodied energy is distributed.

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[132] Tally Report generated using Revit model by Thomas Shreve. KT Innovations, Tally, computer software, version 2017.06.15.0, Choose Tally, 2016, http://choosetally.com/.
[133] David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives*, 13.

By examining the entire lifecycle of a building, architects can see how both internal and external forces affect the embodied energy of a building. Examining a material from extraction to end-of-life can show how the manufacturing process can affect a material embodied energy. A material that is produced near a building site with an energy intensive manufacturing process, may be substituted for a material that is produced further from a building site, but requires less energy to manufacture. Designing with embodied energy allows architects to examine the impacts associated with the extraction, manufacture, transportation, and life span of a material, allowing for an examination of the forces affecting a building's embodied impacts.

The process of implementing LCA into the design process is still taking root in the architecture profession, and many questions remain. Is there an element of embodied energy that isn't being considered, and being overlooked? LCA examines many factors to determine the embodied energy of a building, even energy consumed in the construction phase. Yet this bring up the question of human energy. Should the labor involved in the construction of a building be included in the analysis? Another unknown is the effectiveness of designing for embodied energy. Is there a limit to how low the embodied energy of a building can be reduced? Will there always be embodied energy present in the building process, or will architects and designers be able to achieve a truly net zero energy building?

As the practice of examining embodied energy becomes more common place in architecture, how will it affect the design process? As technology progresses and BIM software like Revit become a universal language more design professional will become familiar with embodied energy. Implementing BIM based LCA like Tally, the examination of embodied energy becomes more approachable, and is easier to integrate into the existing framework of the design process. The integration of BIM and LCA removes many of the problems that were involved in the process of conducting LCA for buildings, allowing architects to act, further strengthening the commitment to sustainable design.

The use of BIM integrated LCA is not intended to synthesize the design process into a purely data driven process, rather it is intended as a tool in an architect's toolbox. Integrating embodied energy analysis into the design process strengthens the design decisions made, informing architects of the impacts associated with a design or material. Using the information gleaned from the LCA not only validates design decisions, it also provides architects a chance to examine the entire lifecycle of a design.

As designing for embodied energy becomes integrated into the design process, a greater understanding of embodied energy will be achieved. The implementation of LCA in the design process will change the way architects think. According to David Benjamin, as the practice of designing for embodied energy grows 4 key points will need to be considered:

1. Embodied Energy has a History: Embodied energy comes as the result of a plethora of materials and energy streams combining into the design of a building. Life cycle assessment examine where these streams came from and where they are going through the course of the life-cycle from cradle-to-grave.

2. Duration is Crucial: Designing for embodied energy and other embodied impacts carries the design process beyond the use phase of a building. The LCA process allows for architects to design a building for all stages of its life-cycle even the end-of-life stages.

3. Selection of Materials should involve more than tangible characteristics: The process of BIM integrated LCA allows for decision making that extends beyond the aesthetics of a building.

4. Embodied Energy is part of a larger equation: The embodied energy of a building does not show the entirety of a buildings impacts. Embodied energy represents only one part of the LCA and the energy consumption of a building[134].

By considering the 4 ideas above architects can change the design process, considering all the environmental impacts of a building both tangible and abstract. Through this, a new level of environmentally conscious design can take place, resulting in a new level of efficiency in architecture.

[134] David N. Benjamin, ed., *Embodied Energy and Design: Making Architecture between Metrics and Narratives,* 19-20.

Appendix A:

Tally Reports

Contents:

Baseline House

Full building summary

4/29/2018

Table of Contents

Report Summary

Created with Tally
Non-commercial Version 2017.06.15.01

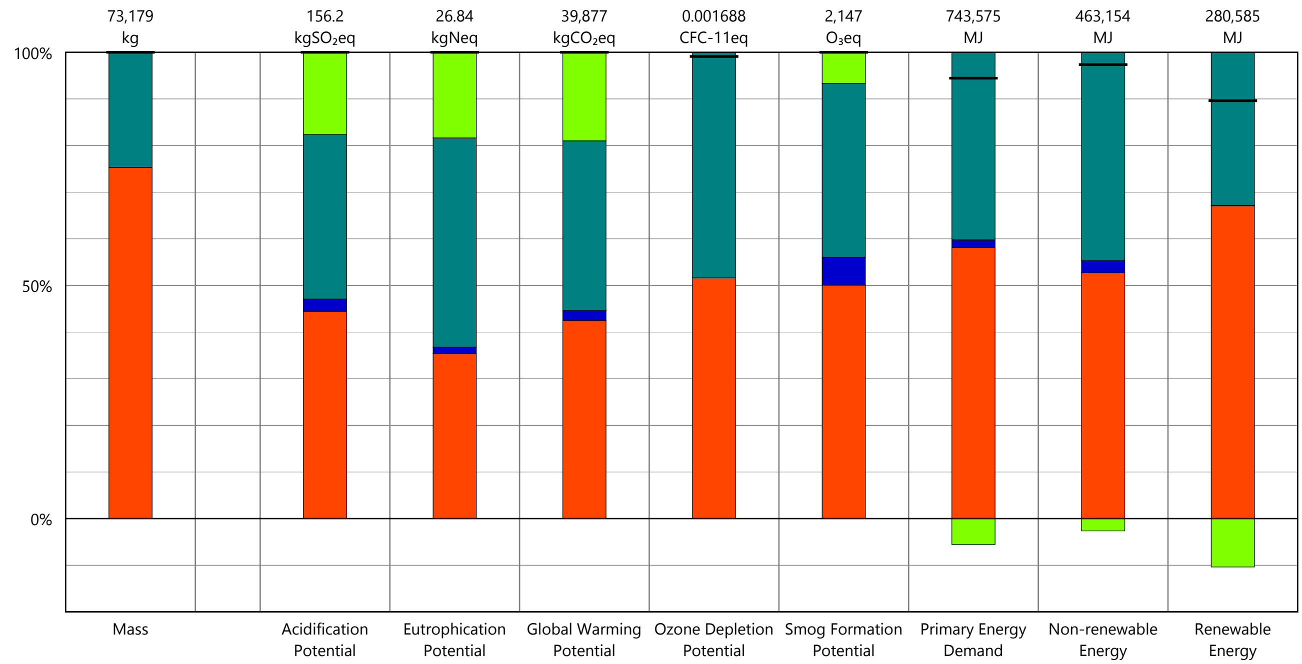
Author	Thomas Shreve
Company	RIT Architecture
Date	4/29/2018
Project	Baseline House
Location	Enter address here
Gross Area	1272 ft^2
Building Life	60
Boundaries	Cradle-to-Grave; see appendix for a full list of materials and processes
On-site Construction [A5]	Not included
Operational Energy [B6]	Not included

Goal and Scope of Assessment

To analyze the embodied energy of a baseline or typical residence in Rochester, NY.

Environmental Impact Totals	**Product Stage [A1-A3]**	**Construction Stage [A4-A5]**	**Use Stage [B2-B4, B6]**	**End of Life Stage [C2-C4, D]**
Acidification ($kgSO_2eq$)	69.49	4.077	55.12	27.55
Eutrophication (kgNeq)	9.504	0.3714	12.04	4.928
Global Warming ($kgCO_2eq$)	16,953	839.7	14,514	7,570
Ozone Depletion (CFC-11eq)	8.715E-004	7.196E-009	8.166E-004	-1.509E-005
Smog Formation (O_3eq)	1,075	128.9	799.5	143.3
Primary Energy (MJ)	432,573	12,012	298,990	-41,302
Non-renewable Energy (MJ)	244,292	11,901	206,960	-12,196
Renewable Energy (MJ)	188,306	186.2	92,093	-29,108
Environmental Impacts / Area				
Acidification ($kgSO_2eq/m^2$)	0.5881	0.0345	0.4665	0.2331
Eutrophication ($kgNeq/m^2$)	0.08042	0.003143	0.1019	0.0417
Global Warming ($kgCO_2eq/m^2$)	143.5	7.106	122.8	64.06
Ozone Depletion ($CFC\text{-}11eq/m^2$)	7.375E-006	6.089E-011	6.910E-006	-1.277E-007
Smog Formation (O_3eq/m^2)	9.096	1.091	6.766	1.213
Primary Energy (MJ/m^2)	3,661	101.6	2,530	-350
Non-renewable Energy (MJ/m^2)	2,067	100.7	1,751	-103
Renewable Energy (MJ/m^2)	1,593	1.576	779.3	-246

Results per Life Cycle Stage



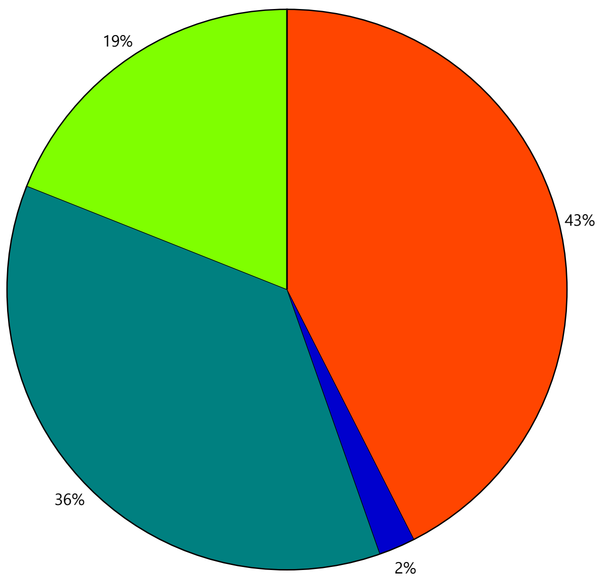
Legend

— Net value (impacts + credits)

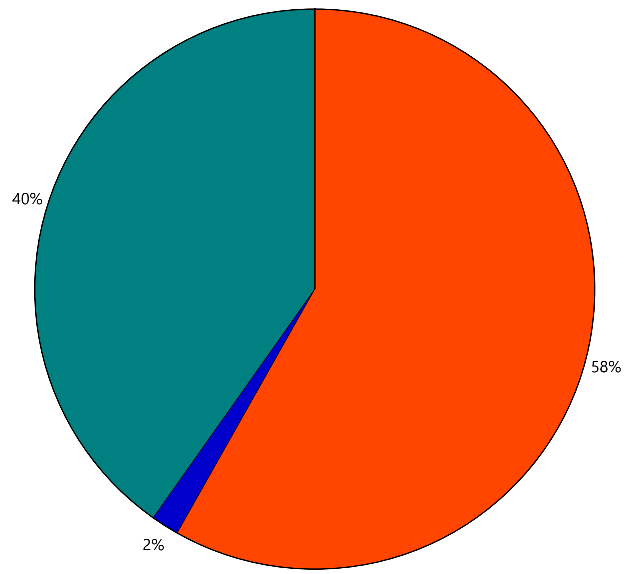
Life Cycle Stages

- Manufacturing [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B4]
- End of Life [C2-C4, D]

Results per Life Cycle Stage



Global Warming Potential



Primary Energy Demand

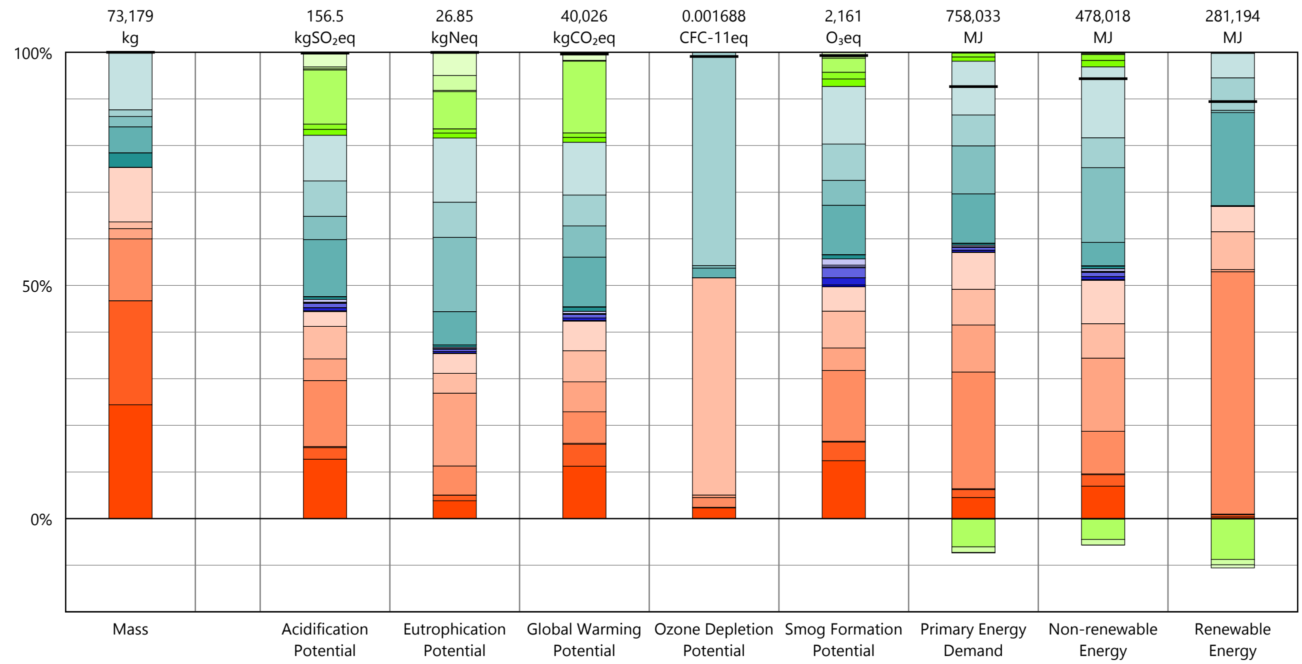
Legend

Net value (impacts + credits)

Life Cycle Stages

- Manufacturing [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B4]
- End of Life [C2-C4, D]

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Transportation [A4]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

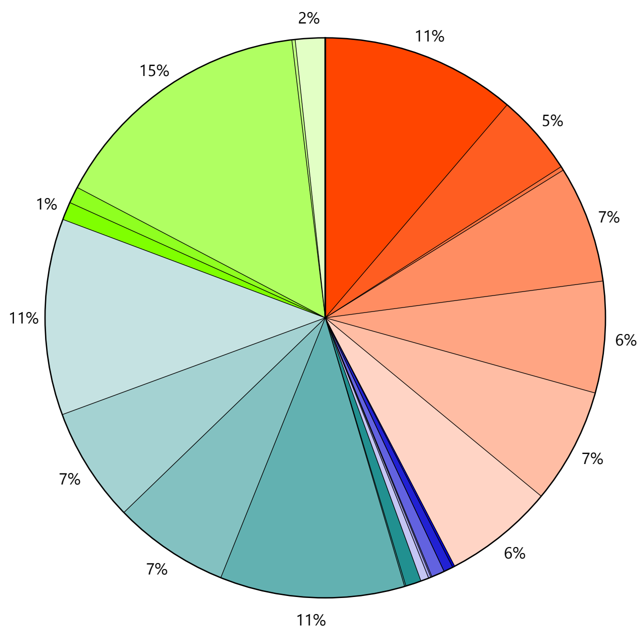
Maintenance and Replacement [B2-B4]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

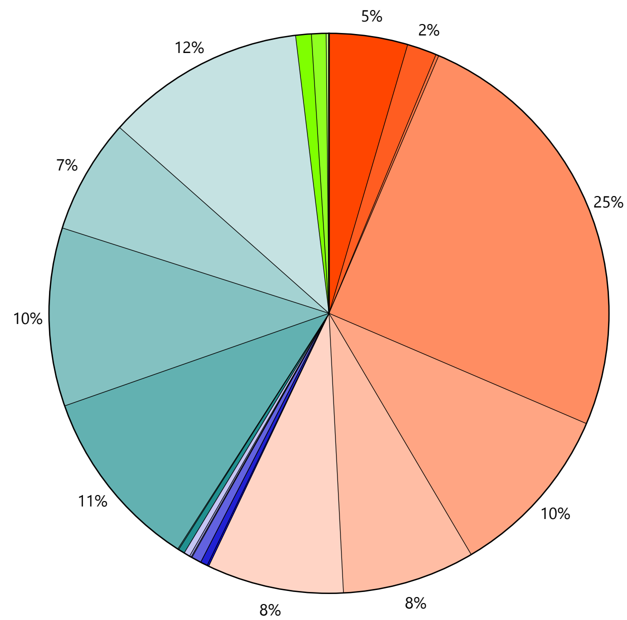
End of Life [C2-C4, D]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Life Cycle Stage, itemized by Division



Global Warming Potential



Primary Energy Demand

Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Transportation [A4]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

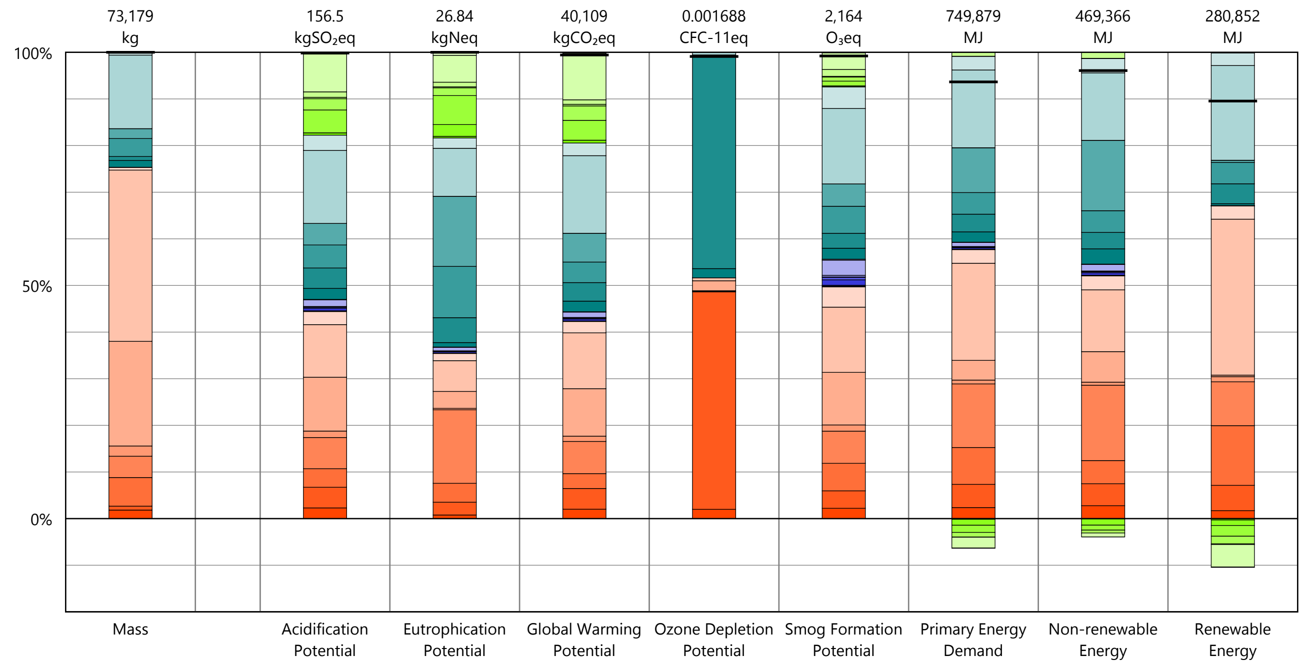
Maintenance and Replacement [B2-B4]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

End of Life [C2-C4, D]

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Life Cycle Stage, itemized by Revit Category



Legend

Net value (impacts + credits)

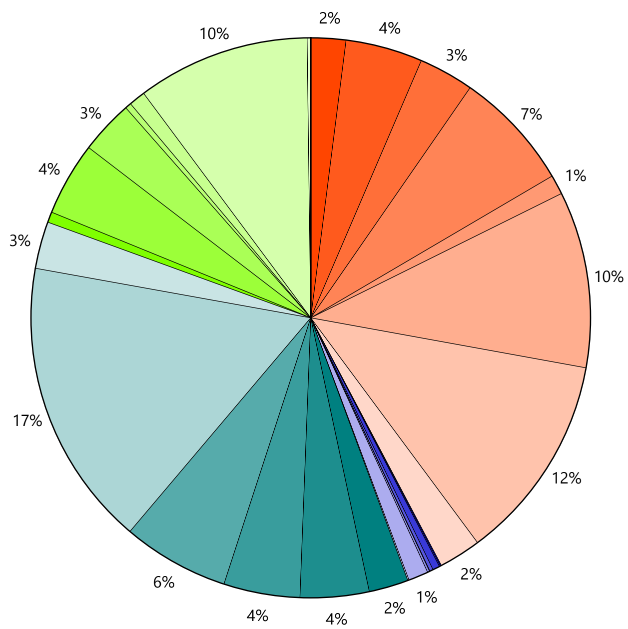
Manufacturing [A1-A3]
- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Transportation [A4]
- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

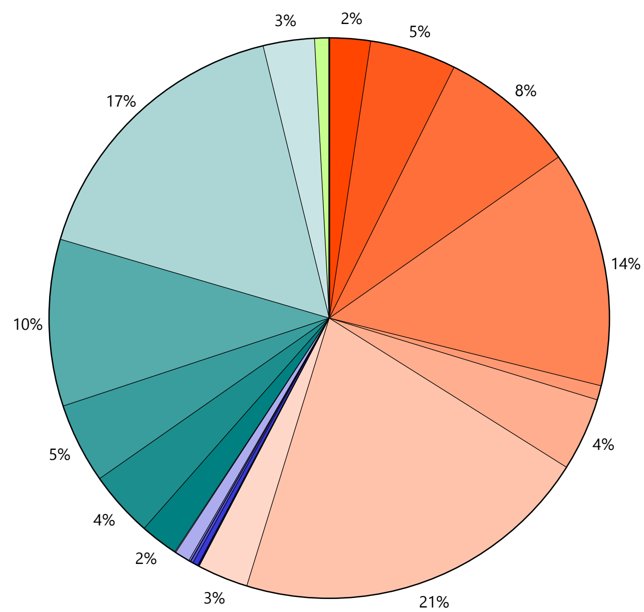
Maintenance and Replacement [B2-B4]
- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

End of Life [C2-C4, D]
- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Life Cycle Stage, itemized by Revit Category



Global Warming Potential



Primary Energy Demand

Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Transportation [A4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

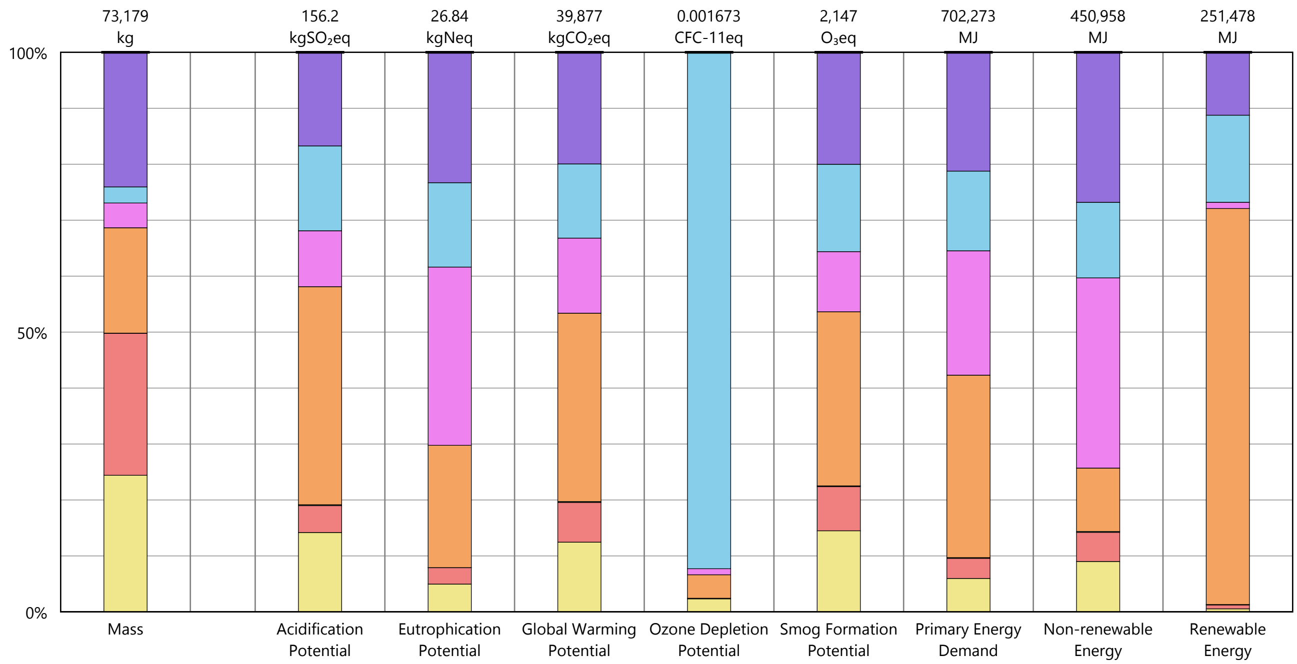
Maintenance and Replacement [B2-B4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

End of Life [C2-C4, D]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Division

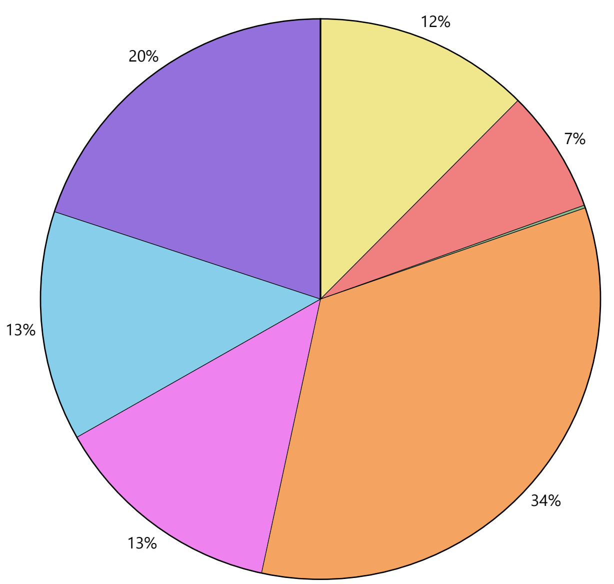


Legend

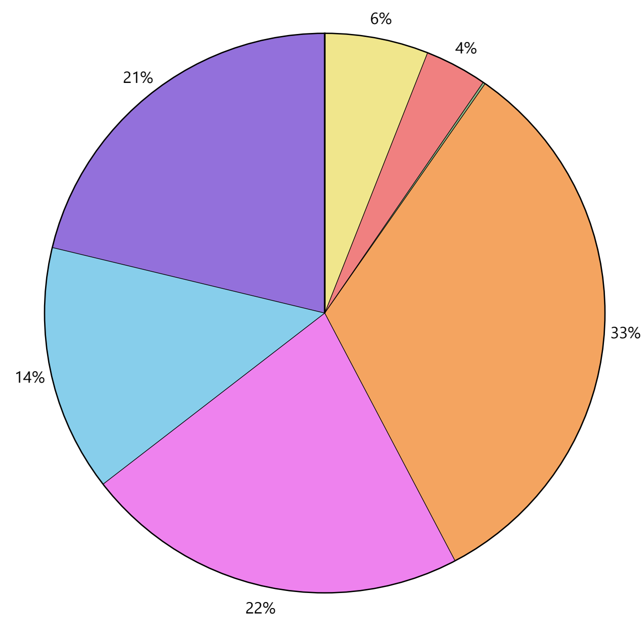
Divisions

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Division



Global Warming Potential



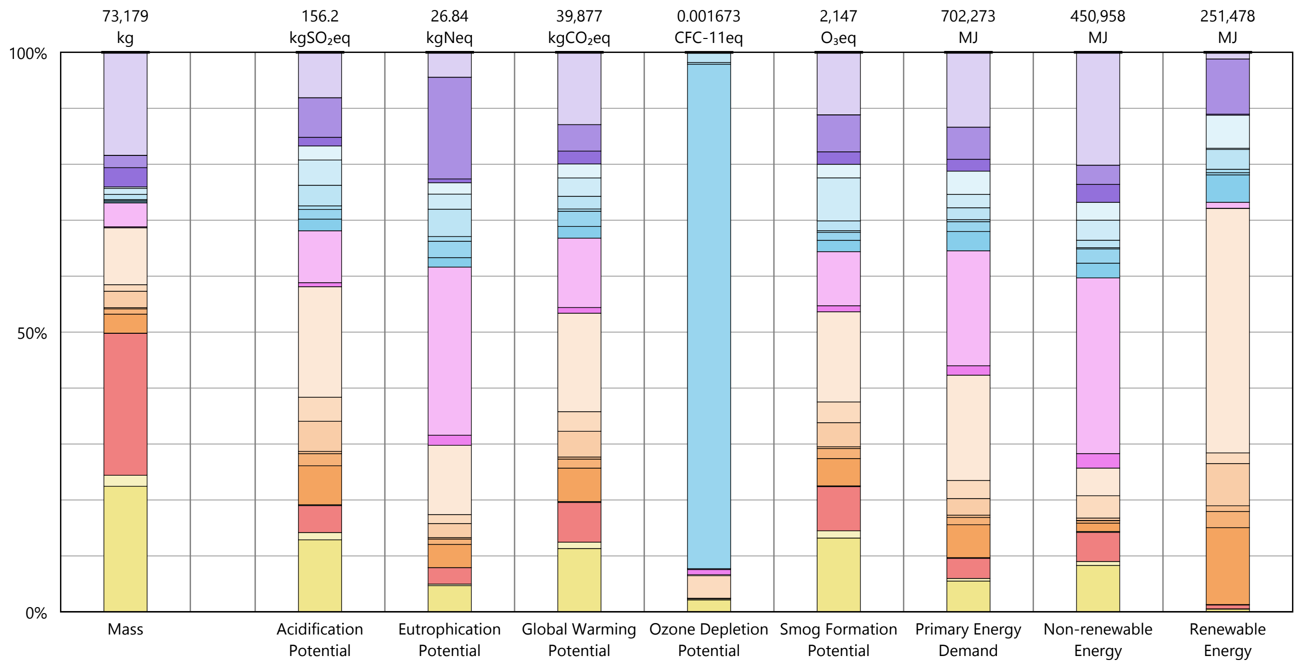
Primary Energy Demand

Legend

Divisions

- 03 - Concrete
- 04 - Masonry
- 05 - Metals
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Division, itemized by Tally Entry



Legend

03 - Concrete

- Cast-in-place concrete, slab on grade
- Stair, cast-in-place concrete

04 - Masonry

- Hollow-core CMU, ungrouted

05 - Metals

- Aluminum, hardware

06 - Wood/Plastics/Composites

- Plywood, exterior grade
- Plywood, interior grade
- Stair, hardwood
- Wood framing
- Wood framing with insulation
- Wood siding, hardwood

07 - Thermal and Moisture Protection

- Expanded polystyrene (EPS), board
- SBS modified asphalt shingles

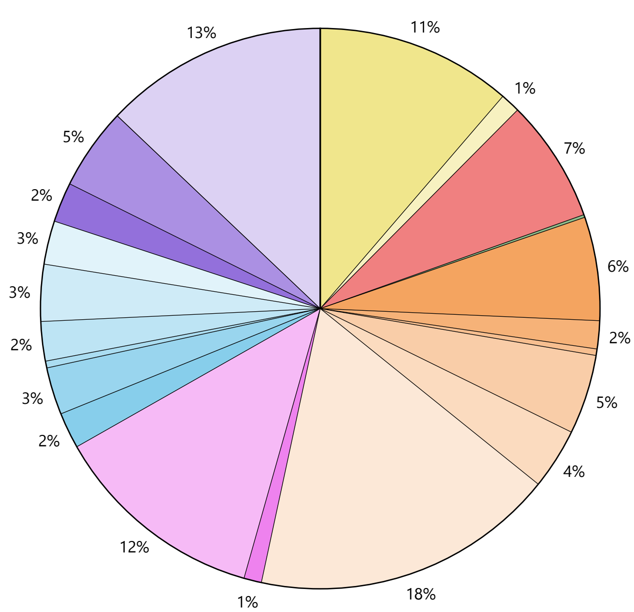
08 - Openings and Glazing

- Door frame, wood
- Door, exterior, aluminum
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU
- Window frame, wood

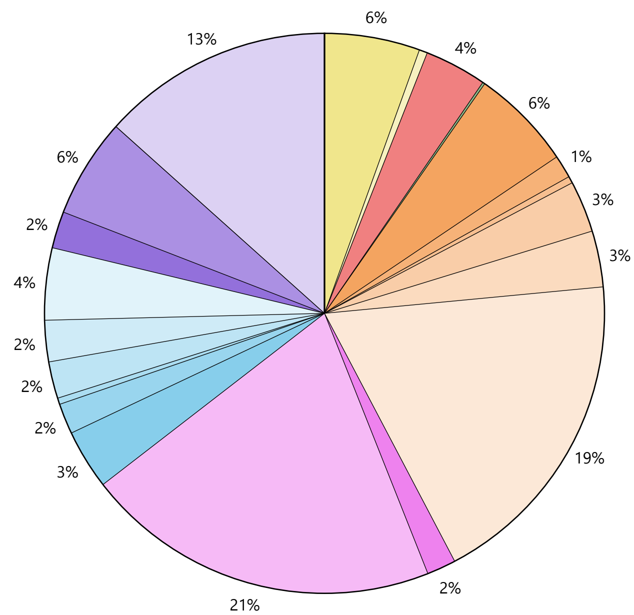
09 - Finishes

- Ceramic tile, unglazed
- Flooring, solid wood plank
- Trim, wood
- Wall board, gypsum

Results per Division, itemized by Tally Entry



Global Warming Potential



Primary Energy Demand

Legend

03 - Concrete
- Cast-in-place concrete, slab on grade
- Stair, cast-in-place concrete

04 - Masonry
- Hollow-core CMU, ungrouted

05 - Metals
- Aluminum, hardware

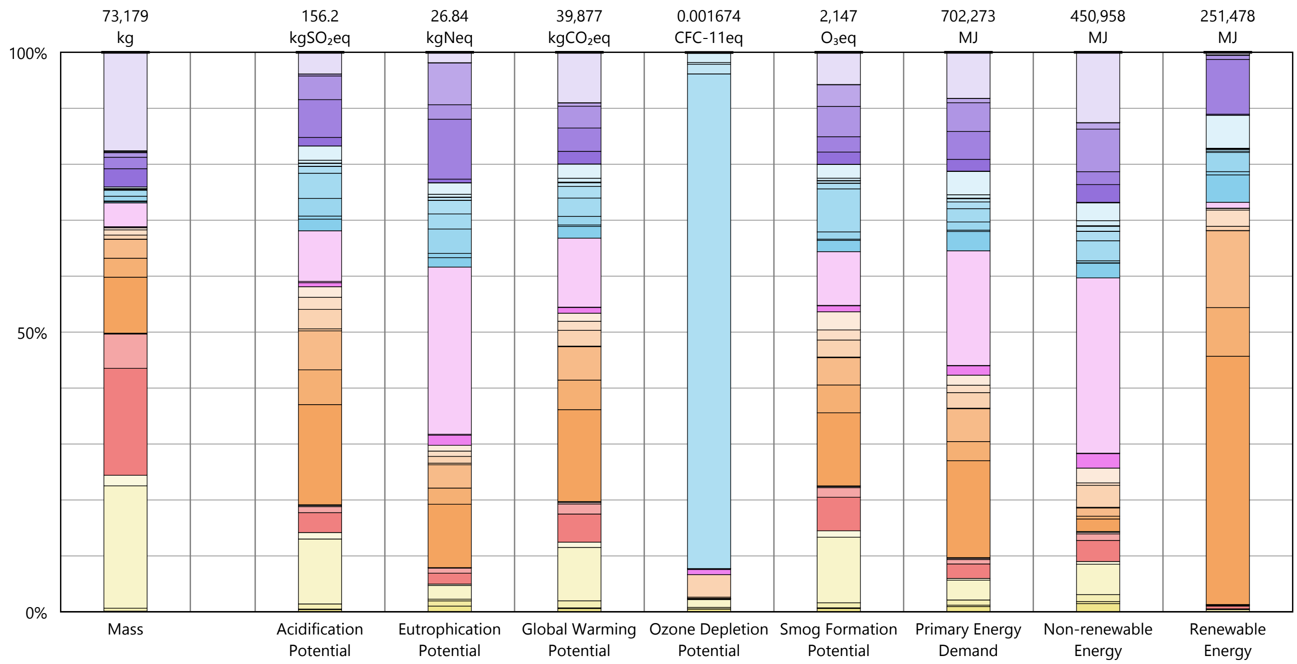
06 - Wood/Plastics/Composites
- Plywood, exterior grade
- Plywood, interior grade
- Stair, hardwood
- Wood framing
- Wood framing with insulation
- Wood siding, hardwood

07 - Thermal and Moisture Protection
- Expanded polystyrene (EPS), board
- SBS modified asphalt shingles

08 - Openings and Glazing
- Door frame, wood
- Door, exterior, aluminum
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU
- Window frame, wood

09 - Finishes
- Ceramic tile, unglazed
- Flooring, solid wood plank
- Trim, wood
- Wall board, gypsum

Results per Division, itemized by Material



Legend

03 - Concrete

- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic
- Structural concrete, 5000 psi, generic

04 - Masonry

- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Steel, reinforcing rod

05 - Metals

- Hardware, aluminum

06 - Wood/Plastics/Composites

- Domestic hardwood, US
- Domestic softwood, US
- Exterior grade plywood, US
- Fasteners, stainless steel
- Fiberglass blanket insulation, unfaced
- Interior grade plywood, US
- Paint, exterior acrylic latex

07 - Thermal and Moisture Protection

- Expanded polystyrene (EPS), board
- Fasteners, stainless steel
- Roofing shingles, SBS modified asphalt, strip

08 - Openings and Glazing

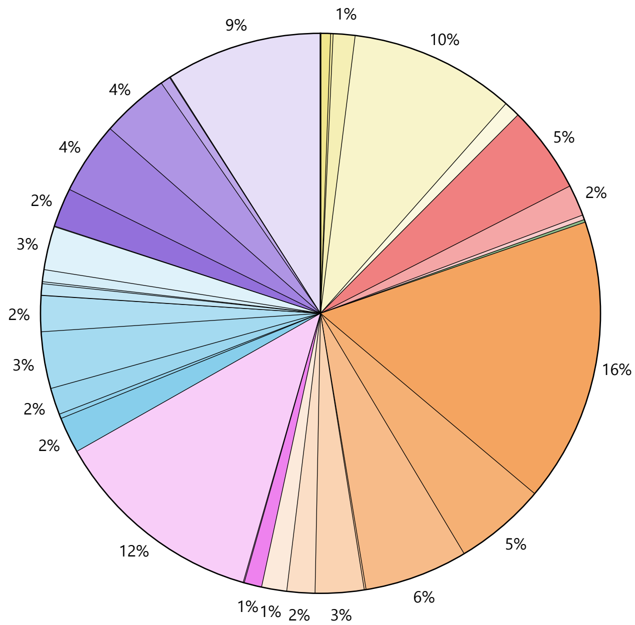
- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, aluminum, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Stainless steel, door hardware, lever lock + push bar, exterior, commercial
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Window frame, wood, divided operable
- Wood stain, water based

09 - Finishes

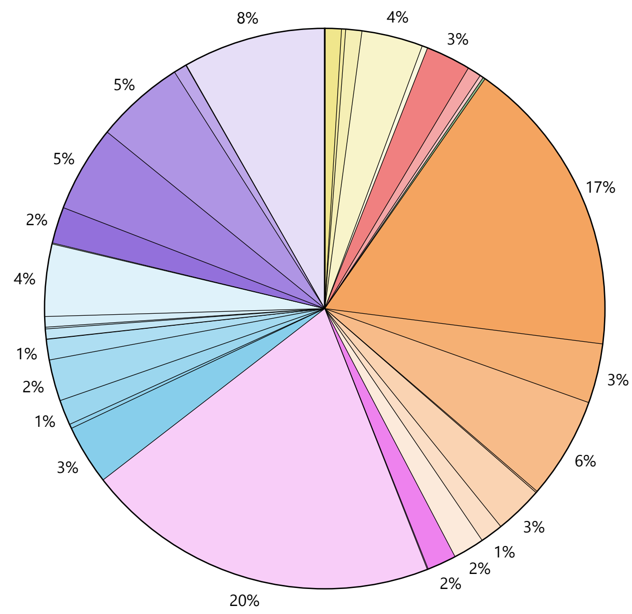
- Ceramic tile, unglazed
- Flooring, hardwood plank
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Thinset mortar
- Trim, wood
- Wall board, gypsum, natural

tally

Results per Division, itemized by Material



Global Warming Potential



Primary Energy Demand

Legend

03 - Concrete

- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic
- Structural concrete, 5000 psi, generic

04 - Masonry

- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Steel, reinforcing rod

05 - Metals

- Hardware, aluminum

06 - Wood/Plastics/Composites

- Domestic hardwood, US
- Domestic softwood, US
- Exterior grade plywood, US
- Fasteners, stainless steel
- Fiberglass blanket insulation, unfaced
- Interior grade plywood, US
- Paint, exterior acrylic latex

07 - Thermal and Moisture Protection

- Expanded polystyrene (EPS), board
- Fasteners, stainless steel
- Roofing shingles, SBS modified asphalt, strip

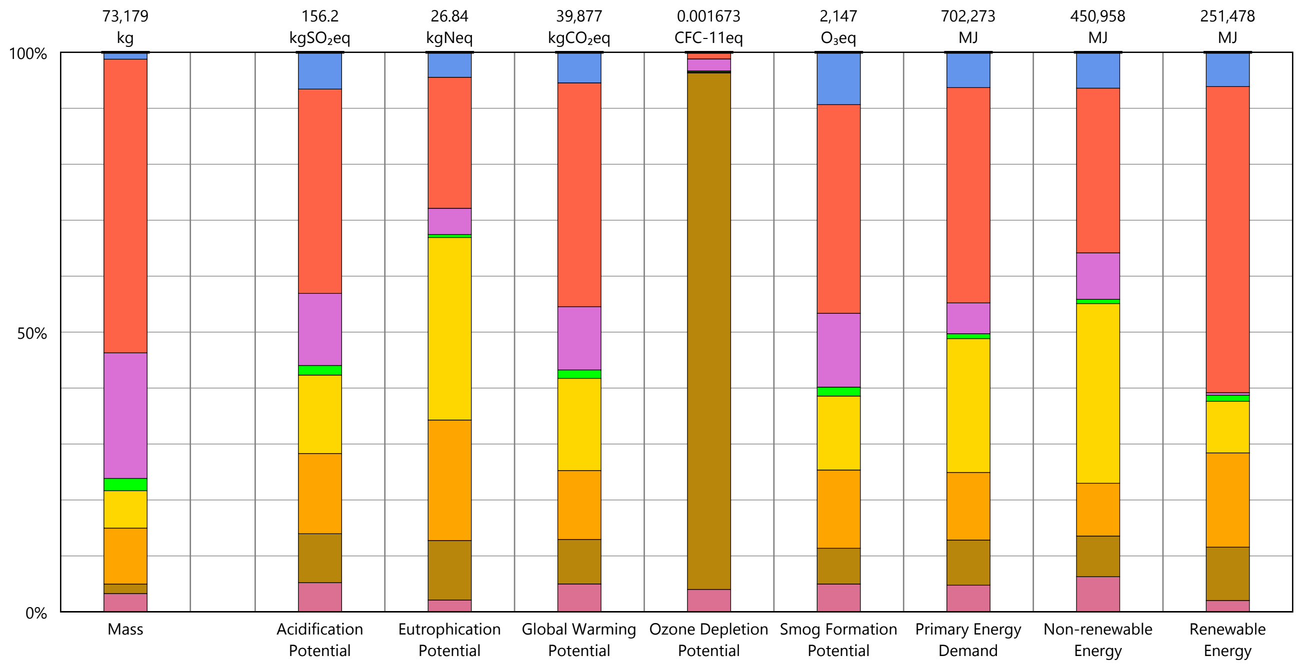
08 - Openings and Glazing

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, aluminum, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Stainless steel, door hardware, lever lock + push bar, exterior, commercial
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Window frame, wood, divided operable
- Wood stain, water based

09 - Finishes

- Ceramic tile, unglazed
- Flooring, hardwood plank
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Thinset mortar
- Trim, wood
- Wall board, gypsum, natural

Results per Revit Category

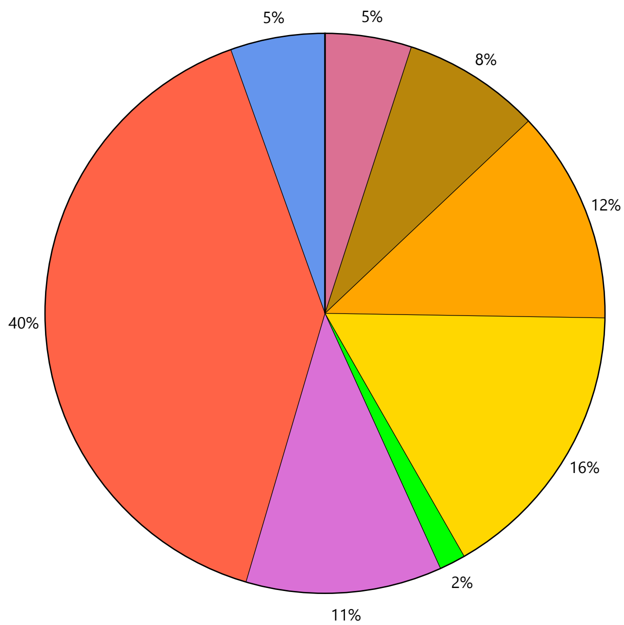


Legend

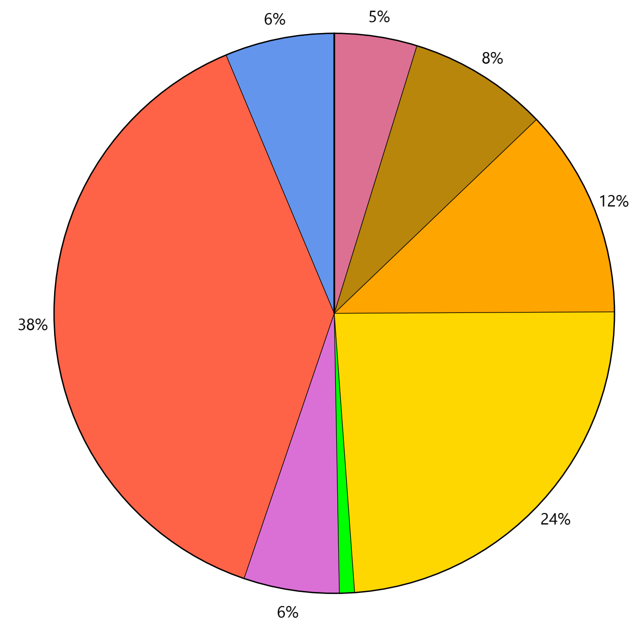
Revit Categories

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Revit Category



Global Warming Potential



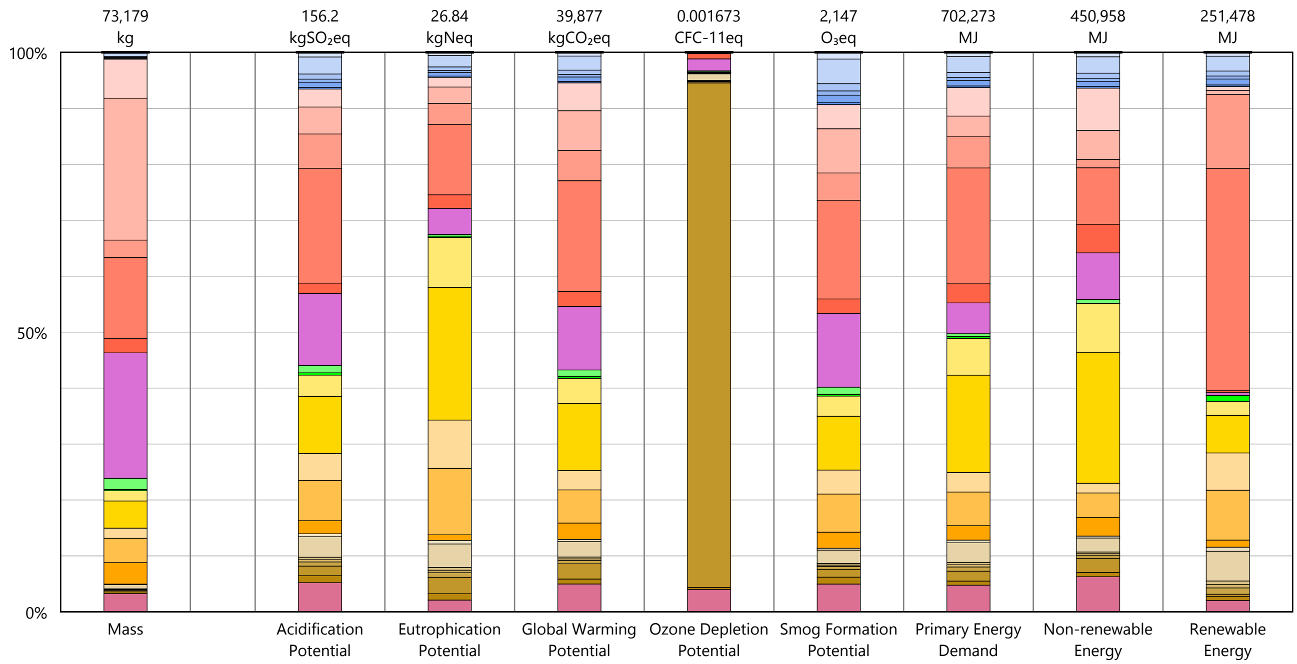
Primary Energy Demand

Legend

Revit Categories

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Revit Category, itemized by Family



Legend

Ceilings

- GWB on Mtl. Stud

Doors

- Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84"
- Door-Overhead-Sectional: 8' x 6'-6"
- Single-Flush: 22" x 80"
- Single-Flush: 24" x 80"
- Single-Flush: 28" x 30"
- Single-Flush: 30" x 80"
- Single-Flush: 36" x 80"

Floors

- Wood Joist 10" - Tile Finish - Exposed Structure 2
- Wood Joist 10" - Wood Finish
- Wood Joist 10" - Wood Finish - Exposed Structure

Roofs

- Wood Rafter 8" - Asphalt Shingle - Insulated
- Wood Rafter 8" - Asphalt Shingle - Uninsulated

Stairs and Railings

- 7" max riser 11" tread
- Monolithic Stair

Structure

- 6" Foundation Slab

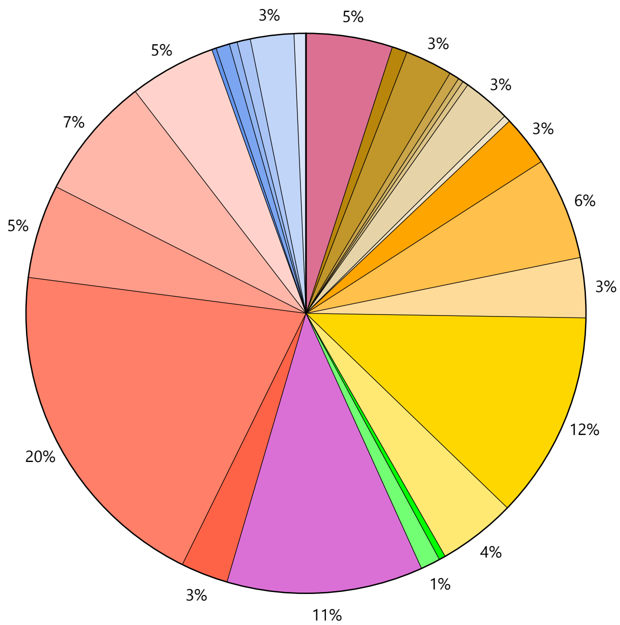
Walls

- Basement Wall Furring
- Exterior - Wood Shingle on Wood Dtud
- Exterior - Wood Shingle on Wood Stud (Garage)
- Generic - 8" Masonry
- Interior - Gyp. Board Over Wood Stud (2x4)

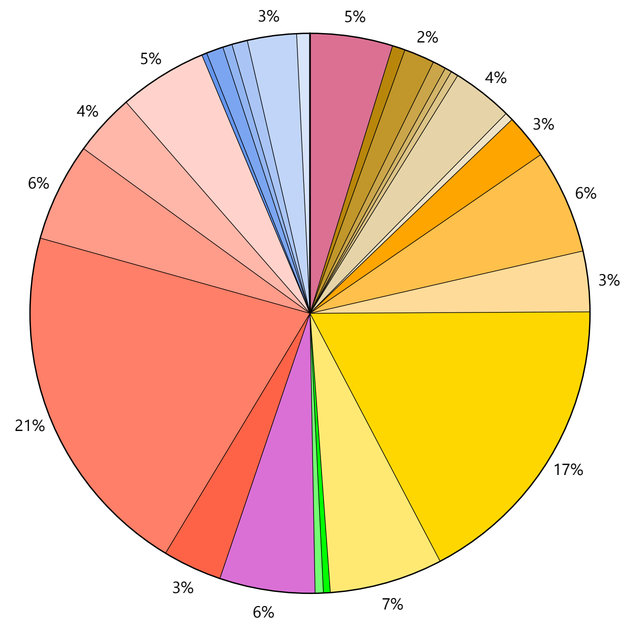
Windows

- Casement Dbl without Trim: 36" x 32"
- Double Hung: 16" x 48"
- Double Hung: 24" x 42"
- Double Hung: 24" x 48"
- Double Hung: 32" x 48"
- Fixed: 36" x 48"

Results per Revit Category, itemized by Family



Global Warming Potential



Primary Energy Demand

Legend

Ceilings
- GWB on Mtl. Stud

Doors
- Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84"
- Door-Overhead-Sectional: 8' x 6'-6"
- Single-Flush: 22" x 80"
- Single-Flush: 24" x 80"
- Single-Flush: 28" x 30"
- Single-Flush: 30" x 80"
- Single-Flush: 36" x 80"

Floors
- Wood Joist 10" - Tile Finish - Exposed Structure 2
- Wood Joist 10" - Wood Finish
- Wood Joist 10" - Wood Finish - Exposed Structure

Roofs
- Wood Rafter 8" - Asphalt Shingle - Insulated
- Wood Rafter 8" - Asphalt Shingle - Uninsulated

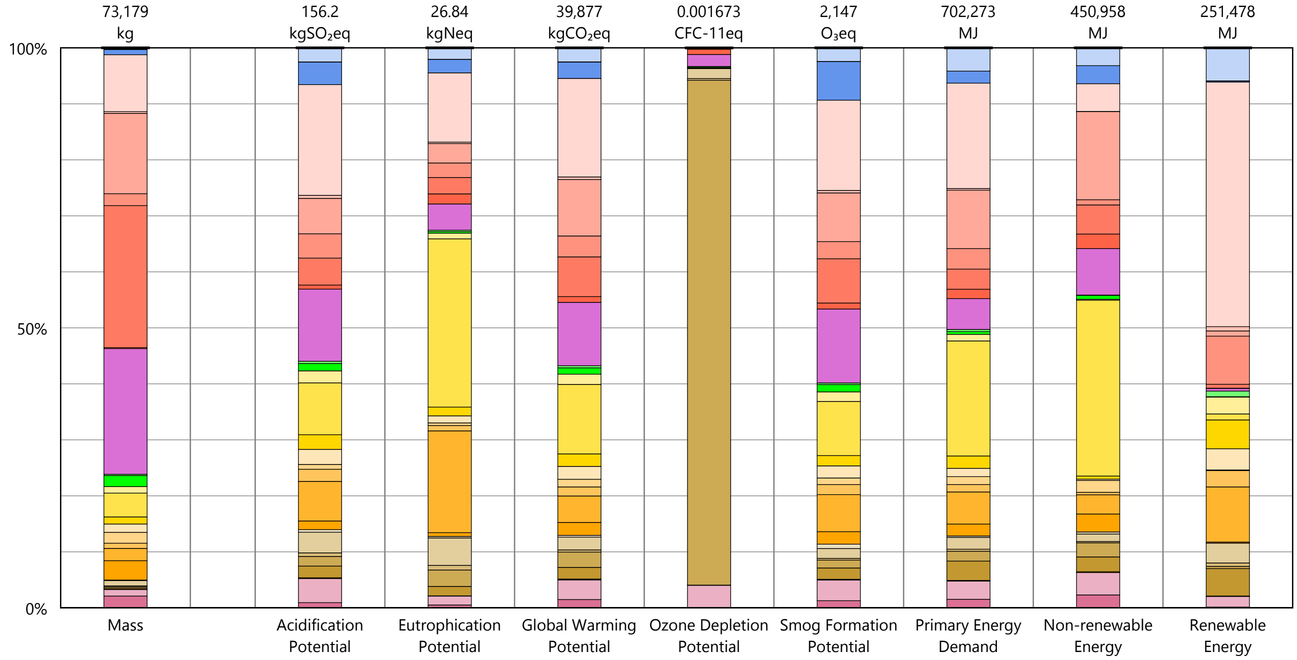
Stairs and Railings
- 7" max riser 11" tread
- Monolithic Stair

Structure
- 6" Foundation Slab

Walls
- Basement Wall Furring
- Exterior - Wood Shingle on Wood Dtud
- Exterior - Wood Shingle on Wood Stud (Garage)
- Generic - 8" Masonry
- Interior - Gyp. Board Over Wood Stud (2x4)

Windows
- Casement Dbl without Trim: 36" x 32"
- Double Hung: 16" x 48"
- Double Hung: 24" x 42"
- Double Hung: 24" x 48"
- Double Hung: 32" x 48"
- Fixed: 36" x 48"

Results per Revit Category, itemized by Tally Entry



Legend

Ceilings
- Wall board, gypsum
- Wood framing with insulation

Doors
- Aluminum, hardware
- Door frame, wood
- Door, exterior, aluminum
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU

Floors
- Ceramic tile, unglazed
- Flooring, solid wood plank
- Plywood, interior grade
- Wall board, gypsum
- Wood framing

Roofs
- Plywood, exterior grade
- SBS modified asphalt shingles
- Wood framing

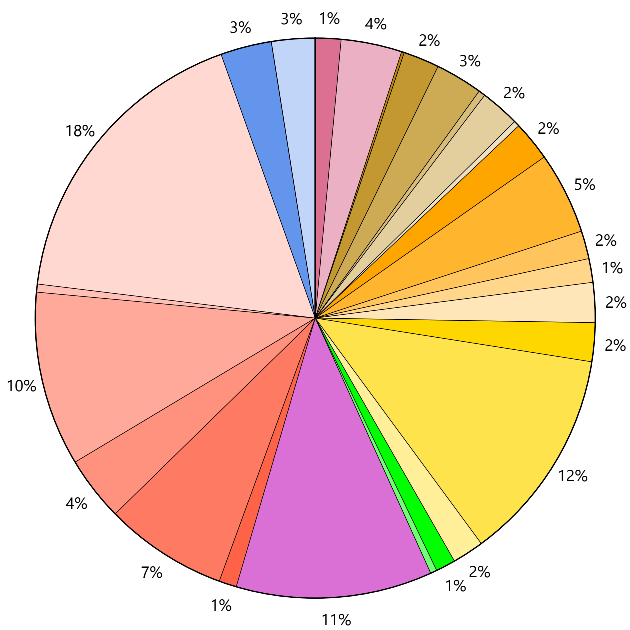
Stairs and Railings
- Stair, cast-in-place concrete
- Stair, hardwood

Structure
- Cast-in-place concrete, slab on grade

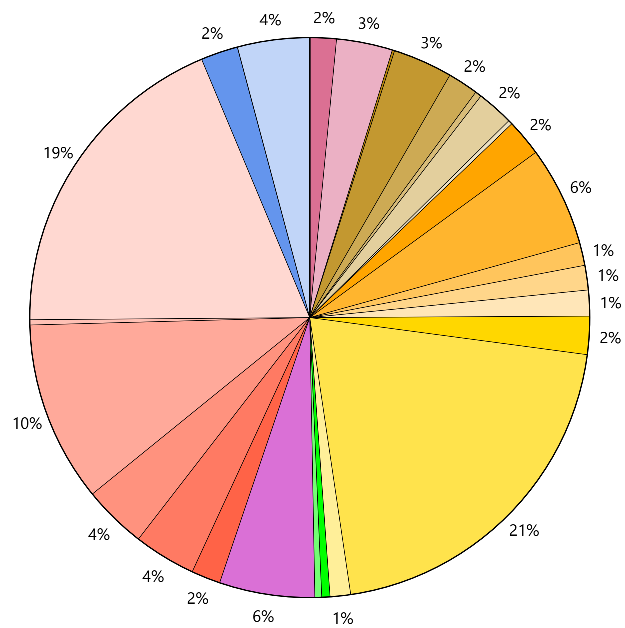
Walls
- Expanded polystyrene (EPS), board
- Hollow-core CMU, ungrouted
- Plywood, exterior grade
- Wall board, gypsum
- Wood framing
- Wood siding, hardwood

Windows
- Glazing, double pane IGU
- Trim, wood
- Window frame, wood

Results per Revit Category, itemized by Tally Entry



Global Warming Potential



Primary Energy Demand

Legend

Ceilings

- Wall board, gypsum
- Wood framing with insulation

Doors

- Aluminum, hardware
- Door frame, wood
- Door, exterior, aluminum
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU

Floors

- Ceramic tile, unglazed
- Flooring, solid wood plank
- Plywood, interior grade
- Wall board, gypsum
- Wood framing

Roofs

- Plywood, exterior grade
- SBS modified asphalt shingles
- Wood framing

Stairs and Railings

- Stair, cast-in-place concrete
- Stair, hardwood

Structure

- Cast-in-place concrete, slab on grade

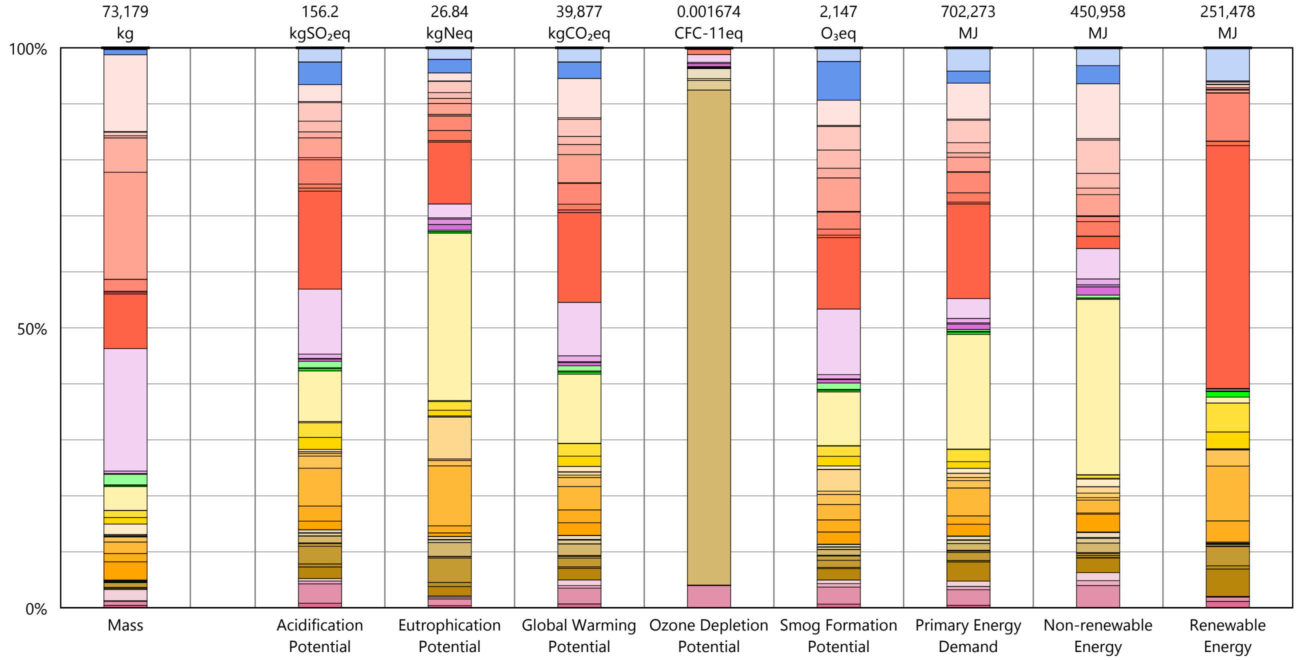
Walls

- Expanded polystyrene (EPS), board
- Hollow-core CMU, ungrouted
- Plywood, exterior grade
- Wall board, gypsum
- Wood framing
- Wood siding, hardwood

Windows

- Glazing, double pane IGU
- Trim, wood
- Window frame, wood

Results per Revit Category, itemized by Material



Legend

Ceilings

- Domestic softwood, US
- Fiberglass blanket insulation, unfaced
- Paint, interior acrylic latex
- Wall board, gypsum, natural

Doors

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hardware, aluminum
- Hollow door, exterior, aluminum, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Stainless steel, door hardware, lever lock + push bar, exterior, commercial
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Wood stain, water based

Floors

- Ceramic tile, unglazed
- Domestic softwood, US
- Flooring, hardwood plank
- Interior grade plywood, US
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Thinset mortar
- Wall board, gypsum, natural

Roofs

- Domestic softwood, US
- Exterior grade plywood, US
- Fasteners, stainless steel
- Roofing shingles, SBS modified asphalt, strip

Stairs and Railings

- Domestic hardwood, US
- Steel, reinforcing rod
- Structural concrete, 5000 psi, generic

Structure

- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic

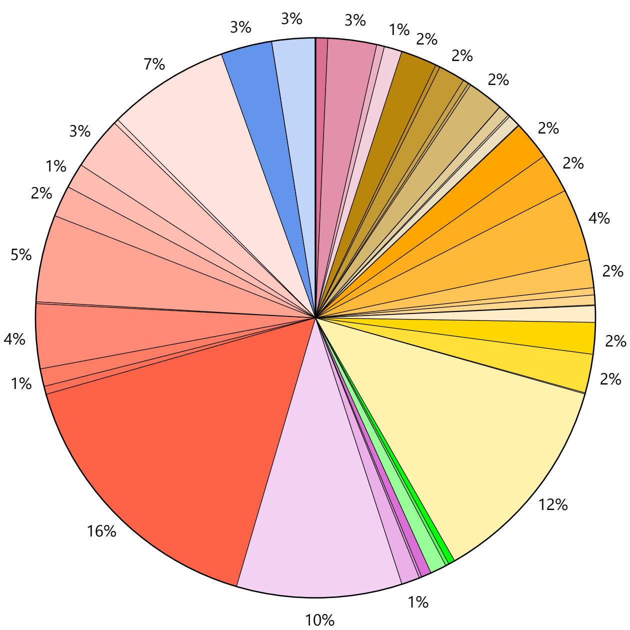
Walls

- Domestic hardwood, US
- Domestic softwood, US
- Expanded polystyrene (EPS), board
- Exterior grade plywood, US
- Fasteners, stainless steel
- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Steel, reinforcing rod
- Wall board, gypsum, natural

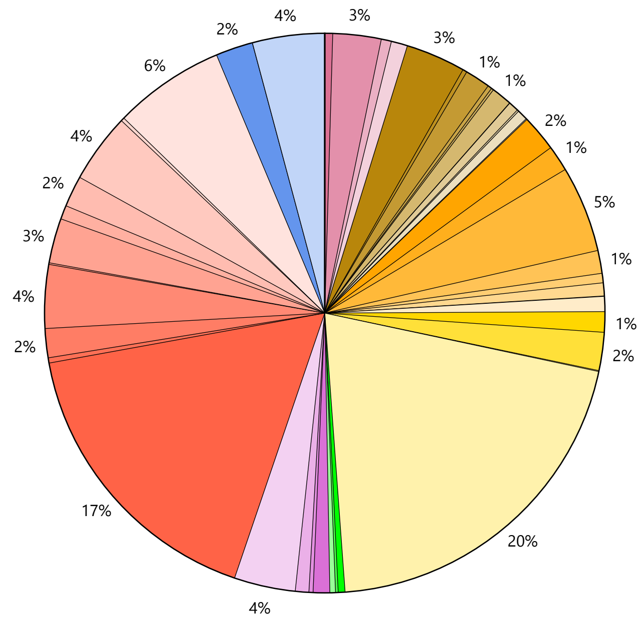
Windows

- Glazing, double, insulated (argon), low-E
- Trim, wood
- Window frame, wood, divided operable

Results per Revit Category, itemized by Material



Global Warming Potential



Primary Energy Demand

Legend

Ceilings

- Domestic softwood, US
- Fiberglass blanket insulation, unfaced
- Paint, interior acrylic latex
- Wall board, gypsum, natural

Doors

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hardware, aluminum
- Hollow door, exterior, aluminum, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Stainless steel, door hardware, lever lock + push bar, exterior, commercial
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Wood stain, water based

Floors

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- Domestic softwood, US
- Flooring, hardwood plank
- Interior grade plywood, US
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Thinset mortar
- Wall board, gypsum, natural

Roofs

- Domestic softwood, US
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- Fasteners, stainless steel
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Stairs and Railings

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- Mortar type S
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Steel, reinforcing rod
- Wall board, gypsum, natural

Windows

- Glazing, double, insulated (argon), low-E
- Trim, wood
- Window frame, wood, divided operable

Calculation Methodology

Studied objects
The life cycle assessment (LCA) results reported represent either an analysis of a single building or a comparative analysis of two or more building design options. The single building may represent the complete architectural, structural, and finish systems of a building or a subset of those systems, and it 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 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 flow
The functional unit of a single building is the usable floor space of the building under study. For a design option comparison of a partial building, the functional unit is the complete set of building systems that performs a given function. The reference flow is the amount of material required to produce a building or portion thereof, and is designed 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 flow also includes the energy, water, and fuel consumed on the building site during construction. If operational energy is included in the assessment, the reference flow includes the electrical and thermal energy consumed on site over the life of the building. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope, size, and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the practitioner.

System boundaries and delimitations
The analysis accounts for the full cradle-to-grave life cycle of the design options studied, including material manufacturing, maintenance and replacement, eventual end-of-life, and the materials and energy used across all life cycle stages. Optionally, the construction impacts and operational energy of the building can be included within the scope.

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 with the exception of known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

Manufacturing [EN 15978 A1-A3] encompases the full product stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The manufacturing 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] between the manufacturer and building site is included separately and can be modified by the practitioner. Transportation at the product's end-of-life is excluded from this study.

On-site Construction [EN 15978 A5] includes the anticipated or measured energy and water consumed on-site during the construction installation process, as entered by the tool user.

Maintenance and Replacement [EN 15978 B2-B4] encompasses the replacement of materials in accordance with the expected service life. This includes the end of life treatment of the existing products, transportation to site, and cradle-to-gate manufacturing of the replacement products. The service life is specified separately for each product.

Operational Energy [EN 15978 B6] is based on the anticipated energy consumed at the building site over the lifetime of the building. Each associated dataset includes relevant upstream impacts associated with extraction of energy resources (such as coal or crude oil), including refining, combustion, transmission, losses, and other associated factors. For further detail, see Energy Metadata in the appendix.

End of Life [EN 15978 C2-C4, D] is based on average US construction and demolition waste treatment methods and rates. This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. 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. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Specific end-of-life scenarios are detailed for each entry.

Data source and quality
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 6 using GaBi databases and in accordance with GaBi databases and modeling principles.

The data used are intended to represent the US and the year 2013. 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.

Uncertainty in results can stem from both the data used and its 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.

Tally methodology is consistent with LCA standards ISO 14040-14044 and EN 15978:2011.

Glossary of LCA Terminology

Environmental Impact Categories

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme. References: [Bare 2010, EPA 2012, Guinée 2001]

Acidification Potential (AP) kg SO_2 eq

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 N eq

Eutrophication covers potential 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, because of the additional consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP) kg CO_2 eq

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-11 eq

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.

Smog Formation Potential (SFP) kg O_3 eq

Ground level ozone is created by various chemical reactions, which occur 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. The primary sources of ozone precursors are motor vehicles, electric power utilities, and industrial facilities.

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

A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.

Building Life-Cycle Stages

The following diagram illustrates the organization of building life-cycle stages as described in EN 15978. Processes included in Tally modeling scope are shown in bold.

PRODUCT	CONSTRUCTION	USE	END OF LIFE
A1. Raw material supply	**A4. Transport**	B1. Use	C1. Demolition
A2. Transport	**A5. Construction installation process**	**B2. Maintenance**	**C2. Transport**
A3. Manufacturing		**B3. Repair**	**C3. Waste processing**
		B4. Replacement	**C4. Disposal**
		B5. Refurbishment	
			D. Reuse, recovery, and recycling potential
		B6. Operational energy	
		B7. Operational water	

LCA Metadata

NOTES

The following list provides a summary of all energy, construction, transportation, and materials inputs present in the selected study. Materials are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur and any notes and system boundaries accompanying their database entries. The mass given here refers to the full life-cycle mass of material, including manufacturing and replacement. The service life of the material used in each Revit family is indicated in parentheses. Values shown with an asterisk (*) indicate user-defined changes to default settings.

Transportation by Barge

Description:
Barge

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by barge. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Barge PE (2012), US: Diesel mix at filling station PE (2011)

Transportation by Container Ship

Description:
Container Ship

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by container ship. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Container ship PE (2013), US: Heavy fuel oil at refinery (0.3wt.% S) PE (2011)

Transportation by Rail

Description:
Rail

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by cargo rail. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Rail transport cargo - Diesel PE (2013), US: Diesel mix at filling station PE (2011)

Transportation by Truck

Description:
Truck

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by diesel truck. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
US: Truck - Trailer, basic enclosed / 45,000 lb payload - 8b PE (2013), US: Diesel mix at filling station PE (2011)

Model Elements

Revit Categories
Ceilings, Curtainwall Mullions, Curtainwall Panels, Doors, Floors, Roofs, Stairs and Railings, Structure, Walls, Windows

Thesis Baseline.rvt Worksets
N/A

Thesis Baseline.rvt Phases
Existing, New Construction

Ceramic tile, unglazed — **2,387.0 kg**

Used in the following Revit families:
Wood Joist 10" - Tile Finish - Exposed Structure 2 — 2,387.0 kg (30 yrs)

Used in the following Tally entries:
Ceramic tile, unglazed

Description:
Ceramic tile, unglazed

Life Cycle Inventory:
Ceramic tile

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 805 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Stoneware tiles, unglazed (EN15804 A1-A3) PE (2012)

Domestic hardwood, US — **7,319.5 kg**

Used in the following Revit families:
7" max riser 11" tread — 166.1 kg (60 yrs)
Exterior - Wood Shingle on Wood Dtud — 5,356.8 kg (50 yrs)
Exterior - Wood Shingle on Wood Stud (Garage) — 1,796.6 kg (50 yrs)

Used in the following Tally entries:
Stair, hardwood
Wood siding, hardwood

Description:
Dimensional lumber, sawn, planed, dried and cut for standard framing or planking

Life Cycle Inventory:
38% PNW
62% SE
Dimensional lumber
Proxied by softwood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
US: Surfaced dried lumber, at planer mill, PNW USLCI/PE (2009)
US: Surfaced dried lumber, at planer mill, SE USLCI/PE (2009)

LCA Metadata (continued)

Domestic softwood, US **2,478.5 kg**

Used in the following Revit families:

Basement Wall Furring	43.1 kg (60 yrs)
Exterior - Wood Shingle on Wood Dtud	78.2 kg (60 yrs)
Exterior - Wood Shingle on Wood Stud (Garage)	24.0 kg (60 yrs)
GWB on Mtl. Stud	328.8 kg (60 yrs)
Interior - Gyp. Board Over Wood Stud (2x4)	72.3 kg (60 yrs)
Wood Joist 10" - Tile Finish - Exposed Structure 2	175.4 kg (60 yrs)
Wood Joist 10" - Wood Finish	512.9 kg (60 yrs)
Wood Joist 10" - Wood Finish - Exposed Structure	389.4 kg (60 yrs)
Wood Rafter 8" - Asphalt Shingle - Insulated	621.0 kg (60 yrs)
Wood Rafter 8" - Asphalt Shingle - Uninsulated	233.4 kg (60 yrs)

Used in the following Tally entries:
Wood framing
Wood framing with insulation

Description:
Dimensional lumber, sawn, planed, dried and cut for standard framing or planking

Life Cycle Inventory:
17% US Pacific Northwest
30% US Southeast
11% US Inland Northwest
US Northeast/North Central 3%
39% CA
Softwood lumber

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
RNA: Softwood lumber CORRIM (2011)

Door frame, wood, no door **161.9 kg**

Used in the following Revit families:

Single-Flush: 22" x 80"	24.0 kg (40 yrs)
Single-Flush: 24" x 80"	12.2 kg (40 yrs)
Single-Flush: 28" x 30"	12.4 kg (40 yrs)
Single-Flush: 30" x 80"	100.4 kg (40 yrs)
Single-Flush: 36" x 80"	12.9 kg (40 yrs)

Used in the following Tally entries:
Door frame, wood

Description:
Wood door frame

Life Cycle Inventory:
Dimensional lumber

Manufacturing Scope:
Cradle to gate, excludes hardware, jamnb, casing, sealant

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Door, exterior, wood, solid core **106.5 kg**

Used in the following Revit families:

Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84"	106.5 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, wood, solid core

Description:
Exterior wood door

Life Cycle Inventory:
28.9 kg/m² wood

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% wood products recovered (credited as avoided burden)
22% wood products incinerated with energy recovery
63.5% wood products landfilled (wood product waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Door, interior, wood, hollow core, flush **622.1 kg**

Used in the following Revit families:

Single-Flush: 22" x 80"	73.6 kg (40 yrs)
Single-Flush: 24" x 80"	40.1 kg (40 yrs)
Single-Flush: 28" x 30"	46.8 kg (40 yrs)
Single-Flush: 30" x 80"	401.3 kg (40 yrs)
Single-Flush: 36" x 80"	60.2 kg (40 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush

Description:
Interior wood door with hollow core

Life Cycle Inventory:
16.2 kg/m²

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% wood products recovered (credited as avoided burden)
22% wood products incinerated with energy recovery
63.5% wood products landfilled (wood product waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Expanded polystyrene (EPS), board **202.4 kg**

Used in the following Revit families:

6" Foundation Slab	73.4 kg (60 yrs)
Basement Wall Furring	129.0 kg (30 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade
Expanded polystyrene (EPS), board

Description:
Insulation foam board

Life Cycle Inventory:
Expanded polystyrene board

LCA Metadata (continued)

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1299 km

End of Life Scope:
100% landfilled (plastic waste)

Entry Source:
RER: EPS - expanded polystyrene (white, 15kg/m^3 cradle-to-gate, A1-A5) EUMEPS (2011)

Exterior grade plywood, US **2,490.6 kg**

Used in the following Revit families:

Exterior - Wood Shingle on Wood Dtud	1,166.0 kg (60 yrs)
Exterior - Wood Shingle on Wood Stud (Garage)	391.1 kg (60 yrs)
Wood Rafter 8" - Asphalt Shingle - Insulated	678.5 kg (60 yrs)
Wood Rafter 8" - Asphalt Shingle - Uninsulated	255.0 kg (60 yrs)

Used in the following Tally entries:
Plywood, exterior grade

Description:
Plywood, unfinished

Life Cycle Inventory:
33% PNW
67% SE
Plywood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 468 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Fasteners, stainless steel **15.2 kg**

Used in the following Revit families:

Exterior - Wood Shingle on Wood Dtud	7.1 kg (50 yrs)
Exterior - Wood Shingle on Wood Stud (Garage)	2.4 kg (50 yrs)
Wood Rafter 8" - Asphalt Shingle - Insulated	4.1 kg (30 yrs)
Wood Rafter 8" - Asphalt Shingle - Uninsulated	1.6 kg (30 yrs)

Used in the following Tally entries:
SBS modified asphalt shingles
Wood siding, hardwood

Description:
Stainless steel part. Used for fasteners and some specialized hardware (bolts, rails, clips, etc.) that are linked to other entries by volume or weight of metal.

Life Cycle Inventory:
Stainless steel

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1001 km

End of Life Scope:
98% recovered (product has 58.1% scrap input while remainder is processed and credited as avoided burden)
2% landfilled (inert material)

Entry Source:
RER: Stainless steel Quarto plate (304) Eurofer (2008)
GLO: Steel turning PE (2011)
US: Electricity grid mix PE (2010)
RER: Stainless steel flat product (304) - value of scrap Eurofer (2008)

Fiberglass blanket insulation, unfaced **529.4 kg**

Used in the following Revit families:

GWB on Mtl. Stud	529.4 kg (30 yrs)

Used in the following Tally entries:
Wood framing with insulation

Description:
Fiberglass batt
density varies from 10-14 kg/m^3

Life Cycle Inventory:
Fiberglass

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
100% landfilled (inert waste)

Entry Source:
US: Fiberglass Batt NAIMA (2007)

Flooring, hardwood plank **1,499.4 kg**

Used in the following Revit families:

Wood Joist 10" - Wood Finish	852.3 kg (30 yrs)
Wood Joist 10" - Wood Finish - Exposed Structure	647.1 kg (30 yrs)

Used in the following Tally entries:
Flooring, solid wood plank

Description:
Hardwood plank flooring
Proxied by laminated wood panel board

Life Cycle Inventory:
Laminated wood board

Manufacturing Scope:
Cradle to gate, excludes finishes
laminate as proxy for glue and adhesives during installation

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Laminated wood panel board PE (2012)

Glazing, double, insulated (argon), low-E **781.3 kg**

Used in the following Revit families:

Casement Dbl without Trim: 36" x 32"	31.8 kg (40 yrs)
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84"	78.9 kg (40 yrs)
Double Hung: 16" x 48"	84.8 kg (40 yrs)
Double Hung: 24" x 42"	55.7 kg (40 yrs)
Double Hung: 24" x 48"	95.4 kg (40 yrs)
Double Hung: 32" x 48"	339.3 kg (40 yrs)
Fixed: 36" x 48"	95.4 kg (40 yrs)

Used in the following Tally entries:
Glazing, double pane IGU

LCA Metadata (continued)

Description:
Glazing, double, insulated (argon filled), 1/4" float glass, low-E, inclusive of argon gas fill, sealant, and spacers

Life Cycle Inventory:
21.4 kg/m² glass. Argon filled, 0.15 kg/m² low-e coating

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 940 km

End of Life Scope:
100% to landfill (inert waste)

Entry Source:
DE: Double glazing unit PE (2012)

Hardware, aluminum **31.7 kg**

Used in the following Revit families:
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84" 31.7 kg (40 yrs)

Used in the following Tally entries:
Aluminum, hardware

Description:
Finished milled aluminum applicable for door, window or other accessory hardware

Life Cycle Inventory:
Aluminum, process energy
50% secondary aluminum

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1001 km

End of Life Scope:
95% recovered (50% scrap input to product with remaining processed and credited as avoided burden)
5% landfilled (inert material)

Entry Source:
NA: Casting (aluminium) AA (2011)
DE: Aluminium cast machining PE (2012)
NA: Primary Aluminium Ingot AA (2011)
US: Electricity grid mix PE (2010)
EU-27: Aluminium clean scrap remelting & casting (2010) EAA (2011)
EU-27: Aluminium recycling (2010) EAA (2011)

Hollow door, exterior, aluminum, powder-coated, with small vision p... **128.2 kg**

Used in the following Revit families:
Door-Overhead-Sectional: 8' x 6'-6" 128.2 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, aluminum

Description:
Hollow, powder-coated aluminum exterior door inclusive of small vision panel, polyurethane foam insulation, no frame

Life Cycle Inventory:
Alum: 7.21 kg/m²
PU foam: 2.51 kg/m²
steel: 0.46 kg/m²
glass: 3.09 kg/m²

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 568 km

End of Life Scope:
70% steel recovered (product has 10.3% scrap input while remainder is processed and credited as avoided burden)
30% steel landfilled (inert material)
95% aluminum recovered (includes processing and avoided burden credit)
5% aluminum is landfilled (inert material)
100% insulation landfilled (plastic material)
100% glass landfilled (inert material)

Entry Source:
DE: Top coat powder (aluminium) (EN15804 A1-A3) PE (2012)
DE: Polyurethane foam (PUR) PE (2012)
NA: Primary Aluminium Ingot AA (2012)
EU-27: Aluminium sheet PE (2012)
GLO: Steel sheet stamping and bending (5% loss) PE (2012)
US: Electricity grid mix PE (2010)
US: Lubricants at refinery PE (2010)
GLO: Compressed air 7 bar (medium power consumption) PE (2010)
NA: Steel hot dip galvanized worldsteel (2007)
EU-27: Aluminium clean scrap remelting & casting (2010) EAA (2011)
DE: Window glass simple (E

Hollow-core CMU, 8x8x16 ungrouted **13,982.6 kg**

Used in the following Revit families:
Generic - 8" Masonry 13,982.6 kg (60 yrs)

Used in the following Tally entries:
Hollow-core CMU, ungrouted

Description:
Hollow-Core CMU, 8x8x16 without grout
mortar to be linked

Life Cycle Inventory:
105 pcf material density

Manufacturing Scope:
Cradle to gate
excludes mortar
anchors, ties, and metal accessories outside of scope (<1% mass)

Transportation Distance:
By truck: 172 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Concrete bricks (EN15804 A1-A3) PE (2012)

Interior grade plywood, US **675.6 kg**

Used in the following Revit families:
Wood Joist 10" - Tile Finish - Exposed Structure 2 110.0 kg (60 yrs)
Wood Joist 10" - Wood Finish 321.5 kg (60 yrs)
Wood Joist 10" - Wood Finish - Exposed Structure 244.1 kg (60 yrs)

Used in the following Tally entries:
Plywood, interior grade

Description:
Plywood, unfinished

Life Cycle Inventory:
22% US Pacific Northwest
66% US Southeast
12% CA
Softwood plywood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 468 km

LCA Metadata (continued)

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
RNA: Softwood plywood CORRIM (2011)

Mortar type S **4,490.1 kg**

Used in the following Revit families:
Generic - 8" Masonry 4,490.1 kg (50 yrs)

Used in the following Tally entries:
Hollow-core CMU, ungrouted

Description:
Mortar Type S (medium strength mortar for use with masonry walls and flooring)

Life Cycle Inventory:
72% aggregate
16% cement
12% water

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Siliceous sand (grain size 0/2) PE (2012)
DE: Cement (CEM I 32.5) (EN15804 A1-A3) PE (2012)
DE: Gravel (Grain size 2/32) (EN15804 A1-A3) PE (2012)
US: Tap water from groundwater PE (2012)

Paint, exterior acrylic latex **281.4 kg**

Used in the following Revit families:
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84" 2.7 kg (10 yrs)
Exterior - Wood Shingle on Wood Dtud 208.7 kg (10 yrs)
Exterior - Wood Shingle on Wood Stud (Garage) 70.0 kg (10 yrs)

Used in the following Tally entries:
Door, exterior, wood, solid core
Wood siding, hardwood

Description:
Application paint emulsion (building, exterior, white). Associated reference table includes primer.

Life Cycle Inventory:
4.5% organic solvents

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
100% to landfill (plastic waste)

Entry Source:
DE: Application paint emulsion (building, exterior, white) PE (2012)

Paint, interior acrylic latex **594.0 kg**

Used in the following Revit families:
Basement Wall Furring 74.4 kg (10 yrs)
Exterior - Wood Shingle on Wood Dtud 167.0 kg (10 yrs)
GWB on Mtl. Stud 67.8 kg (10 yrs)
Interior - Gyp. Board Over Wood Stud (2x4) 221.9 kg (10 yrs)
Wood Joist 10" - Wood Finish 62.9 kg (10 yrs)

Used in the following Tally entries:
Wall board, gypsum

Description:
Application paint emulsion (building, interior, white, wear resistant)

Life Cycle Inventory:
2% organic solvents

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
100% to landfill (plastic waste)

Entry Source:
DE: Application paint emulsion (building, interior, white, wear resistant) PE (2012)

Polyethelene sheet vapor barrier (HDPE) **20.4 kg**

Used in the following Revit families:
6" Foundation Slab 20.4 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade

Description:
Polyethelene sheet vapor barrier (HDPE) membrane (entry exclusive of adhesive or other co-products)

Life Cycle Inventory:
Polyethylene film

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1299 km

End of Life Scope:
10.5% recycled into HDPE (includes processing and avoided burden credit)
89.5% landiflled (plastic waste)

Entry Source:
US: Polyethylene High Density Granulate (PE-HD) PE (2012)
GLO: Plastic Film (PE, PP, PVC) PE (2012)
US: Electricity grid mix PE (2010)
US: Thermal energy from natural gas PE (2010)
US: Lubricants at refinery PE (2010)

Polyurethane floor finish, water-based **110.7 kg**

Used in the following Revit families:
Wood Joist 10" - Wood Finish 62.9 kg (20 yrs)
Wood Joist 10" - Wood Finish - Exposed Structure 47.8 kg (20 yrs)

Used in the following Tally entries:
Flooring, solid wood plank

Description:
Water-based polyurethane wood stain, inclusive of catalyst

Life Cycle Inventory:
97.7% stain (50% water, 35% polyurethane dispersions, 5% dipropylene glycol dimethyl ether, 5% tri-butoxyethyl phosphate, 5% dipropylene glycol methyl ether), 2.3% catalyst (75% polyfunctional aziridine, 25% 2-propoxyethanol)

LCA Metadata (continued)

24.5% NMVOC emissions during application

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
26.7% solids to landfill (plastic waste)

Entry Source:
DE: Ethylene glycol butyl ether PE (2012)
US: Epichlorohydrin (by product calcium chloride, hydrochloric acid) PE (2012)
DE: Propylenglycolmonomethylether (Methoxypropanol) PGME PE (2012)
US: Tap water from groundwater PE (2012)
DE: Polyurethane (copolymer-component) (estimation from TPU adhesive) PE (2012)
US: Electricity grid mix PE (2010)

Roofing shingles, SBS modified asphalt, strip **3,103.3 kg**

Used in the following Revit families:
Wood Rafter 8" - Asphalt Shingle - Insulated 2,255.6 kg (30 yrs)
Wood Rafter 8" - Asphalt Shingle - Uninsulated 847.7 kg (30 yrs)

Used in the following Tally entries:
SBS modified asphalt shingles

Description:
SBS-modified asphalt shingles

Life Cycle Inventory:
Glass fibers: 5%
Asphalt: 45%
SBS polymer: 10%
white chips (plastic): 15%
filler (limestone): 25%

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
5% recycled into bitumen (includes grinding energy and avoided burden credit)
95% landfilled (inert waste)

Entry Source:
DE: Bitumen sheets G 200 S4 (EN15804 A1-A3) PE (2012)
DE: Glass fibre fleece (21% UF resin) (estimation) PE (2012)
US: Styrene-butadiene rubber (SBR) PE (2012)
US: Limestone (CaCO3
washed) PE (2012)
US: Polyethylene High Density Granulate (HDPE/PE-HD) PE (2012)
GLO: Plastic Film (PE, PP, PVC) PE (2012)
US: Electricity grid mix PE (2010)
US: Thermal energy from natural gas PE (2010)
US: Lubricants at refinery PE (2010)

Stainless steel, door hardware, lever lock + push bar, exterior, co... **41.3 kg**

Used in the following Revit families:
Door-Overhead-Sectional: 8' x 6'-6" 41.3 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, aluminum

Description:
Stainless steel door fitting (hinges and lockset) for use on commercial exterior door assemblies with a push bar and lever lockset.

Life Cycle Inventory:
Door hinges 0.622 kg/part, 3.08 kg Yale Mortise Lockset, 5.44kg Yale Rim Pullman Bolt Push Bar

Manufacturing Scope:
Cradle to gate, including disposal of packaging.

Transportation Distance:
By truck: 1001 km

End of Life Scope:
90% collection rate
remaining 10% deposited in the LCA model without recycling
material recycling efficiency dependant on the metal (89% steel, 90.2% aluminum, stainless steel 83%, zinc 91%, brass 94%)
Plastic components incinerated resulting in credits for electricity and thermal energy

Entry Source:
DE: Fitting stainless steel - FSB (2009)

Stainless steel, door hardware, lever lock, exterior, residential **7.1 kg**

Used in the following Revit families:
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84" 7.1 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, wood, solid core

Description:
Stainless steel door fitting (hinges and lockset) for use on residential exterior door assemblies.

Life Cycle Inventory:
Door hinges 0.622 kg/part, Light duty mortise lockset 2.32kg/part

Manufacturing Scope:
Cradle to gate, including disposal of packaging.

Transportation Distance:
By truck: 1001 km

End of Life Scope:
90% collection rate
remaining 10% deposited in the LCA model without recycling
material recycling efficiency dependant on the metal (89% steel, 90.2% aluminum, stainless steel 83%, zinc 91%, brass 94%)
Plastic components incinerated resulting in credits for electricity and thermal energy

Entry Source:
DE: Fitting stainless steel - FSB (2009)

Stainless steel, door hardware, lever lock, interior, residential **43.4 kg**

Used in the following Revit families:
Single-Flush: 22" x 80" 5.1 kg (40 yrs)
Single-Flush: 24" x 80" 2.8 kg (40 yrs)
Single-Flush: 28" x 30" 3.3 kg (40 yrs)
Single-Flush: 30" x 80" 28.0 kg (40 yrs)
Single-Flush: 36" x 80" 4.2 kg (40 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush

Description:
Stainless steel door fitting (hinges and lockset) for use on residential interior door assemblies.

Life Cycle Inventory:
Door hinges 0.622 kg/part, Battalion Lever Lockset, Light Duty, Privacy 0.70 kg/part

Manufacturing Scope:
Cradle to gate, including disposal of packaging.

Transportation Distance:
By truck: 1001 km

End of Life Scope:
90% collection rate
remaining 10% deposited in the LCA model without recycling
material recycling efficiency dependant on the metal (89% steel, 90.2% aluminum, stainless steel 83%, zinc 91%, brass 94%)

LCA Metadata (continued)

Plastic components incinerated resulting in credits for electricity and thermal energy

Entry Source:
DE: Fitting stainless steel - FSB (2009)

Steel, reinforcing rod **464.6 kg**

Used in the following Revit families:
6" Foundation Slab 320.1 kg (60 yrs)
Generic - 8" Masonry 82.4 kg (60 yrs)
Monolithic Stair 62.1 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade
Hollow-core CMU, ungrouted
Stair, cast-in-place concrete

Description:
Steel rod suitable for structural reinforcement (rebar), common unfinished tempered steel

Life Cycle Inventory:
Steel rebar

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 431 km

End of Life Scope:
70% recovered (product has 69.8% scrap input while remainder is processed and credited as avoided burden)
30% landfilled (inert material)

Entry Source:
GLO: Steel rebar worldsteel (2007)

Structural concrete, 3000 psi, generic **16,005.5 kg**

Used in the following Revit families:
6" Foundation Slab 16,005.5 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade

Description:
Structural concrete, generic, 3000 psi

Life Cycle Inventory:
13% cement
40% gravel
39% sand
7% water

Manufacturing Scope:
Cradle to gate
excludes mixing and pouring impacts

Transportation Distance:
By truck: 24 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
US: Portland cement, at plant USLCI/PE (2009)
US: Tap water from groundwater PE (2012)
EU-27: Gravel 2/32 PE (2012)
US: Silica sand (Excavation and processing) PE (2012)

Structural concrete, 5000 psi, generic **1,380.4 kg**

Used in the following Revit families:
Monolithic Stair 1,380.4 kg (60 yrs)

Used in the following Tally entries:
Stair, cast-in-place concrete

Description:
Structural concrete, generic, 5000 psi

Life Cycle Inventory:
15% cement
46% gravel
31% sand
7% water

Manufacturing Scope:
Cradle to gate
excludes mixing and pouring impacts

Transportation Distance:
By truck: 24 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
US: Portland cement, at plant USLCI/PE (2009)
US: Tap water from groundwater PE (2012)
EU-27: Gravel 2/32 PE (2012)
US: Silica sand (Excavation and processing) PE (2012)

Thinset mortar **138.1 kg**

Used in the following Revit families:
Wood Joist 10" - Tile Finish - Exposed Structure 2 138.1 kg (30 yrs)

Used in the following Tally entries:
Ceramic tile, unglazed

Description:
Mortar Type N (moderate strength mortar for use in masonry walls and flooring)

Life Cycle Inventory:
72% aggregate
16% cement
12% water

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Masonry mortar (MG II a) PE (2012)

Trim, wood **2.5 kg**

Used in the following Revit families:
Casement Dbl without Trim: 36" x 32" 2.5 kg (30 yrs)

Used in the following Tally entries:
Trim, wood

Description:
Wood trim

Life Cycle Inventory:
38% PNW

LCA Metadata (continued)

62% SE

Manufacturing Scope:
Cradle to gate, excludes fill or chemical treatments

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
US: Panel trim, from trim and saw at plywood plant, US PNW USLCI/PE (2009)
US: Panel trim, from trim and saw at plywood plant, US SE USLCI/PE (2009)

Wall board, gypsum, natural **12,875.6 kg**

Used in the following Revit families:

Basement Wall Furring	1,612.8 kg (30 yrs)
Exterior - Wood Shingle on Wood Dtud	3,619.4 kg (30 yrs)
GWB on Mtl. Stud	1,470.6 kg (30 yrs)
Interior - Gyp. Board Over Wood Stud (2x4)	4,809.0 kg (30 yrs)
Wood Joist 10" - Wood Finish	1,363.7 kg (30 yrs)

Used in the following Tally entries:
Wall board, gypsum

Description:
Natural gypsum board

Life Cycle Inventory:
1 kg gypsum wallboard

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
54% recycled into gypsum stone (includes grinding and avoided burden credit)
46% landfilled (inert waste)

Entry Source:
DE: Gypsum wallboard (EN15804 A1-A3) PE (2012)

Window frame, wood, divided operable **195.5 kg**

Used in the following Revit families:

Casement Dbl without Trim: 36" x 32"	9.0 kg (30 yrs)
Double Hung: 16" x 48"	33.8 kg (30 yrs)
Double Hung: 24" x 42"	17.4 kg (30 yrs)
Double Hung: 24" x 48"	28.5 kg (30 yrs)
Double Hung: 32" x 48"	84.5 kg (30 yrs)
Fixed: 36" x 48"	22.2 kg (30 yrs)

Used in the following Tally entries:
Window frame, wood

Description:
Wood divided operable window frame inclusive of paint

Life Cycle Inventory:
1.30 kg/m

Manufacturing Scope:
Cradle to gate
excludes hardware, casing, sealant beyond paint

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Wood stain, water based **12.7 kg**

Used in the following Revit families:

Single-Flush: 22" x 80"	1.5 kg (10 yrs)
Single-Flush: 24" x 80"	0.8 kg (10 yrs)
Single-Flush: 28" x 30"	1.0 kg (10 yrs)
Single-Flush: 30" x 80"	8.2 kg (10 yrs)
Single-Flush: 36" x 80"	1.2 kg (10 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush

Description:
Semi-transparent stain for interior and exterior wood surfaces

Life Cycle Inventory:
60% water, 28% acrylate resin, 7% acrylate emulsion, 5% dipropylene glycol
1.3% NMVOC emissions

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
38.7% solids to landfill (plastic waste)

Entry Source:
US: Tap water from groundwater PE (2012)
US: Acrylate resin (solvent-systems) PE (2012)
DE: Acrylate (emulsion) PE (2012)
US: Dipropylene glycol by product propylene glycol via PO hydrogenation PE (2012)

Final Prototype

Full building summary

4/29/2018

Table of Contents

Report Summary

Created with Tally
Non-commercial Version 2017.06.15.01

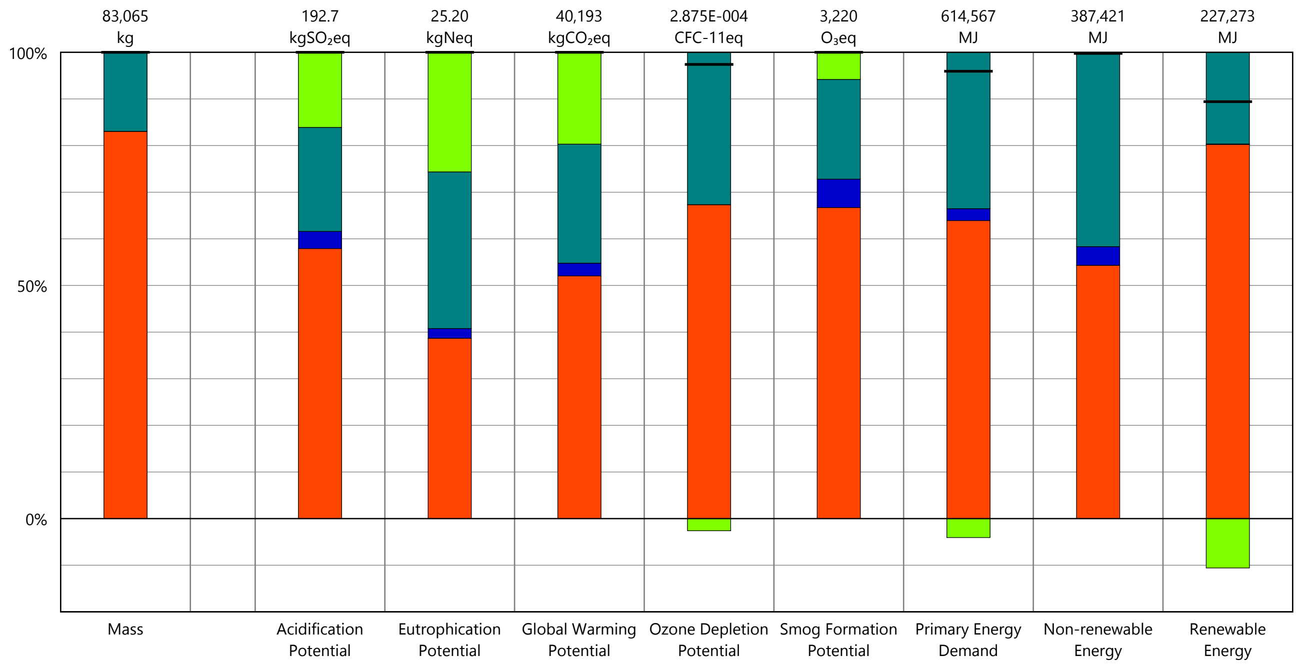
Author	Thomas Shreve
Company	RIT Architecture
Date	4/29/2018
Project	Corrected Final Prototype
Location	Enter address here
Gross Area	1428 ft^2
Building Life	60
Boundaries	Cradle-to-Grave; see appendix for a full list of materials and processes
On-site Construction [A5]	Not included
Operational Energy [B6]	Not included

Goal and Scope of Assessment

To analyze the effects of implementing design strategies to reduce the embodied energy, as well as show the opportunities presented by BIM integrated LCA.

Environmental Impact Totals	**Product Stage [A1-A3]**	**Construction Stage [A4-A5]**	**Use Stage [B2-B4, B6]**	**End of Life Stage [C2-C4, D]**
Acidification ($kgSO_2eq$)	111.6	7.066	42.99	31.04
Eutrophication (kgNeq)	9.747	0.5254	8.464	6.464
Global Warming ($kgCO_2eq$)	20,915	1,103	10,261	7,914
Ozone Depletion (CFC-11eq)	1.936E-004	9.332E-009	9.390E-005	-7.476E-006
Smog Formation (O_3eq)	2,148	196.5	688.2	187.5
Primary Energy (MJ)	392,790	15,655	206,121	-24,964
Non-renewable Energy (MJ)	210,445	15,515	161,461	-910
Renewable Energy (MJ)	182,345	232.1	44,696	-24,053
Environmental Impacts / Area				
Acidification ($kgSO_2eq/m^2$)	0.8411	0.05326	0.3241	0.234
Eutrophication ($kgNeq/m^2$)	0.07347	0.003961	0.0638	0.04873
Global Warming ($kgCO_2eq/m^2$)	157.7	8.315	77.34	59.66
Ozone Depletion ($CFC\text{-}11eq/m^2$)	1.459E-006	7.035E-011	7.078E-007	-5.635E-008
Smog Formation (O_3eq/m^2)	16.19	1.481	5.187	1.414
Primary Energy (MJ/m^2)	2,961	118.0	1,554	-188
Non-renewable Energy (MJ/m^2)	1,586	116.9	1,217	-6.86
Renewable Energy (MJ/m^2)	1,374	1.750	336.9	-181

Results per Life Cycle Stage



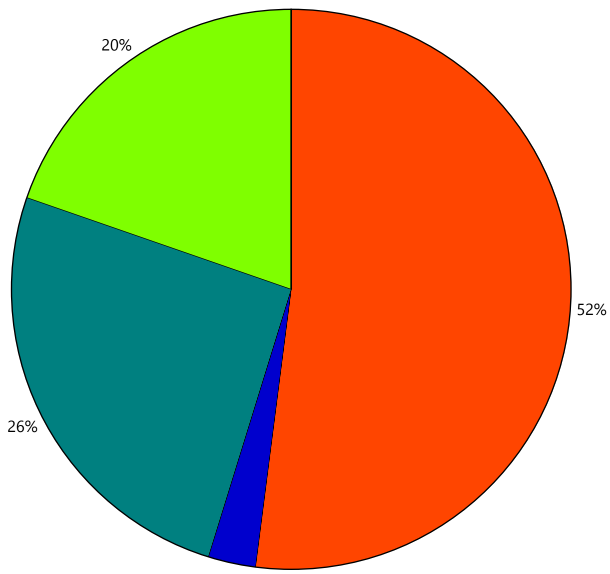
Legend

Net value (impacts + credits)

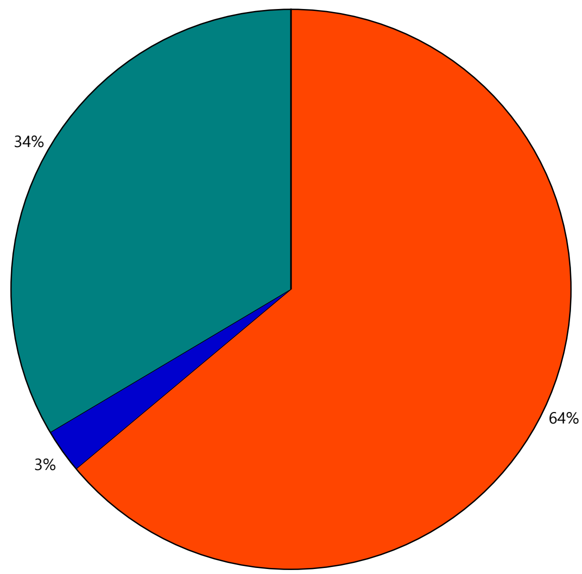
Life Cycle Stages

- Manufacturing [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B4]
- End of Life [C2-C4, D]

Results per Life Cycle Stage



Global Warming Potential



Primary Energy Demand

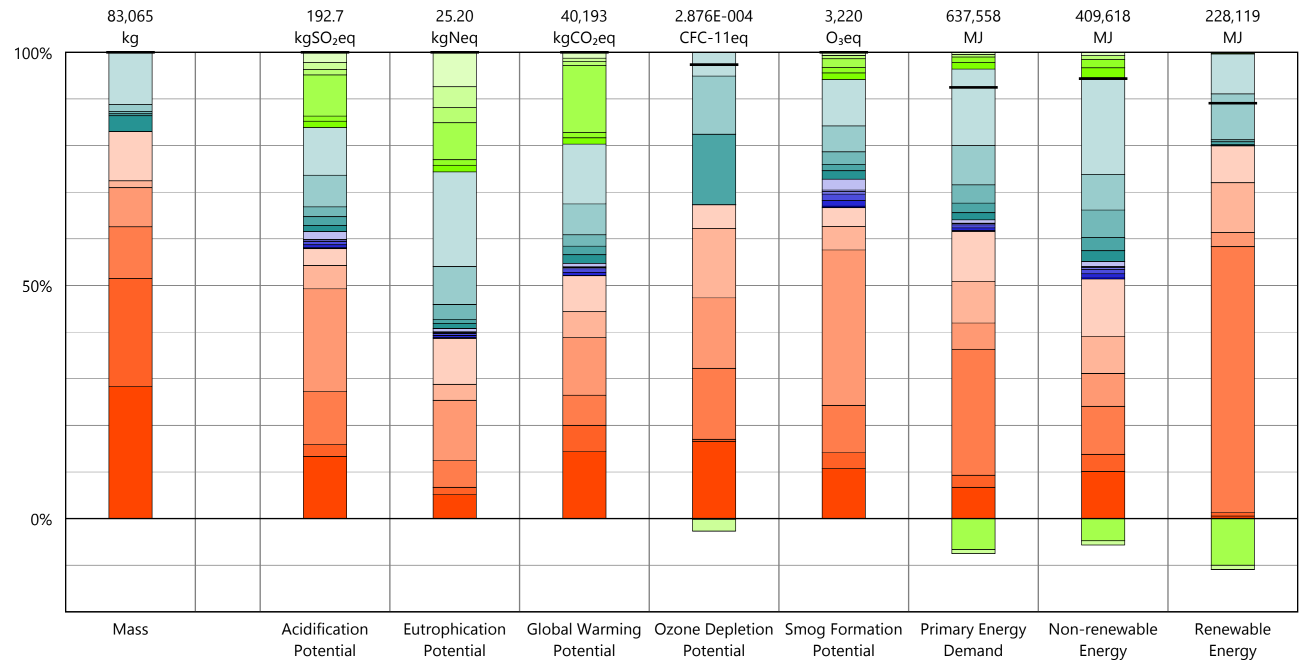
Legend

Net value (impacts + credits)

Life Cycle Stages

- Manufacturing [A1-A3]
- Transportation [A4]
- Maintenance and Replacement [B2-B4]
- End of Life [C2-C4, D]

Results per Life Cycle Stage, itemized by Division



Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Transportation [A4]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

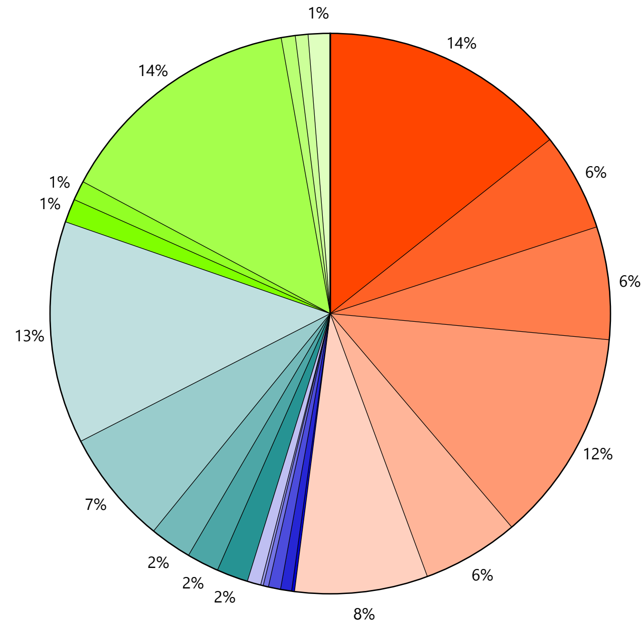
Maintenance and Replacement [B2-B4]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

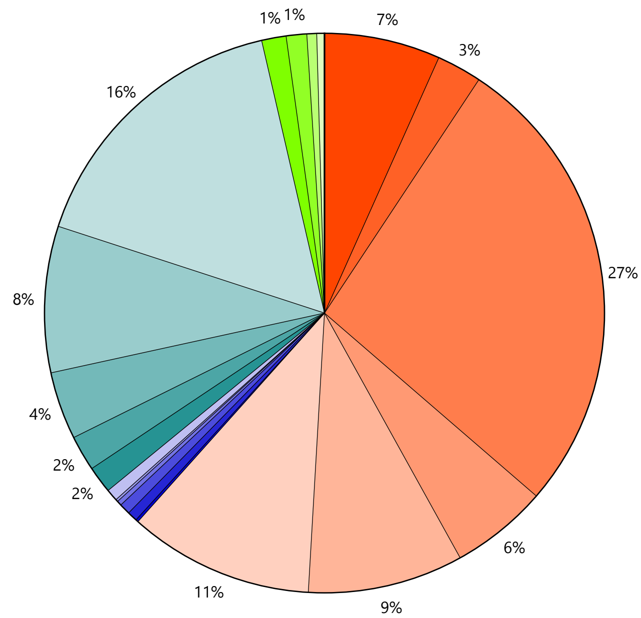
End of Life [C2-C4, D]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Life Cycle Stage, itemized by Division



Global Warming Potential



Primary Energy Demand

Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Transportation [A4]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

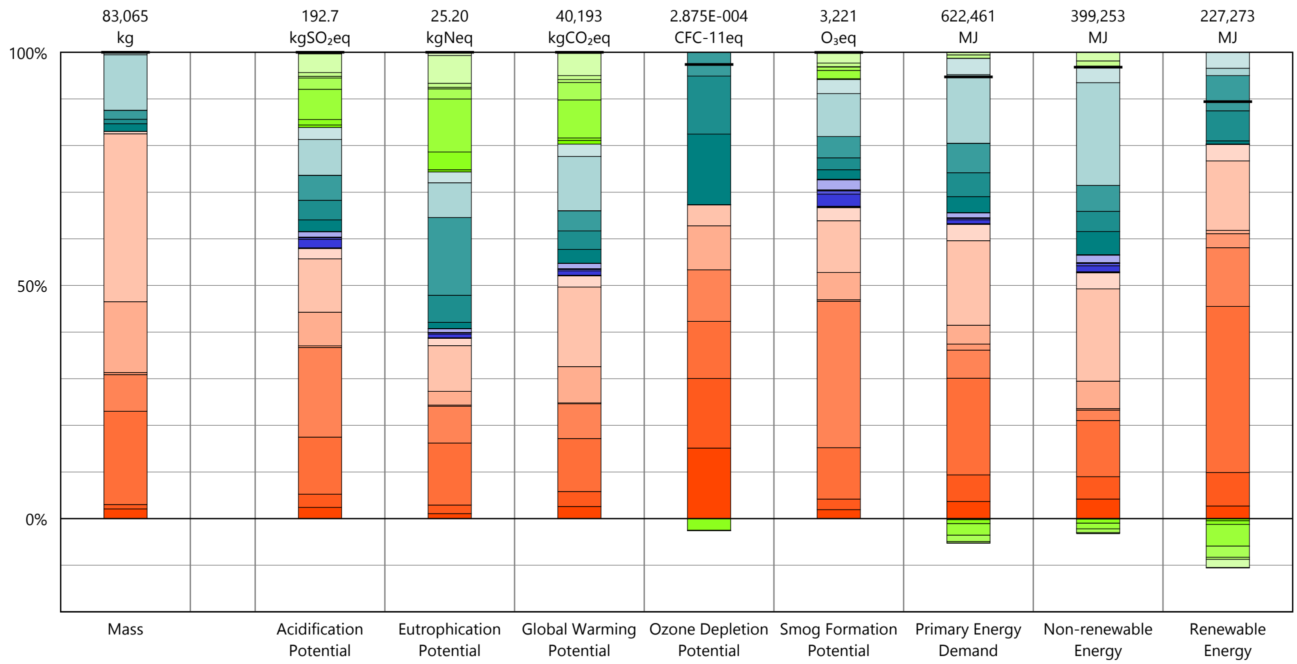
Maintenance and Replacement [B2-B4]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

End of Life [C2-C4, D]

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Life Cycle Stage, itemized by Revit Category



Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Transportation [A4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

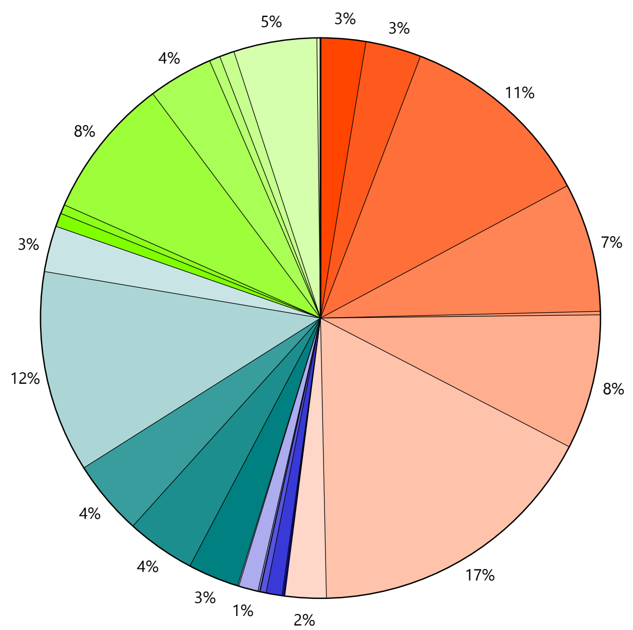
Maintenance and Replacement [B2-B4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

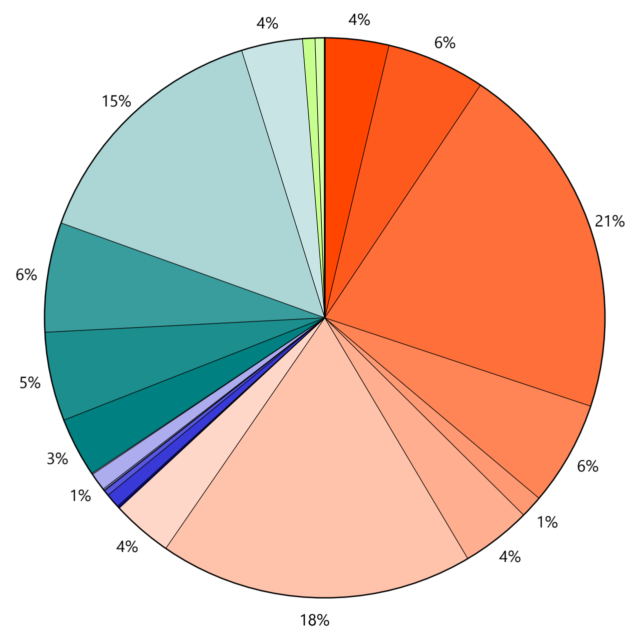
End of Life [C2-C4, D]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Life Cycle Stage, itemized by Revit Category



Global Warming Potential



Primary Energy Demand

Legend

Net value (impacts + credits)

Manufacturing [A1-A3]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Transportation [A4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

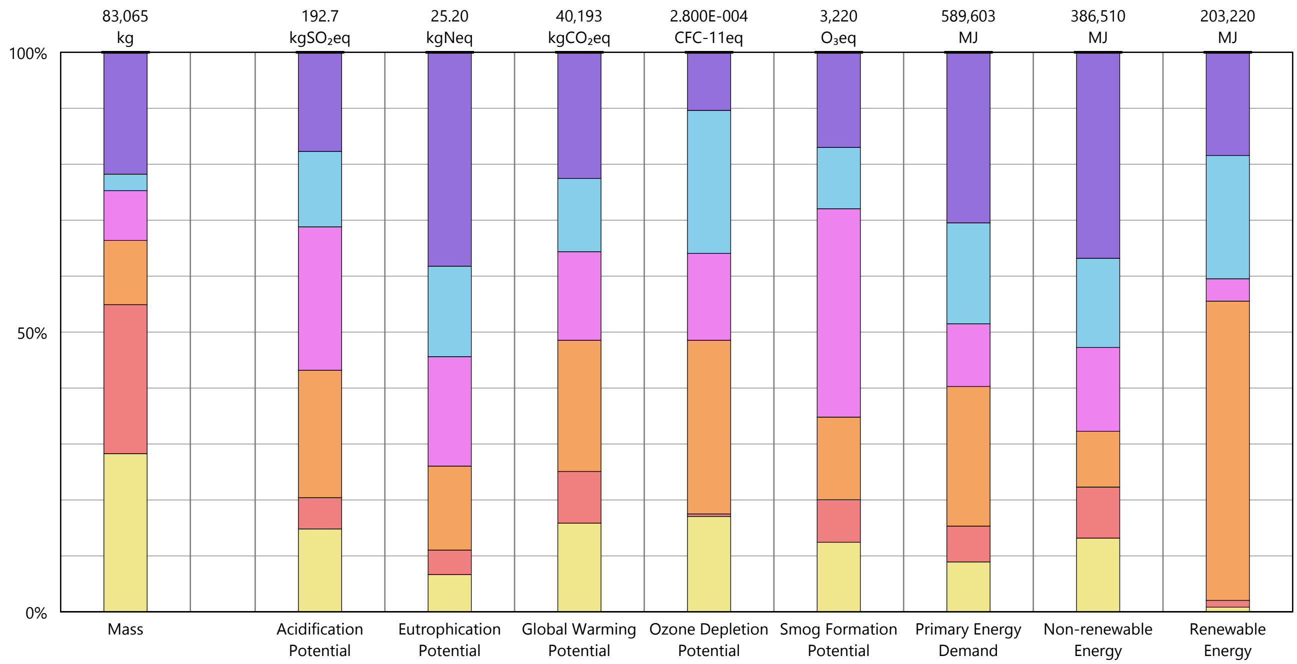
Maintenance and Replacement [B2-B4]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

End of Life [C2-C4, D]

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Division

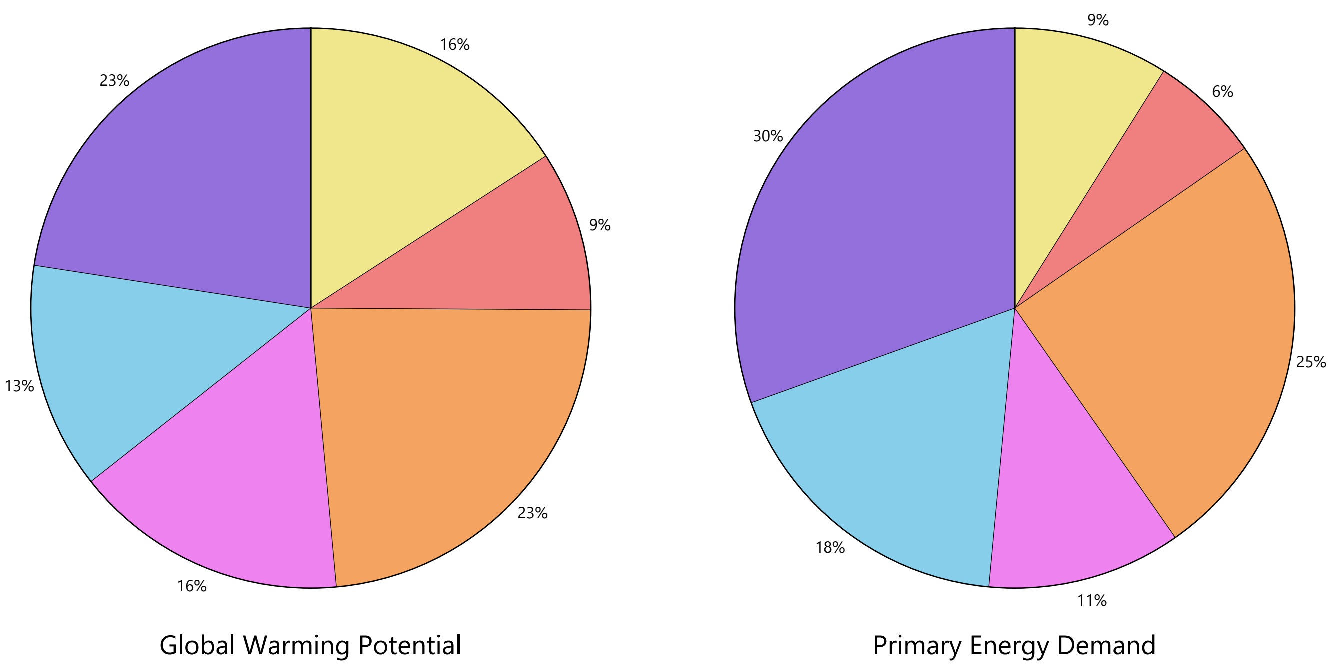


Legend

Divisions

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Division

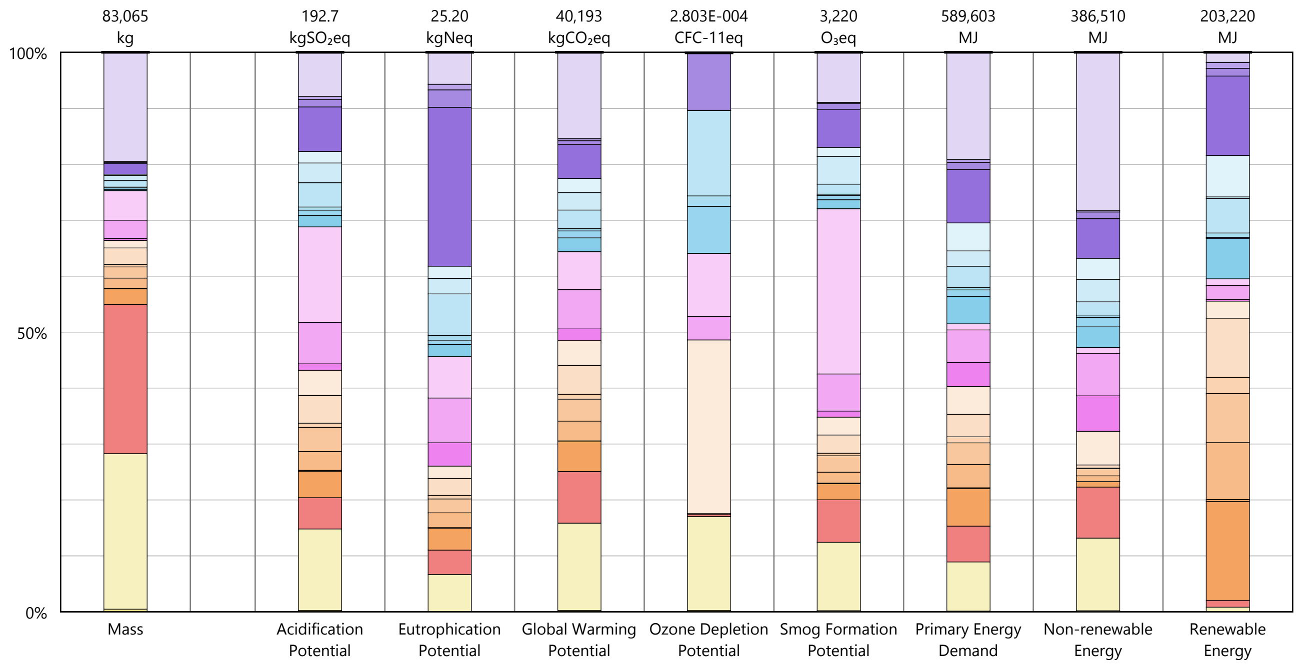


Legend

Divisions

- 03 - Concrete
- 04 - Masonry
- 06 - Wood/Plastics/Composites
- 07 - Thermal and Moisture Protection
- 08 - Openings and Glazing
- 09 - Finishes

Results per Division, itemized by Tally Entry



Legend

03 - Concrete

- Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
- Cast-in-place concrete, slab on grade

04 - Masonry

- Hollow-core CMU, ungrouted

06 - Wood/Plastics/Composites

- Domestic hardwood
- Domestic softwood
- Plywood, exterior grade
- Plywood, interior grade
- Stair, hardwood
- Wood framing
- Wood framing with insulation

07 - Thermal and Moisture Protection

- Extruded polystyrene (XPS), board
- Fiber cement siding
- Slate roofing shingles, EPD - Rathscheck Schiefer

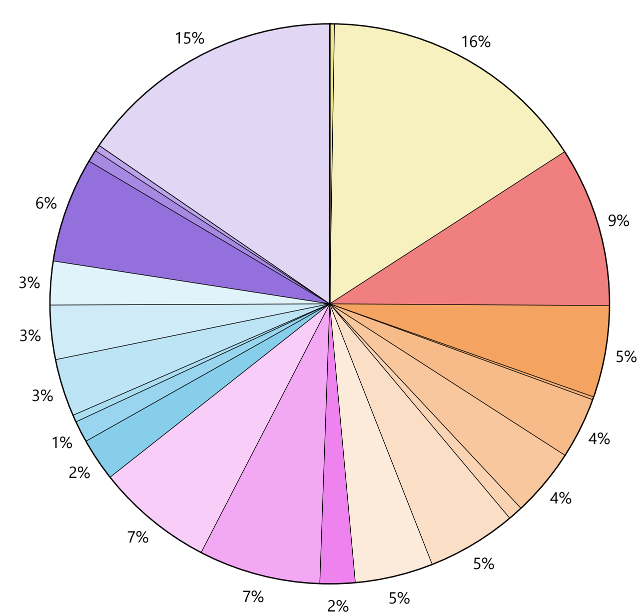
08 - Openings and Glazing

- Door frame, wood
- Door, exterior, steel
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU
- Window frame, wood

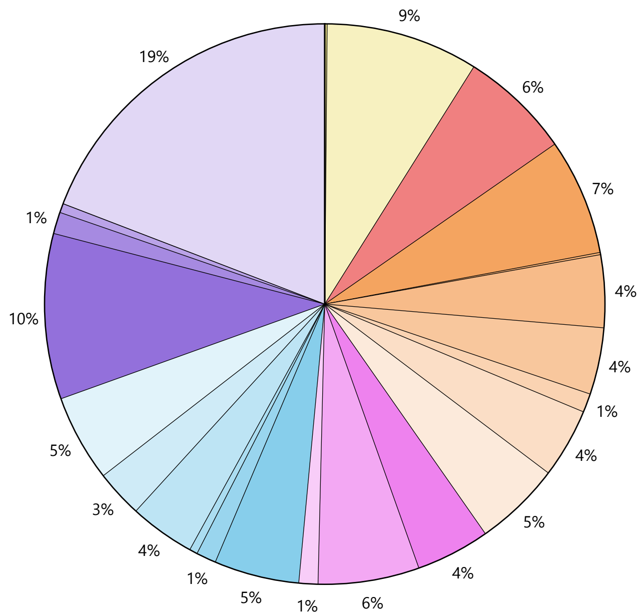
09 - Finishes

- Flooring, cork tile
- Flooring, linoleum, generic
- Flooring, solid wood plank
- Trim, wood
- Wall board, gypsum

Results per Division, itemized by Tally Entry



Global Warming Potential



Primary Energy Demand

Legend

03 - Concrete

- Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
- Cast-in-place concrete, slab on grade

04 - Masonry

- Hollow-core CMU, ungrouted

06 - Wood/Plastics/Composites

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- Domestic softwood
- Plywood, exterior grade
- Plywood, interior grade
- Stair, hardwood
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- Wood framing with insulation

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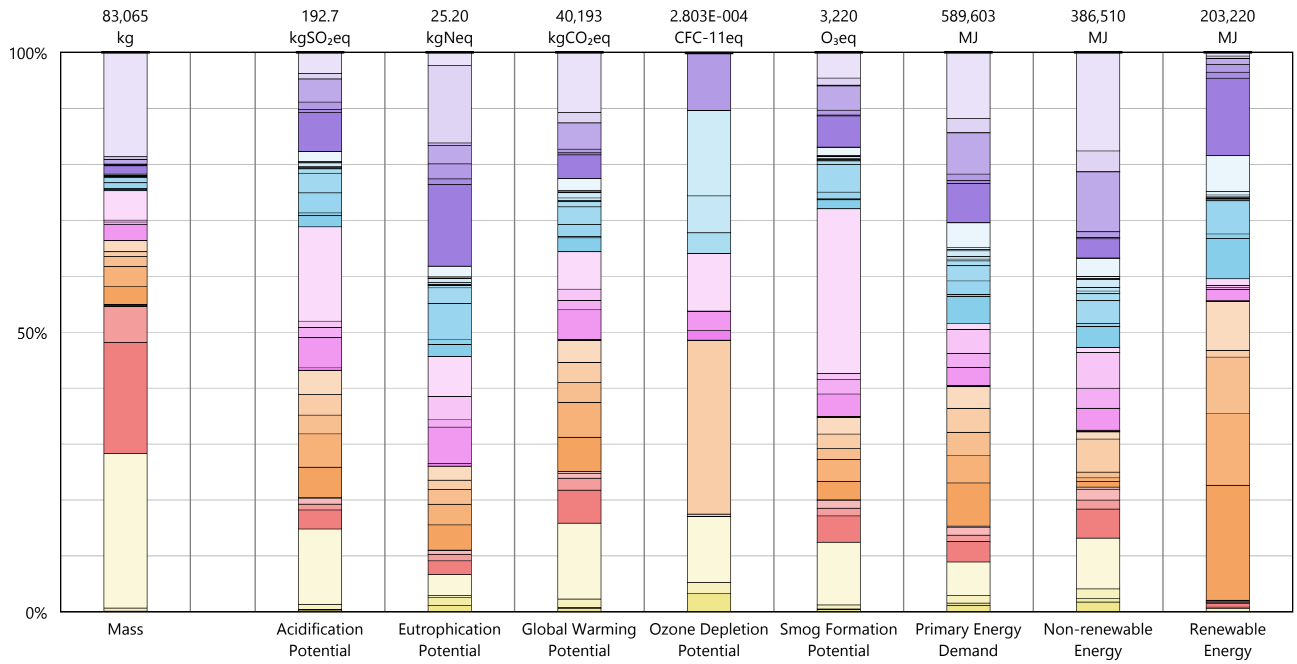
- Door frame, wood
- Door, exterior, steel
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU
- Window frame, wood

09 - Finishes

- Flooring, cork tile
- Flooring, linoleum, generic
- Flooring, solid wood plank
- Trim, wood
- Wall board, gypsum

Results per Division, itemized by Material



Legend

03 - Concrete

- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic

04 - Masonry

- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Paint, exterior acrylic latex
- Steel, reinforcing rod

06 - Wood/Plastics/Composites

- Domestic hardwood, US
- Domestic softwood, US
- Exterior grade plywood, US
- Fiberglass blanket insulation, unfaced
- Interior grade plywood, US
- Paint, exterior acrylic latex

07 - Thermal and Moisture Protection

- Fasteners, stainless steel
- Fiber cement board, lap siding
- Paint, exterior acrylic latex
- Polystyrene board (XPS), Pentane foaming agent
- Roofing shingles, slate, Rathscheck Schiefer, Colored Slate, EPD

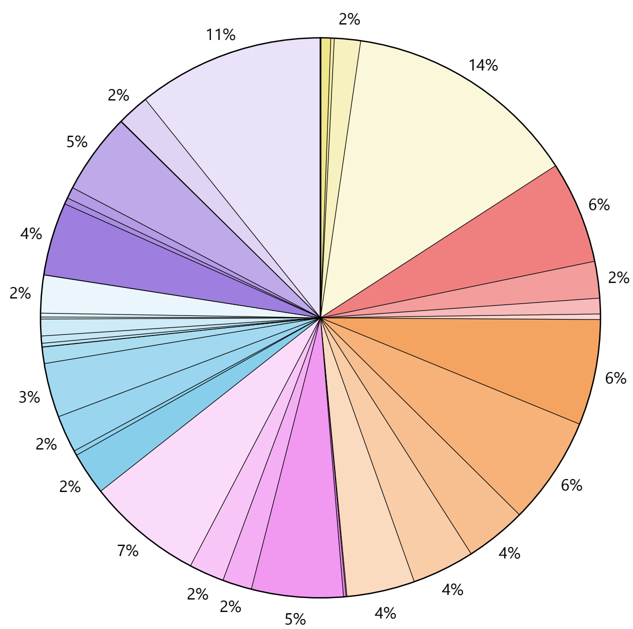
08 - Openings and Glazing

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, steel, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Window frame, wood, divided operable
- Window frame, wood, fixed
- Window frame, wood, operable

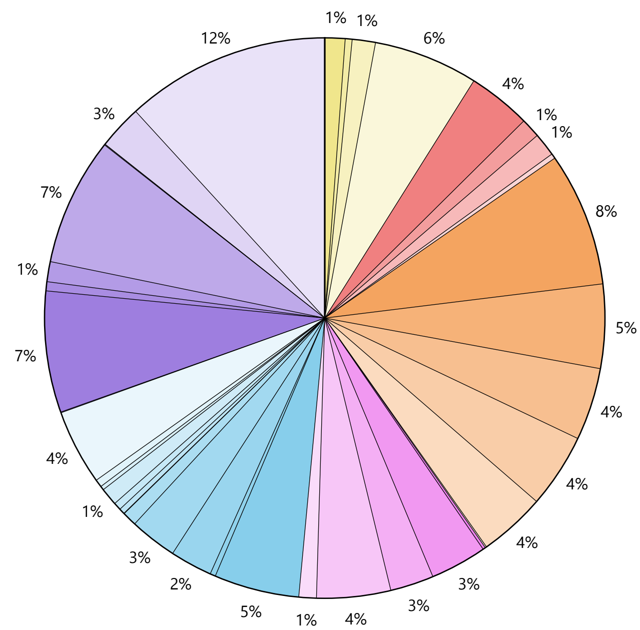
09 - Finishes

- Acrylic adhesive
- Cork tile
- Flooring, hardwood plank
- Flooring, linoleum, tile
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Trim, wood
- Urethane adhesive
- Wall board, gypsum, natural

Results per Division, itemized by Material



Global Warming Potential



Primary Energy Demand

Legend

03 - Concrete

- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic

04 - Masonry

- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Paint, exterior acrylic latex
- Steel, reinforcing rod

06 - Wood/Plastics/Composites

- Domestic hardwood, US
- Domestic softwood, US
- Exterior grade plywood, US
- Fiberglass blanket insulation, unfaced
- Interior grade plywood, US
- Paint, exterior acrylic latex

07 - Thermal and Moisture Protection

- Fasteners, stainless steel
- Fiber cement board, lap siding
- Paint, exterior acrylic latex
- Polystyrene board (XPS), Pentane foaming agent
- Roofing shingles, slate, Rathscheck Schiefer, Colored Slate, EPD

08 - Openings and Glazing

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, steel, powder-coated, with small vision panel
- Paint, exterior acrylic latex
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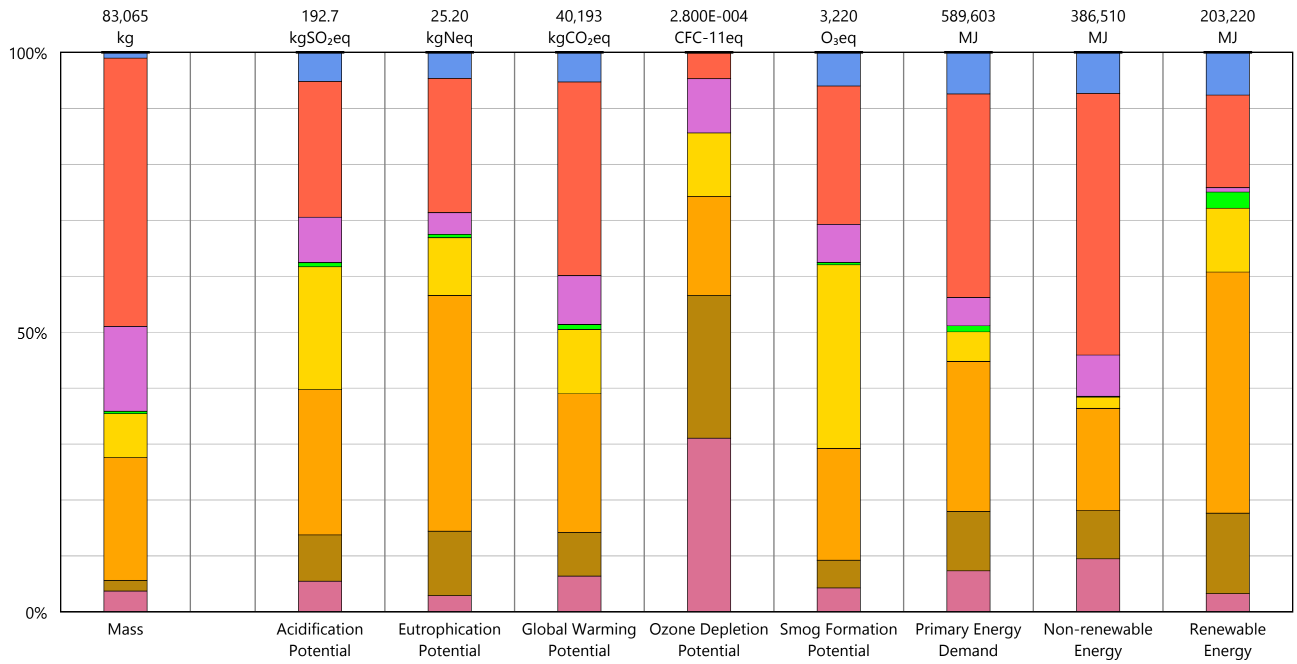
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential
- Window frame, wood, divided operable
- Window frame, wood, fixed
- Window frame, wood, operable

09 - Finishes

- Acrylic adhesive
- Cork tile
- Flooring, hardwood plank
- Flooring, linoleum, tile
- Paint, interior acrylic latex
- Polyurethane floor finish, water-based
- Trim, wood
- Urethane adhesive
- Wall board, gypsum, natural

Results per Revit Category

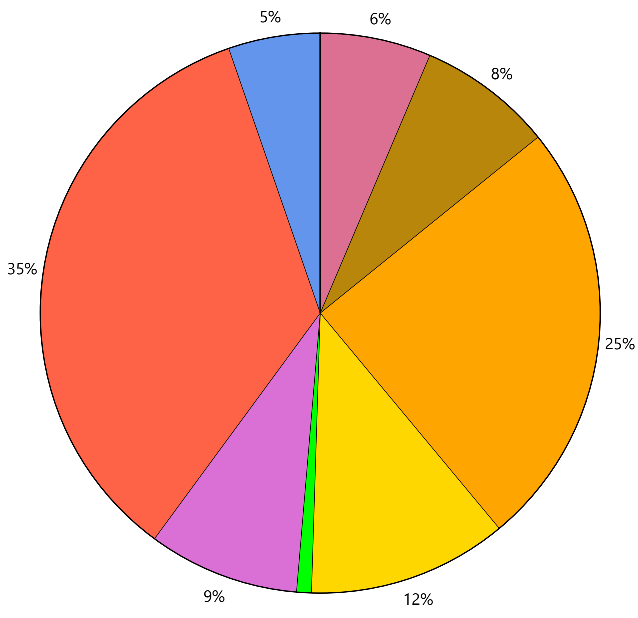


Legend

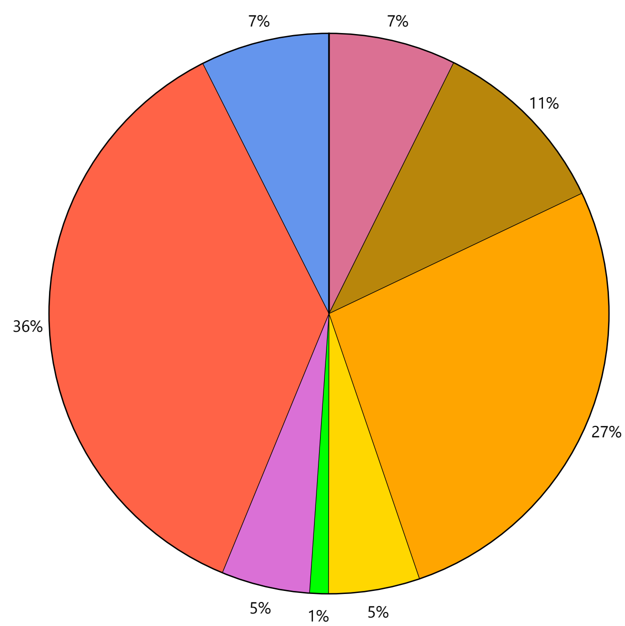
Revit Categories

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Revit Category



Global Warming Potential



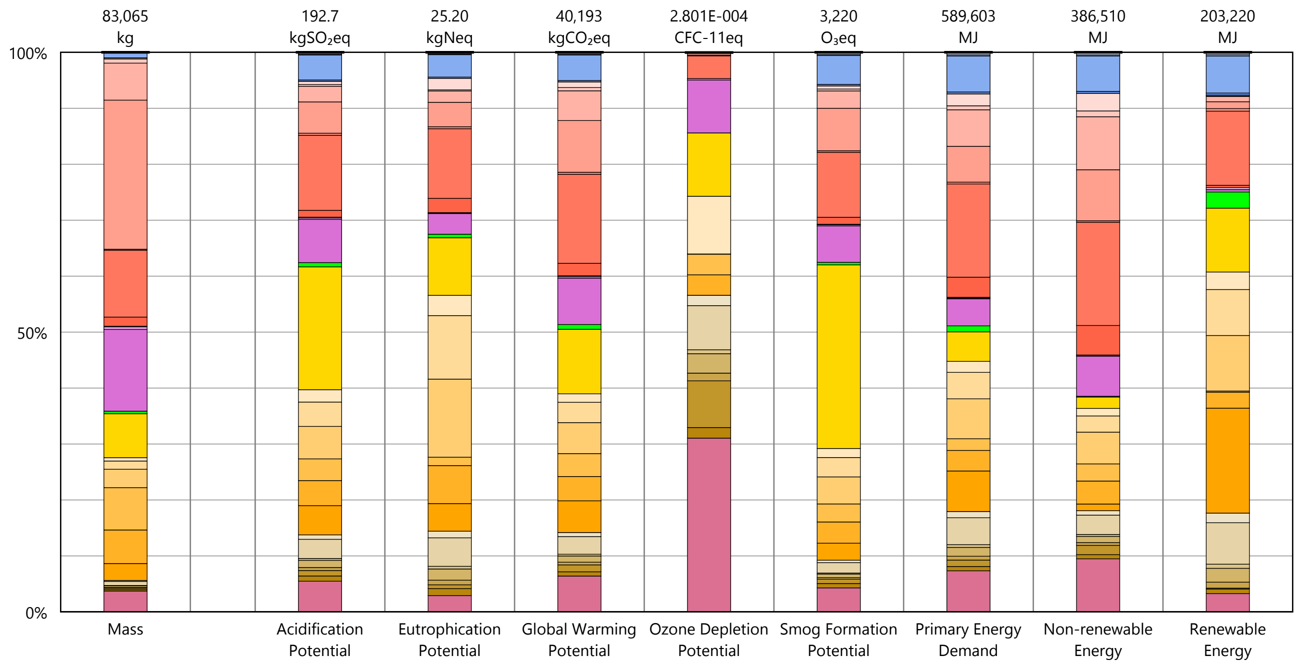
Primary Energy Demand

Legend

Revit Categories

- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Results per Revit Category, itemized by Family



Legend

Ceilings

- GWB on Mtl. Stud

Doors

- Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"
- Door-Overhead-Sectional: 8' x 6'-6"
- Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"
- Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"
- Single-Flush: 24" x 80"
- Single-Flush: 30" x 80"
- Single-Flush: 30" x 84"

Floors

- Porch Floor
- Slab on Grade - Cork Tile
- Slab on Grade - Uninsulated
- Wood Joist 10" - Cork Tile
- Wood Joist 10" - Cork Tile - Exposed Structure
- Wood Joist 10" - Linoleum

Roofs

- Wood Rafter 8" - Slate Shingle - Insulated

Stairs and Railings

- 7" max riser 11" tread

Structure

- 6" Foundation Slab
- Concrete-Round-Column: 12"
- Timber-Column: 6x6

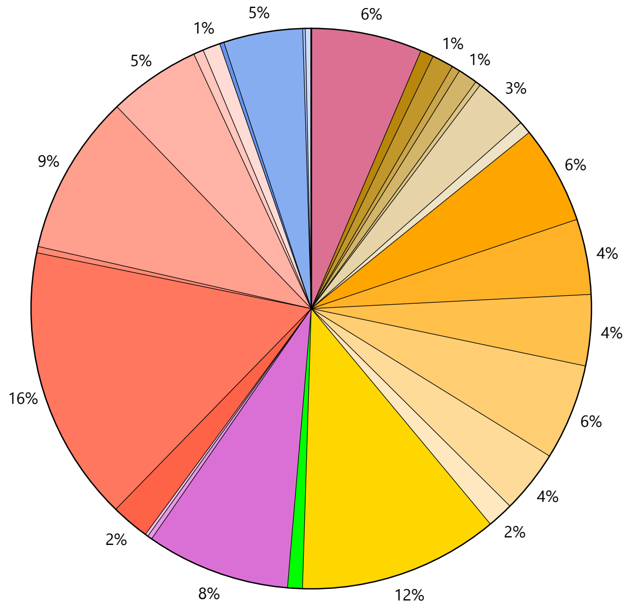
Walls

- Basement Wall Furring
- Exterior - Fiber Cement Siding on Wood Dtud 2
- Exterior - Fiber Cement Siding on Wood Stud (Garage) 2
- Generic - 8" Masonry
- Interior - Gyp. Board Over Wood Stud (2x4)
- Interior - Gyp. Board Over Wood Stud (2x6)
- Rigid Insulation

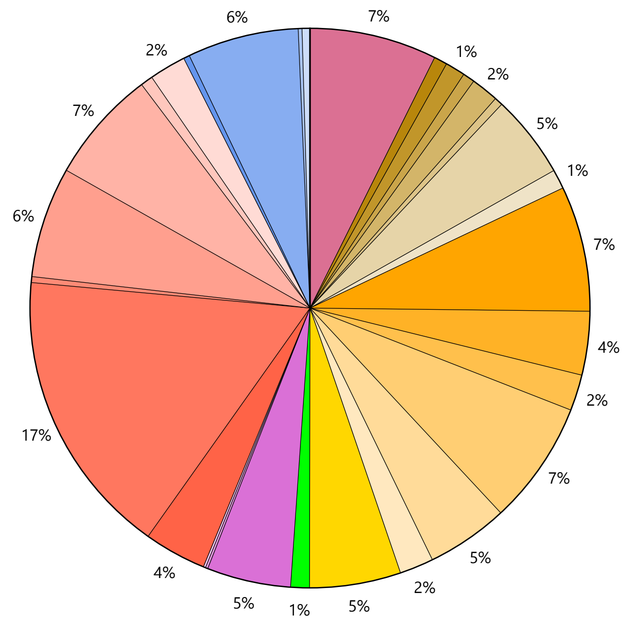
Windows

- Casement Dbl without Trim: 36" x 32"
- Double Hung: 24" x 48"
- Fixed: 24" x 24"
- Fixed: 36" x 48"

Results per Revit Category, itemized by Family



Global Warming Potential



Primary Energy Demand

Legend

Ceilings

- GWB on Mtl. Stud

Doors

- Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"
- Door-Overhead-Sectional: 8' x 6'-6"
- Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"
- Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"
- Single-Flush: 24" x 80"
- Single-Flush: 30" x 80"
- Single-Flush: 30" x 84"

Floors

- Porch Floor
- Slab on Grade - Cork Tile
- Slab on Grade - Uninsulated
- Wood Joist 10" - Cork Tile
- Wood Joist 10" - Cork Tile - Exposed Structure
- Wood Joist 10" - Linoleum

Roofs

- Wood Rafter 8" - Slate Shingle - Insulated

Stairs and Railings

- 7" max riser 11" tread

Structure

- 6" Foundation Slab
- Concrete-Round-Column: 12"
- Timber-Column: 6x6

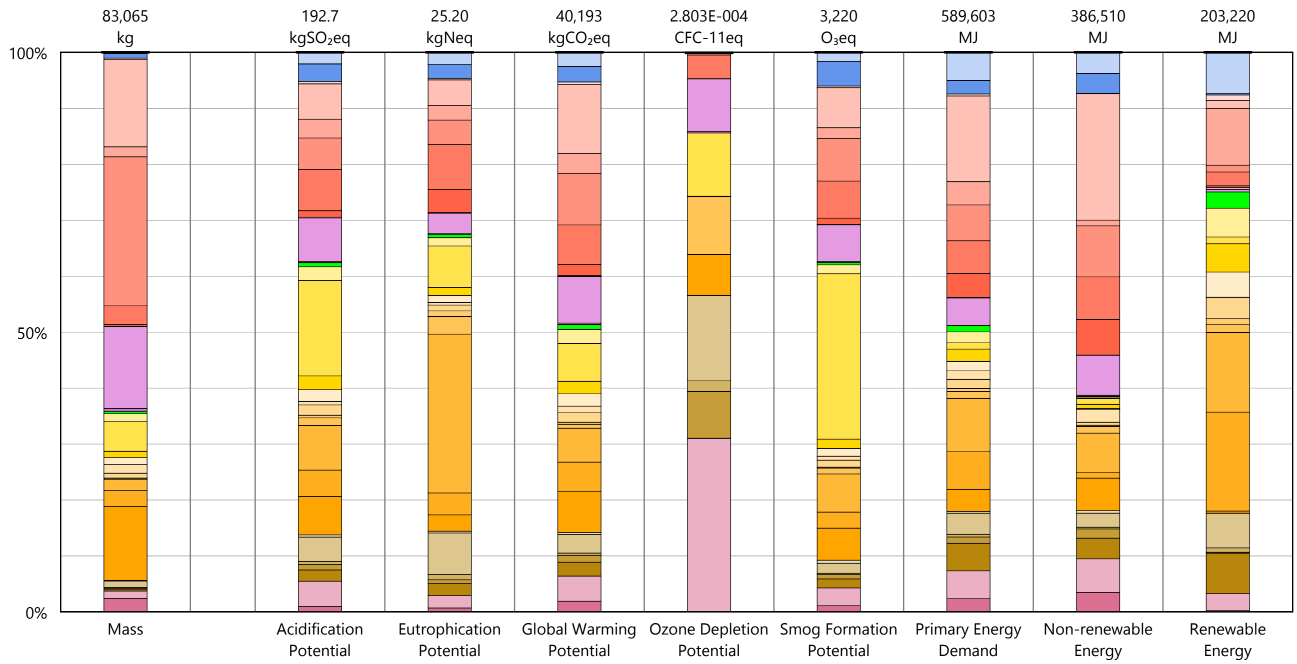
Walls

- Basement Wall Furring
- Exterior - Fiber Cement Siding on Wood Dtud 2
- Exterior - Fiber Cement Siding on Wood Stud (Garage) 2
- Generic - 8" Masonry
- Interior - Gyp. Board Over Wood Stud (2x4)
- Interior - Gyp. Board Over Wood Stud (2x6)
- Rigid Insulation

Windows

- Casement Dbl without Trim: 36" x 32"
- Double Hung: 24" x 48"
- Fixed: 24" x 24"
- Fixed: 36" x 48"

Results per Revit Category, itemized by Tally Entry



Legend

Ceilings

- Wall board, gypsum
- Wood framing with insulation

Doors

- Door frame, wood
- Door, exterior, steel
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU

Floors

- Cast-in-place concrete, slab on grade
- Domestic hardwood
- Flooring, cork tile
- Flooring, linoleum, generic
- Flooring, solid wood plank
- Plywood, interior grade
- Wall board, gypsum
- Wood framing

Roofs

- Plywood, interior grade
- Slate roofing shingles, EPD - Rathscheck Schiefer
- Wood framing

Stairs and Railings

- Stair, hardwood

Structure

- Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
- Cast-in-place concrete, slab on grade
- Domestic softwood

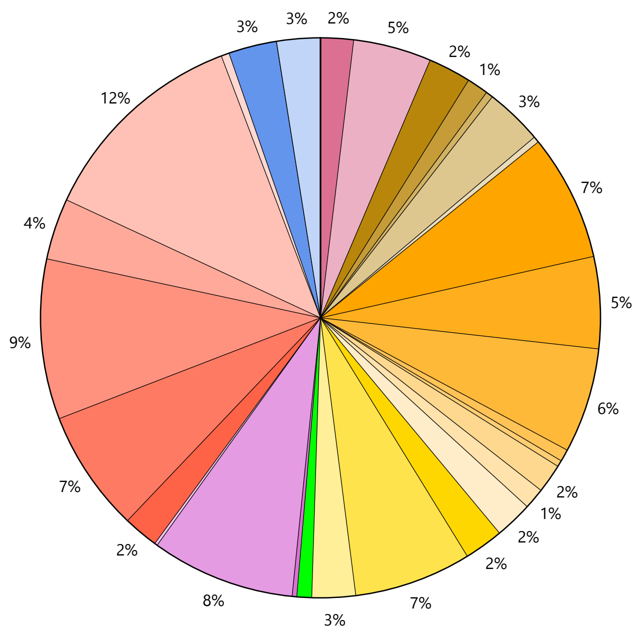
Walls

- Extruded polystyrene (XPS), board
- Fiber cement siding
- Hollow-core CMU, ungrouted
- Plywood, exterior grade
- Wall board, gypsum
- Wood framing

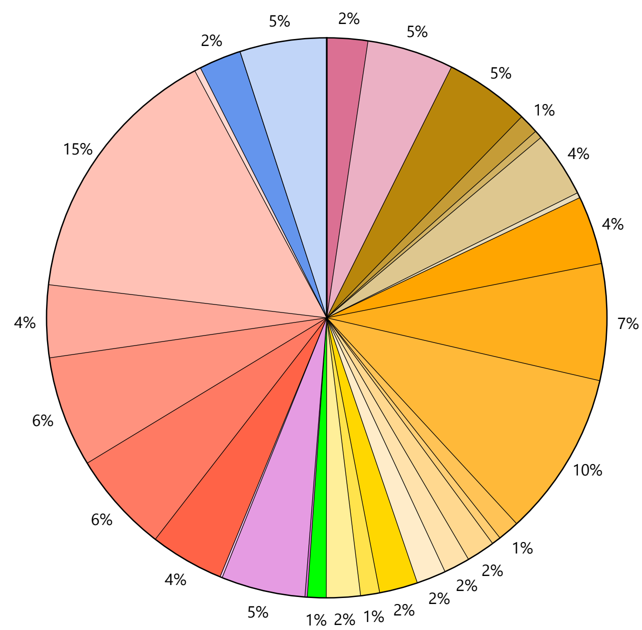
Windows

- Glazing, double pane IGU
- Trim, wood
- Window frame, wood

Results per Revit Category, itemized by Tally Entry



Global Warming Potential



Primary Energy Demand

Legend

Ceilings
- Wall board, gypsum
- Wood framing with insulation

Doors
- Door frame, wood
- Door, exterior, steel
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double pane IGU

Floors
- Cast-in-place concrete, slab on grade
- Domestic hardwood
- Flooring, cork tile
- Flooring, linoleum, generic
- Flooring, solid wood plank
- Plywood, interior grade
- Wall board, gypsum
- Wood framing

Roofs
- Plywood, interior grade
- Slate roofing shingles, EPD - Rathscheck Schiefer
- Wood framing

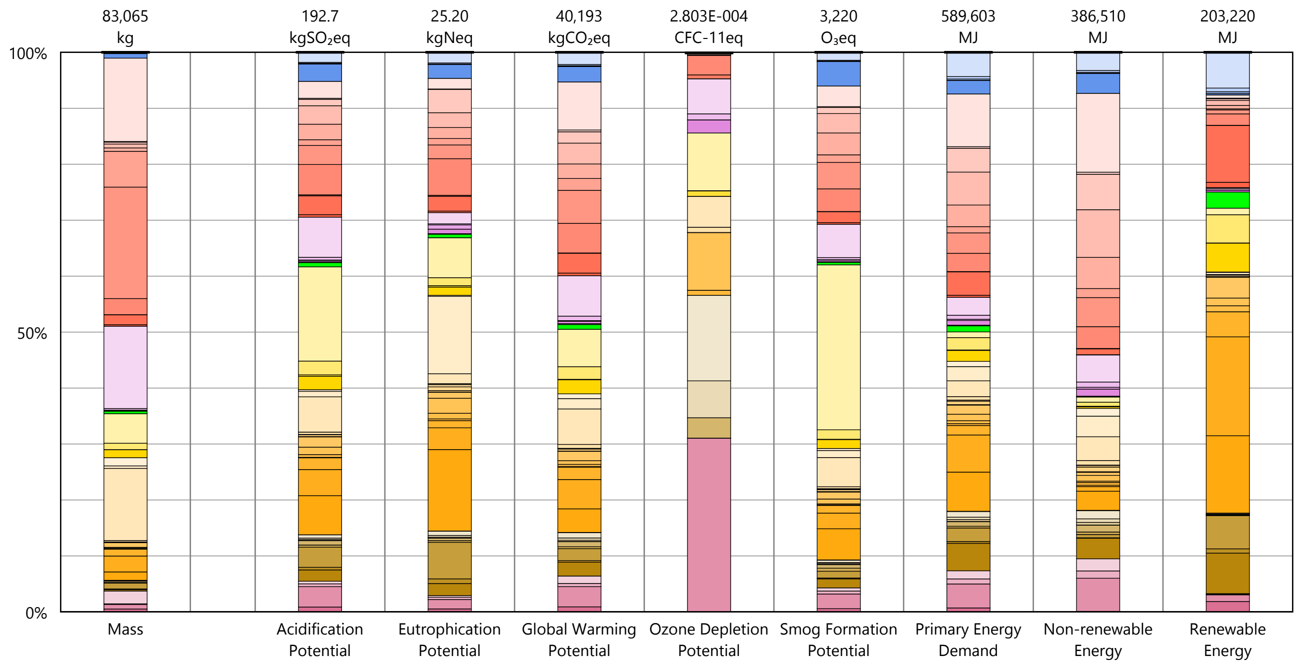
Stairs and Railings
- Stair, hardwood

Structure
- Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
- Cast-in-place concrete, slab on grade
- Domestic softwood

Walls
- Extruded polystyrene (XPS), board
- Fiber cement siding
- Hollow-core CMU, ungrouted
- Plywood, exterior grade
- Wall board, gypsum
- Wood framing

Windows
- Glazing, double pane IGU
- Trim, wood
- Window frame, wood

Results per Revit Category, itemized by Material



Legend

Ceilings

- Domestic softwood, US
- Fiberglass blanket insulation, unfaced
- Paint, interior acrylic latex
- Wall board, gypsum, natural

Doors

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, steel, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential

Floors

- Acrylic adhesive
- Cork tile
- Domestic hardwood, US
- Domestic softwood, US
- Expanded polystyrene (EPS), board
- Flooring, hardwood plank
- Flooring, linoleum, tile
- Interior grade plywood, US
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Polyethelene sheet vapor barrier (HDPE)
- Polyurethane floor finish, water-based
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic
- Urethane adhesive
- Wall board, gypsum, natural

Roofs

- Domestic softwood, US
- Fasteners, stainless steel
- Interior grade plywood, US
- Roofing shingles, slate, Rathscheck Schiefer, Colored Slate, EPD

Stairs and Railings

- Domestic hardwood, US

Structure

- Domestic softwood, US
- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic

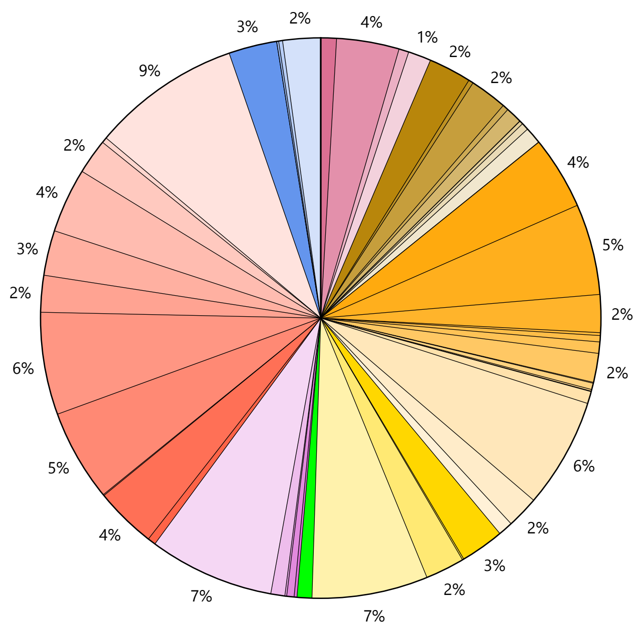
Walls

- Domestic softwood, US
- Exterior grade plywood, US
- Fasteners, stainless steel
- Fiber cement board, lap siding
- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Polystyrene board (XPS), Pentane foaming agent
- Steel, reinforcing rod
- Wall board, gypsum, natural

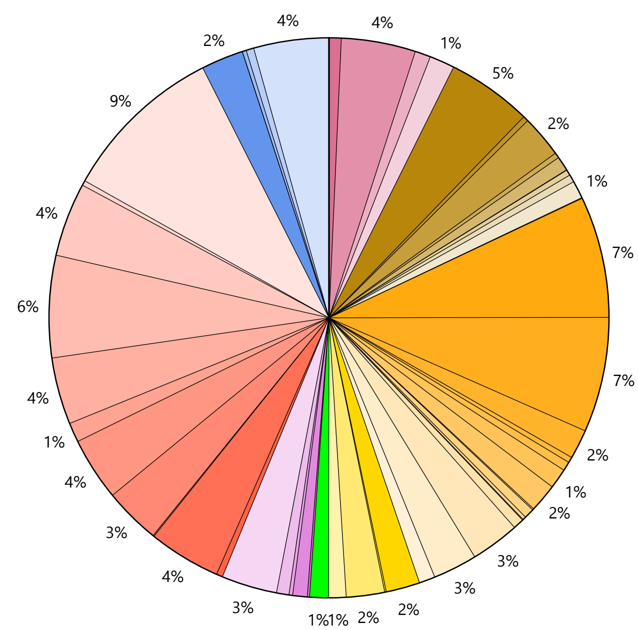
Windows

- Glazing, double, insulated (argon), low-E
- Trim, wood
- Window frame, wood, divided operable
- Window frame, wood, fixed
- Window frame, wood, operable

Results per Revit Category, itemized by Material



Global Warming Potential



Primary Energy Demand

Legend

Ceilings

- Domestic softwood, US
- Fiberglass blanket insulation, unfaced
- Paint, interior acrylic latex
- Wall board, gypsum, natural

Doors

- Door frame, wood, no door
- Door, exterior, wood, solid core
- Door, interior, wood, hollow core, flush
- Glazing, double, insulated (argon), low-E
- Hollow door, exterior, steel, powder-coated, with small vision panel
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Stainless steel, door hardware, lever lock, exterior, residential
- Stainless steel, door hardware, lever lock, interior, residential

Floors

- Acrylic adhesive
- Cork tile
- Domestic hardwood, US
- Domestic softwood, US
- Expanded polystyrene (EPS), board
- Flooring, hardwood plank
- Flooring, linoleum, tile
- Interior grade plywood, US
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Polyethelene sheet vapor barrier (HDPE)
- Polyurethane floor finish, water-based
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic
- Urethane adhesive
- Wall board, gypsum, natural

Roofs

- Domestic softwood, US
- Fasteners, stainless steel
- Interior grade plywood, US
- Roofing shingles, slate, Rathscheck Schiefer, Colored Slate, EPD

Stairs and Railings

- Domestic hardwood, US

Structure

- Domestic softwood, US
- Expanded polystyrene (EPS), board
- Polyethelene sheet vapor barrier (HDPE)
- Steel, reinforcing rod
- Structural concrete, 3000 psi, generic

Walls

- Domestic softwood, US
- Exterior grade plywood, US
- Fasteners, stainless steel
- Fiber cement board, lap siding
- Hollow-core CMU, 8x8x16 ungrouted
- Mortar type S
- Paint, exterior acrylic latex
- Paint, interior acrylic latex
- Polystyrene board (XPS), Pentane foaming agent
- Steel, reinforcing rod
- Wall board, gypsum, natural

Windows

- Glazing, double, insulated (argon), low-E
- Trim, wood
- Window frame, wood, divided operable
- Window frame, wood, fixed
- Window frame, wood, operable

Calculation Methodology

Studied objects
The life cycle assessment (LCA) results reported represent either an analysis of a single building or a comparative analysis of two or more building design options. The single building may represent the complete architectural, structural, and finish systems of a building or a subset of those systems, and it 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 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 flow
The functional unit of a single building is the usable floor space of the building under study. For a design option comparison of a partial building, the functional unit is the complete set of building systems that performs a given function. The reference flow is the amount of material required to produce a building or portion thereof, and is designed 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 flow also includes the energy, water, and fuel consumed on the building site during construction. If operational energy is included in the assessment, the reference flow includes the electrical and thermal energy consumed on site over the life of the building. It is the responsibility of the modeler to assure that reference buildings or design options are functionally equivalent in terms of scope, size, and relevant performance. The expected life of the building has a default value of 60 years and can be modified by the practitioner.

System boundaries and delimitations
The analysis accounts for the full cradle-to-grave life cycle of the design options studied, including material manufacturing, maintenance and replacement, eventual end-of-life, and the materials and energy used across all life cycle stages. Optionally, the construction impacts and operational energy of the building can be included within the scope.

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 with the exception of known materials that have high environmental impacts at low levels. In these cases, a 1% cut-off was implemented by impact.

Manufacturing [EN 15978 A1-A3] encompases the full product stage, including raw material extraction and processing, intermediate transportation, and final manufacturing and assembly. The manufacturing 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] between the manufacturer and building site is included separately and can be modified by the practitioner. Transportation at the product's end-of-life is excluded from this study.

On-site Construction [EN 15978 A5] includes the anticipated or measured energy and water consumed on-site during the construction installation process, as entered by the tool user.

Maintenance and Replacement [EN 15978 B2-B4] encompasses the replacement of materials in accordance with the expected service life. This includes the end of life treatment of the existing products, transportation to site, and cradle-to-gate manufacturing of the replacement products. The service life is specified separately for each product.

Operational Energy [EN 15978 B6] is based on the anticipated energy consumed at the building site over the lifetime of the building. Each associated dataset includes relevant upstream impacts associated with extraction of energy resources (such as coal or crude oil), including refining, combustion, transmission, losses, and other associated factors. For further detail, see Energy Metadata in the appendix.

End of Life [EN 15978 C2-C4, D] is based on average US construction and demolition waste treatment methods and rates. This includes the relevant material collection rates for recycling, processing requirements for recycled materials, incineration rates, and landfilling rates. 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. The impacts associated with landfilling are based on average material properties, such as plastic waste, biodegradable waste, or inert material. Specific end-of-life scenarios are detailed for each entry.

Data source and quality
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 6 using GaBi databases and in accordance with GaBi databases and modeling principles.

The data used are intended to represent the US and the year 2013. 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.

Uncertainty in results can stem from both the data used and its 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.

Tally methodology is consistent with LCA standards ISO 14040-14044 and EN 15978:2011.

Glossary of LCA Terminology

Environmental Impact Categories

The following list provides a description of environmental impact categories reported according to the TRACI 2.1 characterization scheme. References: [Bare 2010, EPA 2012, Guinée 2001]

Acidification Potential (AP) kg SO_2 eq

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 N eq

Eutrophication covers potential 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, because of the additional consumption of oxygen in biomass decomposition.

Global Warming Potential (GWP) kg CO_2 eq

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-11 eq

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.

Smog Formation Potential (SFP) kg O_3 eq

Ground level ozone is created by various chemical reactions, which occur 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. The primary sources of ozone precursors are motor vehicles, electric power utilities, and industrial facilities.

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

A measure of the total amount of primary energy extracted from the earth. PED is expressed in energy demand from non-renewable resources (e.g. petroleum, natural gas, etc.) and energy demand from renewable resources (e.g. hydropower, wind energy, solar, etc.). Efficiencies in energy conversion (e.g. power, heat, steam, etc.) are taken into account.

Building Life-Cycle Stages

The following diagram illustrates the organization of building life-cycle stages as described in EN 15978. Processes included in Tally modeling scope are shown in bold.

PRODUCT	CONSTRUCTION	USE	END OF LIFE
A1. Raw material supply	**A4. Transport**	B1. Use	C1. Demolition
A2. Transport	**A5. Construction installation process**	**B2. Maintenance**	**C2. Transport**
A3. Manufacturing		**B3. Repair**	**C3. Waste processing**
		B4. Replacement	**C4. Disposal**
		B5. Refurbishment	
		B6. Operational energy	**D. Reuse, recovery, and recycling potential**
		B7. Operational water	

LCA Metadata

NOTES

The following list provides a summary of all energy, construction, transportation, and materials inputs present in the selected study. Materials are listed in alphabetical order along with a list of all Revit families and Tally entries in which they occur and any notes and system boundaries accompanying their database entries. The mass given here refers to the full life-cycle mass of material, including manufacturing and replacement. The service life of the material used in each Revit family is indicated in parentheses. Values shown with an asterisk (*) indicate user-defined changes to default settings.

Transportation by Barge

Description:
Barge

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by barge. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Barge PE (2012), US: Diesel mix at filling station PE (2011)

Transportation by Container Ship

Description:
Container Ship

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by container ship. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Container ship PE (2013), US: Heavy fuel oil at refinery (0.3wt.% S) PE (2011)

Transportation by Rail

Description:
Rail

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by cargo rail. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
GLO: Rail transport cargo - Diesel PE (2013), US: Diesel mix at filling station PE (2011)

Transportation by Truck

Description:
Truck

Transportation Scope:
The data set represents the transportation of 1 kg of material from the manufacturer location to the building site by diesel truck. The default transportation distances are based on the transportation distances by three-digit material commodity code in the 2012 Commodity Flow Survey published by the US Department of Transportation Bureau of Transportation Statistics and the US Department of Commerce where more specific industry-level transportation was not available.

Entry Source:
US: Truck - Trailer, basic enclosed / 45,000 lb payload - 8b PE (2013), US: Diesel mix at filling station PE (2011)

Model Elements

Revit Categories
Ceilings, Curtainwall Mullions, Curtainwall Panels, Doors, Floors, Roofs, Stairs and Railings, Structure, Walls, Windows

Thesis Prototype w Analyzed Materials.rvt Worksets
N/A

Thesis Prototype w Analyzed Materials.rvt Phases
Existing, New Construction

Acrylic adhesive **14.3 kg**

Used in the following Revit families:
Wood Joist 10" - Linoleum 14.3 kg (35 yrs)

Used in the following Tally entries:
Flooring, linoleum, generic

Description:
Acrylic adhesive for use with linoleum flooring and assorted wall products.

Life Cycle Inventory:
40% limestone, 35% kaolin, 25% Naphtha
3.5% NMVOC emissions

Manufacturing Scope:
Cradle to gate, plus emissions during application

Transportation Distance:
By truck: 840 km

End of Life Scope:
96.5% solids to landfill (inert waste)

Entry Source:
US: Electricity grid mix PE (2010)
US: Limestone flour (5mm) PE (2012)
US: Kaolin (mining and processing) PE (2012)
US: Naphtha at refinery PE (2010)

Cork tile **1,244.2 kg**

Used in the following Revit families:
Slab on Grade - Cork Tile 235.4 kg (40 yrs)
Wood Joist 10" - Cork Tile 548.2 kg (40 yrs)
Wood Joist 10" - Cork Tile - Exposed Structure 460.6 kg (40 yrs)

Used in the following Tally entries:
Flooring, cork tile

Description:
Based on 3/16" thick cork flooring tile

Life Cycle Inventory:
Cork tile

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By container ship: 6437 km
By truck: 2414 km

End of Life Scope:
100% landfilled (biodegradable material)

Entry Source:
DE: Corkboard, 1m2, 8 mm (EN15804 A1-A3) PE (2012)

LCA Metadata (continued)

Domestic hardwood, US **2,739.3 kg**

Used in the following Revit families:

7" max riser 11" tread	383.4 kg (60 yrs)
Porch Floor	2,355.8 kg (60 yrs)

Used in the following Tally entries:
Domestic hardwood
Stair, hardwood

Description:
Dimensional lumber, sawn, planed, dried and cut for standard framing or planking

Life Cycle Inventory:
38% PNW
62% SE
Dimensional lumber
Proxied by softwood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
US: Surfaced dried lumber, at planer mill, PNW USLCI/PE (2009)
US: Surfaced dried lumber, at planer mill, SE USLCI/PE (2009)

Domestic softwood, US **2,939.5 kg**

Used in the following Revit families:

Basement Wall Furring	27.5 kg (60 yrs)
Exterior - Fiber Cement Siding on Wood Dtud 2	94.3 kg (60 yrs)
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2	11.9 kg (60 yrs)
GWB on Mtl. Stud	425.3 kg (60 yrs)
Interior - Gyp. Board Over Wood Stud (2x4)	78.3 kg (60 yrs)
Interior - Gyp. Board Over Wood Stud (2x6)	6.8 kg (60 yrs)
Timber-Column: 6x6	78.6 kg (60 yrs)
Wood Joist 10" - Cork Tile	458.2 kg (60 yrs)
Wood Joist 10" - Cork Tile - Exposed Structure	385.0 kg (60 yrs)
Wood Joist 10" - Linoleum	186.4 kg (60 yrs)
Wood Rafter 8" - Slate Shingle - Insulated	1,187.0 kg (60 yrs)

Used in the following Tally entries:
Domestic softwood
Wood framing
Wood framing with insulation

Description:
Dimensional lumber, sawn, planed, dried and cut for standard framing or planking

Life Cycle Inventory:
17% US Pacific Northwest
30% US Southeast
11% US Inland Northwest
US Northeast/North Central 3%
39% CA
Softwood lumber

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
RNA: Softwood lumber CORRIM (2011)

Door frame, wood, no door **193.6 kg**

Used in the following Revit families:

Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"	13.6 kg (40 yrs)
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"	28.8 kg (40 yrs)
Single-Flush: 24" x 80"	12.2 kg (40 yrs)
Single-Flush: 30" x 80"	112.9 kg (40 yrs)
Single-Flush: 30" x 84"	26.2 kg (40 yrs)

Used in the following Tally entries:
Door frame, wood

Description:
Wood door frame

Life Cycle Inventory:
Dimensional lumber

Manufacturing Scope:
Cradle to gate, excludes hardware, jamnb, casing, sealant

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Door, exterior, wood, solid core **112.8 kg**

Used in the following Revit families:

Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"	112.8 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, wood, solid core

Description:
Exterior wood door

Life Cycle Inventory:
28.9 kg/m² wood

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% wood products recovered (credited as avoided burden)
22% wood products incinerated with energy recovery
63.5% wood products landfilled (wood product waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Door, interior, wood, hollow core, flush **874.4 kg**

Used in the following Revit families:

Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"	79.3 kg (40 yrs)
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"	198.2 kg (40 yrs)
Single-Flush: 24" x 80"	40.1 kg (40 yrs)
Single-Flush: 30" x 80"	451.5 kg (40 yrs)
Single-Flush: 30" x 84"	105.4 kg (40 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush

Description:
Interior wood door with hollow core

LCA Metadata (continued)

Life Cycle Inventory:
16.2 kg/m²

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% wood products recovered (credited as avoided burden)
22% wood products incinerated with energy recovery
63.5% wood products landfilled (wood product waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Expanded polystyrene (EPS), board **75.1 kg**

Used in the following Revit families:
6" Foundation Slab 54.2 kg (60 yrs)
Slab on Grade - Cork Tile 20.9 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade

Description:
Insulation foam board

Life Cycle Inventory:
Expanded polystyrene board

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1299 km

End of Life Scope:
100% landfilled (plastic waste)

Entry Source:
RER: EPS - expanded polystyrene (white, 15kg/m³ cradle-to-gate, A1-A5) EUMEPS (2011)

Exterior grade plywood, US **1,488.2 kg**

Used in the following Revit families:
Exterior - Fiber Cement Siding on Wood Dtud 2 1,440.4 kg (60 yrs)
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2 47.8 kg (60 yrs)

Used in the following Tally entries:
Plywood, exterior grade

Description:
Plywood, unfinished

Life Cycle Inventory:
33% PNW
67% SE
Plywood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 468 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
US: Plywood, at plywood plant, PNW USLCI/PE (2009)
US: Plywood, at plywood plant, SE USLCI/PE (2009)

Fasteners, stainless steel **13.5 kg**

Used in the following Revit families:
Exterior - Fiber Cement Siding on Wood Dtud 2 5.4 kg (60 yrs)
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2 0.2 kg (60 yrs)
Wood Rafter 8" - Slate Shingle - Insulated 7.9 kg (60 yrs)

Used in the following Tally entries:
Fiber cement siding
Slate roofing shingles, EPD - Rathscheck Schiefer

Description:
Stainless steel part. Used for fasteners and some specialized hardware (bolts, rails, clips, etc.) that are linked to other entries by volume or weight of metal.

Life Cycle Inventory:
Stainless steel

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1001 km

End of Life Scope:
98% recovered (product has 58.1% scrap input while remainder is processed and credited as avoided burden)
2% landfilled (inert material)

Entry Source:
RER: Stainless steel Quarto plate (304) Eurofer (2008)
GLO: Steel turning PE (2011)
US: Electricity grid mix PE (2010)
RER: Stainless steel flat product (304) - value of scrap Eurofer (2008)

Fiber cement board, lap siding **2,395.6 kg**

Used in the following Revit families:
Exterior - Fiber Cement Siding on Wood Dtud 2 2,318.7 kg (60 yrs)
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2 76.9 kg (60 yrs)

Used in the following Tally entries:
Fiber cement siding

Description:
Fiber cement siding intended for exterior use

Life Cycle Inventory:
40% cement
10% cellulose
25% sand
25% fly ash

Manufacturing Scope:
Cradle to gate, excluding any coatings

Transportation Distance:
By truck: 172 km

End of Life Scope:
100% landfilled (10% biodegradable waste, 90% inert waste)

Entry Source:
DE: Fly ash (EN15804 A1-A3) PE (2012)
US: Portland cement, at plant USLCI/PE (2009)
DE: Cellulose fibre boards (EN 15804 A1-A3) PE (2012)
US: Silica sand (Excavation and processing) PE (2012)

Fiberglass blanket insulation, unfaced **684.8 kg**

Used in the following Revit families:
GWB on Mtl. Stud 684.8 kg (30 yrs)

Used in the following Tally entries:
Wood framing with insulation

Description:
Fiberglass batt

LCA Metadata (continued)

density varies from 10-14 kg/m³

Life Cycle Inventory:
Fiberglass

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
100% landfilled (inert waste)

Entry Source:
US: Fiberglass Batt NAIMA (2007)

Flooring, hardwood plank **132.6 kg**

Used in the following Revit families:
Porch Floor 132.6 kg (30 yrs)

Used in the following Tally entries:
Flooring, solid wood plank

Description:
Hardwood plank flooring
Proxied by laminated wood panel board

Life Cycle Inventory:
Laminated wood board

Manufacturing Scope:
Cradle to gate, excludes finishes
laminate as proxy for glue and adhesives during installation

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Laminated wood panel board PE (2012)

Flooring, linoleum, tile **112.4 kg**

Used in the following Revit families:
Wood Joist 10" - Linoleum 112.4 kg (30 yrs)

Used in the following Tally entries:
Flooring, linoleum, generic

Description:
Linoleum tile flooring

Life Cycle Inventory:
Linoleum

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By container ship: 8047 km
By truck: 2414 km

End of Life Scope:
100% landfilled (inert material)

Entry Source:
EU-25: Linoleum flooring ERFMI (2005)

Glazing, double, insulated (argon), low-E **751.5 kg**

Used in the following Revit families:
Casement Dbl without Trim: 36" x 32" 31.8 kg (40 yrs)
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84" 83.5 kg (40 yrs)
Double Hung: 24" x 48" 572.6 kg (40 yrs)
Fixed: 24" x 24" 15.9 kg (40 yrs)
Fixed: 36" x 48" 47.7 kg (40 yrs)

Used in the following Tally entries:
Glazing, double pane IGU

Description:
Glazing, double, insulated (argon filled), 1/4" float glass, low-E, inclusive of argon gas fill, sealant, and spacers

Life Cycle Inventory:
21.4 kg/m² glass. Argon filled, 0.15 kg/m² low-e coating

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 940 km

End of Life Scope:
100% to landfill (inert waste)

Entry Source:
DE: Double glazing unit PE (2012)

Hollow door, exterior, steel, powder-coated, with small vision panel **187.4 kg**

Used in the following Revit families:
Door-Overhead-Sectional: 8' x 6'-6" 187.4 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, steel

Description:
Hollow door, exterior, powder-coated steel 18 ga. inclusive of small vision panel, EPS insulation, no frame

Life Cycle Inventory:
Insulation: 0.79 kg/m²
Steel: 15.5 kg/m²
glass: 3.09 kg/m²

Manufacturing Scope:
Cradle to gate, excludes assembly, frame, hardware, and adhesives

Transportation Distance:
By truck: 568 km

End of Life Scope:
70% steel recovered (product has 7.14% scrap input while remainder is processed and credited as avoided burden)
30% steel landfilled (inert material)
100% insulation landfilled (plastic material)
100% glass landfilled (inert material)

Entry Source:
DE: Expanded Polystyrene (PS 25) (EN15804 A1-A3) PE (2012)
GLO: Steel sheet stamping and bending (5% loss) PE (2012)
GLO: Value of scrap worldsteel (2007)
US: Electricity grid mix PE (2010)
US: Lubricants at refinery PE (2007)
GLO: Compressed air 7 bar (medium power consumption) PE (2010)
GLO: Steel organic coated worldsteel (2007)
DE: Window glass simple (EN15804 A1-A3) PE (2012)

LCA Metadata (continued)

Hollow-core CMU, 8x8x16 ungrouted **16,542.4 kg**

Used in the following Revit families:
Generic - 8" Masonry 16,542.4 kg (60 yrs)

Used in the following Tally entries:
Hollow-core CMU, ungrouted

Description:
Hollow-Core CMU, 8x8x16 without grout
mortar to be linked

Life Cycle Inventory:
105 pcf material density

Manufacturing Scope:
Cradle to gate
excludes mortar
anchors, ties, and metal accessories outside of scope (<1% mass)

Transportation Distance:
By truck: 172 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Concrete bricks (EN15804 A1-A3) PE (2012)

Interior grade plywood, US **1,653.0 kg**

Used in the following Revit families:

Wood Joist 10" - Cork Tile	287.2 kg (60 yrs)
Wood Joist 10" - Cork Tile - Exposed Structure	241.3 kg (60 yrs)
Wood Joist 10" - Linoleum	175.2 kg (60 yrs)
Wood Rafter 8" - Slate Shingle - Insulated	949.2 kg (60 yrs)

Used in the following Tally entries:
Plywood, interior grade

Description:
Plywood, unfinished

Life Cycle Inventory:
22% US Pacific Northwest
66% US Southeast
12% CA
Softwood plywood

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 468 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

Entry Source:
RNA: Softwood plywood CORRIM (2011)

Mortar type S **5,312.1 kg**

Used in the following Revit families:
Generic - 8" Masonry 5,312.1 kg (50 yrs)

Used in the following Tally entries:
Hollow-core CMU, ungrouted

Description:
Mortar Type S (medium strength mortar for use with masonry walls and flooring)

Life Cycle Inventory:
72% aggregate
16% cement
12% water

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: Siliceous sand (grain size 0/2) PE (2012)
DE: Cement (CEM I 32.5) (EN15804 A1-A3) PE (2012)
DE: Gravel (Grain size 2/32) (EN15804 A1-A3) PE (2012)
US: Tap water from groundwater PE (2012)

Paint, exterior acrylic latex **515.7 kg**

Used in the following Revit families:

Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"	2.9 kg (10 yrs)
Exterior - Fiber Cement Siding on Wood Dtud 2	316.9 kg (10 yrs)
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2	10.5 kg (10 yrs)
Generic - 8" Masonry	175.2 kg (10 yrs)
Porch Floor	10.2 kg (10 yrs)

Used in the following Tally entries:
Domestic hardwood
Door, exterior, wood, solid core
Fiber cement siding
Hollow-core CMU, ungrouted

Description:
Application paint emulsion (building, exterior, white). Associated reference table includes primer.

Life Cycle Inventory:
4.5% organic solvents

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
100% to landfill (plastic waste)

Entry Source:
DE: Application paint emulsion (building, exterior, white) PE (2012)

Paint, interior acrylic latex **746.4 kg**

Used in the following Revit families:

Basement Wall Furring	52.4 kg (10 yrs)
Exterior - Fiber Cement Siding on Wood Dtud 2	253.6 kg (10 yrs)
GWB on Mtl. Stud	87.8 kg (10 yrs)
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"	2.9 kg (10 yrs)
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"	7.2 kg (10 yrs)
Interior - Gyp. Board Over Wood Stud (2x4)	238.7 kg (10 yrs)
Interior - Gyp. Board Over Wood Stud (2x6)	26.1 kg (10 yrs)
Single-Flush: 24" x 80"	1.5 kg (10 yrs)
Single-Flush: 30" x 80"	16.3 kg (10 yrs)
Single-Flush: 30" x 84"	3.8 kg (10 yrs)
Wood Joist 10" - Cork Tile	56.2 kg (10 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush
Wall board, gypsum

Description:
Application paint emulsion (building, interior, white, wear resistant)

LCA Metadata (continued)

Life Cycle Inventory:
2% organic solvents

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
100% to landfill (plastic waste)

Entry Source:
DE: Application paint emulsion (building, interior, white, wear resistant) PE (2012)

Polyethelene sheet vapor barrier (HDPE) **28.7 kg**

Used in the following Revit families:

6" Foundation Slab	15.1 kg (60 yrs)
Slab on Grade - Cork Tile	5.8 kg (60 yrs)
Slab on Grade - Uninsulated	7.8 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, slab on grade

Description:
Polyethelene sheet vapor barrier (HDPE) membrane (entry exclusive of adhesive or other co-products)

Life Cycle Inventory:
Polyethylene film

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1299 km

End of Life Scope:
10.5% recycled into HDPE (includes processing and avoided burden credit)
89.5% landiflled (plastic waste)

Entry Source:
US: Polyethylene High Density Granulate (PE-HD) PE (2012)
GLO: Plastic Film (PE, PP, PVC) PE (2012)
US: Electricity grid mix PE (2010)
US: Thermal energy from natural gas PE (2010)
US: Lubricants at refinery PE (2010)

Polystyrene board (XPS), Pentane foaming agent **288.6 kg**

Used in the following Revit families:

Basement Wall Furring	145.4 kg (30 yrs)
Rigid Insulation	143.3 kg (30 yrs)

Used in the following Tally entries:
Extruded polystyrene (XPS), board

Description:
XPS board, inclusive of pentane foaming agent

Life Cycle Inventory:
Extruded polystyrol rigid foam (XPS)

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 1299 km

End of Life Scope:
100% landfilled (plastic waste)

Entry Source:
DE: Extruded polystyrene (XPS) (EN15804 A1-A3) PE (2012)

Polyurethane floor finish, water-based **5.7 kg**

Used in the following Revit families:

Wood Joist 10" - Linoleum	5.7 kg (20 yrs)

Used in the following Tally entries:
Flooring, linoleum, generic

Description:
Water-based polyurethane wood stain, inclusive of catalyst

Life Cycle Inventory:
97.7% stain (50% water, 35% polyurethane dispersions, 5% dipropylene glycol dimethyl ether, 5% tri-butoxyethyl phosphate, 5% dipropylene glycol methyl ether), 2.3% catalyst (75% polyfunctional aziridine, 25% 2-propoxyethanol)
24.5% NMVOC emissions during application

Manufacturing Scope:
Cradle to gate, including emissions during application

Transportation Distance:
By truck: 642 km

End of Life Scope:
26.7% solids to landfill (plastic waste)

Entry Source:
DE: Ethylene glycol butyl ether PE (2012)
US: Epichlorohydrin (by product calcium chloride, hydrochloric acid) PE (2012)
DE: Propylenglycolmonomethylether (Methoxypropanol) PGME PE (2012)
US: Tap water from groundwater PE (2012)
DE: Polyurethane (copolymer-component) (estimation from TPU adhesive) PE (2012)
US: Electricity grid mix PE (2010)

Roofing shingles, slate, Rathscheck Schiefer, Colored Slate, EPD **4,378.5 kg**

Used in the following Revit families:

Wood Rafter 8" - Slate Shingle - Insulated	4,378.5 kg (60 yrs)

Used in the following Tally entries:
Slate roofing shingles, EPD - Rathscheck Schiefer

Description:
Roof and facade slate tile, exclusive of clips/fasteners
ColorSklent slate from Rathscheck Slate.

Life Cycle Inventory:
Slate

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 217 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
DE: ColorSklent (coloured slate) - Rathscheck Schiefer PE-EPD (2008)

Stainless steel, door hardware, lever lock, exterior, residential **26.3 kg**

Used in the following Revit families:

Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"	7.6 kg (30 yrs)
Door-Overhead-Sectional: 8' x 6'-6"	18.7 kg (30 yrs)

Used in the following Tally entries:
Door, exterior, steel
Door, exterior, wood, solid core

Description:
Stainless steel door fitting (hinges and lockset) for use on residential exterior door assemblies.

LCA Metadata (continued)

Life Cycle Inventory:
Door hinges 0.622 kg/part, Light duty mortise lockset 2.32kg/part

Manufacturing Scope:
Cradle to gate, including disposal of packaging.

Transportation Distance:
By truck: 1001 km

End of Life Scope:
90% collection rate
remaining 10% deposited in the LCA model without recycling
material recycling efficiency dependant on the metal (89% steel, 90.2% aluminum, stainless steel 83%, zinc 91%, brass 94%)
Plastic components incinerated resulting in credits for electricity and thermal energy

Entry Source:
DE: Fitting stainless steel - FSB (2009)

Stainless steel, door hardware, lever lock, interior, residential **61.0 kg**

Used in the following Revit families:

Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"	5.5 kg (40 yrs)
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"	13.8 kg (40 yrs)
Single-Flush: 24" x 80"	2.8 kg (40 yrs)
Single-Flush: 30" x 80"	31.5 kg (40 yrs)
Single-Flush: 30" x 84"	7.3 kg (40 yrs)

Used in the following Tally entries:
Door, interior, wood, hollow core, flush

Description:
Stainless steel door fitting (hinges and lockset) for use on residential interior door assemblies.

Life Cycle Inventory:
Door hinges 0.622 kg/part, Battalion Lever Lockset, Light Duty, Privacy 0.70 kg/part

Manufacturing Scope:
Cradle to gate, including disposal of packaging.

Transportation Distance:
By truck: 1001 km

End of Life Scope:
90% collection rate
remaining 10% deposited in the LCA model without recycling
material recycling efficiency dependant on the metal (89% steel, 90.2% aluminum, stainless steel 83%, zinc 91%, brass 94%)
Plastic components incinerated resulting in credits for electricity and thermal energy

Entry Source:
DE: Fitting stainless steel - FSB (2009)

Steel, reinforcing rod **559.9 kg**

Used in the following Revit families:

6" Foundation Slab	236.5 kg (60 yrs)
Concrete-Round-Column: 12"	11.6 kg (60 yrs)
Generic - 8" Masonry	97.5 kg (60 yrs)
Slab on Grade - Cork Tile	91.3 kg (60 yrs)
Slab on Grade - Uninsulated	123.0 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
Cast-in-place concrete, slab on grade
Hollow-core CMU, ungrouted

Description:
Steel rod suitable for structural reinforcement (rebar), common unfinished tempered steel

Life Cycle Inventory:
Steel rebar

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 431 km

End of Life Scope:
70% recovered (product has 69.8% scrap input while remainder is processed and credited as avoided burden)
30% landfilled (inert material)

Entry Source:
GLO: Steel rebar worldsteel (2007)

Structural concrete, 3000 psi, generic **22,922.7 kg**

Used in the following Revit families:

6" Foundation Slab	11,823.8 kg (60 yrs)
Concrete-Round-Column: 12"	388.0 kg (60 yrs)
Slab on Grade - Cork Tile	4,563.3 kg (60 yrs)
Slab on Grade - Uninsulated	6,147.5 kg (60 yrs)

Used in the following Tally entries:
Cast-in-place concrete, reinforced structural concrete, 3000 psi (20 Mpa)
Cast-in-place concrete, slab on grade

Description:
Structural concrete, generic, 3000 psi

Life Cycle Inventory:
13% cement
40% gravel
39% sand
7% water

Manufacturing Scope:
Cradle to gate
excludes mixing and pouring impacts

Transportation Distance:
By truck: 24 km

End of Life Scope:
50% recycled into coarse aggregate (includes grinding energy and avoided burden credit)
50% landfilled (inert material)

Entry Source:
US: Portland cement, at plant USLCI/PE (2009)
US: Tap water from groundwater PE (2012)
EU-27: Gravel 2/32 PE (2012)
US: Silica sand (Excavation and processing) PE (2012)

Trim, wood **2.5 kg**

Used in the following Revit families:

Casement Dbl without Trim: 36" x 32"	2.5 kg (30 yrs)

Used in the following Tally entries:
Trim, wood

Description:
Wood trim

Life Cycle Inventory:
38% PNW
62% SE

Manufacturing Scope:
Cradle to gate, excludes fill or chemical treatments

Transportation Distance:
By truck: 383 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (untreated wood waste)

LCA Metadata (continued)

Entry Source:
US: Panel trim, from trim and saw at plywood plant, US PNW USLCI/PE (2009)
US: Panel trim, from trim and saw at plywood plant, US SE USLCI/PE (2009)

Urethane adhesive **372.0 kg**

Used in the following Revit families:

Slab on Grade - Cork Tile	70.4 kg (40 yrs)
Wood Joist 10" - Cork Tile	163.9 kg (40 yrs)
Wood Joist 10" - Cork Tile - Exposed Structure	137.7 kg (40 yrs)

Used in the following Tally entries:
Flooring, cork tile

Description:
Urethane adhesive for use with flooring and wall coverings.

Life Cycle Inventory:
50% limestone, 13% lime, 30% polyurethane, 1.5% stearic acid, 5% Methylene bis(phenylisocyanate) (MDI)
1.3% NMVOC emissions

Manufacturing Scope:
Cradle to gate, plus emissions during application

Transportation Distance:
By truck: 840 km

End of Life Scope:
98.7% solids to landfill (plastic waste)

Entry Source:
US: Limestone flour (5mm) PE (2012)
DE: Polyurethane (copolymer-component) (estimation from TPU adhesive) PE (2012)
US: Lime (CaO) calcination PE (2012)
US: Methylene diisocyanate (MDI) PE (2012)
DE: Stearic acid PE (2012)
US: Electricity grid mix PE (2010)

Wall board, gypsum, natural **15,492.7 kg**

Used in the following Revit families:

Basement Wall Furring	1,135.6 kg (30 yrs)
Exterior - Fiber Cement Siding on Wood Dtud 2	5,496.1 kg (30 yrs)
GWB on Mtl. Stud	1,902.2 kg (30 yrs)
Interior - Gyp. Board Over Wood Stud (2x4)	5,174.8 kg (30 yrs)
Interior - Gyp. Board Over Wood Stud (2x6)	565.7 kg (30 yrs)
Wood Joist 10" - Cork Tile	1,218.3 kg (30 yrs)

Used in the following Tally entries:
Wall board, gypsum

Description:
Natural gypsum board

Life Cycle Inventory:
1 kg gypsum wallboard

Manufacturing Scope:
Cradle to gate

Transportation Distance:
By truck: 172 km

End of Life Scope:
54% recycled into gypsum stone (includes grinding and avoided burden credit)
46% landfilled (inert waste)

Entry Source:
DE: Gypsum wallboard (EN15804 A1-A3) PE (2012)

Window frame, wood, divided operable **9.0 kg**

Used in the following Revit families:

Casement Dbl without Trim: 36" x 32"	9.0 kg (30 yrs)

Used in the following Tally entries:
Window frame, wood

Description:
Wood divided operable window frame inclusive of paint

Life Cycle Inventory:
1.30 kg/m

Manufacturing Scope:
Cradle to gate
excludes hardware, casing, sealant beyond paint

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Window frame, wood, fixed **17.4 kg**

Used in the following Revit families:

Fixed: 24" x 24"	6.3 kg (30 yrs)
Fixed: 36" x 48"	11.1 kg (30 yrs)

Used in the following Tally entries:
Window frame, wood

Description:
Wood fixed window frame inclusive of paint

Life Cycle Inventory:
1.30 kg/m

Manufacturing Scope:
Cradle to gate
excludes hardware, casing, sealant beyond paint

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Window frame, wood, operable **171.2 kg**

Used in the following Revit families:

Double Hung: 24" x 48"	171.2 kg (30 yrs)

Used in the following Tally entries:
Window frame, wood

Description:
Operable wood casement window frame inclusive of paint

Life Cycle Inventory:
1.30 kg/m

Manufacturing Scope:
Cradle to gate
excludes hardware, casing, sealant beyond paint

LCA Metadata (continued)

Transportation Distance:
By truck: 496 km

End of Life Scope:
14.5% recovered (credited as avoided burden)
22% incinerated with energy recovery
63.5% landfilled (wood product waste)

Entry Source:
DE: Wooden frame (EN15804 A1-A3) PE (2012)

Appendix B:

Complete Tally Datasets

Contents:

Table B-1: Total Embodied Impacts of Baseline Model:

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Thesis Baseline.rvt	156.25	26.84	39,876.89	1.67E-03	2,146.67	702,272.69	450,957.72	251,477.56	73,178.52
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-2: Embodied Impacts by Life Cycle Stage (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	27.55	4.93	7,570.22	-1.51E-05	143.30	-41,301.82	-12,196.12	-29,107.93	
Maintenance and Replacement	55.12	12.04	14,513.64	8.17E-04	799.52	298,990.17	206,959.99	92,093.42	18,034.96
Manufacturing	69.49	9.50	16,953.32	8.72E-04	1,074.91	432,572.65	244,292.38	188,305.83	55,143.56
Transportation	4.08	0.37	839.72	7.20E-09	128.93	12,011.68	11,901.48	186.24	
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-3: Embodied Impacts by Life Cycle Stage and CSI Division (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	**27.55**	**4.93**	**7,570.22**	**-1.51E-05**	**143.30**	**-41,301.82**	**-12,196.12**	**-29,107.93**	
03 - Concrete	1.97	0.28	415.20	4.83E-08	34.45	6,857.15	6,567.50	289.65	
04 - Masonry	1.75	0.24	382.63	1.99E-08	31.37	6,368.55	6,104.17	264.38	
05 - Metals	-0.28	-0.01	-61.44	-6.93E-07	-2.48	-829.75	-546.26	-283.48	
06 - Wood/Plastics/Composites	18.16	2.14	6,159.19	-4.44E-07	64.88	-45,100.56	-20,781.85	-24,318.72	
07 - Thermal and Moisture Protection	0.41	0.07	75.59	1.07E-08	7.00	1,232.37	1,178.15	54.21	
08 - Openings and Glazing	0.64	0.86	-87.41	-1.40E-05	-12.33	-8,995.34	-5,732.36	-3,265.22	
09 - Finishes	4.90	1.34	686.47	-2.91E-08	20.41	-834.23	1,014.52	-1,848.76	
Maintenance and Replacement	**55.12**	**12.04**	**14,513.64**	**8.17E-04**	**799.52**	**298,990.17**	**206,959.99**	**92,093.42**	**18,034.96**
03 - Concrete	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
04 - Masonry	0.84	0.12	359.57	5.06E-09	18.49	2,800.46	2,634.87	168.25	2,245.05
05 - Metals	0.12	0.00	31.52	3.59E-07	1.35	463.86	371.22	92.75	15.87
06 - Wood/Plastics/Composites	19.14	1.92	4,261.99	3.51E-05	228.84	80,030.88	23,966.63	56,075.08	4,078.45
07 - Thermal and Moisture Protection	7.81	4.28	2,675.11	9.04E-06	115.37	78,035.48	76,630.08	1,407.84	1,619.01
08 - Openings and Glazing	11.87	2.03	2,649.89	7.72E-04	168.13	50,173.68	30,628.26	19,573.76	1,056.51
09 - Finishes	15.36	3.69	4,535.56	6.23E-08	267.34	87,485.81	72,728.93	14,775.74	9,020.07
Manufacturing	**69.49**	**9.50**	**16,953.32**	**8.72E-04**	**1,074.91**	**432,572.65**	**244,292.38**	**188,305.83**	**55,143.56**
03 - Concrete	19.93	1.03	4,499.45	3.89E-05	268.32	34,365.66	33,292.08	1,073.58	17,861.85
04 - Masonry	3.89	0.32	1,874.65	1.02E-06	86.78	12,936.65	11,670.68	1,265.97	16,310.06
05 - Metals	0.39	0.01	91.75	1.05E-06	3.65	1,276.29	900.33	375.97	15.87
06 - Wood/Plastics/Composites	22.13	1.67	2,699.74	3.54E-05	327.96	189,748.00	43,617.08	146,130.92	9,703.36
07 - Thermal and Moisture Protection	7.26	4.19	2,572.58	9.03E-06	104.23	76,417.76	75,070.10	1,347.66	1,619.01
08 - Openings and Glazing	10.92	1.14	2,667.98	7.86E-04	170.89	58,025.13	35,232.67	22,818.02	1,046.24
09 - Finishes	4.98	1.14	2,547.18	4.72E-08	113.09	59,803.16	44,509.45	15,293.71	8,587.18
Transportation	**4.08**	**0.37**	**839.72**	**7.20E-09**	**128.93**	**12,011.68**	**11,901.48**	**186.24**	
03 - Concrete	0.26	0.02	53.63	4.60E-10	8.23	767.15	760.11	11.89	
04 - Masonry	1.05	0.10	215.39	1.85E-09	33.07	3,081.09	3,052.82	47.77	
05 - Metals	0.01	0.00	1.21	1.04E-11	0.19	17.31	17.15	0.27	
06 - Wood/Plastics/Composites	1.46	0.13	300.58	2.58E-09	46.15	4,299.64	4,260.20	66.66	
07 - Thermal and Moisture Protection	0.13	0.01	26.94	2.31E-10	4.14	385.36	381.82	5.97	
08 - Openings and Glazing	0.27	0.02	54.91	4.71E-10	8.43	785.41	778.20	12.18	
09 - Finishes	0.91	0.08	187.06	1.60E-09	28.72	2,675.73	2,651.18	41.49	
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-4: Embodied Impacts by Life Cycle Stage and Revit Category (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	**27.55**	**4.93**	**7,570.22**	**-1.51E-05**	**143.30**	**-41,301.82**	**-12,196.12**	**-29,107.93**	
Ceilings	0.77	0.09	243.70	-1.50E-08	4.62	-1,113.90	-282.08	-831.83	
Doors	-0.25	0.68	-231.63	-1.47E-05	-17.10	-9,599.66	-6,298.04	-3,303.86	
Floors	7.68	1.67	1,704.16	-1.21E-07	21.98	-11,465.74	-4,985.67	-6,480.07	
Roofs	3.79	0.45	1,242.51	-7.68E-08	18.61	-7,456.69	-2,874.85	-4,581.84	
Stairs and Railings	0.47	0.06	141.82	-1.40E-09	3.85	-249.70	157.59	-407.29	
Structure	1.82	0.26	382.04	4.15E-08	31.72	6,304.30	6,037.76	266.54	
Walls	12.67	1.55	4,004.04	-2.21E-07	77.31	-17,489.03	-3,967.48	-13,521.55	
Windows	0.61	0.17	83.59	-4.51E-09	2.31	-231.39	16.65	-248.04	
Maintenance and Replacement	**55.12**	**12.04**	**14,513.64**	**8.17E-04**	**799.52**	**298,990.17**	**206,959.99**	**92,093.42**	**18,034.96**
Ceilings	3.69	0.26	914.18	3.36E-05	50.74	16,510.13	15,330.99	1,180.57	1,056.57
Doors	6.85	1.43	1,594.09	7.72E-04	69.16	28,501.14	16,548.59	11,978.38	623.40
Floors	7.72	2.95	1,766.50	-2.41E-10	125.54	34,716.49	21,858.16	12,868.38	2,820.30
Roofs	7.24	4.03	2,472.47	1.24E-06	103.80	72,139.25	70,797.56	1,343.55	1,554.50
Stairs and Railings	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
Structure	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
Walls	24.49	2.76	6,677.90	9.38E-06	349.90	124,966.39	67,970.55	57,017.26	11,529.98
Windows	5.14	0.60	1,088.49	3.28E-08	100.37	22,156.78	14,454.12	7,705.28	450.21
Manufacturing	**69.49**	**9.50**	**16,953.32**	**8.72E-04**	**1,074.91**	**432,572.65**	**244,292.38**	**188,305.83**	**55,143.56**
Ceilings	3.59	0.21	808.30	3.36E-05	47.87	17,734.81	12,963.67	4,771.14	1,340.11
Doors	6.92	0.74	1,784.04	7.87E-04	80.94	37,352.31	22,110.46	15,267.42	613.13
Floors	6.22	1.09	1,275.96	1.52E-07	127.72	59,293.38	23,351.07	35,942.30	4,494.81
Roofs	10.48	4.23	2,770.57	1.25E-06	149.22	102,216.71	75,814.23	26,402.48	3,342.42
Stairs and Railings	2.16	0.08	451.96	3.11E-06	28.85	6,207.17	3,093.63	3,113.54	1,608.53
Structure	18.06	0.97	4,082.50	3.58E-05	243.96	31,650.90	30,730.32	920.58	16,419.38
Walls	17.66	1.77	4,803.97	1.05E-05	302.72	156,142.42	62,200.96	93,941.45	26,874.97
Windows	4.38	0.41	976.01	3.70E-08	93.63	21,974.95	14,028.03	7,946.91	450.21
Transportation	**4.08**	**0.37**	**839.72**	**7.20E-09**	**128.93**	**12,011.68**	**11,901.48**	**186.24**	
Ceilings	0.11	0.01	23.26	1.99E-10	3.57	332.65	329.60	5.16	
Doors	0.13	0.01	27.26	2.34E-10	4.19	390.00	386.42	6.05	
Floors	0.79	0.07	162.80	1.40E-09	25.00	2,328.70	2,307.34	36.11	
Roofs	0.38	0.03	78.78	6.75E-10	12.10	1,126.91	1,116.57	17.47	
Stairs and Railings	0.05	0.00	9.41	8.06E-11	1.44	134.61	133.37	2.09	
Structure	0.24	0.02	49.07	4.20E-10	7.53	701.87	695.43	10.88	
Walls	2.23	0.20	460.26	3.94E-09	70.67	6,583.70	6,523.30	102.08	
Windows	0.14	0.01	28.89	2.48E-10	4.44	413.23	409.44	6.41	
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-5: Embodied Impacts by CSI Division (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	22.16	1.33	4,968.27	3.90E-05	311.01	41,989.96	40,619.68	1,375.13	17,861.85
04 - Masonry	7.53	0.78	2,832.23	1.05E-06	169.71	25,186.75	23,462.54	1,746.37	18,555.12
05 - Metals	0.23	0.01	63.04	7.17E-07	2.71	927.72	742.44	185.50	31.73
06 - Wood/Plastics/Composites	60.88	5.86	13,421.50	7.01E-05	667.83	228,977.96	51,062.06	177,953.95	13,781.81
07 - Thermal and Moisture Protection	15.61	8.55	5,350.22	1.81E-05	230.73	156,070.96	153,260.16	2,815.69	3,238.02
08 - Openings and Glazing	23.69	4.05	5,285.36	1.54E-03	335.11	99,988.88	60,906.77	39,138.74	2,102.75
09 - Finishes	26.15	6.25	7,956.27	8.20E-08	429.56	149,130.46	120,904.08	28,262.17	17,607.24
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-6: Embodied Impacts by CSI Division and Tally Entry (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	**22.16**	**1.33**	**4,968.27**	**3.90E-05**	**311.01**	**41,989.96**	**40,619.68**	**1,375.13**	**17,861.85**
Cast-in-place concrete; slab on grade	20.12	1.26	4,513.60	3.58E-05	283.22	38,657.07	37,463.51	1,198.00	16,419.38
Stair; cast-in-place concrete	2.04	0.08	454.67	3.12E-06	27.79	3,332.89	3,156.17	177.13	1,442.47
04 - Masonry	**7.53**	**0.78**	**2,832.23**	**1.05E-06**	**169.71**	**25,186.75**	**23,462.54**	**1,746.37**	**18,555.12**
Hollow-core CMU; ungrouted	7.53	0.78	2,832.23	1.05E-06	169.71	25,186.75	23,462.54	1,746.37	18,555.12
05 - Metals	**0.23**	**0.01**	**63.04**	**7.17E-07**	**2.71**	**927.72**	**742.44**	**185.50**	**31.73**
Aluminum; hardware	0.23	0.01	63.04	7.17E-07	2.71	927.72	742.44	185.50	31.73
06 - Wood/Plastics/Composites	**60.88**	**5.86**	**13,421.50**	**7.01E-05**	**667.83**	**228,977.96**	**51,062.06**	**177,953.95**	**13,781.81**
Plywood; exterior grade	10.87	1.11	2,380.42	-9.04E-08	104.90	41,210.48	6,680.11	34,538.41	2,490.57
Plywood; interior grade	3.39	0.26	644.61	7.90E-08	38.61	9,277.29	1,984.82	7,294.65	675.57
Stair; hardwood	0.63	0.07	148.52	-6.42E-09	6.36	2,759.19	228.42	2,531.21	166.06
Wood framing	8.41	0.67	1,829.56	-7.92E-08	92.61	20,885.84	1,898.38	18,993.14	2,149.75
Wood framing with insulation	6.71	0.43	1,400.99	6.72E-05	79.43	22,737.25	17,955.81	4,782.94	858.20
Wood siding; hardwood	30.87	3.32	7,017.39	3.01E-06	345.92	132,107.91	22,314.51	109,813.61	7,441.66
07 - Thermal and Moisture Protection	**15.61**	**8.55**	**5,350.22**	**1.81E-05**	**230.73**	**156,070.96**	**153,260.16**	**2,815.69**	**3,238.02**
Expanded polystyrene (EPS); board	1.13	0.48	405.28	1.56E-05	23.13	11,792.47	11,665.03	128.60	129.03
SBS modified asphalt shingles	14.48	8.07	4,944.94	2.47E-06	207.61	144,278.50	141,595.13	2,687.09	3,108.99
08 - Openings and Glazing	**23.69**	**4.05**	**5,285.36**	**1.54E-03**	**335.11**	**99,988.88**	**60,906.77**	**39,138.74**	**2,102.75**
Door frame; wood	3.26	0.45	828.66	4.26E-08	43.27	24,189.85	11,895.28	12,295.12	161.93
Door; exterior; aluminum	2.69	0.79	1,088.29	1.51E-03	30.13	12,369.62	11,393.69	1,023.36	169.47
Door; exterior; wood; solid core	1.00	0.23	156.15	5.02E-06	6.87	2,572.99	1,052.15	1,521.26	116.35
Door; interior; wood; hollow core; flush	5.76	1.31	905.80	3.04E-05	37.55	14,891.65	6,031.33	8,862.81	678.19
Glazing; double pane IGU	7.04	0.72	1,306.13	1.58E-08	165.06	16,763.33	16,174.61	593.79	781.33
Window frame; wood	3.93	0.55	1,000.34	5.14E-08	52.23	29,201.45	14,359.72	14,842.40	195.48
09 - Finishes	**26.15**	**6.25**	**7,956.27**	**8.20E-08**	**429.56**	**149,130.46**	**120,904.08**	**28,262.17**	**17,607.24**
Ceramic tile; unglazed	2.42	0.18	915.24	1.37E-08	47.81	14,907.46	14,453.91	466.97	2,525.04
Flooring; solid wood plank	11.05	4.88	1,886.64	-3.16E-08	142.00	40,270.50	15,509.29	24,765.67	1,610.12
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Wall board; gypsum	12.67	1.19	5,152.04	9.99E-08	239.65	93,911.73	90,934.41	2,995.23	13,469.62
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-7: Embodied Impacts by CSI Division and Material (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	**22.16**	**1.33**	**4,968.27**	**3.90E-05**	**311.01**	**41,989.96**	**40,619.68**	**1,375.13**	**17,861.85**
Expanded polystyrene (EPS); board	0.64	0.28	230.51	8.88E-06	13.15	6,707.16	6,634.68	73.14	73.39
Polyethelene sheet vapor barrier (HDPE)	0.14	0.25	56.88	4.50E-09	2.44	1,667.37	1,650.69	16.86	20.39
Steel; reinforcing rod	1.43	0.08	501.33	4.66E-06	19.30	6,532.83	5,624.17	909.79	382.20
Structural concrete; 3000 psi; generic	18.14	0.66	3,806.32	2.31E-05	251.46	24,810.97	24,467.62	346.00	16,005.49
Structural concrete; 5000 psi; generic	1.81	0.06	373.23	2.36E-06	24.65	2,271.63	2,242.53	29.33	1,380.38
04 - Masonry	**7.53**	**0.78**	**2,832.23**	**1.05E-06**	**169.71**	**25,186.75**	**23,462.54**	**1,746.37**	**18,555.12**
Hollow-core CMU; 8x8x16 ungrouted	5.54	0.52	2,004.96	3.46E-08	128.57	18,176.61	16,979.58	1,213.62	13,982.56
Mortar type S	1.68	0.24	719.13	1.01E-08	36.97	5,600.91	5,269.74	336.50	4,490.11
Steel; reinforcing rod	0.31	0.02	108.14	1.01E-06	4.16	1,409.23	1,213.22	196.26	82.45
05 - Metals	**0.23**	**0.01**	**63.04**	**7.17E-07**	**2.71**	**927.72**	**742.44**	**185.50**	**31.73**
Hardware; aluminum	0.23	0.01	63.04	7.17E-07	2.71	927.72	742.44	185.50	31.73
06 - Wood/Plastics/Composites	**60.88**	**5.86**	**13,421.50**	**7.01E-05**	**667.83**	**228,977.96**	**51,062.06**	**177,953.95**	**13,781.81**
Domestic hardwood; US	27.97	3.04	6,546.34	-2.83E-07	280.22	121,614.56	10,067.69	111,566.22	7,319.49
Domestic softwood; US	9.69	0.78	2,109.37	-9.13E-08	106.78	24,080.04	2,188.71	21,897.87	2,478.52
Exterior grade plywood; US	10.87	1.11	2,380.42	-9.04E-08	104.90	41,210.48	6,680.11	34,538.41	2,490.57
Fasteners; stainless steel	0.57	0.08	41.46	3.27E-06	2.32	636.33	545.33	91.07	9.51
Fiberglass blanket insulation; unfaced	5.43	0.33	1,121.18	6.72E-05	65.27	19,543.05	17,665.48	1,878.20	529.43
Interior grade plywood; US	3.39	0.26	644.61	7.90E-08	38.61	9,277.29	1,984.82	7,294.65	675.57
Paint; exterior acrylic latex	2.96	0.27	578.11	2.57E-08	69.73	12,616.20	11,929.90	687.53	278.72
07 - Thermal and Moisture Protection	**15.61**	**8.55**	**5,350.22**	**1.81E-05**	**230.73**	**156,070.96**	**153,260.16**	**2,815.69**	**3,238.02**
Expanded polystyrene (EPS); board	1.13	0.48	405.28	1.56E-05	23.13	11,792.47	11,665.03	128.60	129.03
Fasteners; stainless steel	0.34	0.05	24.86	1.96E-06	1.39	381.52	326.96	54.60	5.70
Roofing shingles; SBS modified asphalt; strip	14.14	8.02	4,920.08	5.16E-07	206.21	143,896.98	141,268.17	2,632.49	3,103.29
08 - Openings and Glazing	**23.69**	**4.05**	**5,285.36**	**1.54E-03**	**335.11**	**99,988.88**	**60,906.77**	**39,138.74**	**2,102.75**
Door frame; wood; no door	3.26	0.45	828.66	4.26E-08	43.27	24,189.85	11,895.28	12,295.12	161.93
Door; exterior; wood; solid core	0.84	0.20	104.99	-3.90E-09	4.72	1,747.47	274.29	1,473.54	106.50
Door; interior; wood; hollow core; flush	4.92	1.17	613.28	-2.28E-08	27.58	10,207.06	1,602.14	8,607.04	622.08
Glazing; double; insulated (argon); low-E	7.04	0.72	1,306.13	1.58E-08	165.06	16,763.33	16,174.61	593.79	781.33
Hollow door; exterior; aluminum; powder-coated; with small vision panel	1.93	0.66	825.41	1.48E-03	21.63	8,310.69	7,571.46	786.37	128.21
Paint; exterior acrylic latex	0.03	0.00	5.60	2.48E-10	0.68	122.16	115.52	6.66	2.70
Stainless steel; door hardware; lever lock + push bar; exterior; commercial	0.76	0.13	262.88	2.90E-05	8.50	4,058.93	3,822.23	236.98	41.26
Stainless steel; door hardware; lever lock; exterior; residential	0.13	0.02	45.55	5.02E-06	1.47	703.36	662.34	41.07	7.15
Stainless steel; door hardware; lever lock; interior; residential	0.80	0.14	276.49	3.05E-05	8.94	4,269.03	4,020.08	249.25	43.39
Window frame; wood; divided operable	3.93	0.55	1,000.34	5.14E-08	52.23	29,201.45	14,359.72	14,842.40	195.48
Wood stain; water based	0.04	0.01	16.04	6.31E-10	1.03	415.56	409.11	6.51	12.72

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
09 - Finishes	**26.15**	**6.25**	**7,956.27**	**8.20E-08**	**429.56**	**149,130.46**	**120,904.08**	**28,262.17**	**17,607.24**
Ceramic tile; unglazed	2.37	0.17	897.06	1.35E-08	46.78	14,749.09	14,304.58	457.77	2,386.98
Flooring; hardwood plank	10.56	2.87	1,660.60	-3.92E-08	58.98	34,997.13	10,404.31	24,596.79	1,499.44
Paint; interior acrylic latex	6.62	0.70	1,559.25	6.02E-08	116.18	36,125.06	34,278.18	1,849.51	593.99
Polyurethane floor finish; water-based	0.49	2.01	226.04	7.61E-09	83.02	5,273.37	5,104.98	168.88	110.68
Thinset mortar	0.05	0.01	18.18	2.80E-10	1.03	158.37	149.33	9.20	138.06
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Wall board; gypsum; natural	6.05	0.50	3,592.79	3.97E-08	123.47	57,786.67	56,656.23	1,145.72	12,875.62
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-8: Embodied Impacts by Revit Category (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	8.16	0.57	1,989.45	6.72E-05	106.81	33,463.69	28,342.19	5,125.05	2,396.68
Doors	13.65	2.86	3,173.77	1.54E-03	137.19	56,643.79	32,747.43	23,947.98	1,236.53
Floors	22.41	5.78	4,909.41	3.21E-08	300.24	84,872.83	42,530.91	42,366.72	7,315.11
Roofs	21.90	8.75	6,564.33	2.41E-06	283.73	168,026.18	144,853.52	23,181.66	4,896.92
Stairs and Railings	2.68	0.14	603.19	3.11E-06	34.15	6,092.07	3,384.59	2,708.34	1,608.53
Structure	20.12	1.26	4,513.60	3.58E-05	283.22	38,657.07	37,463.51	1,198.00	16,419.38
Walls	57.05	6.28	15,946.17	1.97E-05	800.60	270,203.48	132,727.33	137,539.25	38,404.95
Windows	10.28	1.20	2,176.98	6.56E-08	200.74	44,313.57	28,908.25	15,410.55	900.42
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-9: Embodied Impacts by Revit Category and Family (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**8.16**	**0.57**	**1,989.45**	**6.72E-05**	**106.81**	**33,463.69**	**28,342.19**	**5,125.05**	**2,396.68**
GWB on Mtl. Stud	8.16	0.57	1,989.45	6.72E-05	106.81	33,463.69	28,342.19	5,125.05	2,396.68
Doors	**13.65**	**2.86**	**3,173.77**	**1.54E-03**	**137.19**	**56,643.79**	**32,747.43**	**23,947.98**	**1,236.53**
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 34" x 84"	1.95	0.31	351.02	5.73E-06	26.24	5,192.68	3,427.14	1,766.70	226.94
Door-Overhead-Sectional: 8' x 6'-6"	2.69	0.79	1,088.29	1.51E-03	30.13	12,369.62	11,393.69	1,023.36	169.47
Single-Flush: 22" x 80"	1.17	0.22	230.15	3.61E-06	10.86	5,352.37	2,479.24	2,873.50	104.25
Single-Flush: 24" x 80"	0.62	0.12	120.62	1.97E-06	5.67	2,775.98	1,281.75	1,494.43	55.91
Single-Flush: 28" x 30"	0.68	0.13	131.71	2.29E-06	6.14	2,975.56	1,366.01	1,609.79	63.46
Single-Flush: 30" x 80"	5.74	1.13	1,098.07	1.97E-05	51.05	24,602.85	11,265.09	13,339.71	537.92
Single-Flush: 36" x 80"	0.82	0.16	153.90	2.95E-06	7.09	3,374.74	1,534.52	1,840.50	78.58
Floors	**22.41**	**5.78**	**4,909.41**	**3.21E-08**	**300.24**	**84,872.83**	**42,530.91**	**42,366.72**	**7,315.11**
Wood Joist 10" - Tile Finish - Exposed Structure 2	3.66	0.28	1,169.45	2.01E-08	61.65	18,121.65	14,931.86	3,204.03	2,810.41
Wood Joist 10" - Wood Finish	11.24	3.18	2,361.36	1.13E-08	146.57	42,235.24	19,844.41	22,397.66	3,176.25
Wood Joist 10" - Wood Finish - Exposed Structure	7.52	2.32	1,378.60	5.76E-10	92.01	24,515.94	7,754.64	16,765.03	1,328.46
Roofs	**21.90**	**8.75**	**6,564.33**	**2.41E-06**	**283.73**	**168,026.18**	**144,853.52**	**23,181.66**	**4,896.92**
Wood Rafter 8" - Asphalt Shingle - Insulated	15.92	6.36	4,771.25	1.75E-06	206.23	122,129.11	105,286.16	16,849.49	3,559.30
Wood Rafter 8" - Asphalt Shingle - Uninsulated	5.98	2.39	1,793.07	6.58E-07	77.50	45,897.07	39,567.36	6,332.17	1,337.61
Stairs and Railings	**2.68**	**0.14**	**603.19**	**3.11E-06**	**34.15**	**6,092.07**	**3,384.59**	**2,708.34**	**1,608.53**
7" max riser 11" tread	0.63	0.07	148.52	-6.42E-09	6.36	2,759.19	228.42	2,531.21	166.06
Monolithic Stair	2.04	0.08	454.67	3.12E-06	27.79	3,332.89	3,156.17	177.13	1,442.47
Structure	**20.12**	**1.26**	**4,513.60**	**3.58E-05**	**283.22**	**38,657.07**	**37,463.51**	**1,198.00**	**16,419.38**
6" Foundation Slab	20.12	1.26	4,513.60	3.58E-05	283.22	38,657.07	37,463.51	1,198.00	16,419.38
Walls	**57.05**	**6.28**	**15,946.17**	**1.97E-05**	**800.60**	**270,203.48**	**132,727.33**	**137,539.25**	**38,404.95**
Basement Wall Furring	2.89	0.65	1,087.29	1.56E-05	55.00	23,974.48	23,093.73	884.26	1,859.33
Exterior - Wood Shingle on Wood Dtud	32.07	3.37	7,884.16	2.24E-06	378.89	145,379.92	45,468.81	99,935.24	10,603.23
Exterior - Wood Shingle on Wood Stud (Garage)	9.55	1.02	2,156.64	7.42E-07	104.38	39,883.63	6,674.55	33,215.49	2,284.06
Generic - 8" Masonry	7.53	0.78	2,832.23	1.05E-06	169.71	25,186.75	23,462.54	1,746.37	18,555.12
Interior - Gyp. Board Over Wood Stud (2x4)	5.01	0.47	1,985.85	3.47E-08	92.62	35,778.70	34,027.70	1,757.89	5,103.22
Windows	**10.28**	**1.20**	**2,176.98**	**6.56E-08**	**200.74**	**44,313.57**	**28,908.25**	**15,410.55**	**900.42**
Casement Dbl without Trim: 36" x 32"	0.48	0.06	101.48	2.92E-09	9.22	2,064.93	1,324.75	740.42	43.26
Double Hung: 16" x 48"	1.45	0.17	314.83	1.06E-08	26.95	6,871.00	4,239.87	2,631.80	118.64
Double Hung: 24" x 42"	0.85	0.10	182.28	5.71E-09	16.42	3,798.79	2,433.12	1,366.09	73.10
Double Hung: 24" x 48"	1.43	0.17	305.52	9.44E-09	27.78	6,309.26	4,071.27	2,238.71	123.96
Double Hung: 32" x 48"	4.76	0.55	999.79	2.91E-08	94.27	19,907.40	13,233.70	6,676.20	423.84
Fixed: 36" x 48"	1.31	0.15	273.08	7.77E-09	26.09	5,362.19	3,605.55	1,757.34	117.62
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-10: Embodied Impacts by Revit Category and Tally Entry (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**8.16**	**0.57**	**1,989.45**	**6.72E-05**	**106.81**	**33,463.69**	**28,342.19**	**5,125.05**	**2,396.68**
Wall board; gypsum	1.45	0.14	588.46	1.14E-08	27.37	10,726.44	10,386.38	342.11	1,538.48
Wood framing with insulation	6.71	0.43	1,400.99	6.72E-05	79.43	22,737.25	17,955.81	4,782.94	858.20
Doors	**13.65**	**2.86**	**3,173.77**	**1.54E-03**	**137.19**	**56,643.79**	**32,747.43**	**23,947.98**	**1,236.53**
Aluminum; hardware	0.23	0.01	63.04	7.17E-07	2.71	927.72	742.44	185.50	31.73
Door frame; wood	3.26	0.45	828.66	4.26E-08	43.27	24,189.85	11,895.28	12,295.12	161.93
Door; exterior; aluminum	2.69	0.79	1,088.29	1.51E-03	30.13	12,369.62	11,393.69	1,023.36	169.47
Door; exterior; wood; solid core	1.00	0.23	156.15	5.02E-06	6.87	2,572.99	1,052.15	1,521.26	116.35
Door; interior; wood; hollow core; flush	5.76	1.31	905.80	3.04E-05	37.55	14,891.65	6,031.33	8,862.81	678.19
Glazing; double pane IGU	0.71	0.07	131.83	1.59E-09	16.66	1,691.97	1,632.55	59.93	78.86
Floors	**22.41**	**5.78**	**4,909.41**	**3.21E-08**	**300.24**	**84,872.83**	**42,530.91**	**42,366.72**	**7,315.11**
Ceramic tile; unglazed	2.42	0.18	915.24	1.37E-08	47.81	14,907.46	14,453.91	466.97	2,525.04
Flooring; solid wood plank	11.05	4.88	1,886.64	-3.16E-08	142.00	40,270.50	15,509.29	24,765.67	1,610.12
Plywood; interior grade	3.39	0.26	644.61	7.90E-08	38.61	9,277.29	1,984.82	7,294.65	675.57
Wall board; gypsum	1.34	0.13	545.67	1.06E-08	25.38	9,946.48	9,631.14	317.23	1,426.61
Wood framing	4.22	0.34	917.25	-3.97E-08	46.43	10,471.10	951.75	9,522.19	1,077.77
Roofs	**21.90**	**8.75**	**6,564.33**	**2.41E-06**	**283.73**	**168,026.18**	**144,853.52**	**23,181.66**	**4,896.92**
Plywood; exterior grade	4.07	0.42	892.25	-3.39E-08	39.32	15,446.89	2,503.90	12,946.00	933.54
SBS modified asphalt shingles	14.48	8.07	4,944.94	2.47E-06	207.61	144,278.50	141,595.13	2,687.09	3,108.99
Wood framing	3.34	0.27	727.13	-3.15E-08	36.81	8,300.79	754.49	7,548.56	854.39
Stairs and Railings	**2.68**	**0.14**	**603.19**	**3.11E-06**	**34.15**	**6,092.07**	**3,384.59**	**2,708.34**	**1,608.53**
Stair; cast-in-place concrete	2.04	0.08	454.67	3.12E-06	27.79	3,332.89	3,156.17	177.13	1,442.47
Stair; hardwood	0.63	0.07	148.52	-6.42E-09	6.36	2,759.19	228.42	2,531.21	166.06
Structure	**20.12**	**1.26**	**4,513.60**	**3.58E-05**	**283.22**	**38,657.07**	**37,463.51**	**1,198.00**	**16,419.38**
Cast-in-place concrete; slab on grade	20.12	1.26	4,513.60	3.58E-05	283.22	38,657.07	37,463.51	1,198.00	16,419.38
Walls	**57.05**	**6.28**	**15,946.17**	**1.97E-05**	**800.60**	**270,203.48**	**132,727.33**	**137,539.25**	**38,404.95**
Expanded polystyrene (EPS); board	1.13	0.48	405.28	1.56E-05	23.13	11,792.47	11,665.03	128.60	129.03
Hollow-core CMU; ungrouted	7.53	0.78	2,832.23	1.05E-06	169.71	25,186.75	23,462.54	1,746.37	18,555.12
Plywood; exterior grade	6.80	0.70	1,488.17	-5.65E-08	65.58	25,763.59	4,176.21	21,592.41	1,557.03
Wall board; gypsum	9.88	0.93	4,017.92	7.79E-08	186.89	73,238.81	70,916.89	2,335.89	10,504.53
Wood framing	0.85	0.07	185.18	-8.01E-09	9.37	2,113.95	192.14	1,922.38	217.59
Wood siding; hardwood	30.87	3.32	7,017.39	3.01E-06	345.92	132,107.91	22,314.51	109,813.61	7,441.66
Windows	**10.28**	**1.20**	**2,176.98**	**6.56E-08**	**200.74**	**44,313.57**	**28,908.25**	**15,410.55**	**900.42**
Glazing; double pane IGU	6.33	0.65	1,174.30	1.42E-08	148.40	15,071.36	14,542.06	533.86	702.47
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Window frame; wood	3.93	0.55	1,000.34	5.14E-08	52.23	29,201.45	14,359.72	14,842.40	195.48
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-11: Embodied Impacts by Revit Category and Materials (Baseline):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**8.16**	**0.57**	**1,989.45**	**6.72E-05**	**106.81**	**33,463.69**	**28,342.19**	**5,125.05**	**2,396.68**
Domestic softwood; US	1.29	0.10	279.81	-1.21E-08	14.16	3,194.20	290.33	2,904.74	328.77
Fiberglass blanket insulation; unfaced	5.43	0.33	1,121.18	6.72E-05	65.27	19,543.05	17,665.48	1,878.20	529.43
Paint; interior acrylic latex	0.76	0.08	178.10	6.88E-09	13.27	4,126.15	3,915.20	211.25	67.84
Wall board; gypsum; natural	0.69	0.06	410.36	4.53E-09	14.10	6,600.30	6,471.18	130.86	1,470.63
Doors	**13.65**	**2.86**	**3,173.77**	**1.54E-03**	**137.19**	**56,643.79**	**32,747.43**	**23,947.98**	**1,236.53**
Door frame; wood; no door	3.26	0.45	828.66	4.26E-08	43.27	24,189.85	11,895.28	12,295.12	161.93
Door; exterior; wood; solid core	0.84	0.20	104.99	-3.90E-09	4.72	1,747.47	274.29	1,473.54	106.50
Door; interior; wood; hollow core; flush	4.92	1.17	613.28	-2.28E-08	27.58	10,207.06	1,602.14	8,607.04	622.08
Glazing; double; insulated (argon); low-E	0.71	0.07	131.83	1.59E-09	16.66	1,691.97	1,632.55	59.93	78.86
Hardware; aluminum	0.23	0.01	63.04	7.17E-07	2.71	927.72	742.44	185.50	31.73
Hollow door; exterior; aluminum; powder-coated; with small vision panel	1.93	0.66	825.41	1.48E-03	21.63	8,310.69	7,571.46	786.37	128.21
Paint; exterior acrylic latex	0.03	0.00	5.60	2.48E-10	0.68	122.16	115.52	6.66	2.70
Stainless steel; door hardware; lever lock + push bar; exterior; commercial	0.76	0.13	262.88	2.90E-05	8.50	4,058.93	3,822.23	236.98	41.26
Stainless steel; door hardware; lever lock; exterior; residential	0.13	0.02	45.55	5.02E-06	1.47	703.36	662.34	41.07	7.15
Stainless steel; door hardware; lever lock; interior; residential	0.80	0.14	276.49	3.05E-05	8.94	4,269.03	4,020.08	249.25	43.39
Wood stain; water based	0.04	0.01	16.04	6.31E-10	1.03	415.56	409.11	6.51	12.72
Floors	**22.41**	**5.78**	**4,909.41**	**3.21E-08**	**300.24**	**84,872.83**	**42,530.91**	**42,366.72**	**7,315.11**
Ceramic tile; unglazed	2.37	0.17	897.06	1.35E-08	46.78	14,749.09	14,304.58	457.77	2,386.98
Domestic softwood; US	4.22	0.34	917.25	-3.97E-08	46.43	10,471.10	951.75	9,522.19	1,077.77
Flooring; hardwood plank	10.56	2.87	1,660.60	-3.92E-08	58.98	34,997.13	10,404.31	24,596.79	1,499.44
Interior grade plywood; US	3.39	0.26	644.61	7.90E-08	38.61	9,277.29	1,984.82	7,294.65	675.57
Paint; interior acrylic latex	0.70	0.07	165.15	6.38E-09	12.30	3,826.11	3,630.51	195.89	62.91
Polyurethane floor finish; water-based	0.49	2.01	226.04	7.61E-09	83.02	5,273.37	5,104.98	168.88	110.68
Thinset mortar	0.05	0.01	18.18	2.80E-10	1.03	158.37	149.33	9.20	138.06
Wall board; gypsum; natural	0.64	0.05	380.52	4.20E-09	13.08	6,120.36	6,000.63	121.35	1,363.70
Roofs	**21.90**	**8.75**	**6,564.33**	**2.41E-06**	**283.73**	**168,026.18**	**144,853.52**	**23,181.66**	**4,896.92**
Domestic softwood; US	3.34	0.27	727.13	-3.15E-08	36.81	8,300.79	754.49	7,548.56	854.39
Exterior grade plywood; US	4.07	0.42	892.25	-3.39E-08	39.32	15,446.89	2,503.90	12,946.00	933.54
Fasteners; stainless steel	0.34	0.05	24.86	1.96E-06	1.39	381.52	326.96	54.60	5.70
Roofing shingles; SBS modified asphalt; strip	14.14	8.02	4,920.08	5.16E-07	206.21	143,896.98	141,268.17	2,632.49	3,103.29
Stairs and Railings	**2.68**	**0.14**	**603.19**	**3.11E-06**	**34.15**	**6,092.07**	**3,384.59**	**2,708.34**	**1,608.53**
Domestic hardwood; US	0.63	0.07	148.52	-6.42E-09	6.36	2,759.19	228.42	2,531.21	166.06
Steel; reinforcing rod	0.23	0.01	81.44	7.57E-07	3.14	1,061.25	913.64	147.80	62.09
Structural concrete; 5000 psi; generic	1.81	0.06	373.23	2.36E-06	24.65	2,271.63	2,242.53	29.33	1,380.38

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Structure	**20.12**	**1.26**	**4,513.60**	**3.58E-05**	**283.22**	**38,657.07**	**37,463.51**	**1,198.00**	**16,419.38**
Expanded polystyrene (EPS); board	0.64	0.28	230.51	8.88E-06	13.15	6,707.16	6,634.68	73.14	73.39
Polyethelene sheet vapor barrier (HDPE)	0.14	0.25	56.88	4.50E-09	2.44	1,667.37	1,650.69	16.86	20.39
Steel; reinforcing rod	1.20	0.07	419.89	3.90E-06	16.17	5,471.58	4,710.53	762.00	320.11
Structural concrete; 3000 psi; generic	18.14	0.66	3,806.32	2.31E-05	251.46	24,810.97	24,467.62	346.00	16,005.49
Walls	**57.05**	**6.28**	**15,946.17**	**1.97E-05**	**800.60**	**270,203.48**	**132,727.33**	**137,539.25**	**38,404.95**
Domestic hardwood; US	27.33	2.97	6,397.82	-2.76E-07	273.87	118,855.38	9,839.28	109,035.01	7,153.42
Domestic softwood; US	0.85	0.07	185.18	-8.01E-09	9.37	2,113.95	192.14	1,922.38	217.59
Expanded polystyrene (EPS); board	1.13	0.48	405.28	1.56E-05	23.13	11,792.47	11,665.03	128.60	129.03
Exterior grade plywood; US	6.80	0.70	1,488.17	-5.65E-08	65.58	25,763.59	4,176.21	21,592.41	1,557.03
Fasteners; stainless steel	0.57	0.08	41.46	3.27E-06	2.32	636.33	545.33	91.07	9.51
Hollow-core CMU; 8x8x16 ungrouted	5.54	0.52	2,004.96	3.46E-08	128.57	18,176.61	16,979.58	1,213.62	13,982.56
Mortar type S	1.68	0.24	719.13	1.01E-08	36.97	5,600.91	5,269.74	336.50	4,490.11
Paint; exterior acrylic latex	2.96	0.27	578.11	2.57E-08	69.73	12,616.20	11,929.90	687.53	278.72
Paint; interior acrylic latex	5.16	0.54	1,216.01	4.70E-08	90.60	28,172.80	26,732.48	1,442.38	463.24
Steel; reinforcing rod	0.31	0.02	108.14	1.01E-06	4.16	1,409.23	1,213.22	196.26	82.45
Wall board; gypsum; natural	4.72	0.39	2,801.90	3.10E-08	96.29	45,066.01	44,184.42	893.51	10,041.29
Windows	**10.28**	**1.20**	**2,176.98**	**6.56E-08**	**200.74**	**44,313.57**	**28,908.25**	**15,410.55**	**900.42**
Glazing; double; insulated (argon); low-E	6.33	0.65	1,174.30	1.42E-08	148.40	15,071.36	14,542.06	533.86	702.47
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Window frame; wood; divided operable	3.93	0.55	1,000.34	5.14E-08	52.23	29,201.45	14,359.72	14,842.40	195.48
Grand Total	**156.25**	**26.84**	**39,876.89**	**1.67E-03**	**2,146.67**	**702,272.69**	**450,957.72**	**251,477.56**	**73,178.52**

Table B-12: Total Embodied Impacts of Prototype Model:

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Thesis Prototype w Analyzed Materials.rvt	192.69	25.20	40,193.00	2.80E-04	3,219.82	589,603.18	386,510.42	203,219.58	83,065.15
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-13: Embodied Impacts by Life Cycle Stage (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	31.04	6.46	7,914.27	-7.48E-06	187.53	-24,963.52	-910.09	-24,053.43	
Maintenance and Replacement	42.99	8.46	10,260.69	9.39E-05	688.18	206,121.39	161,460.65	44,695.68	14,086.00
Manufacturing	111.59	9.75	20,914.93	1.94E-04	2,147.64	392,789.98	210,444.81	182,345.18	68,979.15
Transportation	7.07	0.53	1,103.12	9.33E-09	196.48	15,655.32	15,515.05	232.15	
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-14: Embodied Impacts by Life Cycle Stage and CSI Division (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	**31.04**	**6.46**	**7,914.27**	**-7.48E-06**	**187.53**	**-24,963.52**	**-910.09**	**-24,053.43**	
03 - Concrete	2.58	0.36	545.85	5.98E-08	45.23	9,009.12	8,628.35	380.77	
04 - Masonry	2.10	0.30	454.01	2.36E-08	37.30	7,556.38	7,242.63	313.75	
06 - Wood/Plastics/Composites	17.02	2.00	5,786.86	-4.31E-07	60.84	-42,367.06	-19,518.93	-22,848.13	
07 - Thermal and Moisture Protection	2.27	0.81	325.04	4.58E-08	21.42	3,600.83	3,449.72	151.12	
08 - Openings and Glazing	2.87	1.13	294.21	-7.17E-06	1.40	-5,588.25	-3,588.42	-1,999.82	
09 - Finishes	4.20	1.86	508.29	-2.04E-09	21.33	2,825.45	2,876.57	-51.12	
Maintenance and Replacement	**42.99**	**8.46**	**10,260.69**	**9.39E-05**	**688.18**	**206,121.39**	**161,460.65**	**44,695.68**	**14,086.00**
03 - Concrete	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
04 - Masonry	2.54	0.29	728.25	1.94E-08	58.40	9,922.46	9,367.02	559.23	2,802.08
06 - Wood/Plastics/Composites	3.60	0.22	742.73	4.35E-05	44.34	13,023.73	11,788.53	1,235.65	350.89
07 - Thermal and Moisture Protection	4.01	0.79	972.64	5.15E-08	85.82	24,921.29	23,929.02	994.77	417.20
08 - Openings and Glazing	13.11	2.05	2,657.27	3.58E-05	178.76	53,846.29	31,442.48	22,409.40	1,231.07
09 - Finishes	19.73	5.11	5,159.81	1.46E-05	320.86	104,407.62	84,933.59	19,496.63	9,284.76
Manufacturing	**111.59**	**9.75**	**20,914.93**	**1.94E-04**	**2,147.64**	**392,789.98**	**210,444.81**	**182,345.18**	**68,979.15**
03 - Concrete	25.66	1.29	5,760.63	4.77E-05	344.80	42,677.84	41,378.84	1,299.00	23,488.85
04 - Masonry	4.88	0.40	2,275.65	1.21E-06	109.56	16,584.54	15,016.05	1,568.49	19,325.23
06 - Wood/Plastics/Composites	21.88	1.44	2,610.70	4.38E-05	327.10	172,441.58	42,226.69	130,214.89	9,164.08
07 - Thermal and Moisture Protection	42.51	3.27	4,942.71	4.33E-05	1,073.24	35,752.26	28,818.82	6,933.44	6,986.54
08 - Openings and Glazing	9.69	0.86	2,243.13	4.30E-05	163.45	57,198.81	32,873.38	24,325.43	1,208.08
09 - Finishes	6.97	2.49	3,082.10	1.45E-05	129.49	68,134.94	50,131.03	18,003.92	8,806.37
Transportation	**7.07**	**0.53**	**1,103.12**	**9.33E-09**	**196.48**	**15,655.32**	**15,515.05**	**232.15**	
03 - Concrete	0.33	0.03	67.38	5.77E-10	10.35	963.89	955.05	14.94	
04 - Masonry	1.24	0.11	256.26	2.20E-09	39.35	3,665.59	3,631.96	56.83	
06 - Wood/Plastics/Composites	1.37	0.12	282.32	2.42E-09	43.35	4,038.50	4,001.45	62.62	
07 - Thermal and Moisture Protection	0.59	0.05	121.78	1.04E-09	18.70	1,742.05	1,726.07	27.01	
08 - Openings and Glazing	0.29	0.03	60.63	5.20E-10	9.31	867.29	859.33	13.45	
09 - Finishes	3.24	0.18	314.74	2.58E-09	75.43	4,378.00	4,341.19	57.30	
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-15: Embodied Impacts by Life Cycle Stage and Revit Category (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
End of Life	**31.04**	**6.46**	**7,914.27**	**-7.48E-06**	**187.53**	**-24,963.52**	**-910.09**	**-24,053.43**	
Ceilings	0.99	0.12	315.22	-1.94E-08	5.97	-1,440.78	-364.85	-1,075.93	
Doors	2.26	0.96	211.50	-7.17E-06	-0.84	-5,344.60	-3,592.97	-1,751.64	
Floors	12.52	2.87	3,277.91	-1.82E-07	57.24	-15,414.98	-4,834.40	-10,580.57	
Roofs	4.61	0.55	1,505.03	-7.60E-08	23.22	-8,554.37	-3,090.72	-5,463.65	
Stairs and Railings	0.74	0.09	250.89	-1.88E-08	2.58	-1,853.09	-859.29	-993.80	
Structure	1.54	0.22	342.94	2.82E-08	24.72	4,431.38	4,431.86	-0.49	
Walls	7.77	1.50	1,927.26	-3.60E-08	72.38	3,462.54	7,398.51	-3,935.97	
Windows	0.62	0.17	83.52	-4.58E-09	2.24	-249.60	1.78	-251.38	
Maintenance and Replacement	**42.99**	**8.46**	**10,260.69**	**9.39E-05**	**688.18**	**206,121.39**	**161,460.65**	**44,695.68**	**14,086.00**
Ceilings	4.77	0.33	1,182.46	4.35E-05	65.64	21,355.09	19,829.94	1,527.01	1,366.62
Doors	8.11	1.46	1,593.35	3.58E-05	81.80	31,921.72	17,270.67	14,654.14	798.27
Floors	10.35	4.20	1,744.18	1.45E-05	147.16	39,365.08	22,220.16	17,156.66	1,606.06
Roofs	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
Stairs and Railings	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
Structure	0.00	0.00	0.00	0.00E+00	0.00	0.00	0.00	0.00	0.00
Walls	14.76	1.88	4,675.61	1.38E-07	296.57	91,534.54	87,964.83	3,585.46	9,881.02
Windows	5.00	0.59	1,065.09	3.27E-08	97.01	21,944.96	14,175.05	7,772.41	434.03
Manufacturing	**111.59**	**9.75**	**20,914.93**	**1.94E-04**	**2,147.64**	**392,789.98**	**210,444.81**	**182,345.18**	**68,979.15**
Ceilings	4.65	0.27	1,045.50	4.35E-05	61.92	22,939.17	16,767.91	6,171.26	1,733.37
Doors	5.44	0.47	1,289.58	4.29E-05	72.97	35,426.23	19,098.11	16,328.12	775.28
Floors	23.60	3.35	4,566.81	3.52E-05	354.83	129,040.03	48,131.01	80,909.01	16,608.70
Roofs	37.02	1.98	2,991.15	3.18E-05	1,011.31	37,573.53	8,944.51	28,629.01	6,522.70
Stairs and Railings	0.67	0.07	80.86	3.83E-09	10.38	8,063.97	1,228.10	6,835.87	383.44
Structure	13.92	0.74	3,126.26	2.72E-05	188.49	25,123.50	23,515.88	1,607.61	12,607.86
Walls	22.04	2.47	6,860.89	1.30E-05	357.23	112,825.17	78,978.52	33,846.65	29,913.76
Windows	4.25	0.40	953.88	3.71E-08	90.52	21,798.41	13,780.76	8,017.65	434.03
Transportation	**7.07**	**0.53**	**1,103.12**	**9.33E-09**	**196.48**	**15,655.32**	**15,515.05**	**232.15**	
Ceilings	0.15	0.01	30.08	2.58E-10	4.62	430.27	426.32	6.67	
Doors	0.16	0.01	32.97	2.83E-10	5.06	471.65	467.33	7.31	
Floors	3.51	0.20	369.82	3.05E-09	83.88	5,165.89	5,121.85	69.51	
Roofs	0.69	0.06	141.50	1.21E-09	21.73	2,024.07	2,005.50	31.38	
Stairs and Railings	0.05	0.00	11.19	9.59E-11	1.72	160.08	158.61	2.48	
Structure	0.19	0.02	39.63	3.40E-10	6.09	566.94	561.74	8.79	
Walls	2.19	0.20	450.23	3.86E-09	69.13	6,440.27	6,381.19	99.85	
Windows	0.13	0.01	27.69	2.37E-10	4.25	396.15	392.52	6.14	
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-16: Embodied Impacts by CSI Division (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	28.56	1.68	6,373.86	4.78E-05	400.38	52,650.85	50,962.24	1,694.71	23,488.85
04 - Masonry	10.77	1.10	3,714.17	1.26E-06	244.61	37,728.97	35,257.67	2,498.31	22,127.31
06 - Wood/Plastics/Composites	43.87	3.78	9,422.61	8.69E-05	475.63	147,136.76	38,497.74	108,665.03	9,514.98
07 - Thermal and Moisture Protection	49.38	4.93	6,362.17	4.34E-05	1,199.17	66,016.44	57,923.63	8,106.34	7,403.74
08 - Openings and Glazing	25.97	4.07	5,255.24	7.16E-05	352.91	106,324.14	61,586.76	44,748.45	2,439.15
09 - Finishes	34.14	9.63	9,064.94	2.91E-05	547.10	179,746.02	142,282.38	37,506.73	18,091.13
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-17: Embodied Impacts by CSI Division and Tally Entry (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	**28.56**	**1.68**	**6,373.86**	**4.78E-05**	**400.38**	**52,650.85**	**50,962.24**	**1,694.71**	**23,488.85**
Cast-in-place concrete; reinforced structural concrete; 3000 psi (20 Mpa)	0.48	0.02	107.55	7.01E-07	6.68	800.50	764.49	36.10	399.68
Cast-in-place concrete; slab on grade	28.08	1.66	6,266.31	4.71E-05	393.70	51,850.36	50,197.75	1,658.61	23,089.17
04 - Masonry	**10.77**	**1.10**	**3,714.17**	**1.26E-06**	**244.61**	**37,728.97**	**35,257.67**	**2,498.31**	**22,127.31**
Hollow-core CMU; ungrouted	10.77	1.10	3,714.17	1.26E-06	244.61	37,728.97	35,257.67	2,498.31	22,127.31
06 - Wood/Plastics/Composites	**43.87**	**3.78**	**9,422.61**	**8.69E-05**	**475.63**	**147,136.76**	**38,497.74**	**108,665.03**	**9,514.98**
Domestic hardwood	9.11	0.99	2,128.15	-9.01E-08	92.74	39,604.39	3,676.92	35,933.75	2,366.04
Domestic softwood	0.31	0.02	66.93	-2.90E-09	3.39	764.05	69.45	694.81	78.64
Plywood; exterior grade	6.50	0.67	1,422.41	-5.40E-08	62.68	24,625.17	3,991.68	20,638.30	1,488.23
Plywood; interior grade	8.29	0.63	1,577.24	1.93E-07	94.47	22,699.73	4,856.48	17,848.59	1,653.00
Stair; hardwood	1.47	0.16	342.94	-1.48E-08	14.68	6,370.95	527.41	5,844.55	383.44
Wood framing	9.53	0.76	2,072.83	-8.97E-08	104.93	23,662.88	2,150.80	21,518.52	2,435.58
Wood framing with insulation	8.68	0.56	1,812.11	8.70E-05	102.74	29,409.59	23,225.01	6,186.51	1,110.04
07 - Thermal and Moisture Protection	**49.38**	**4.93**	**6,362.17**	**4.34E-05**	**1,199.17**	**66,016.44**	**57,923.63**	**8,106.34**	**7,403.74**
Extruded polystyrene (XPS); board	2.21	1.05	813.29	5.28E-08	35.09	25,138.94	24,498.24	643.29	288.62
Fiber cement siding	14.25	2.02	2,827.17	1.18E-05	213.21	34,402.18	29,403.15	5,003.36	2,728.68
Slate roofing shingles; EPD - Rathscheck Schiefer	32.91	1.86	2,721.71	3.16E-05	950.87	6,475.31	4,022.24	2,459.69	4,386.43
08 - Openings and Glazing	**25.97**	**4.07**	**5,255.24**	**7.16E-05**	**352.91**	**106,324.14**	**61,586.76**	**44,748.45**	**2,439.15**
Door frame; wood	3.90	0.54	990.87	5.09E-08	51.74	28,925.22	14,223.88	14,702.00	193.63
Door; exterior; steel	1.87	0.17	497.90	2.34E-05	24.83	6,762.38	6,448.79	314.45	206.19
Door; exterior; wood; solid core	1.06	0.24	165.33	5.31E-06	7.27	2,724.34	1,114.04	1,610.75	123.19
Door; interior; wood; hollow core; flush	8.39	1.87	1,333.71	4.28E-05	57.52	22,271.55	9,727.83	12,547.27	967.04
Glazing; double pane IGU	6.77	0.70	1,256.28	1.52E-08	158.76	16,123.51	15,557.26	571.13	751.51
Window frame; wood	3.98	0.55	1,011.15	5.20E-08	52.80	29,517.14	14,514.96	15,002.85	197.59
09 - Finishes	**34.14**	**9.63**	**9,064.94**	**2.91E-05**	**547.10**	**179,746.02**	**142,282.38**	**37,506.73**	**18,091.13**
Flooring; cork tile	15.33	7.15	2,435.81	6.94E-08	219.50	56,264.31	27,410.15	28,873.73	1,616.25
Flooring; linoleum; generic	2.62	0.79	280.66	2.89E-05	33.92	7,345.08	4,527.98	2,818.71	132.36
Flooring; solid wood plank	0.93	0.25	146.91	-3.47E-09	5.22	3,096.03	920.42	2,175.96	132.65
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Wall board; gypsum	15.24	1.44	6,199.22	1.20E-07	288.36	112,999.83	109,417.36	3,604.03	16,207.39
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-18: Embodied Impacts by CSI Division and Material (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
03 - Concrete	**28.56**	**1.68**	**6,373.86**	**4.78E-05**	**400.38**	**52,650.85**	**50,962.24**	**1,694.71**	**23,488.85**
Expanded polystyrene (EPS); board	0.66	0.28	236.01	9.09E-06	13.47	6,867.07	6,792.86	74.88	75.14
Polyethelene sheet vapor barrier (HDPE)	0.20	0.36	80.09	6.34E-09	3.43	2,347.54	2,324.05	23.74	28.71
Steel; reinforcing rod	1.73	0.10	606.44	5.64E-06	23.35	7,902.58	6,803.41	1,100.55	462.33
Structural concrete; 3000 psi; generic	25.97	0.95	5,451.32	3.30E-05	360.14	35,533.66	35,041.92	495.53	22,922.67
04 - Masonry	**10.77**	**1.10**	**3,714.17**	**1.26E-06**	**244.61**	**37,728.97**	**35,257.67**	**2,498.31**	**22,127.31**
Hollow-core CMU; 8x8x16 ungrouted	6.55	0.62	2,372.01	4.09E-08	152.11	21,504.28	20,088.12	1,435.80	16,542.42
Mortar type S	1.98	0.29	850.79	1.20E-08	43.74	6,626.30	6,234.50	398.10	5,312.13
Paint; exterior acrylic latex	1.86	0.17	363.43	1.61E-08	43.84	7,931.17	7,499.73	432.22	175.22
Steel; reinforcing rod	0.37	0.02	127.94	1.19E-06	4.93	1,667.22	1,435.33	232.19	97.54
06 - Wood/Plastics/Composites	**43.87**	**3.78**	**9,422.61**	**8.69E-05**	**475.63**	**147,136.76**	**38,497.74**	**108,665.03**	**9,514.98**
Domestic hardwood; US	10.47	1.14	2,449.94	-1.06E-07	104.87	45,513.69	3,767.79	41,753.14	2,739.28
Domestic softwood; US	11.50	0.92	2,501.67	-1.08E-07	126.64	28,558.47	2,595.77	25,970.47	2,939.48
Exterior grade plywood; US	6.50	0.67	1,422.41	-5.40E-08	62.68	24,625.17	3,991.68	20,638.30	1,488.23
Fiberglass blanket insulation; unfaced	7.02	0.42	1,450.20	8.70E-05	84.42	25,278.04	22,849.48	2,429.37	684.79
Interior grade plywood; US	8.29	0.63	1,577.24	1.93E-07	94.47	22,699.73	4,856.48	17,848.59	1,653.00
Paint; exterior acrylic latex	0.11	0.01	21.15	9.39E-10	2.55	461.66	436.54	25.16	10.20
07 - Thermal and Moisture Protection	**49.38**	**4.93**	**6,362.17**	**4.34E-05**	**1,199.17**	**66,016.44**	**57,923.63**	**8,106.34**	**7,403.74**
Fasteners; stainless steel	0.81	0.11	58.90	4.64E-06	3.30	903.86	774.61	129.35	13.51
Fiber cement board; lap siding	10.44	1.65	2,123.63	9.82E-06	129.92	19,206.20	15,066.92	4,142.12	2,395.63
Paint; exterior acrylic latex	3.48	0.32	679.19	3.01E-08	81.93	14,822.19	14,015.88	807.75	327.46
Polystyrene board (XPS); Pentane foaming agent	2.21	1.05	813.29	5.28E-08	35.09	25,138.94	24,498.24	643.29	288.62
Roofing shingles; slate; Rathscheck Schiefer; Colored Slate; EPD	32.44	1.80	2,687.17	2.89E-05	948.93	5,945.25	3,567.97	2,383.83	4,378.51
08 - Openings and Glazing	**25.97**	**4.07**	**5,255.24**	**7.16E-05**	**352.91**	**106,324.14**	**61,586.76**	**44,748.45**	**2,439.15**
Door frame; wood; no door	3.90	0.54	990.87	5.09E-08	51.74	28,925.22	14,223.88	14,702.00	193.63
Door; exterior; wood; solid core	0.89	0.21	111.17	-4.12E-09	5.00	1,850.26	290.42	1,560.22	112.77
Door; interior; wood; hollow core; flush	6.92	1.64	862.05	-3.20E-08	38.76	14,347.50	2,252.05	12,098.45	874.42
Glazing; double; insulated (argon); low-E	6.77	0.70	1,256.28	1.52E-08	158.76	16,123.51	15,557.26	571.13	751.51
Hollow door; exterior; steel; powder-coated; with small vision panel	1.52	0.11	378.46	1.02E-05	20.96	4,918.28	4,712.23	206.78	187.44
Paint; exterior acrylic latex	0.03	0.00	5.93	2.63E-10	0.71	129.35	122.31	7.05	2.86
Paint; interior acrylic latex	0.35	0.04	83.02	3.21E-09	6.19	1,923.31	1,824.98	98.47	31.62
Stainless steel; door hardware; lever lock; exterior; residential	0.48	0.08	167.67	1.85E-05	5.42	2,588.84	2,437.87	151.15	26.31
Stainless steel; door hardware; lever lock; interior; residential	1.12	0.19	388.65	4.28E-05	12.57	6,000.73	5,650.80	350.36	60.99
Window frame; wood; divided operable	0.18	0.03	45.96	2.36E-09	2.40	1,341.69	659.77	681.95	8.98
Window frame; wood; fixed	0.35	0.05	89.22	4.59E-09	4.66	2,604.45	1,280.73	1,323.78	17.43
Window frame; wood; operable	3.45	0.48	875.97	4.50E-08	45.74	25,571.00	12,574.46	12,997.13	171.18

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
09 - Finishes	**34.14**	**9.63**	**9,064.94**	**2.91E-05**	**547.10**	**179,746.02**	**142,282.38**	**37,506.73**	**18,091.13**
Acrylic adhesive	0.03	0.01	5.95	2.90E-10	1.83	251.86	250.27	1.67	14.29
Cork tile	13.45	3.67	1,692.46	3.39E-08	179.11	41,238.87	13,164.33	28,091.96	1,244.22
Flooring; hardwood plank	0.93	0.25	146.91	-3.47E-09	5.22	3,096.03	920.42	2,175.96	132.65
Flooring; linoleum; tile	2.57	0.68	263.03	2.89E-05	27.81	6,820.94	4,014.12	2,808.32	112.36
Paint; interior acrylic latex	7.96	0.84	1,876.18	7.25E-08	139.79	43,467.69	41,245.42	2,225.44	714.73
Polyurethane floor finish; water-based	0.03	0.10	11.67	3.93E-10	4.29	272.28	263.58	8.72	5.71
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Urethane adhesive	1.88	3.48	743.35	3.55E-08	40.40	15,025.44	14,245.82	781.78	372.04
Wall board; gypsum; natural	7.28	0.60	4,323.04	4.78E-08	148.56	69,532.15	68,171.94	1,378.59	15,492.67
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-19: Embodied Impacts by Revit Category (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	10.55	0.73	2,573.26	8.70E-05	138.15	43,283.75	36,659.32	6,629.01	3,099.99
Doors	15.97	2.90	3,127.40	7.15E-05	158.99	62,474.99	33,243.13	29,237.93	1,573.55
Floors	49.97	10.62	9,958.71	4.95E-05	643.11	158,156.02	70,638.62	87,554.61	18,214.76
Roofs	42.32	2.59	4,637.68	3.17E-05	1,056.26	31,043.22	7,859.29	23,196.74	6,522.70
Stairs and Railings	1.47	0.16	342.94	-1.48E-08	14.68	6,370.95	527.41	5,844.55	383.44
Structure	15.65	0.97	3,508.83	2.72E-05	219.30	30,121.81	28,509.49	1,615.91	12,607.86
Walls	46.76	6.05	13,914.00	1.31E-05	795.31	214,262.52	180,723.05	33,596.00	39,794.78
Windows	10.01	1.17	2,130.19	6.54E-08	194.02	43,889.91	28,350.10	15,544.82	868.07
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-20: Embodied Impacts by Revit Category and Family (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**10.55**	**0.73**	**2,573.26**	**8.70E-05**	**138.15**	**43,283.75**	**36,659.32**	**6,629.01**	**3,099.99**
GWB on Mtl. Stud	10.55	0.73	2,573.26	8.70E-05	138.15	43,283.75	36,659.32	6,629.01	3,099.99
Doors	**15.97**	**2.90**	**3,127.40**	**7.15E-05**	**158.99**	**62,474.99**	**33,243.13**	**29,237.93**	**1,573.55**
Door-Exterior-Single-Entry-Half Flat Glass-Wood_Clad: 36" x 84"	1.81	0.32	304.92	5.31E-06	24.91	4,515.84	2,842.62	1,674.21	206.69
Door-Overhead-Sectional: 8' x 6'-6"	1.87	0.17	497.90	2.34E-05	24.83	6,762.38	6,448.79	314.45	206.19
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 48" x 80"	1.03	0.21	190.52	3.88E-06	8.85	4,051.14	1,881.17	2,170.34	101.26
Int-Bifold_door_4_wide-6_panel-Colonial_Reg_Casing_1736: 60" x 80"	2.48	0.50	449.59	9.70E-06	20.73	9,348.49	4,319.68	5,029.72	247.94
Single-Flush: 24" x 80"	0.63	0.12	123.40	1.97E-06	5.89	2,837.44	1,339.12	1,498.53	56.54
Single-Flush: 30" x 80"	6.61	1.28	1,266.56	2.21E-05	59.87	28,369.70	13,318.62	15,053.29	612.26
Single-Flush: 30" x 84"	1.54	0.30	294.52	5.16E-06	13.92	6,590.00	3,093.13	3,497.39	142.66
Floors	**49.97**	**10.62**	**9,958.71**	**4.95E-05**	**643.11**	**158,156.02**	**70,638.62**	**87,554.61**	**18,214.76**
Porch Floor	10.04	1.24	2,275.06	-9.36E-08	97.96	42,700.43	4,597.34	38,109.71	2,498.69
Slab on Grade - Cork Tile	8.64	1.71	1,747.68	1.02E-05	122.27	21,665.68	15,866.69	5,803.96	4,987.08
Slab on Grade - Uninsulated	7.48	0.38	1,645.09	1.04E-05	103.73	12,271.61	11,841.02	432.05	6,278.32
Wood Joist 10" - Cork Tile	11.19	3.52	2,224.78	5.67E-08	155.55	42,073.00	21,930.01	20,155.45	2,732.07
Wood Joist 10" - Cork Tile - Exposed Structure	8.39	2.86	1,459.65	3.97E-08	111.64	27,883.34	11,196.21	16,696.17	1,224.65
Wood Joist 10" - Linoleum	4.23	0.91	606.46	2.89E-05	51.97	11,561.97	5,207.36	6,357.27	493.95
Roofs	**42.32**	**2.59**	**4,637.68**	**3.17E-05**	**1,056.26**	**31,043.22**	**7,859.29**	**23,196.74**	**6,522.70**
Wood Rafter 8" - Slate Shingle - Insulated	42.32	2.59	4,637.68	3.17E-05	1,056.26	31,043.22	7,859.29	23,196.74	6,522.70
Stairs and Railings	**1.47**	**0.16**	**342.94**	**-1.48E-08**	**14.68**	**6,370.95**	**527.41**	**5,844.55**	**383.44**
7" max riser 11" tread	1.47	0.16	342.94	-1.48E-08	14.68	6,370.95	527.41	5,844.55	383.44
Structure	**15.65**	**0.97**	**3,508.83**	**2.72E-05**	**219.30**	**30,121.81**	**28,509.49**	**1,615.91**	**12,607.86**
6" Foundation Slab	14.86	0.93	3,334.35	2.65E-05	209.22	28,557.27	27,675.55	885.01	12,129.54
Concrete-Round-Column: 12"	0.48	0.02	107.55	7.01E-07	6.68	800.50	764.49	36.10	399.68
Timber-Column: 6x6	0.31	0.02	66.93	-2.90E-09	3.39	764.05	69.45	694.81	78.64

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Walls	**46.76**	**6.05**	**13,914.00**	**1.31E-05**	**795.31**	**214,262.52**	**180,723.05**	**33,596.00**	**39,794.78**
Basement Wall Furring	2.34	0.64	887.45	3.44E-08	40.00	21,211.35	20,382.75	831.56	1,360.92
Exterior - Fiber Cement Siding on Wood Dtud 2	25.86	3.14	6,392.60	1.14E-05	373.39	98,135.44	71,222.03	26,930.15	9,925.49
Exterior - Fiber Cement Siding on Wood Stud (Garage) 2	0.71	0.09	146.67	3.76E-07	9.38	2,012.07	1,083.22	929.17	147.40
Generic - 8" Masonry	10.77	1.10	3,714.17	1.26E-06	244.61	37,728.97	35,257.67	2,498.31	22,127.31
Interior - Gyp. Board Over Wood Stud (2x4)	5.40	0.50	2,137.30	3.73E-08	99.69	38,504.64	36,616.20	1,895.85	5,491.84
Interior - Gyp. Board Over Wood Stud (2x6)	0.58	0.05	232.13	4.14E-09	10.82	4,191.84	4,001.00	191.65	598.55
Rigid Insulation	1.10	0.52	403.69	2.62E-08	17.42	12,478.21	12,160.19	319.31	143.26
Windows	**10.01**	**1.17**	**2,130.19**	**6.54E-08**	**194.02**	**43,889.91**	**28,350.10**	**15,544.82**	**868.07**
Casement Dbl without Trim: 36" x 32"	0.48	0.06	101.48	2.92E-09	9.22	2,064.93	1,324.75	740.42	43.26
Double Hung: 24" x 48"	8.61	1.01	1,833.13	5.66E-08	166.70	37,855.57	24,427.60	13,432.27	743.76
Fixed: 24" x 24"	0.27	0.03	59.03	1.99E-09	5.05	1,288.31	794.97	493.46	22.24
Fixed: 36" x 48"	0.65	0.08	136.54	3.88E-09	13.04	2,681.09	1,802.77	878.67	58.81
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-21: Embodied Impacts by Revit Category and Tally Entry (Prototype):

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**10.55**	**0.73**	**2,573.26**	**8.70E-05**	**138.15**	**43,283.75**	**36,659.32**	**6,629.01**	**3,099.99**
Wall board; gypsum	1.87	0.18	761.14	1.48E-08	35.40	13,874.16	13,434.30	442.50	1,989.95
Wood framing with insulation	8.68	0.56	1,812.11	8.70E-05	102.74	29,409.59	23,225.01	6,186.51	1,110.04
Doors	**15.97**	**2.90**	**3,127.40**	**7.15E-05**	**158.99**	**62,474.99**	**33,243.13**	**29,237.93**	**1,573.55**
Door frame; wood	3.90	0.54	990.87	5.09E-08	51.74	28,925.22	14,223.88	14,702.00	193.63
Door; exterior; steel	1.87	0.17	497.90	2.34E-05	24.83	6,762.38	6,448.79	314.45	206.19
Door; exterior; wood; solid core	1.06	0.24	165.33	5.31E-06	7.27	2,724.34	1,114.04	1,610.75	123.19
Door; interior; wood; hollow core; flush	8.39	1.87	1,333.71	4.28E-05	57.52	22,271.55	9,727.83	12,547.27	967.04
Glazing; double pane IGU	0.75	0.08	139.59	1.69E-09	17.64	1,791.50	1,728.58	63.46	83.50
Floors	**49.97**	**10.62**	**9,958.71**	**4.95E-05**	**643.11**	**158,156.02**	**70,638.62**	**87,554.61**	**18,214.76**
Cast-in-place concrete; slab on grade	13.22	0.74	2,931.96	2.06E-05	184.48	23,293.09	22,522.20	773.61	10,959.63
Domestic hardwood	9.11	0.99	2,128.15	-9.01E-08	92.74	39,604.39	3,676.92	35,933.75	2,366.04
Flooring; cork tile	15.33	7.15	2,435.81	6.94E-08	219.50	56,264.31	27,410.15	28,873.73	1,616.25
Flooring; linoleum; generic	2.62	0.79	280.66	2.89E-05	33.92	7,345.08	4,527.98	2,818.71	132.36
Flooring; solid wood plank	0.93	0.25	146.91	-3.47E-09	5.22	3,096.03	920.42	2,175.96	132.65
Plywood; interior grade	3.53	0.27	671.52	8.23E-08	40.22	9,664.49	2,067.66	7,599.10	703.77
Wall board; gypsum	1.20	0.11	487.48	9.46E-09	22.68	8,885.82	8,604.11	283.41	1,274.48
Wood framing	4.03	0.32	876.23	-3.79E-08	44.36	10,002.81	909.19	9,096.34	1,029.57
Roofs	**42.32**	**2.59**	**4,637.68**	**3.17E-05**	**1,056.26**	**31,043.22**	**7,859.29**	**23,196.74**	**6,522.70**
Plywood; interior grade	4.76	0.36	905.73	1.11E-07	54.25	13,035.25	2,788.81	10,249.50	949.23
Slate roofing shingles; EPD - Rathscheck Schiefer	32.91	1.86	2,721.71	3.16E-05	950.87	6,475.31	4,022.24	2,459.69	4,386.43
Wood framing	4.64	0.37	1,010.24	-4.37E-08	51.14	11,532.66	1,048.24	10,487.56	1,187.04
Stairs and Railings	**1.47**	**0.16**	**342.94**	**-1.48E-08**	**14.68**	**6,370.95**	**527.41**	**5,844.55**	**383.44**
Stair; hardwood	1.47	0.16	342.94	-1.48E-08	14.68	6,370.95	527.41	5,844.55	383.44

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Structure	**15.65**	**0.97**	**3,508.83**	**2.72E-05**	**219.30**	**30,121.81**	**28,509.49**	**1,615.91**	**12,607.86**
Cast-in-place concrete; reinforced structural concrete; 3000 psi (20 Mpa)	0.48	0.02	107.55	7.01E-07	6.68	800.50	764.49	36.10	399.68
Cast-in-place concrete; slab on grade	14.86	0.93	3,334.35	2.65E-05	209.22	28,557.27	27,675.55	885.01	12,129.54
Domestic softwood	0.31	0.02	66.93	-2.90E-09	3.39	764.05	69.45	694.81	78.64
Walls	**46.76**	**6.05**	**13,914.00**	**1.31E-05**	**795.31**	**214,262.52**	**180,723.05**	**33,596.00**	**39,794.78**
Extruded polystyrene (XPS); board	2.21	1.05	813.29	5.28E-08	35.09	25,138.94	24,498.24	643.29	288.62
Fiber cement siding	14.25	2.02	2,827.17	1.18E-05	213.21	34,402.18	29,403.15	5,003.36	2,728.68
Hollow-core CMU; ungrouted	10.77	1.10	3,714.17	1.26E-06	244.61	37,728.97	35,257.67	2,498.31	22,127.31
Plywood; exterior grade	6.50	0.67	1,422.41	-5.40E-08	62.68	24,625.17	3,991.68	20,638.30	1,488.23
Wall board; gypsum	12.17	1.15	4,950.60	9.60E-08	230.28	90,239.85	87,378.94	2,878.12	12,942.96
Wood framing	0.86	0.07	186.36	-8.06E-09	9.43	2,127.40	193.37	1,934.62	218.97
Windows	**10.01**	**1.17**	**2,130.19**	**6.54E-08**	**194.02**	**43,889.91**	**28,350.10**	**15,544.82**	**868.07**
Glazing; double pane IGU	6.02	0.62	1,116.69	1.35E-08	141.12	14,332.01	13,828.67	507.67	668.01
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Window frame; wood	3.98	0.55	1,011.15	5.20E-08	52.80	29,517.14	14,514.96	15,002.85	197.59
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

Table B-22: Embodied Impacts by Revit Category and Material (Prototype):

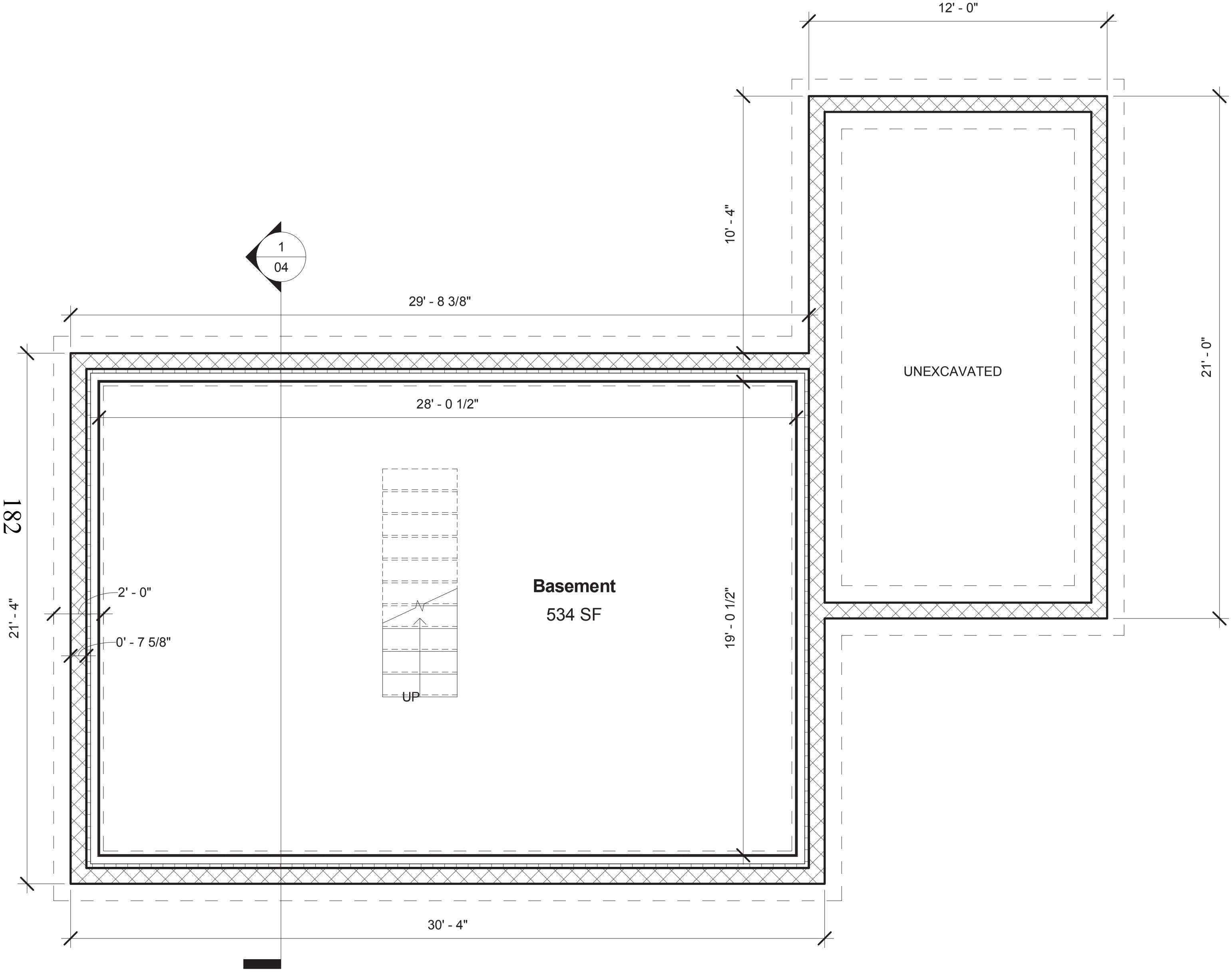
Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Ceilings	**10.55**	**0.73**	**2,573.26**	**8.70E-05**	**138.15**	**43,283.75**	**36,659.32**	**6,629.01**	**3,099.99**
Domestic softwood; US	1.66	0.13	361.92	-1.57E-08	18.32	4,131.55	375.53	3,757.14	425.25
Fiberglass blanket insulation; unfaced	7.02	0.42	1,450.20	8.70E-05	84.42	25,278.04	22,849.48	2,429.37	684.79
Paint; interior acrylic latex	0.98	0.10	230.36	8.90E-09	17.16	5,336.98	5,064.13	273.24	87.75
Wall board; gypsum; natural	0.89	0.07	530.78	5.86E-09	18.24	8,537.18	8,370.18	169.26	1,902.20
Doors	**15.97**	**2.90**	**3,127.40**	**7.15E-05**	**158.99**	**62,474.99**	**33,243.13**	**29,237.93**	**1,573.55**
Door frame; wood; no door	3.90	0.54	990.87	5.09E-08	51.74	28,925.22	14,223.88	14,702.00	193.63
Door; exterior; wood; solid core	0.89	0.21	111.17	-4.12E-09	5.00	1,850.26	290.42	1,560.22	112.77
Door; interior; wood; hollow core; flush	6.92	1.64	862.05	-3.20E-08	38.76	14,347.50	2,252.05	12,098.45	874.42
Glazing; double; insulated (argon); low-E	0.75	0.08	139.59	1.69E-09	17.64	1,791.50	1,728.58	63.46	83.50
Hollow door; exterior; steel; powder-coated; with small vision panel	1.52	0.11	378.46	1.02E-05	20.96	4,918.28	4,712.23	206.78	187.44
Paint; exterior acrylic latex	0.03	0.00	5.93	2.63E-10	0.71	129.35	122.31	7.05	2.86
Paint; interior acrylic latex	0.35	0.04	83.02	3.21E-09	6.19	1,923.31	1,824.98	98.47	31.62
Stainless steel; door hardware; lever lock; exterior; residential	0.48	0.08	167.67	1.85E-05	5.42	2,588.84	2,437.87	151.15	26.31
Stainless steel; door hardware; lever lock; interior; residential	1.12	0.19	388.65	4.28E-05	12.57	6,000.73	5,650.80	350.36	60.99
Floors	**49.97**	**10.62**	**9,958.71**	**4.95E-05**	**643.11**	**158,156.02**	**70,638.62**	**87,554.61**	**18,214.76**
Acrylic adhesive	0.03	0.01	5.95	2.90E-10	1.83	251.86	250.27	1.67	14.29
Cork tile	13.45	3.67	1,692.46	3.39E-08	179.11	41,238.87	13,164.33	28,091.96	1,244.22
Domestic hardwood; US	9.00	0.98	2,107.00	-9.11E-08	90.19	39,142.74	3,240.38	35,908.59	2,355.84
Domestic softwood; US	4.03	0.32	876.23	-3.79E-08	44.36	10,002.81	909.19	9,096.34	1,029.57
Expanded polystyrene (EPS); board	0.18	0.08	65.72	2.53E-06	3.75	1,912.27	1,891.60	20.85	20.92
Flooring; hardwood plank	0.93	0.25	146.91	-3.47E-09	5.22	3,096.03	920.42	2,175.96	132.65
Flooring; linoleum; tile	2.57	0.68	263.03	2.89E-05	27.81	6,820.94	4,014.12	2,808.32	112.36
Interior grade plywood; US	3.53	0.27	671.52	8.23E-08	40.22	9,664.49	2,067.66	7,599.10	703.77
Paint; exterior acrylic latex	0.11	0.01	21.15	9.39E-10	2.55	461.66	436.54	25.16	10.20
Paint; interior acrylic latex	0.63	0.07	147.53	5.70E-09	10.99	3,418.11	3,243.36	175.00	56.20
Polyethelene sheet vapor barrier (HDPE)	0.09	0.17	38.07	3.01E-09	1.63	1,115.80	1,104.64	11.28	13.65
Polyurethane floor finish; water-based	0.03	0.10	11.67	3.93E-10	4.29	272.28	263.58	8.72	5.71
Steel; reinforcing rod	0.80	0.04	280.99	2.61E-06	10.82	3,661.57	3,152.28	509.93	214.22
Structural concrete; 3000 psi; generic	12.14	0.44	2,547.18	1.54E-05	168.28	16,603.45	16,373.68	231.54	10,710.84
Urethane adhesive	1.88	3.48	743.35	3.55E-08	40.40	15,025.44	14,245.82	781.78	372.04
Wall board; gypsum; natural	0.57	0.05	339.95	3.76E-09	11.68	5,467.71	5,360.75	108.41	1,218.28
Roofs	**42.32**	**2.59**	**4,637.68**	**3.17E-05**	**1,056.26**	**31,043.22**	**7,859.29**	**23,196.74**	**6,522.70**
Domestic softwood; US	4.64	0.37	1,010.24	-4.37E-08	51.14	11,532.66	1,048.24	10,487.56	1,187.04
Fasteners; stainless steel	0.48	0.06	34.54	2.72E-06	1.94	530.07	454.26	75.86	7.93
Interior grade plywood; US	4.76	0.36	905.73	1.11E-07	54.25	13,035.25	2,788.81	10,249.50	949.23
Roofing shingles; slate; Rathscheck Schiefer; Colored Slate; EPD	32.44	1.80	2,687.17	2.89E-05	948.93	5,945.25	3,567.97	2,383.83	4,378.51

Row Labels	Sum of Acidification Potential Total (kgSO2eq)	Sum of Eutrophication Potential Total (kgNeq)	Sum of Global Warming Potential Total (kgCO2eq)	Sum of Ozone Depletion Potential Total (CFC-11eq)	Sum of Smog Formation Potential Total (kgO3eq)	Sum of Primary Energy Demand Total (MJ)	Sum of Non-renewable Energy Demand Total (MJ)	Sum of Renewable Energy Demand Total (MJ)	Sum of Mass Total (kg)
Stairs and Railings	**1.47**	**0.16**	**342.94**	**-1.48E-08**	**14.68**	**6,370.95**	**527.41**	**5,844.55**	**383.44**
Domestic hardwood; US	1.47	0.16	342.94	-1.48E-08	14.68	6,370.95	527.41	5,844.55	383.44
Structure	**15.65**	**0.97**	**3,508.83**	**2.72E-05**	**219.30**	**30,121.81**	**28,509.49**	**1,615.91**	**12,607.86**
Domestic softwood; US	0.31	0.02	66.93	-2.90E-09	3.39	764.05	69.45	694.81	78.64
Expanded polystyrene (EPS); board	0.48	0.20	170.29	6.56E-06	9.72	4,954.80	4,901.26	54.03	54.21
Polyethelene sheet vapor barrier (HDPE)	0.10	0.19	42.02	3.33E-09	1.80	1,231.74	1,219.42	12.46	15.06
Steel; reinforcing rod	0.93	0.05	325.45	3.02E-06	12.53	4,241.02	3,651.13	590.63	248.12
Structural concrete; 3000 psi; generic	13.84	0.51	2,904.14	1.76E-05	191.86	18,930.21	18,668.24	263.99	12,211.83
Walls	**46.76**	**6.05**	**13,914.00**	**1.31E-05**	**795.31**	**214,262.52**	**180,723.05**	**33,596.00**	**39,794.78**
Domestic softwood; US	0.86	0.07	186.36	-8.06E-09	9.43	2,127.40	193.37	1,934.62	218.97
Exterior grade plywood; US	6.50	0.67	1,422.41	-5.40E-08	62.68	24,625.17	3,991.68	20,638.30	1,488.23
Fasteners; stainless steel	0.34	0.05	24.36	1.92E-06	1.36	373.80	320.34	53.49	5.59
Fiber cement board; lap siding	10.44	1.65	2,123.63	9.82E-06	129.92	19,206.20	15,066.92	4,142.12	2,395.63
Hollow-core CMU; 8x8x16 ungrouted	6.55	0.62	2,372.01	4.09E-08	152.11	21,504.28	20,088.12	1,435.80	16,542.42
Mortar type S	1.98	0.29	850.79	1.20E-08	43.74	6,626.30	6,234.50	398.10	5,312.13
Paint; exterior acrylic latex	5.35	0.50	1,042.62	4.63E-08	125.77	22,753.36	21,515.61	1,239.97	502.68
Paint; interior acrylic latex	6.36	0.67	1,498.29	5.79E-08	111.63	34,712.60	32,937.93	1,777.20	570.77
Polystyrene board (XPS); Pentane foaming agent	2.21	1.05	813.29	5.28E-08	35.09	25,138.94	24,498.24	643.29	288.62
Steel; reinforcing rod	0.37	0.02	127.94	1.19E-06	4.93	1,667.22	1,435.33	232.19	97.54
Wall board; gypsum; natural	5.81	0.48	3,452.31	3.81E-08	118.64	55,527.25	54,441.01	1,100.92	12,372.20
Windows	**10.01**	**1.17**	**2,130.19**	**6.54E-08**	**194.02**	**43,889.91**	**28,350.10**	**15,544.82**	**868.07**
Glazing; double; insulated (argon); low-E	6.02	0.62	1,116.69	1.35E-08	141.12	14,332.01	13,828.67	507.67	668.01
Trim; wood	0.01	0.00	2.34	-8.97E-11	0.10	40.76	6.47	34.30	2.47
Window frame; wood; divided operable	0.18	0.03	45.96	2.36E-09	2.40	1,341.69	659.77	681.95	8.98
Window frame; wood; fixed	0.35	0.05	89.22	4.59E-09	4.66	2,604.45	1,280.73	1,323.78	17.43
Window frame; wood; operable	3.45	0.48	875.97	4.50E-08	45.74	25,571.00	12,574.46	12,997.13	171.18
Grand Total	**192.69**	**25.20**	**40,193.00**	**2.80E-04**	**3,219.82**	**589,603.18**	**386,510.42**	**203,219.58**	**83,065.15**

<u>Appendix C:</u>

Baseline Drawings

Contents:



1 Basement
1/4" = 1'-0"

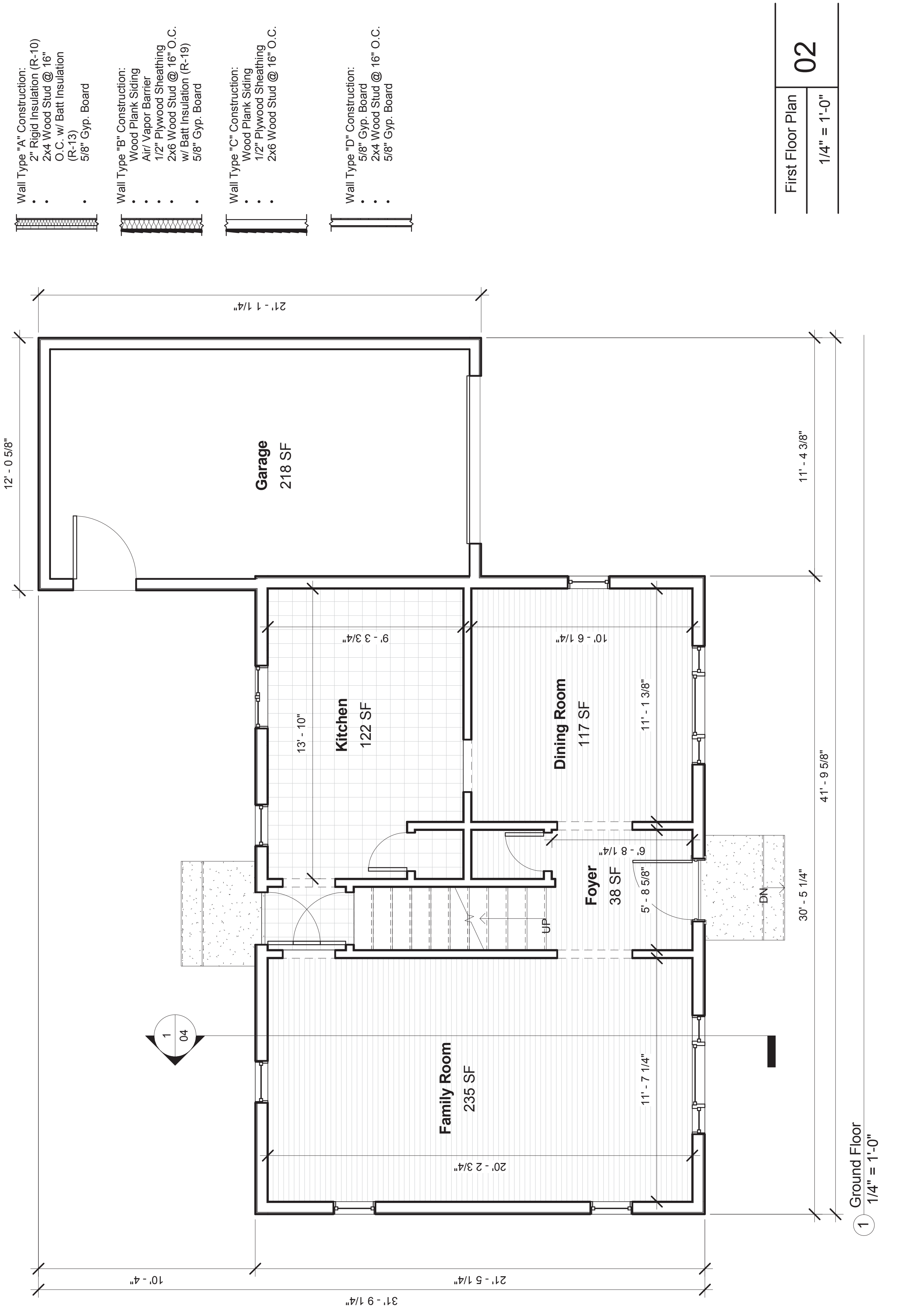
Wall Type "A" Construction:
- 2" Rigid Insulation (R-10)
- 2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
- 5/8" Gyp. Board

Wall Type "B" Construction:
- Wood Plank Siding
- Air/ Vapor Barrier
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
- 5/8" Gyp. Board

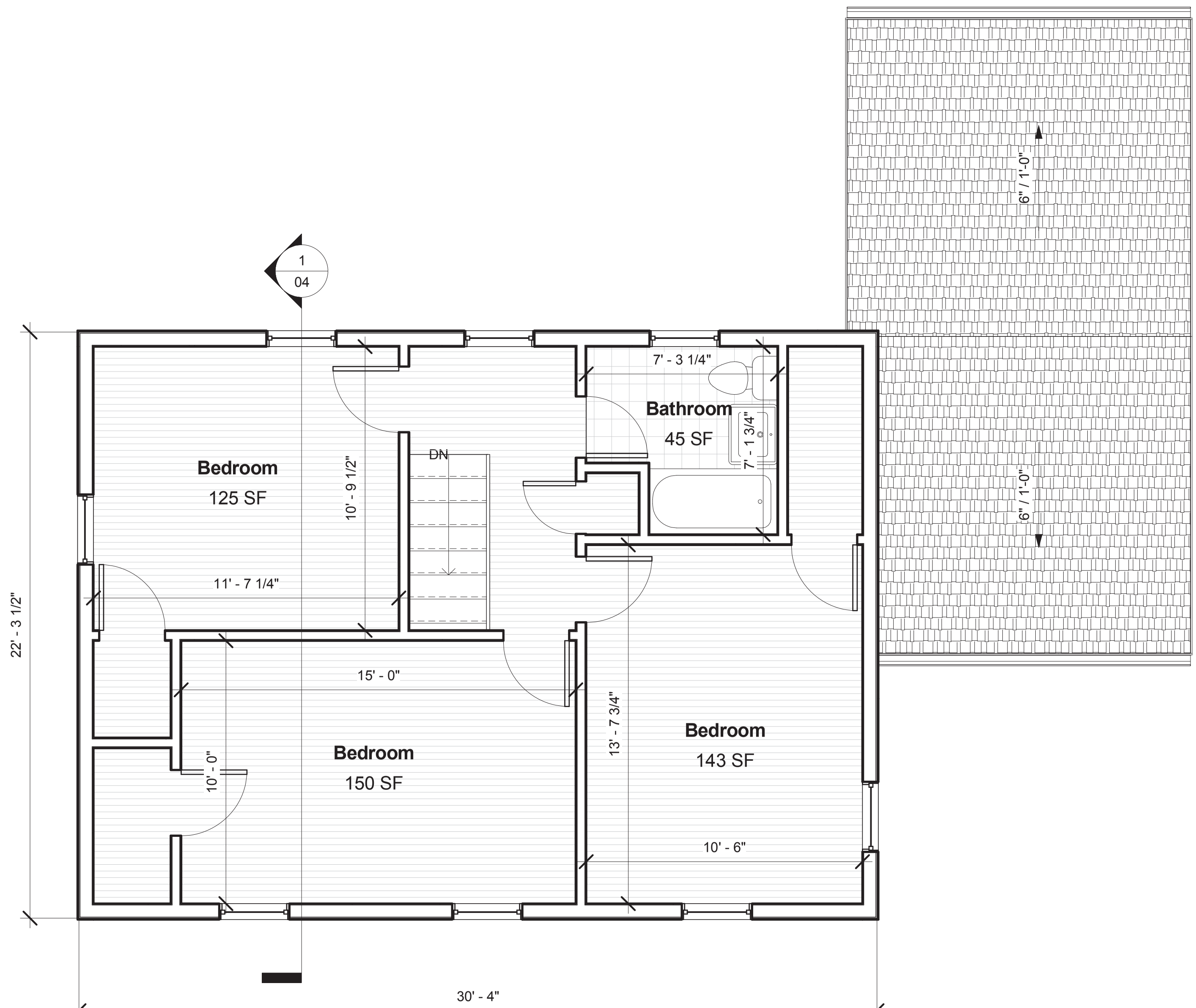
Wall Type "C" Construction:
- Wood Plank Siding
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C.

Wall Type "D" Construction:
- 5/8" Gyp. Board
- 2x4 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Basement Plan	01
1/4" = 1'-0"	



Wall Type "A" Construction:
2" Rigid Insulation (R-10)
2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
5/8" Gyp. Board
Wall Type "B" Construction:
Wood Plank Siding
Air/ Vapor Barrier
1/2" Plywood Sheathing
2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
5/8" Gyp. Board
Wall Type "C" Construction:
Wood Plank Siding
1/2" Plywood Sheathing
2x6 Wood Stud @ 16" O.C.
Wall Type "D" Construction:
5/8" Gyp. Board
2x4 Wood Stud @ 16" O.C.
5/8" Gyp. Board
First Floor Plan
1/4" = 1'-0"
02
21' - 1 1/4"
12' - 0 5/8"
Garage
218 SF
11' - 4 3/8"
9' - 3 3/4"
10' - 6 1/4"
13' - 10"
Kitchen
122 SF
Dining Room
117 SF
11' - 1 3/8"
41' - 9 5/8"
6' - 8 1/4"
Foyer
38 SF
5' - 8 5/8"
UP
DN
30' - 5 1/4"
1
04
Family Room
235 SF
11' - 7 1/4"
20' - 2 3/4"
1 Ground Floor
1/4" = 1'-0"
10' - 4"
21' - 5 1/4"
31' - 9 1/4"



1 Second Floor
1/4" = 1'-0"

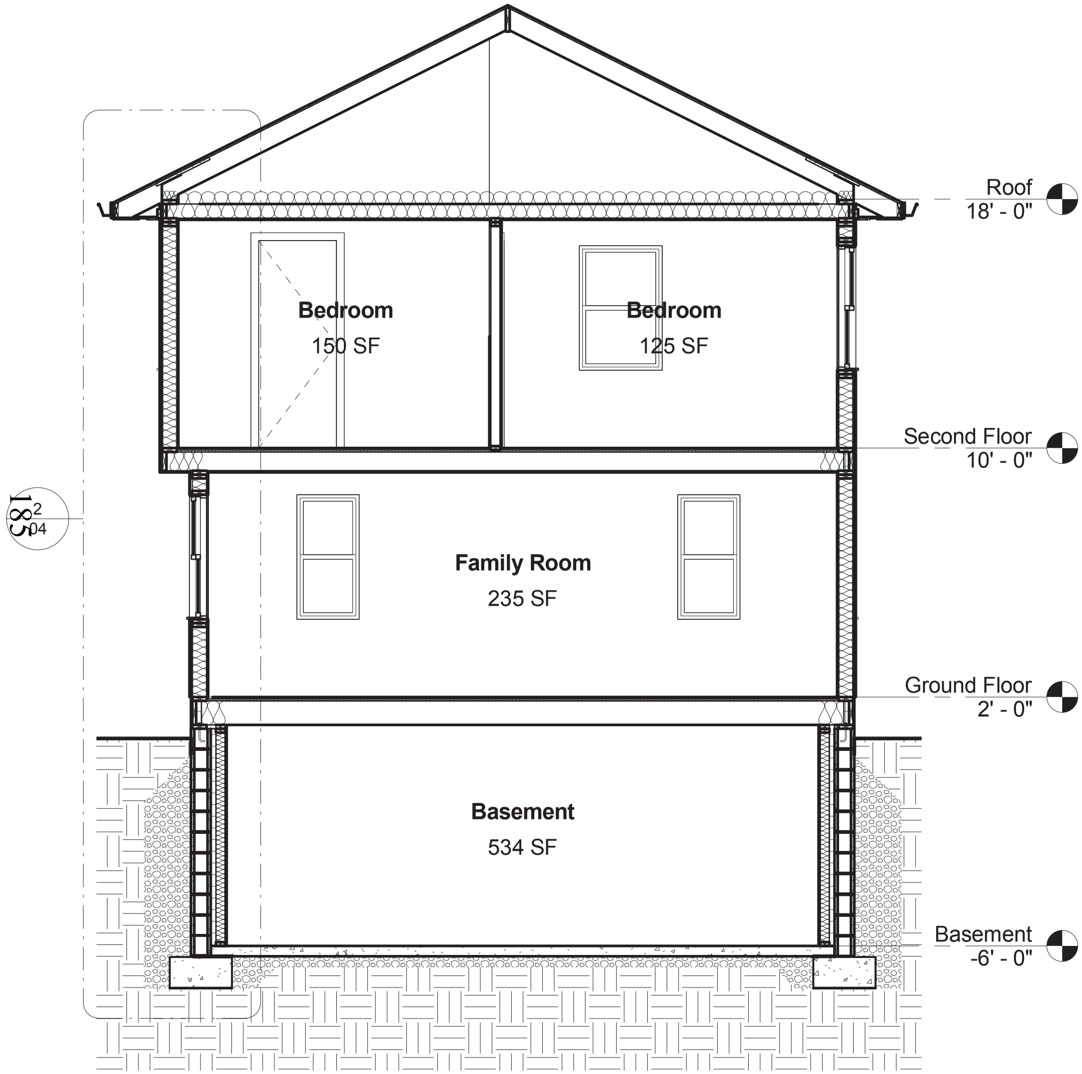
Wall Type "A" Construction:
- 2" Rigid Insulation (R-10)
- 2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
- 5/8" Gyp. Board

Wall Type "B" Construction:
- Wood Plank Siding
- Air/ Vapor Barrier
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
- 5/8" Gyp. Board

Wall Type "C" Construction:
- Wood Plank Siding
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C.

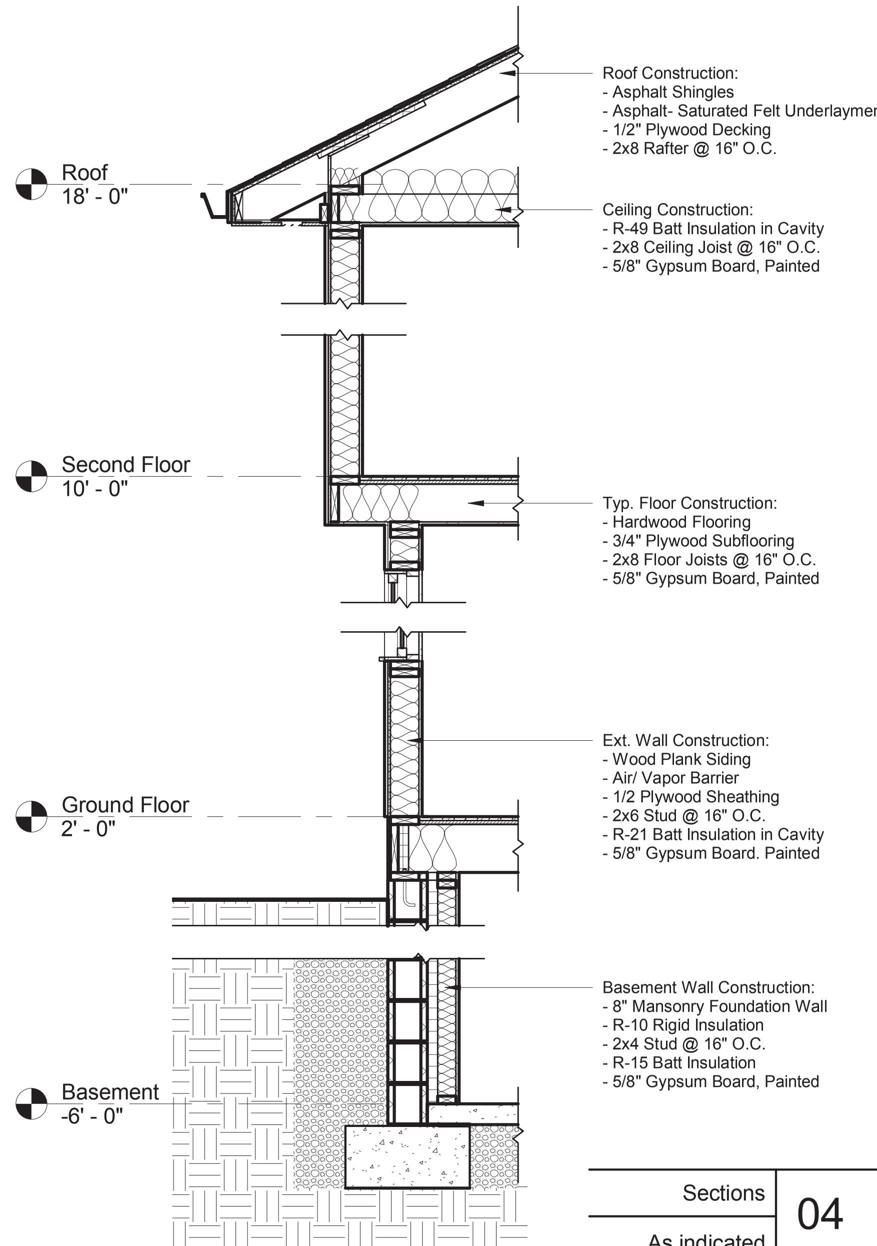
Wall Type "D" Construction:
- 5/8" Gyp. Board
- 2x4 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Second Floor	03
1/4" = 1'-0"	



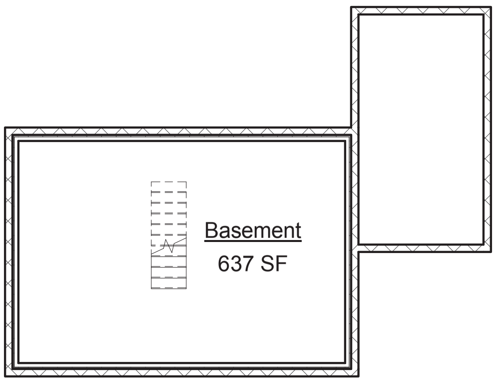
185

1 Building Section
1/4" = 1'-0"

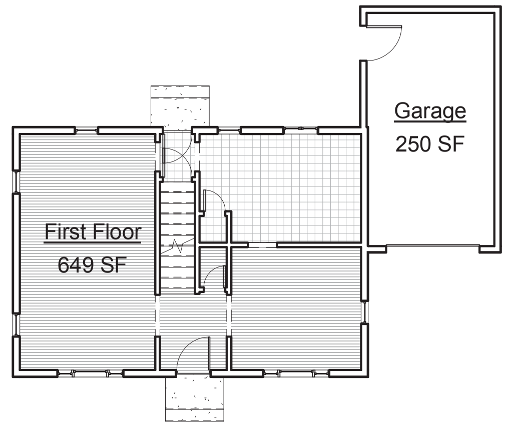


2 Wall Section
1/2" = 1'-0"

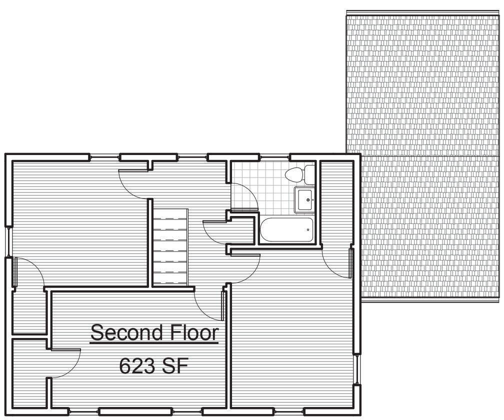
Sections	04
As indicated	



1 Area Plan
3/32" = 1'-0"



2 Area Plan
3/32" = 1'-0"

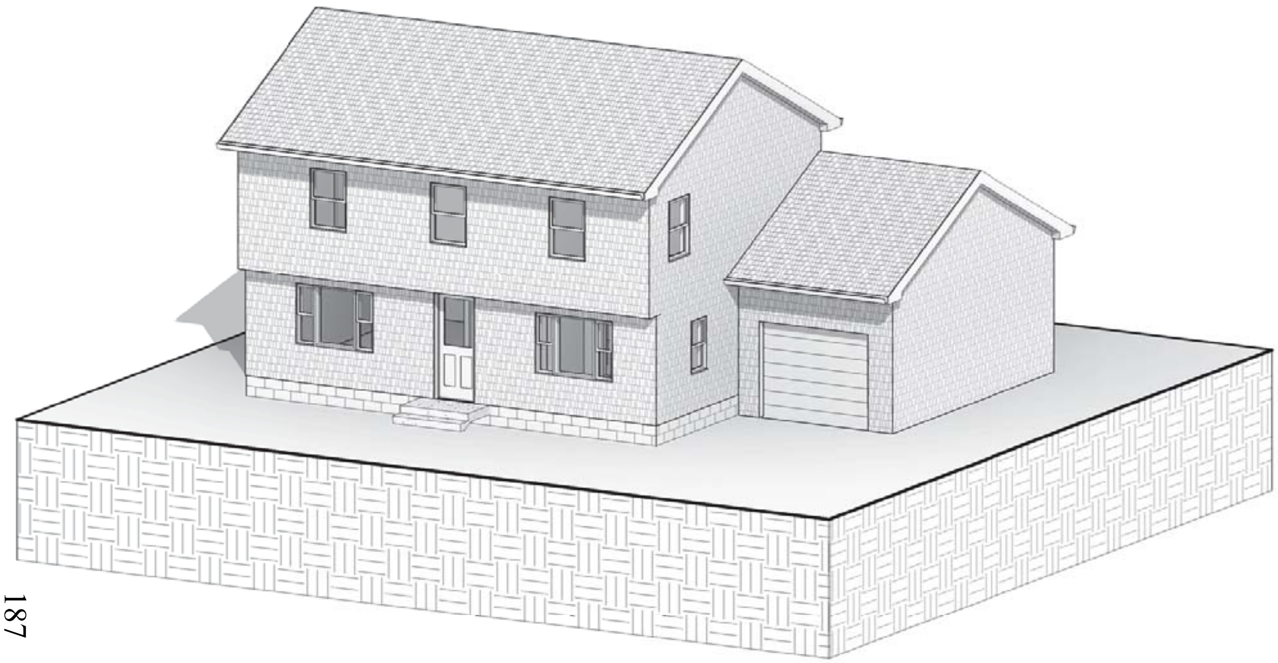


3 Area Plam
3/32" = 1'-0"

Room Schedule	
Name	Area
Basement	
Basement	534 SF
Total: 534 SF	
Ground Floor	
Family Room	235 SF
Garage	218 SF
Kitchen	122 SF
Dining Room	117 SF
Foyer	38 SF
Foyer	11 SF
CL.	8 SF
Pantry	5 SF
Total: 754 SF	
Second Floor	
Bedroom	150 SF
Bedroom	143 SF
Bedroom	125 SF
Landing	68 SF
Bathroom	45 SF
CL.	20 SF
CL.	17 SF
CL.	11 SF
CL.	5 SF
Total: 584 SF	

Gross Area: 1,872 SF
Livable Area: 1,272 SF

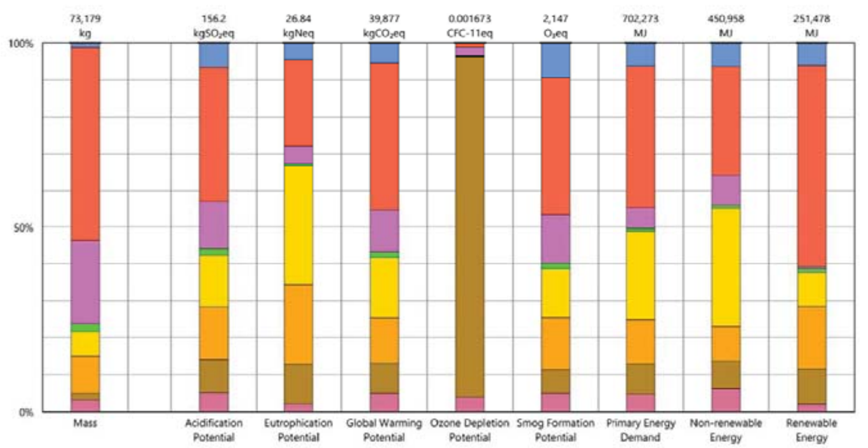
Area Plans
3/32" = 1'-0"
05

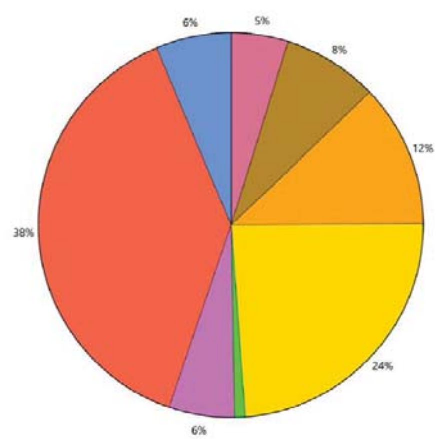


Embodied Energy of Baseline:

Revit Category	*Embodied Energy (MJ)*
Ceilings	33,463.69
Doors	56,643.79
Floors	84,872.83
Roofs	168,026.18
Stairs and Railings	6,092.07
Structure	38,657.07
Walls	270,203.48
Windows	44,313.57
Total	**702,272.69**

Results per Revit Category





Primary Energy Demand

Legend

Revit Categories

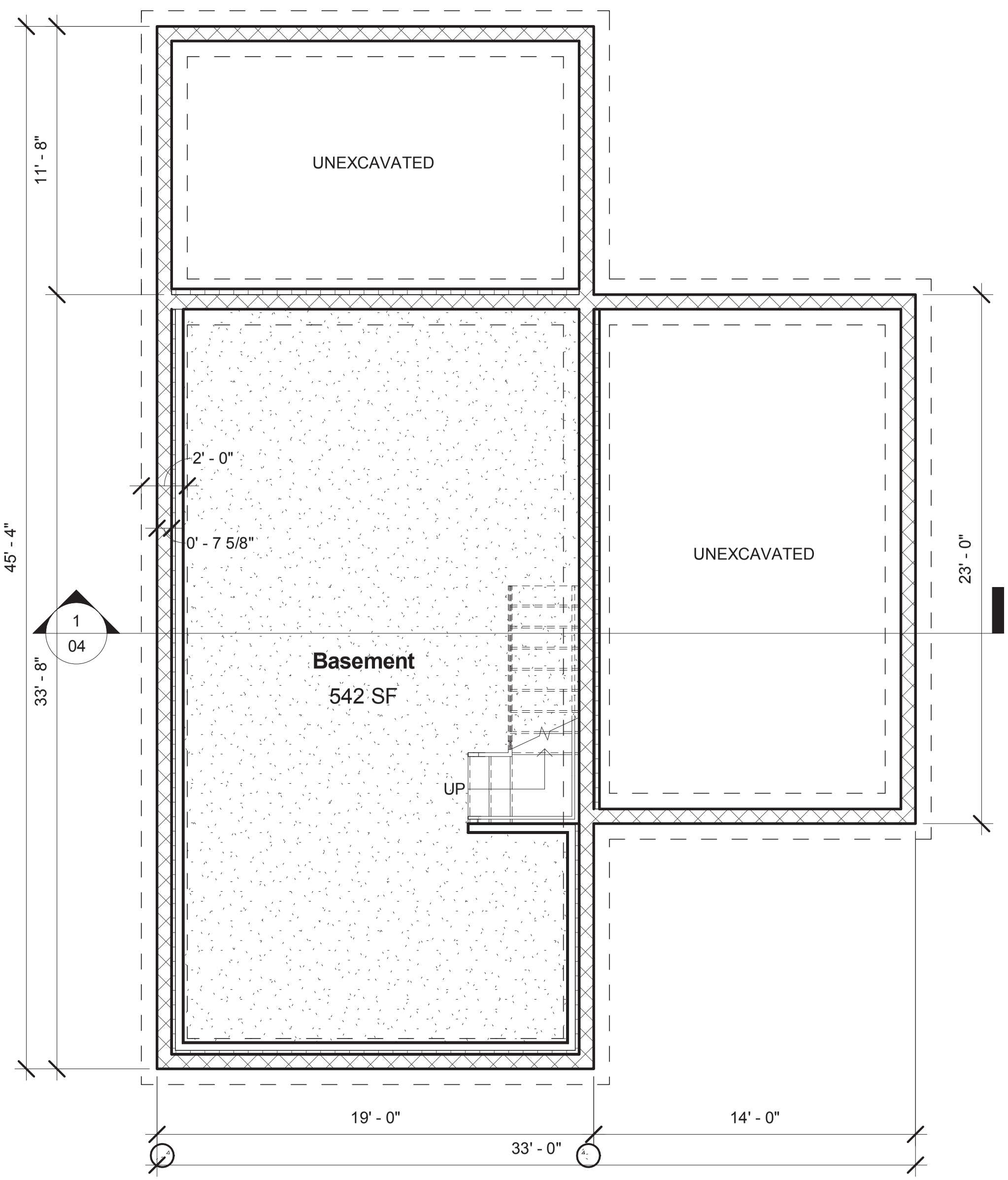
- Ceilings
- Doors
- Floors
- Roofs
- Stairs and Railings
- Structure
- Walls
- Windows

Embodied Impacts 06

Appendix D:

Prototype Drawings

Contents:



1 Basement
3/16" = 1'-0"

Wall Type "A" Construction:
- 2" Rigid Insulation (R-10)
- 2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
- 5/8" Gyp. Board

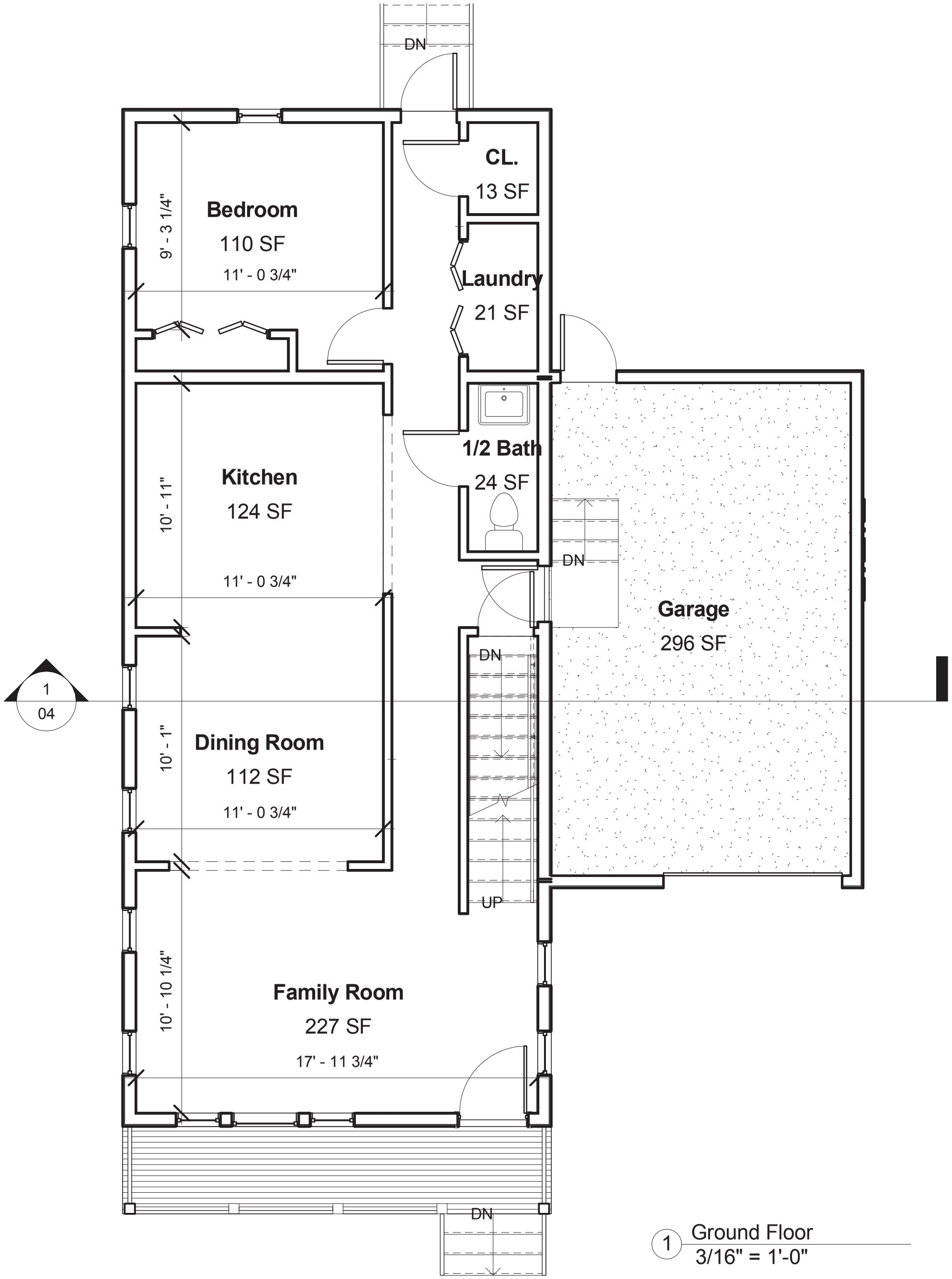
Wall Type "B" Construction:
- Fiber Cement Siding
- Air/ Vapor Barrier
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
- 5/8" Gyp. Board

Wall Type "C" Construction:
- Fiber Cement Siding
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C.

Wall Type "D" Construction:
- 5/8" Gyp. Board
- 2x4 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Wall Type "E" Construction:
- 5/8" Gyp. Board
- 2x6 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Basement Plan	01
As indicated	



1 Ground Floor
3/16" = 1'-0"

Wall Type "A" Construction:
- 2" Rigid Insulation (R-10)
- 2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
- 5/8" Gyp. Board

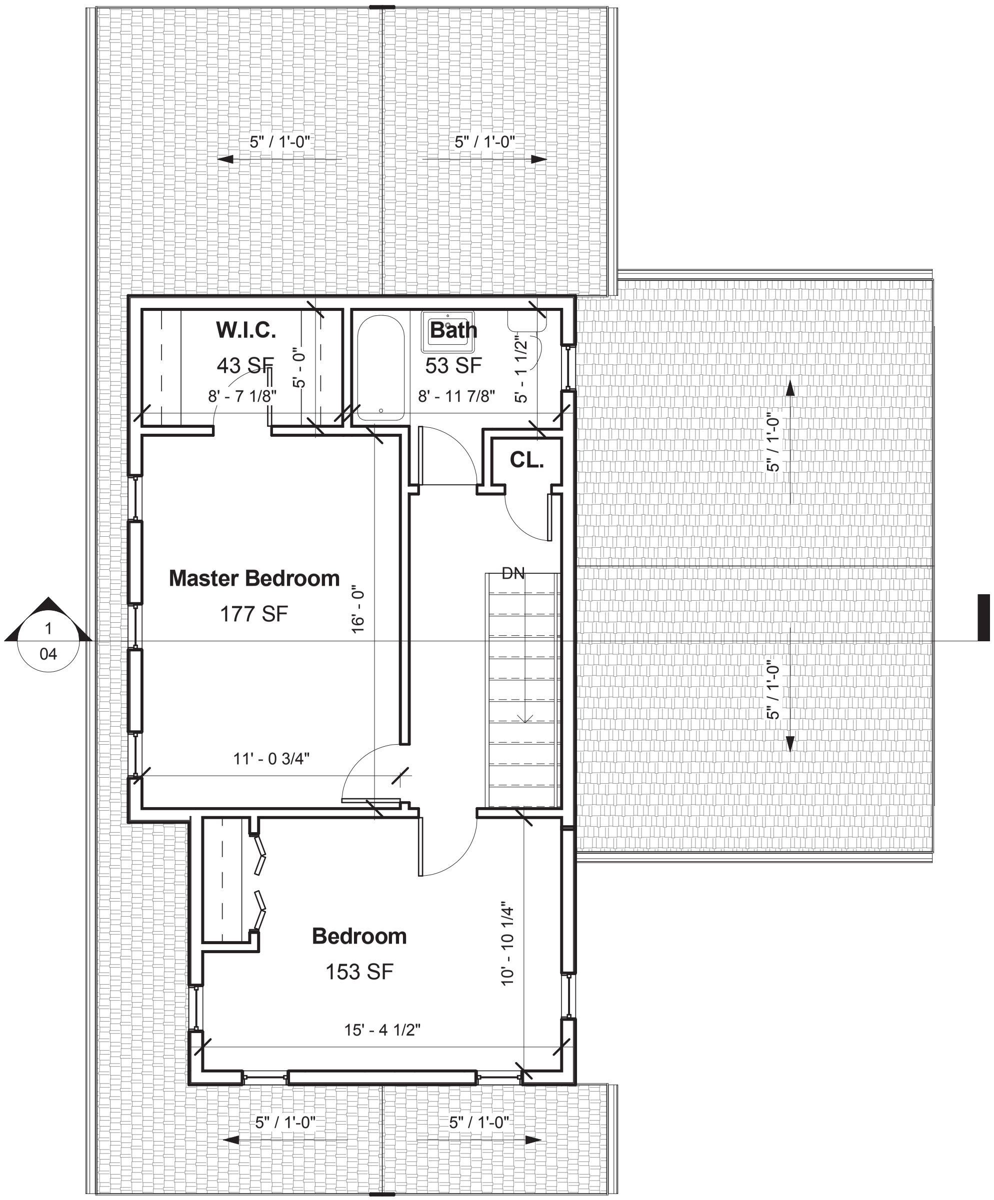
Wall Type "B" Construction:
- Fiber Cement Siding
- Air/ Vapor Barrier
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
- 5/8" Gyp. Board

Wall Type "C" Construction:
- Fiber Cement Siding
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C.

Wall Type "D" Construction:
- 5/8" Gyp. Board
- 2x4 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Wall Type "E" Construction:
- 5/8" Gyp. Board
- 2x6 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

First Floor Plan	02
As indicated	



1 Second Floor
3/16" = 1'-0"

Wall Type "A" Construction:
- 2" Rigid Insulation (R-10)
- 2x4 Wood Stud @ 16" O.C. w/ Batt Insulation (R-13)
- 5/8" Gyp. Board

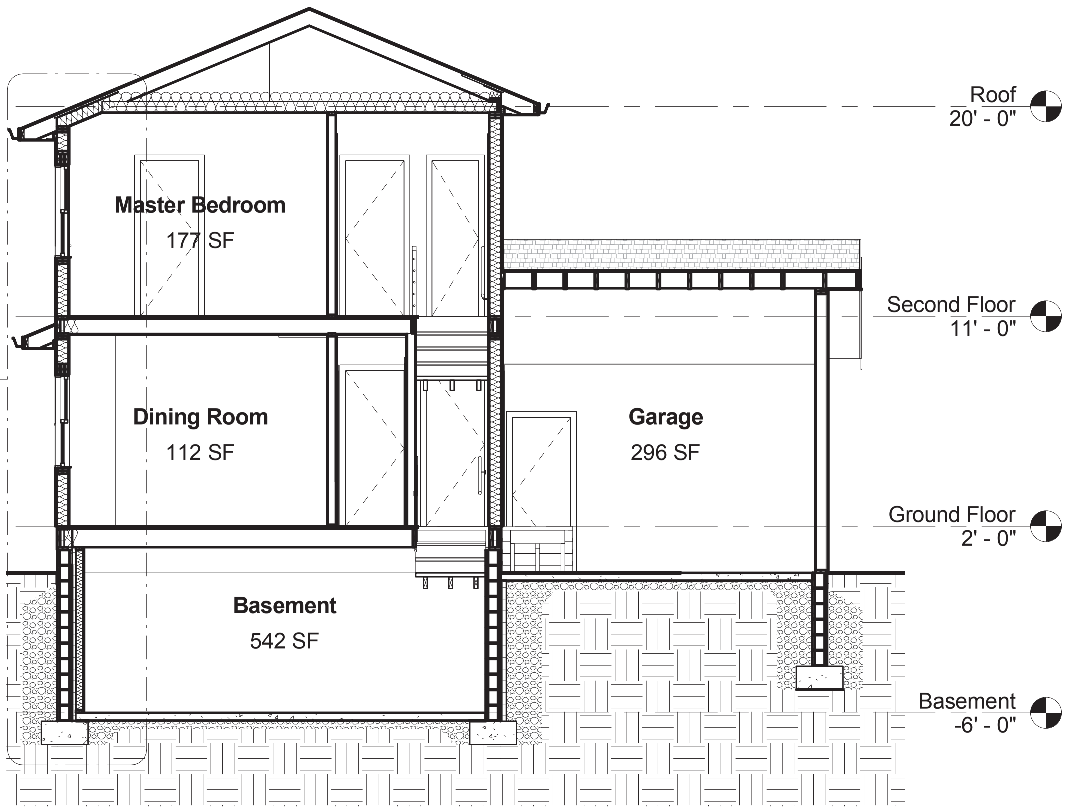
Wall Type "B" Construction:
- Fiber Cement Siding
- Air/ Vapor Barrier
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C. w/ Batt Insulation (R-19)
- 5/8" Gyp. Board

Wall Type "C" Construction:
- Fiber Cement Siding
- 1/2" Plywood Sheathing
- 2x6 Wood Stud @ 16" O.C.

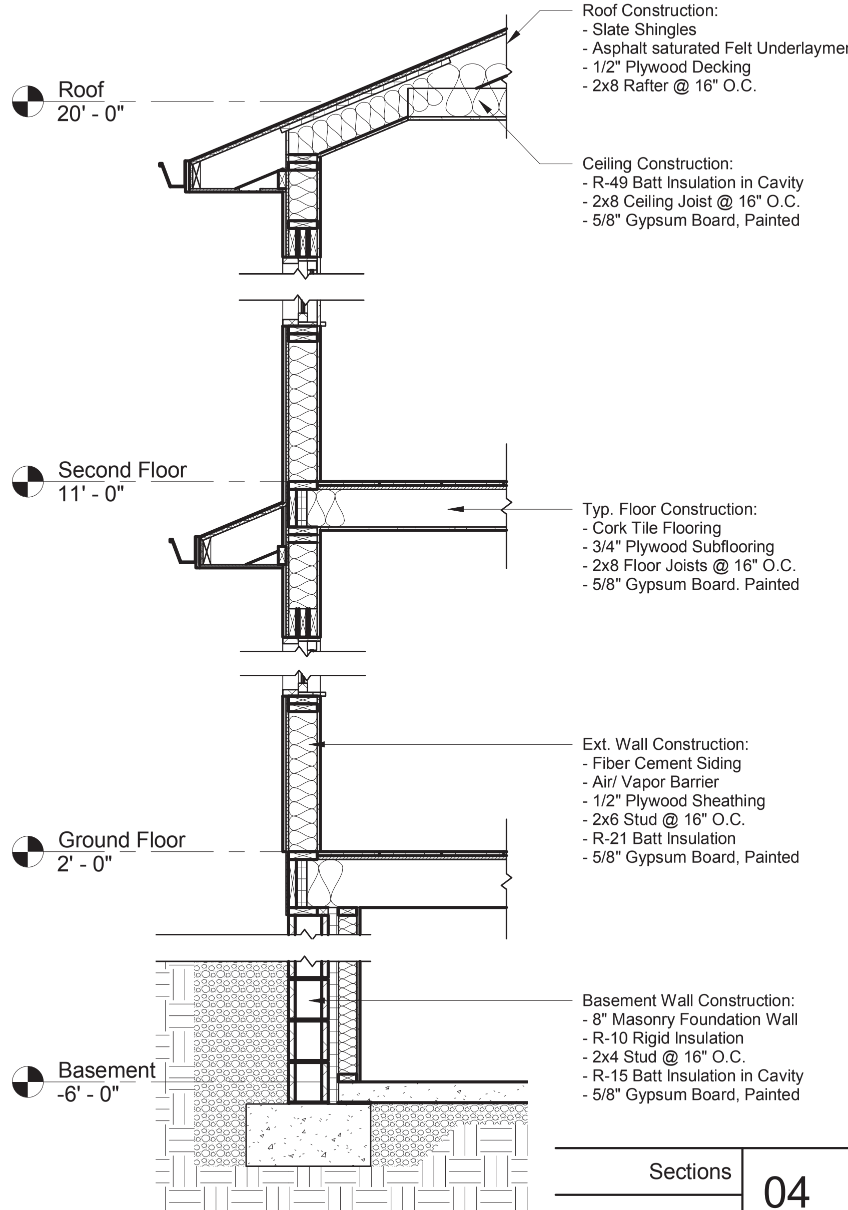
Wall Type "D" Construction:
- 5/8" Gyp. Board
- 2x4 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Wall Type "E" Construction:
- 5/8" Gyp. Board
- 2x6 Wood Stud @ 16" O.C.
- 5/8" Gyp. Board

Second Floor	03
As indicated	

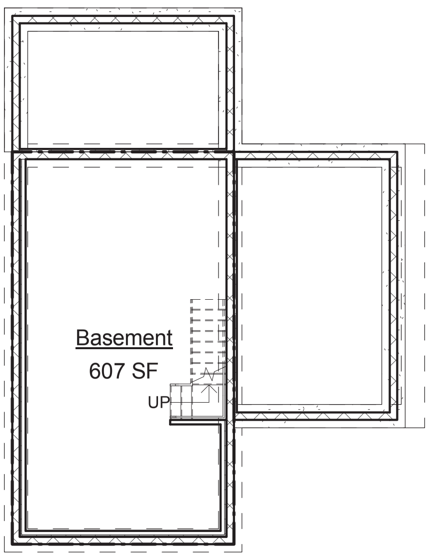


1 Building section
3/16" = 1'-0"

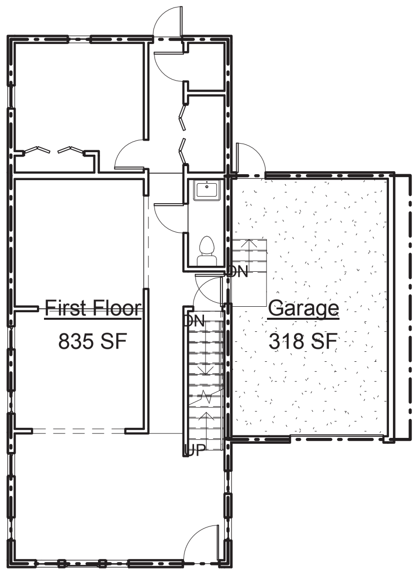


2 Wall Section
1/2" = 1'-0"

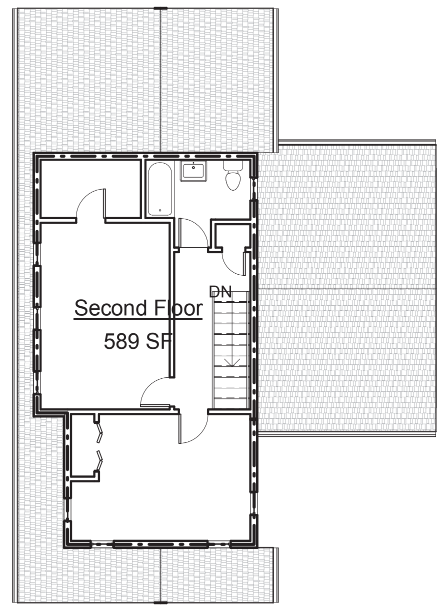
Sections	04
As indicated	



1 Area Plan
3/32" = 1'-0"



2 Area Plan
3/32" = 1'-0"



3 Area Plam
3/32" = 1'-0"

Room Schedule	
Name	Area

Basement

Basement	542 SF

Total: 542 SF

Ground Floor

Garage	296 SF
Family Room	227 SF
Kitchen	124 SF
Dining Room	112 SF
Bedroom	110 SF
1/2 Bath	24 SF
Laundry	21 SF
CL.	13 SF

Total: 927 SF

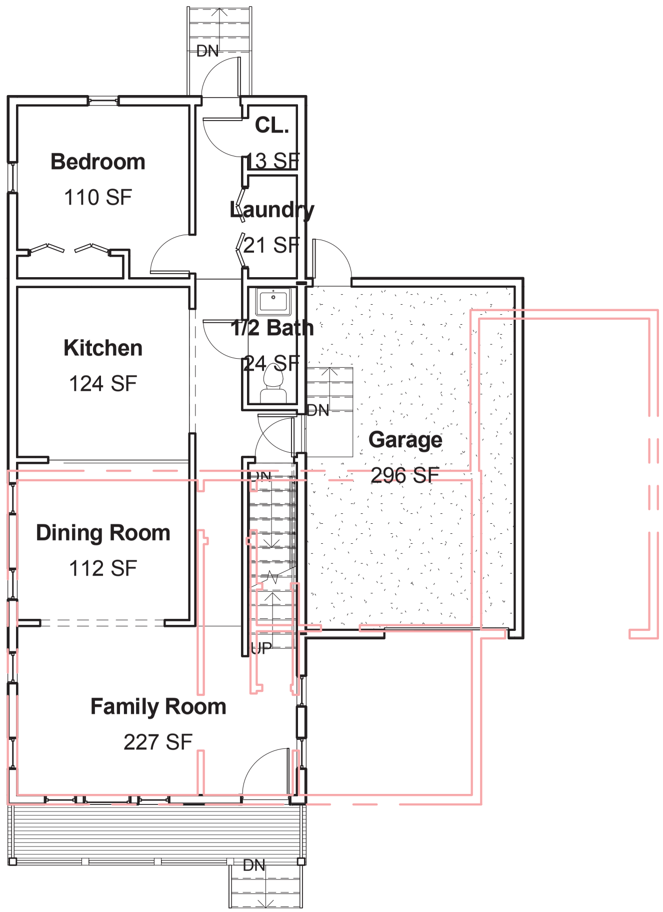
Second Floor

Master Bedroom	177 SF
Bedroom	153 SF
Bath	53 SF
W.I.C.	43 SF
CL.	6 SF

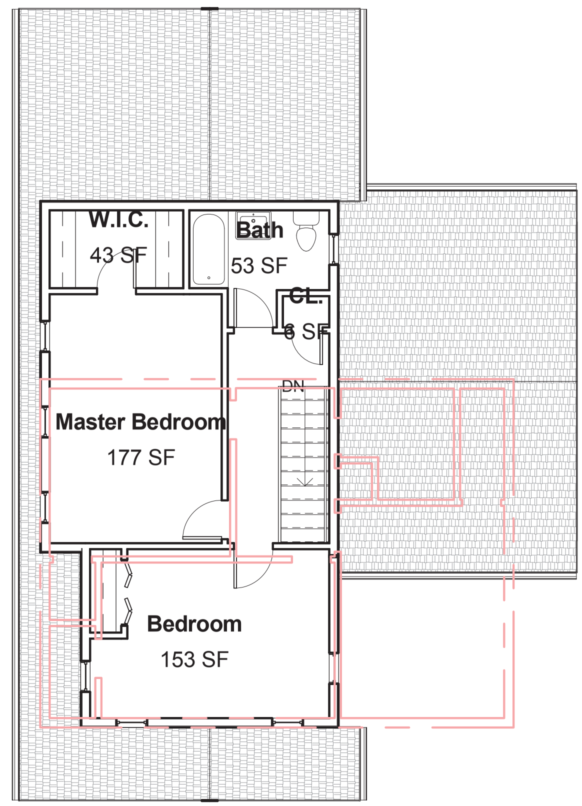
Total: 432 SF

Gross Area: 2,349 SF
Livable Area: 1,428 SF

Area Plans	05
3/32" = 1'-0"	



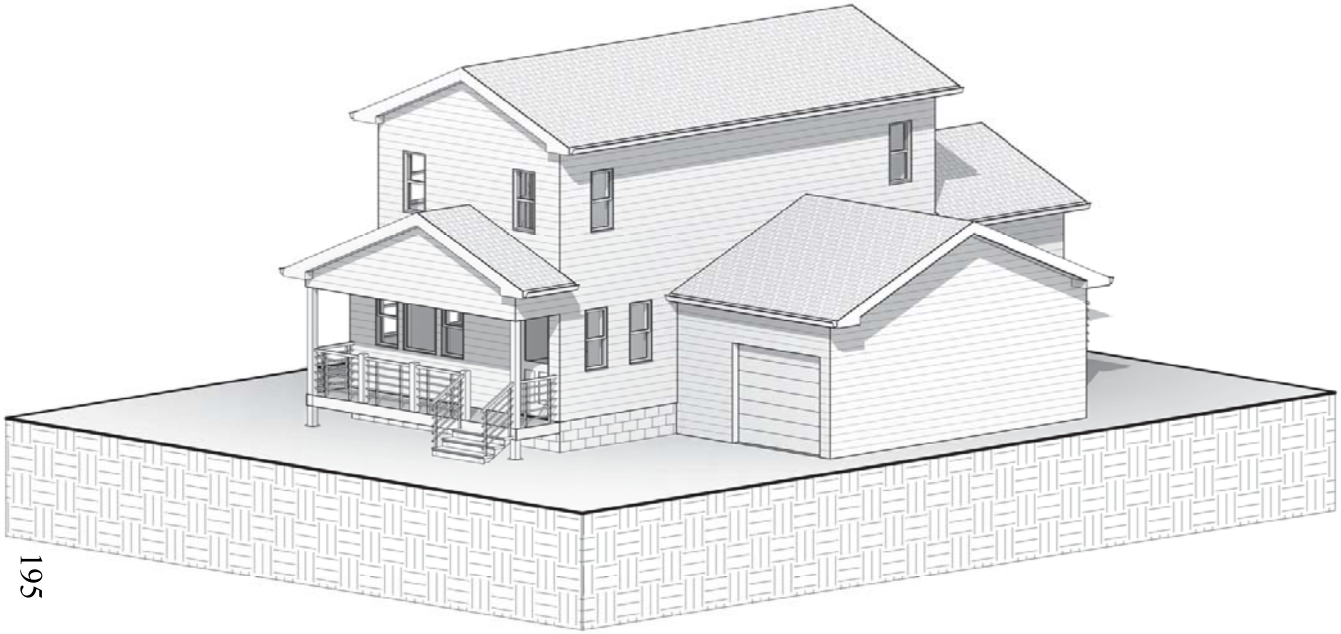
1 Ground Floor - Comparison
1/8" = 1'-0"



2 Second Floor - Comparison
1/8" = 1'-0"

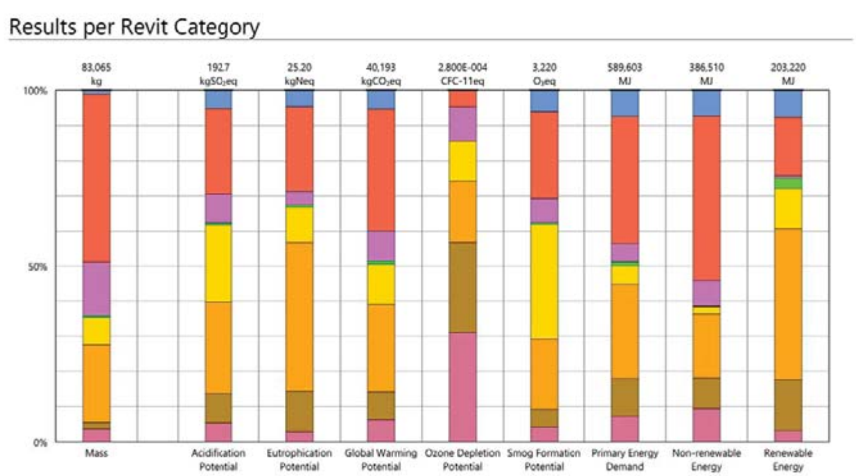
Baseline House:	
Gross Building Area:	2,159 SF
Livable Area:	1,272 SF
Prototype House:	
Gross Building Area:	2,401 SF
Livable Area:	1,428 SF
Precent Change:	
Gross Building Area:	11.21%
Liveable area:	12.26%

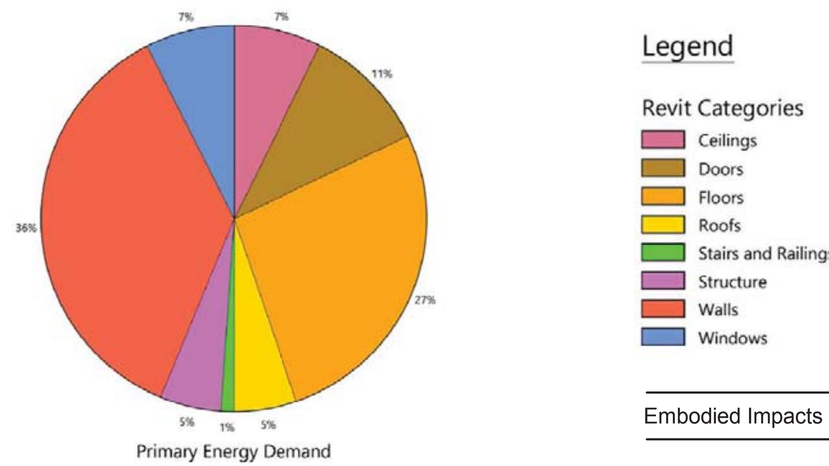
Area Comparison
1/8" = 1'-0"
07



Embodied Energy of Baseline:

Revit Category	*Embodied Energy (MJ)*
Ceilings	42,283.75
Doors	62,474.99
Floors	158,156.02
Roofs	31,043.22
Stairs and Railings	6,370.95
Structure	30,121.81
Walls	214,262.52
Windows	43,889.91
Total	**589,603.18**





Embodied Impacts

08

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