Calculating Energy Consumption for Building Materials

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Abstract

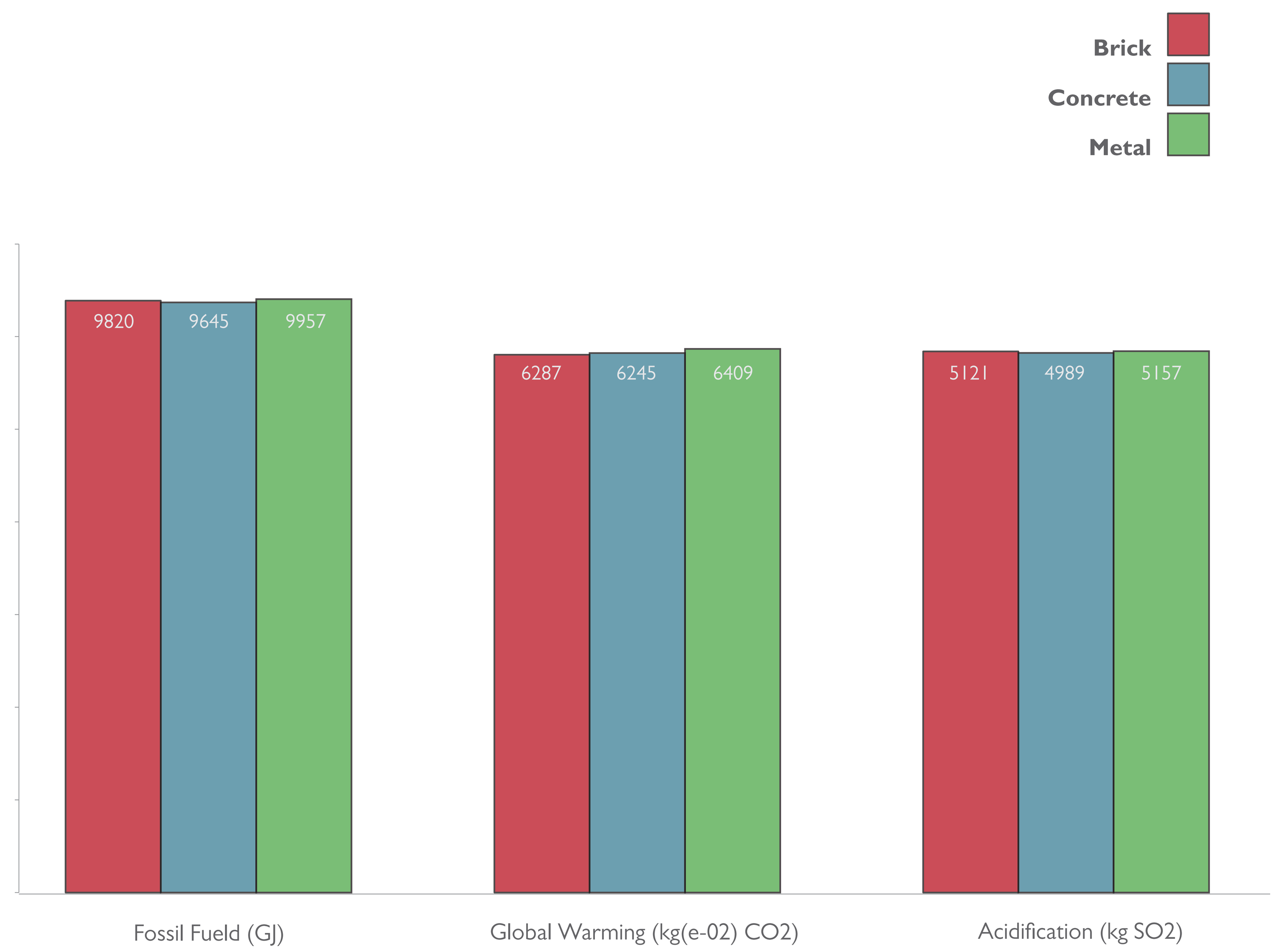
Sustainability is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. With that, Life Cycle Assesment (LCA) was born and is now a standard tool in measuring how sustainable we are in building from material extraction to end of life.

Architects have adopted the responsibility to lead the building industry down a green and sustainable path; as a part of this, many architecture firms have expanded their practices to include studios that work specifically on green buildings or green energy audits for clients. Throughout history sustainable design has used a variety of techniques: construction via local materials, tailored to respond to climatic conditions, and configured to exploit specific ventilation and solar conditions.

Currently, the state building and model codes are based on modest improvements in energy efficiency. There has been legislation proposed and debated regarding the importance of requiring more aggressive energy efficiency improvements. Next generation building code, as well as the International Green Construction Code (IGCC), are both going to be developed based around these ideals.

Each LCA software uses a database referred to as the Life Cycle Inventory (LCI) which is intended to account for all embodied energy for any given phase of construction (manufacturing, transportation, recycling, etc...) Some databases are available via companies that compile the information, one of which is National Renewable Energy Laboratory (NREL). These can be used as an aid to accomodate for any shortcomings that the internal database of the software may have.

Once an LCA has been simulated the firm can then find areas that can easily be improved upon whether it is material choice, manufacturer location or transportation methods; the error of margin that currently exists with LCA makes the analysis more useful as a set of guidelines.



Steps of LCA

1. **Goal and Scope Definition**
In this phase, the products and services to be assessed are defined and the required level of detail is identified. Types of analysis, impact categories to be evaluated and sets of data needed for identification are collected.

2. **Inventory Analysis**
Inventory of all input and outputs to and from the production system is prepared for inventory analysis. The energy and raw materials used and the amount of emissions to atmosphere, water and soil are all considered. Thus, products and processes can be compared and evaluated using Life Cycle Inventory results, if consistent, meaning performs well or poorly in all environmental burdens, there is no need to carry out Step 3.

3. **Impact Assessment**
Impact assessment translated the emissions from a given product or process into human and terrestrial eco-system impacts. To better understand the impacts, the effects of the resource use and emissions generated are quantified into categories, possibly weighted for importance. In other words, data from Step 2 is attributed to appropriate impact categories defined in Step 1. Impact assessment differs among LCA tools used, since there is no one dominant impact framework. For this reason, when using certain LCA tools, impact assessment steps may be skipped and instead present results in terms of bulk emissions.

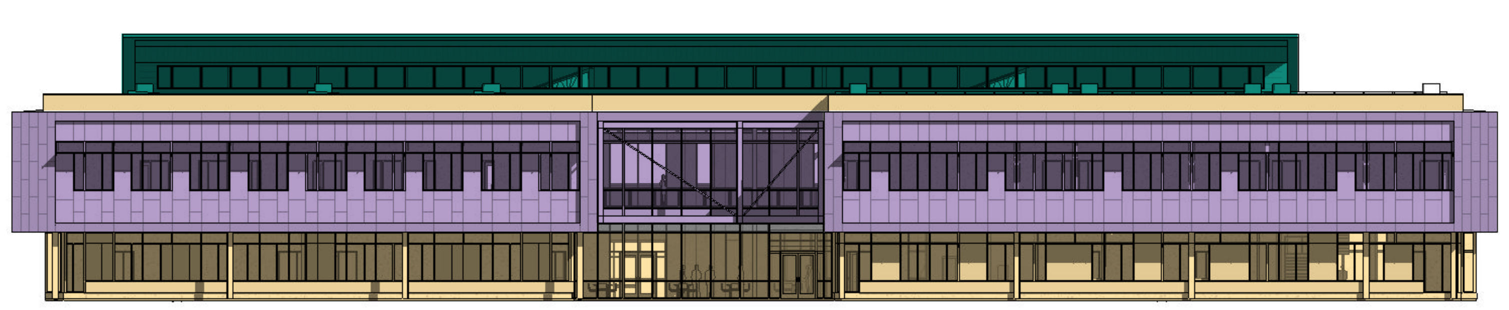
4. **Interpretation**
Results are reported in the most informative way, and the need and opportunities to reduce the negative impacts of products or services environmentally are evaluated. The interpretation of the LCA results can lead to changes in the proposed design, which can lead back to Step 2 in the process.

Building Elevations


East elevation


West elevation


North elevation


South elevation

Box rib metal panel vs brick vs CMU | Dri-Design metal panel (to remain) | Kingspan IMP vs MP w/ insulation

YGH Goals

1. **Chemeketa Community College**
Looking at the Applied Technology Building being designed by YGH located in Salem Oregon, our goal was to achieve LEED points for the LCA category. There are several options that one can achieve for various points explained on board #2. In order to gain 2-3 points one has to prove that the current building being designed is 5-10% better than an established baseline building of equal design and function. Since YGH, at the time of this report, was bordering between design development and construction documents, many of the decisions capable of being influenced by an initial LCA report regards to structure would render irrelevant. A different approach would have to be taken in order to use Athena (our chosen LCA software) and prove or disprove its effectiveness. The Applied Technology Building is largely a machining school and boasts a metal exterior in contrast to the surrounding campus buildings. Our decision was to then test the facade materials as if they were designed to match the other buildings made of brick and concrete. YGH decided on what metal panels would be permanent (Dri-Design) and what panels would be replaced with brick or CMU (Box rib metal panels). The Kingspan panel was also tested as an Insulated Metal Panel versus a Metal Panel with cavity insulation.

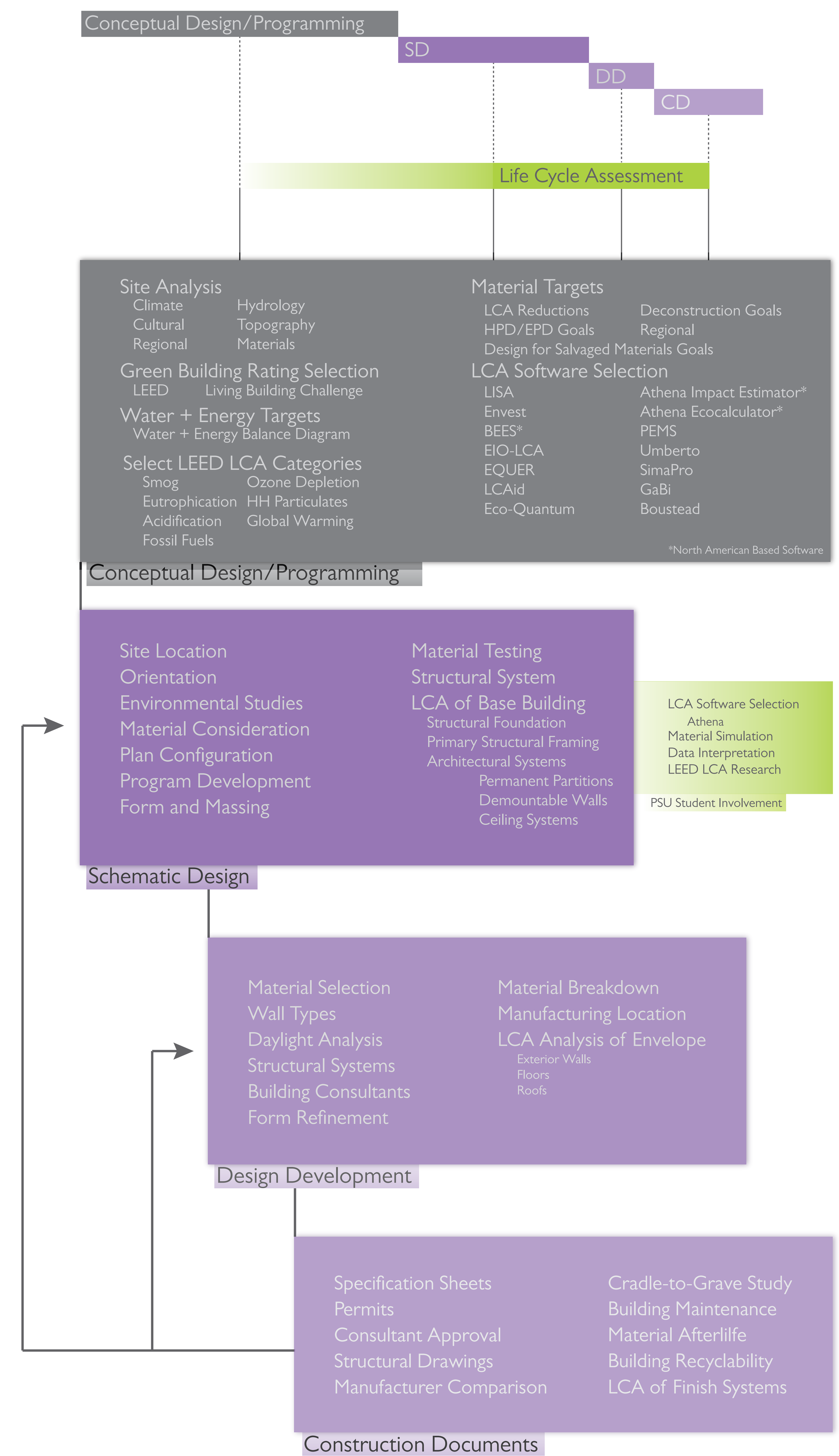
2. **Results**
Inputting metal panels into Athena proved challenging largely because there was no difference between insulated metal panels and regular metal panels. Much of the difference came from types and quatities of insulation being used. The results above show the miniscule difference of the exterior wall panels replaced with brick, CMU, and metal. The graph above only shows the difference in changing the facade material, the graphs on board #2 illustrate the difference that can be achieved by changing the overall wall types in establishing quatifiable data.

Methodology

The methodology for this project was to determine how Life Cycle Assessment formats the design process when selecting materials for a building. During our research we utilized Athena, an LCA analysis computer software to evaluate a current building type that Yost Grube Hall is designing, the Chemekata Community College Engineering Lab in Salem, Oregon.

To validate our results from Athena, we studied scholarly writing on Life Cycle Assessment to determine whether our findings were accurate. When selecting materials and potential insulation types, it is extremely important to consider every stage of the material's life in order to complete LCA analysis fully.

Working alongside YGH we determined the steps that each design phase incorporates and when to introduce LCA into their workflow. Together we concluded that beginning stages of LCA should be established as early as possible on a project. After concluding on a project type, selection of a LCA based software like Athena should be chosen during the conceptual phase of design. From then on, material choice and the environmental impacts they have between cradle-to-grave can be more easily evaluated.



YOST GRUBE HALL
ARCHITECTURE

LIFE CYCLE ASSESSMENT

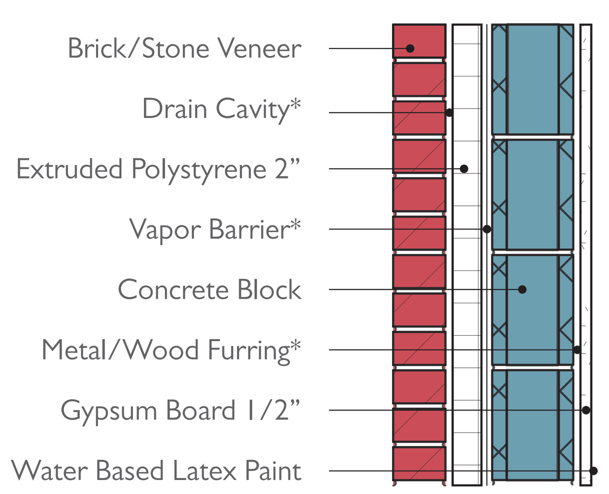
Material Comparison/YGH Results Cont.

One of the shortfalls of using Athena was that it was unable to account for Kingspan's LEED benefits. The fact that Kingspan's single component insulated metal panels are able to reduce installation time by up to 50% compared to traditional multi part site assemblies significantly saves machine and construction time, reducing initial embodied energy for building construction. Kingspan can also optimize energy performance within a whole building design, depending on certain climate zones, by contributing to LEED Energy Efficient (EA) points singularly. Combining EA points with ECM (Energy Conversation Measures), Kingspan can exceed LEED's 48% benchmark. Looking at Kingspan's Envelope First approach, buildings have the potential to go beyond the LEED set criteria for energy efficiency. Envelope First also helps contribute towards Netzero energy buildings which will be required by 2025 by the U.S. Department of Energy.

Many of the wall types tested for the YGH's Applied Technology Building consisted of only replacing the exterior facade material and not by replacing the entire wall system. By taking a step back and looking at 9 different common wall types, Athena was able to produce quatifiable data that has a greater margin of difference than our previous data. Our wall types were based on changing the main structural system of the wall from brick, CMU, and structural steel, to changing interior framing options as well as insulation types. Wall types M2 and M3 are most consistent with the wall types being used in the Applied Technology Building.

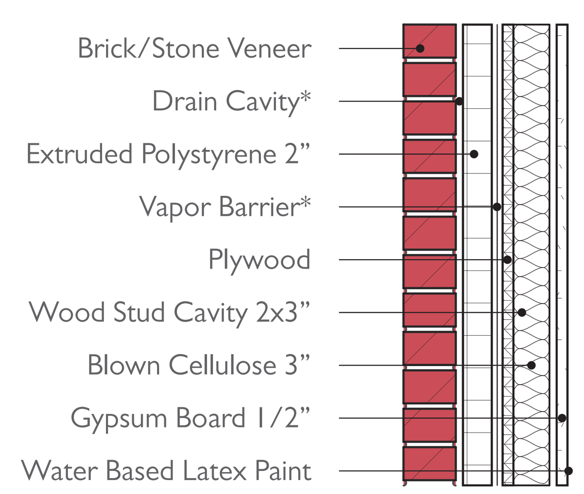
In order to get the LCA LEED points, a baseline model with wall type M2 or M3 is established as the common wall for the building and two additional wall types are selected as candidates: wall type B1 for the Brick category and wall type C3 for the Concrete category. Based on the wall types shown below and the resulting insulation used, wall type M3 shows a significant reduction in the 3 chosen impact categories. For Fossil Fuel, M3 has an 87% reduction compared with B1, and an 81% reduction over C3. For Global Warming Potential, M3 has a 89% reduction over B1, and a 83.5% reduction over C3. For Acidification potential, wall type M3 has a 79% reduction over B1, and a 64% reduction over C3. The baseline building using wall type M2 or M3 show the required 5-10% reduction in 3 chosen impact categories and should receive the LEED LCA points.

Concrete Block w/ Exterior Insulation and Brick Veneer



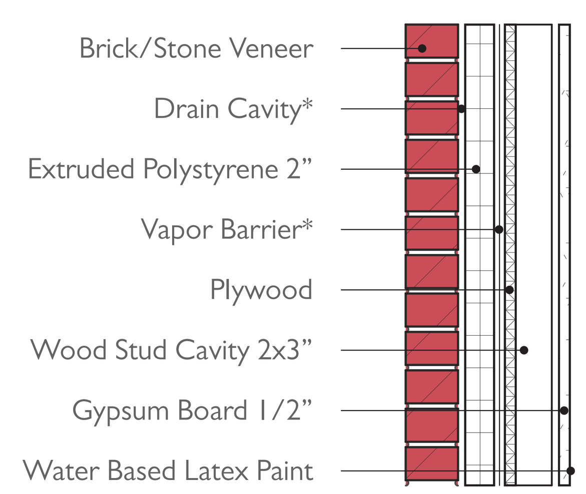
WALL TYPE - B1

Frame Wall w/ Cavity Insulation and Brick Veneer



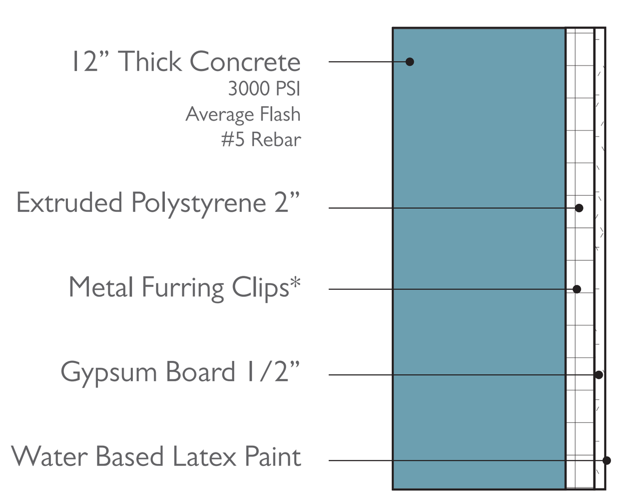
WALL TYPE - B2

Frame Wall w/ Exterior Insulation and Brick Veneer



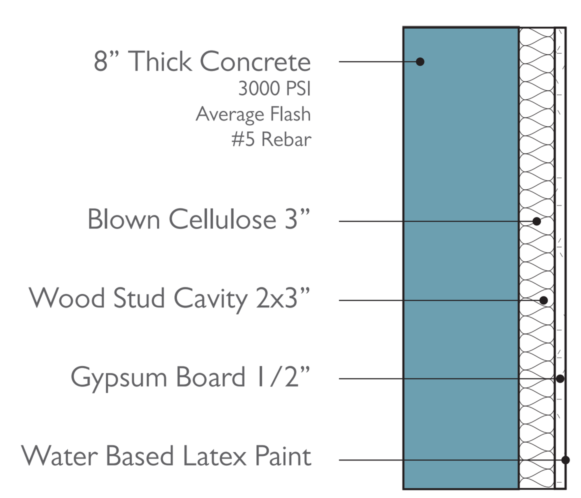
WALL TYPE - B3

Cast in Place Concrete



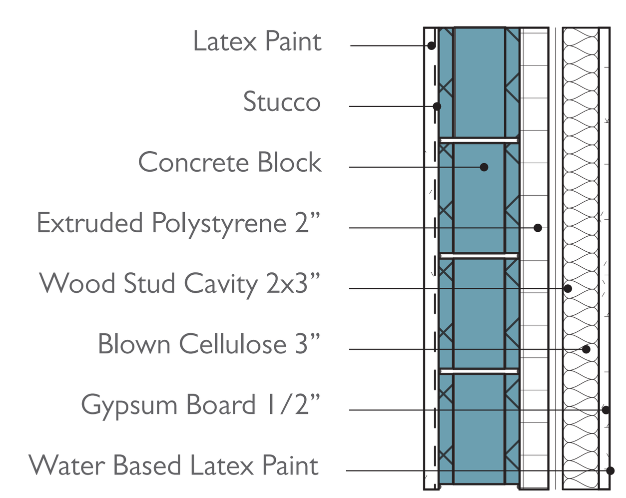
WALL TYPE - C1

Tilt-Up Concrete



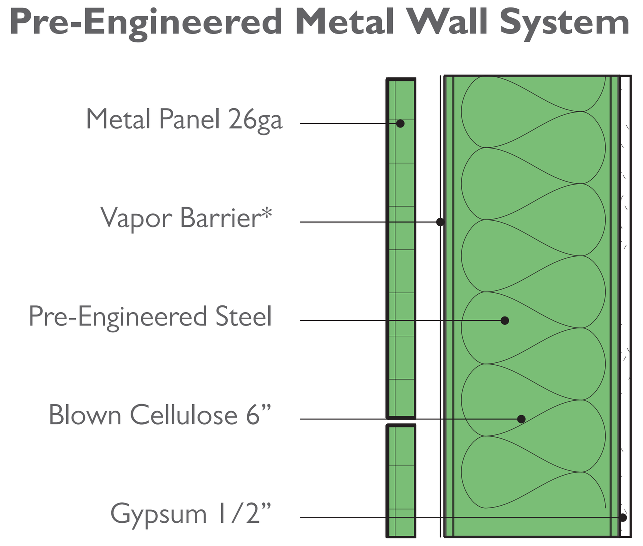
WALL TYPE - C2

Concrete Block w/ Interior Rigid Insulation and Frame Wall Insulation and Stucco



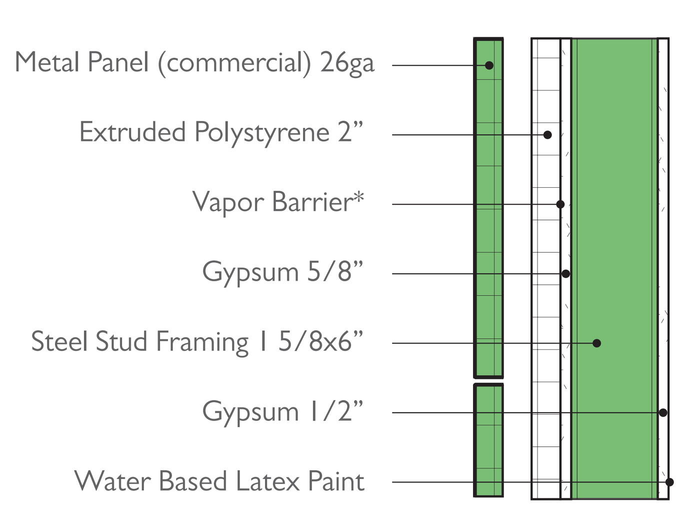
WALL TYPE - C3

Pre-Engineered Metal Wall System



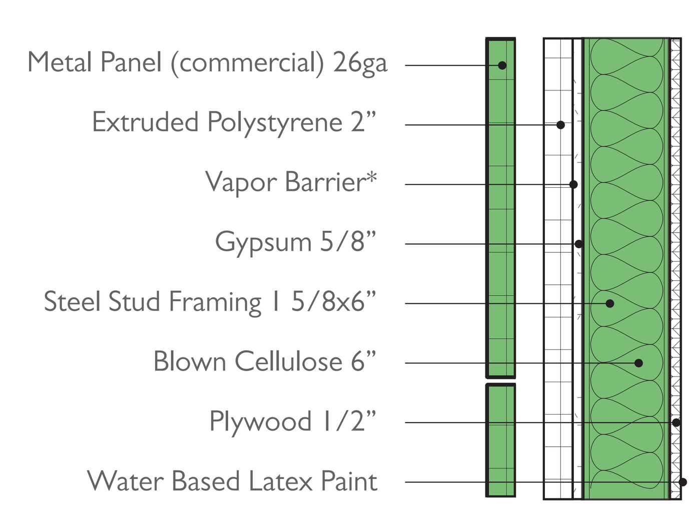
WALL TYPE - M1

Metal Panel Steel Stud Framing No Cavity Insulation



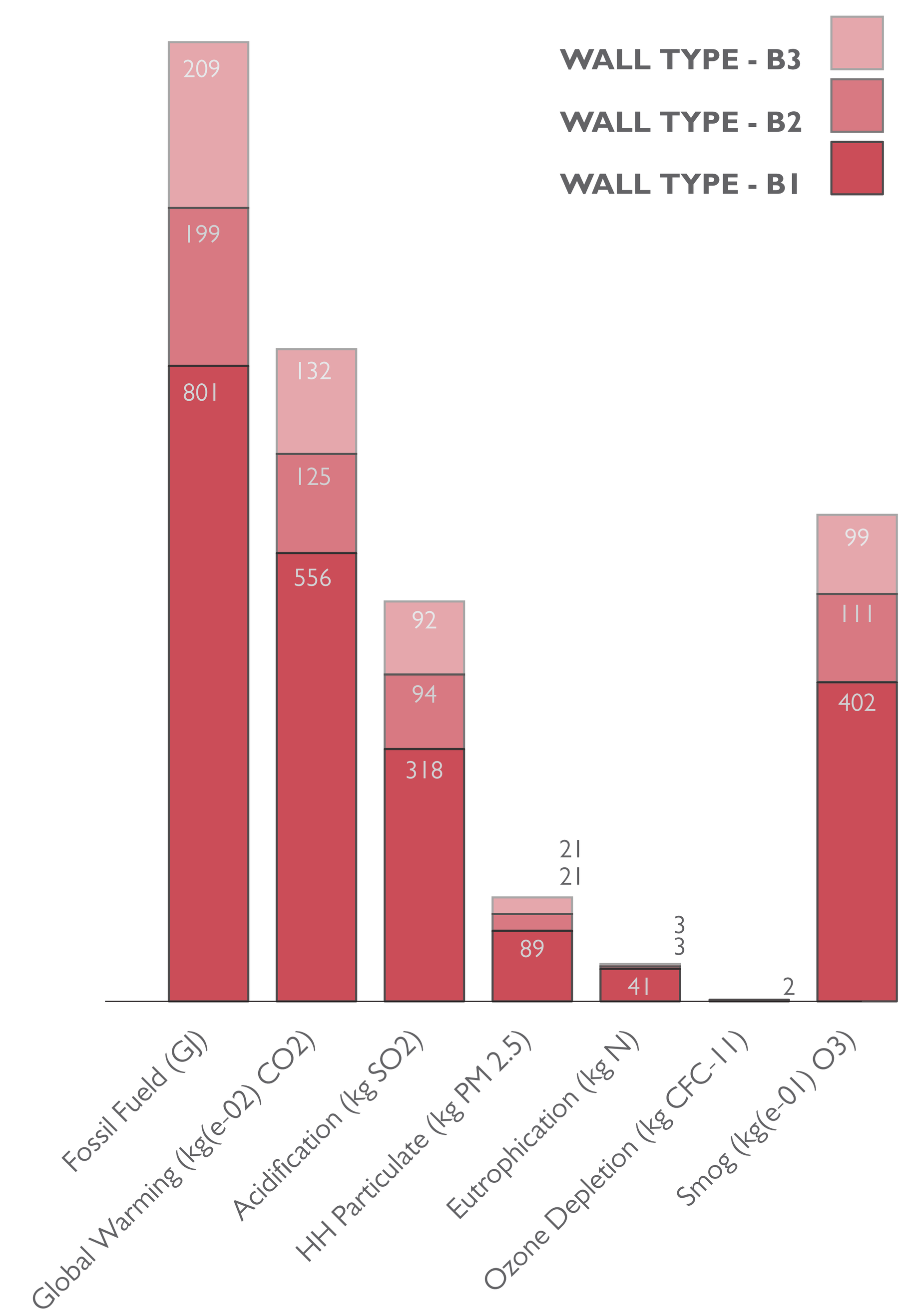
WALL TYPE - M2

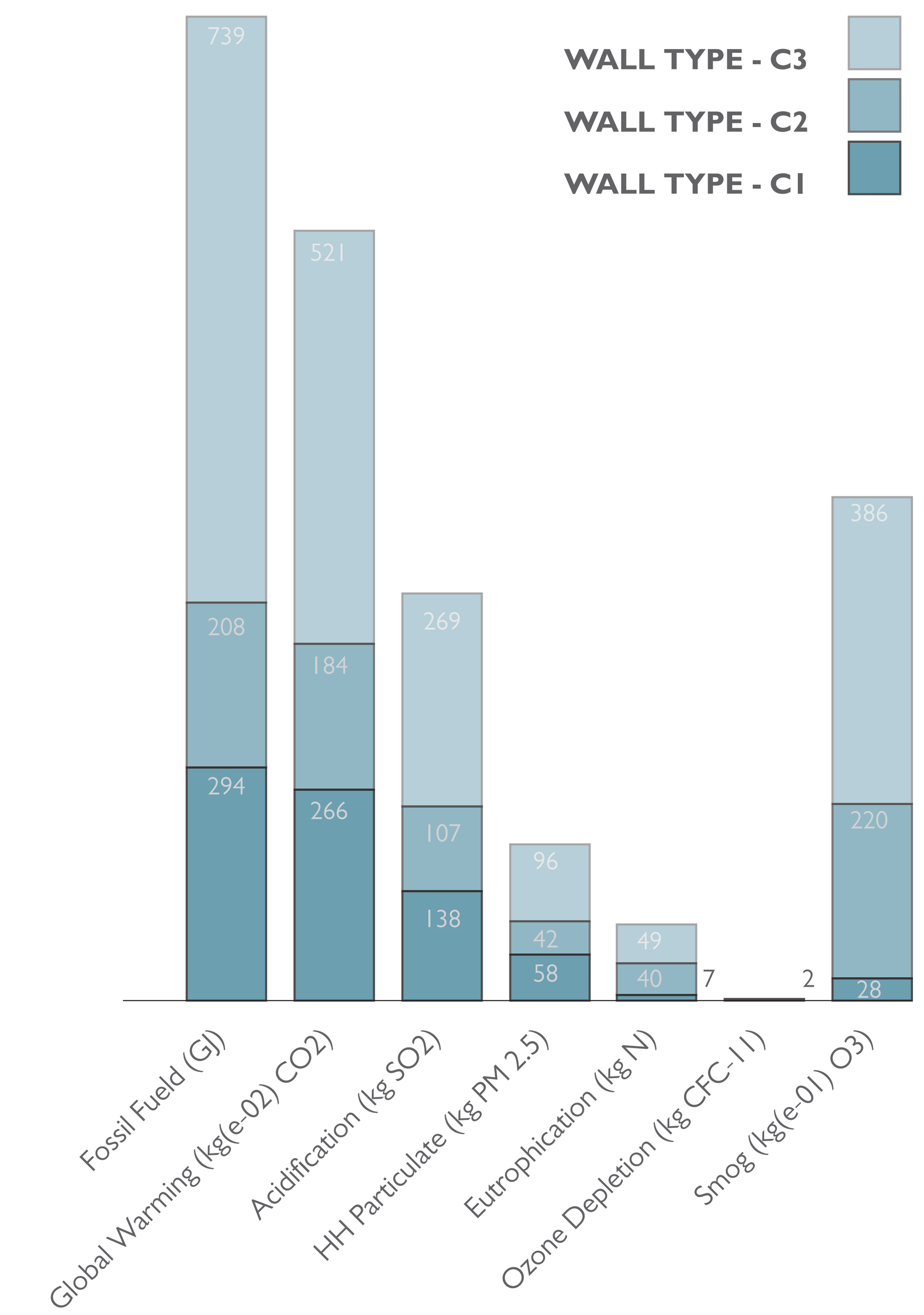
Metal Panel Steel Stud Framing w/ Cavity Insulation

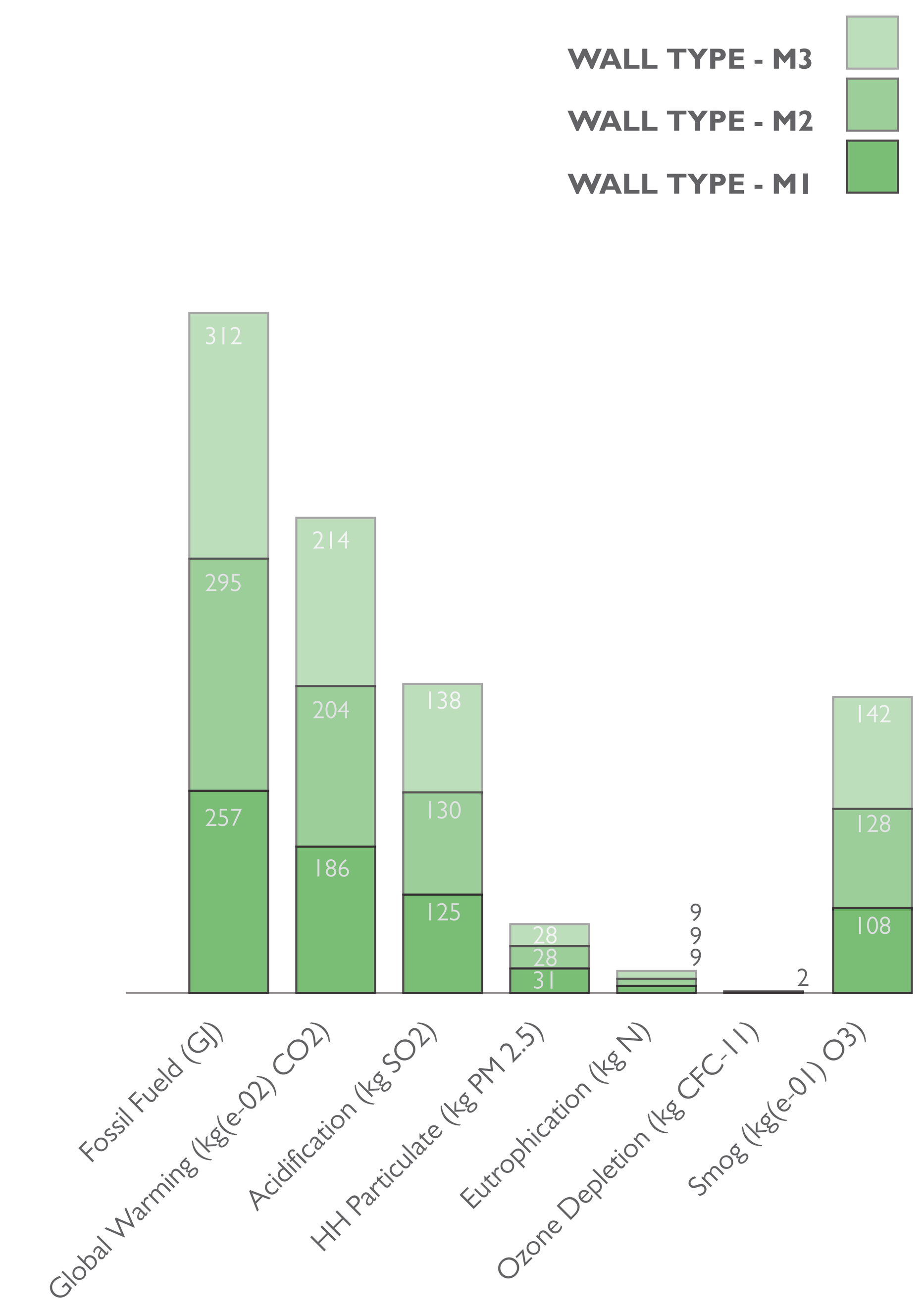


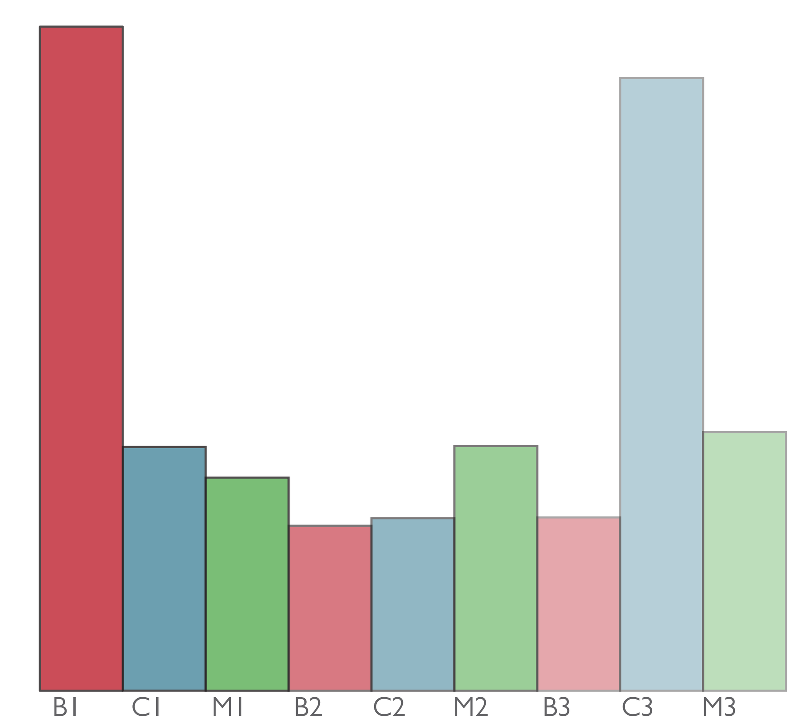
WALL TYPE - M3

*Not Applicable to Athena Inputs



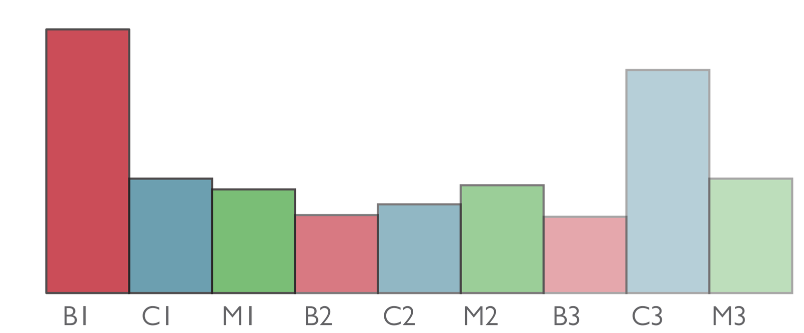






Fossil Fuel (GJ)

Global Warming (kg(e-02) CO2 eq)



Acidification (kg SO2 eq)

LEED CREDIT OPTIONS

Requirements: Achieve one or more of the options below, for a maximum of 2 points.

Option 1: Environmental Product Declaration (EPD) (1 point)

Use at least 20 different permanently installed products from at least 5 different manufacturers who meet the criteria below.

Product-specific definition.

- Life cycle assessment products conforming to ISO 14044 with a cradle to gate scope of at least one quarter of the product lifespan is required for credit achievement.
- Environmental Product Declarations that conform to ISO 14025, 14040, 14044, and EN 15804 or ISO 21930 with a cradle to gate scope.
- Industry wide EPD- Products with third party certification in which the manufacturer is recognized as a participant by the program operator.
- Product specific EPD- Products with third party certification in which the manufacturer is recognized as a participant by the program operator as one whole product.

Option 2: Multi-attribute Optimization (1 point)

Use products that comply with one of the below criteria for 50% reduction by cost.

Third party certified products that demonstrate impact reduction below industry average.

Global Warming Potential	Depletion of Ozone Layer
Acidification	Eutrophication
Formation of Tropospheric Ozone	Depletion of Nonrewable Energy Resources

For credit achievement, products sourced within 100 miles of project site are valued at 200% of their base cost.

Structure and enclosure materials may not constitute for more than 30% of compliant building materials.

Option 3: Whole-Building Life Cycle Assessment (3 points)

For new construction, conduct a life cycle assessment that demonstrates a minimum of 10% reduction, compared with a baseline building. At least three of the six impact categories listed above, one must be global warming, must be tested and must not increase by more than 5% compared to the baseline building.

The baseline and proposed building must be comparable size, function, orientation, and operating energy performance as defined in EA Prerequisite Minimum Energy Performance. The service life of both the baseline and proposed buildings must be 60 years to account for maintenance and replacement.

U.S. GREEN BUILDING COUNCIL LEED USGBC

YOST GRUBE HALL ARCHITECTURE

EMBODIED ENERGY IN BUILDING MATERIALS

WOOD

Forestry Practices

- There are two basic forms of forest management practiced in North America; sustainable forestry and clear-cutting and replanting.
  - Clear-cutting attains sustainable production by cutting all trees in an area, leaving stumps, tops and limbs to decay and become compost.
  - In sustainable forestry, trees are harvested selectively in a way to minimize damage to the forest environment and maintain to biodiversity of its natural ecosystem.
- Environmental problems associated with logging include loss of wildlife habitat, soil erosion, pollution of waterways, and air pollution from machinery and burning of tree wastes.
- Wood product buyers can support sustainable forestry practices by specifying products certified as originating from sustainable forests. For example, FSC-certified wood products satisfy LEED requirements and all other major green building assessment programs.

Mill Practices

- The measure of sawmill performance is the lumber recovery factor (LRF), which is the net volume of wood products produced form a cubic meter of log.
- Manufactured wood products such as OSB, particleboard, I-joists, and laminated strand lumber utilize most of the wood fibers in a tree and can be produced from recycled or young rapidly renewable materials.
- Manufacturers of large, solid timbers generate more unused waste and yields fewer products from each log.
- Kiln drying uses large amounts of fuel but produces more stable lumber than air drying.
- Mill wastes
  - Bark
    - Shredded for mulch
    - Composted
    - Burned
    - Buried in landfills
    - Sawdust, chips and wood scraps can be burned to generate steam for power.

Transportation

- Because most commercial forests are located in concentrated regions of the U.S. and Canada, most lumber must be shipped considerable distances.
- Fuel consumption can be greatly reduced if lumber is dried before it is shipped, reducing both weight and volume.

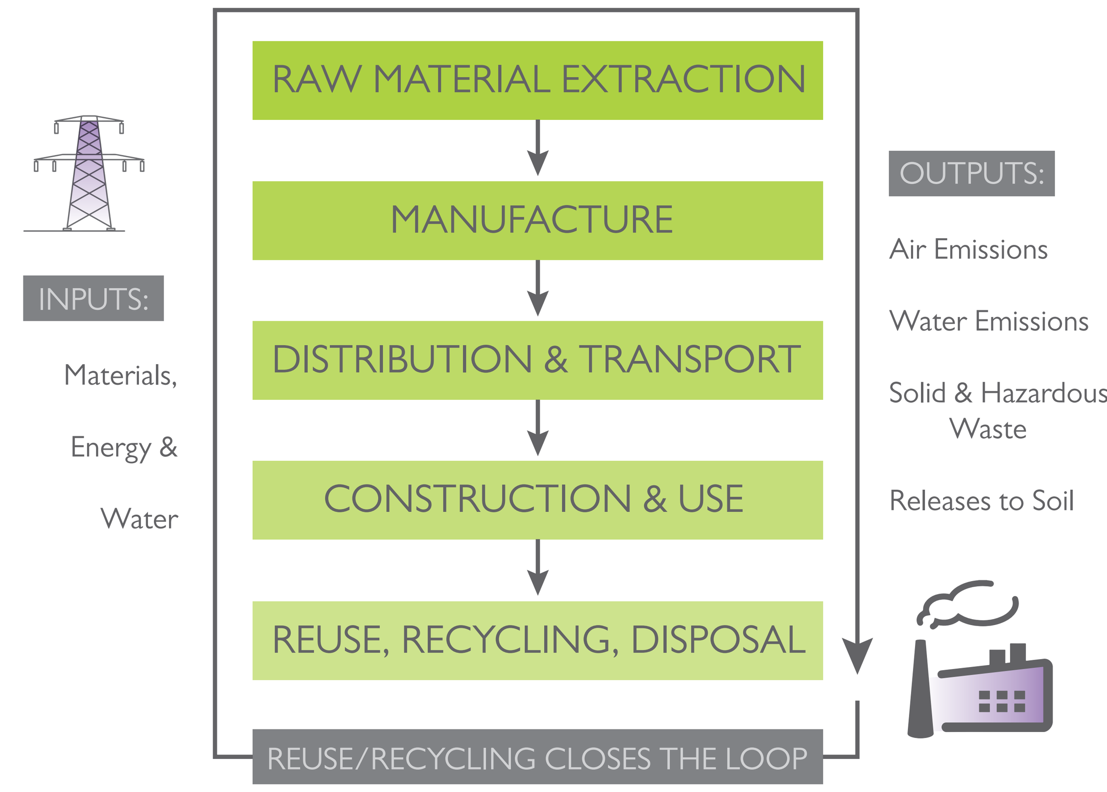
Energy Content

- Solid lumber has embodied energy of roughly 1000 to 3000 Btu.
  - This includes the energy used from chopping the tree down to construction.
- Manufactured wood has a higher embodied energy content then solid lumber, due to glue and resin ingredients.
  - Embodied energy of such products range from 3000 to 7500 Btu per pound.
- Wood construction typically includes large numbers of steel fasteners which considerably increase the total energy embodied in a wood frame building.
- Wood does not have the lowest amount of embodied energy when measured on a pound-per-pound basis.
- However, when compared to structures of either wood, light gauge steel studs, or concrete, most studies indicate that wood has the lowest total embodied energy.

Building Life Cycle

- If wood framing is kept dry and away from fire is will last indefinitely.
- When burned, wood is combustible and gives off toxic gases.
- During demolition, wood framing members can be recycled directly into framing of another building structure, sawn into new boards or timbers, or shredded as raw material.

Life cycle assessment looks at all parts of a product's life cycle from extraction to end of life.



STEEL

Manufacture

- Raw materials in steel
  - Iron ore, Coal, Limestone, Air, Water
- Mining of ore, coal, and limestone cause disruption of land and loss of wildlife habitat.
- Pollution of streams and rivers are also a common result.
- Manufacturing of a ton of steel from iron ore consumes:
  - 3170 pounds of ore
  - 300 pounds of limestone
  - 900 pounds of coke
  - 80 pounds of oxygen
  - 2575 pounds of air.
- Steel produced from ore possesses 14,000 Btu per pound of embodied energy.
- In some modern facilities, scrap steel is added during the production process, resulting in 25 to 35% recycled material content.
- Today, most structural steel in North America is made of recycled scrap by the electric arc furnace process, which is produces one-third less embodied energy then steel made from ore.
- 95% or more of all structural steel in North America building construction are recycled or reused.

Construction

- Steel fabrication and erection are relatively clean, although some paints and oils used on steel members can cause air pollution.
- Steel frames are lighter in weight than concrete frames but are able to do the same job.
- This means that steel framing generally has smaller foundations and requires less excavation work.
- Certain spray on fireproofing materials can pollute the air with stray fibers.

In Service

- If protected from water and fire, steel framing will last for generations with little to no maintenance.
- Steel exposed to weather needs to be repainted periodically unless it is galvanized.
- Framing members in walls and roofs should be thermally broken or insulated so they do not conduct heat between indoors and outdoors.
- During demolition, almost all materials can be recycled.
- Steel seldom causes indoor air quality problems, but surface oils and protective coatings can out gas and cause occupant discomfort.

CONCRETE

Portland Cement

- The production of Portland cement is the largest user of energy in concrete construction process, accounting for about 85 percent.
- Since 1970, the North American cement industry reduced the amount of energy expended in cement production by one-third.
- For every ton of cement produced, almost a ton of carbon dioxide is released into the atmosphere.
- Cement production accounts for approximately 1.5 percent of carbon dioxide emissions in the United States.
- According to the Portland Cement Association, over concrete's lifespan, it reabsorbs roughly half of the carbon dioxide released during the manufacturing process.
- Wood ash and rice-husk ash can be used as cementing agents.
- Used motor oil and used rubber tires can be used as fuel for cement kilns.

Aggregates and Water

- There are abundant sources of sand and crushed stone in many parts of the world, but high-quality aggregates are becoming scarce.
- In rare instances, concrete aggregate has been found to be a source of radon gas.
- Waste materials such as crushed, recycled glass, used foundry sand, and crushed, recycled concrete can be substituted for conventional aggregates.

Formwork

- Formwork components can be reused many times, which represent a large waste of construction materials.
- Low volatile compound content and biodegradability should be chosen for form releasing compounds.

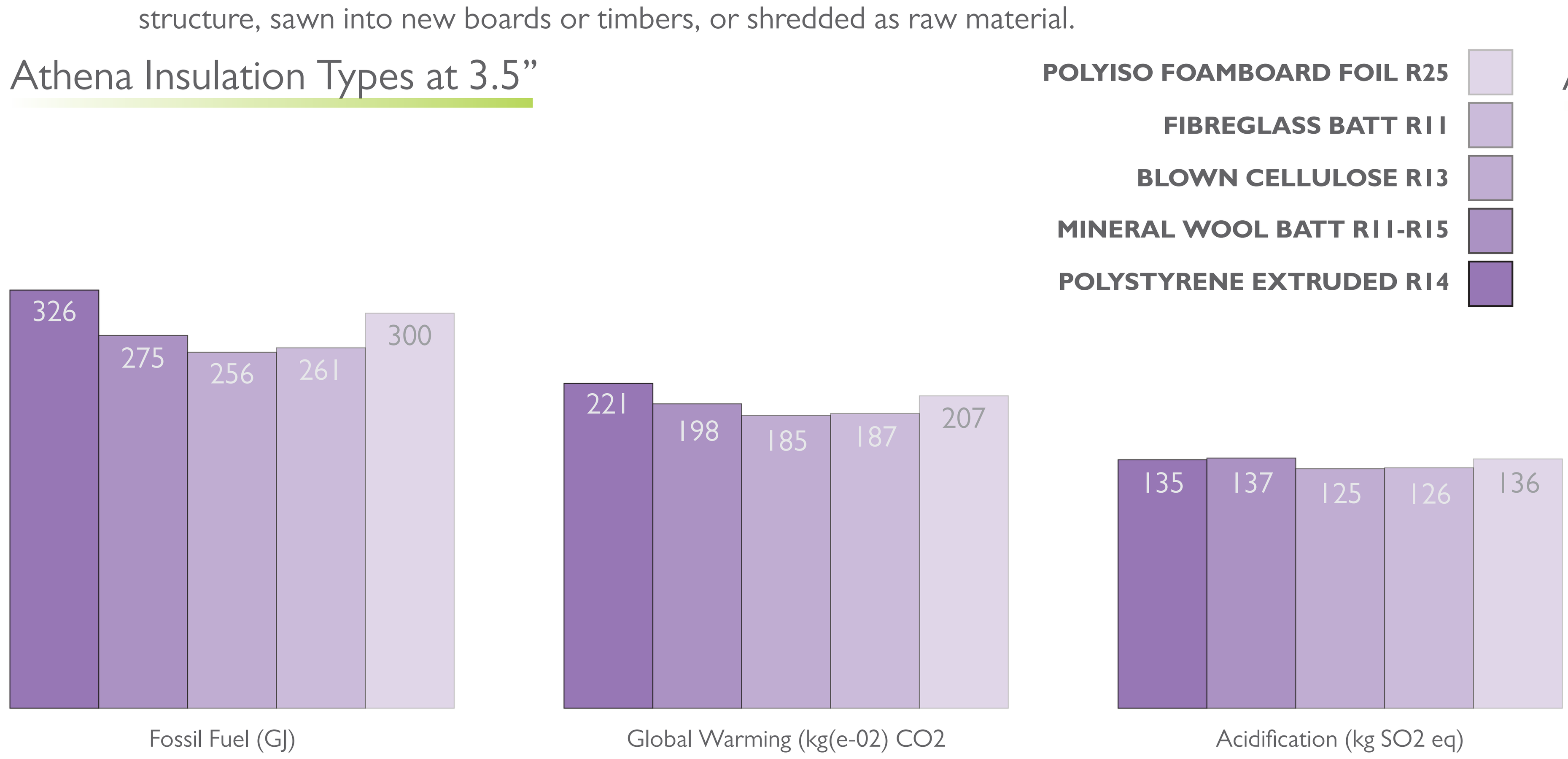
Demolition and Recycling

- The majority of reinforcing steel can be recycled during demolition.
- In most cases, fragments of demolition concrete can be crushed, sorted, and used as aggregates for new concrete.
- Presently, most demolition concrete is buried on site, used to fill other sites, or dumped into landfills.

Green Uses of Concrete

- Pervious concrete, made with course aggregate, can be used for porous paving to allow stormwater to filter into the ground.
  - This helps to recharge aquifers and reduce stormwater runoff.
- Concrete is durable and long-lasting, suitable for adaptation and reuse. Thereby reducing environmental impacts caused by building demolition.
- Within brownfield development, concrete fill materials can be used to stabilize soils and reduce leachate.
- Concrete's thermal mass can reduce building heating and cooling costs by storing excess heat during overheated periods of time.
- Lighter colored concrete pavers reflect solar radiation, lowering dark asphalt temperatures and urban heat island effects.
- Interior concrete slabs made of white concrete can improve illumination, visibility, and worker safety.

Athena Insulation Types at 3.5"



Athena Insulation Results

The insulation types tested were all placed within a common wall system (wall type M2) so that only one paramater was changed at a time. The insulation types that YGH wanted tested included the Polystyrene Extruded, Mineral wool, and blown Cellulose. The Cellulose scored the best in all LCA impact categories due largely to the fact that it is made of 75% post-consumer recovered paper and Mineral wool is made of 75% recovered materials. The polystyrene is made only from about 5-10% recovered material (polyol resin content). The blown Cellulose scores a reduction in Fossil Fuel, GWP, and Acidification of 24%, 17.7%, 7.7% respectively over Polystyrene. However, all insulation types were tested at a consistent 3.5" thickness where Polystyrene is commonly used at a 2" thickness.

LCA LEED Selected Categories

Acidification

- Caused by sulfur dioxide and nitrogen oxides
- SO2 and NOx caused by burning fossil fuels and combustion
- can lead to acid rain causing mineral shifts in soil and water

Global Warming Potential (GWP) depends on:

- the absorption of infrared radiation
- the spectral location (electromagnetic spectrum) of its absorbing wavelengths
- GWP expressed as a factor of carbon dioxide -- same mass of methane and carbon dioxide were introduced into the atmosphere, methan will trap 72x more heat than the CO2

Fossil Fuel

- Hydrocarbons, primarily coal, fuel oil or natural gas, formed from the remains of dead plants and animals
- They range from volatile materials like methane to liquid petroleum
- When burned they produce significant amounts of energy per unit weight

REFERENCES:

Allen, Edward, and Joseph Iano. Fundamentals of Building Construction. Fifth. Hoboken, NJ: John Wiley & Sons, Inc, 2009. 90-91, 417, 477. Print. <www.wiley.com>.

Bayer, Charlene, Michael Gamble, Russell Gentry, and Surabhi Joshi. AIA Guide to Building Life Cycle Assessment in Practice. Washington, DC: The American Institute of Architects, 2010. Web.

Bribian, Ignacio, Antonio Capilla, and Alfonso Uson. Life cycle assessment of building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential. Building and Environment. ScienceDirect, 2010. Print. <www.elsevier.com/locate/buildenv>.

Cole, Raymond J., and Paul C. Kernan. Life-Cycle Energy Use in Office Buildings. Vancouver, British Columbia: Elsevier Science Ltd., 1996. 307-317. Print.

Lstiburek, Joseph W. Understanding Vapor Barriers. ASHRAE Journal, 2004. 40-46. Print. <ashrae.org>.

"Assessment and optimization - life cycle assessment." LEED. U.S. Green Building Council, n.d. Web. 11 Dec 2013. <http://www.usgbc.org/credits/mr41>.

"InsulationMaterials:Environmental Comparisons."BuildingGreen.com. BuildingGreen, Inc, n.d. Web. 9 Dec 2013. <http://www.buildinggreen.com/auth/article.cfm/1995/1/1/Insulation-Materials-Environmental-Comparisons/>.

"LEED Credits." Kingspan. N.p.. Web. 2 Dec 2013. <http://www.kingspanpanels.us/sustainability/leed>.

"Life-Cycle Assessment (LCA) of Building Assemblies and Materials." LEEDuser. BuildingGreen, Inc, n.d. Web. 10 Dec 2013. <http://www.leeduser.com/credit/Pilot-Credits/PC1>.

"Whole building life cycle assessment." LEED. U.S. Green Building Council, n.d. Web. 11 Dec 2013. <http://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthcar-9>.

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