TEAM SHUNYA
Building a sustainable future

Embodied Environmental Impact

U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

Jury Documentation

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Introduction

Environmental concerns such as global warming and waste accumulation have increased worldwide in recent decades. According to the Energy and Resources Institute (TERI), the building sector accounts for 22-25% of India's total carbon dioxide (CO_2) emissions. Also, according to the Bureau of Energy Efficiency (BEE), the building sector accounts for approximately 33% of total energy consumption in India. A building consumes energy throughout its life cycle, from material extraction to demolition. Addressing the environmental issues at every stage of its life cycle is critical for a sector of this size to be sustainable, energy-efficient.

India is increasingly taking steps to promote green building initiatives. Using eco-friendly, locally sourced materials, renewable energy use, and rainwater harvesting are some of the practices that are feasible and implemented in our country.

Methodology

To comprehend the environmental impacts of a typical Indian house, we conducted a Life Cycle Assessment (LCA) encompassing the entire life cycle from material production to demolition and end-of-life. We've performed the cradle-to-grave analysis for 50 years. The life of our structure is designed for 50 years, recommended as per the Indian Standard codes considering all the factors of design. The structure may live on for more than the period considered, but owing to our design, we have chosen the life period for LCA also to be the same.

The analysis has been performed using One Click LCA. The material quantities from the Revit-based BIM Model are used for the LCA analysis. One major challenge was the non-availability of certain novel materials in the eco-invent database. That has been tackled by studying the material and production details and finding the most similar material in the database. And for those materials for which we didn't find any substitutes, calculations have been done based on some research reports [1], including the sequestered emissions in the case of materials involving biogenic masses and are included in the corresponding analysis phase.

According to P. Devi and Sivakumar (2014) [2], it is a standard practice to take a percentage of 7-10% of initial embodied CO2 (kg) as the construction phase emissions. These emissions have been separately added to the analysis while comparing the emissions during the construction phase of a standard house.

Conventional House

Project's client is a family of four in the middle-to-high income group on the socio-economic spectrum. It is only fair to compare our design with an existing, popular mode of housing preferred by the same group of people. Research regarding the typical housing for this market class shows that 2 Bedroom-Hall-Kitchen (2-BHK) apartments are the most common housing for this clientele type. We have derived the details of this typical house from P. Devi and K. Sivakumar (2014). The details of electricity consumption have been taken from a BEE (Bureau of Energy Efficiency) report [3][4] with a floor area of 112.52 sq.m., which is close to our building's floor area of 127 sq.m. And materials used in this house are contemporary with those used for apartments in India. The layout of the house and the mapping of materials considered for the assessment of the minimally code-compliant building are shown in Figure 1.

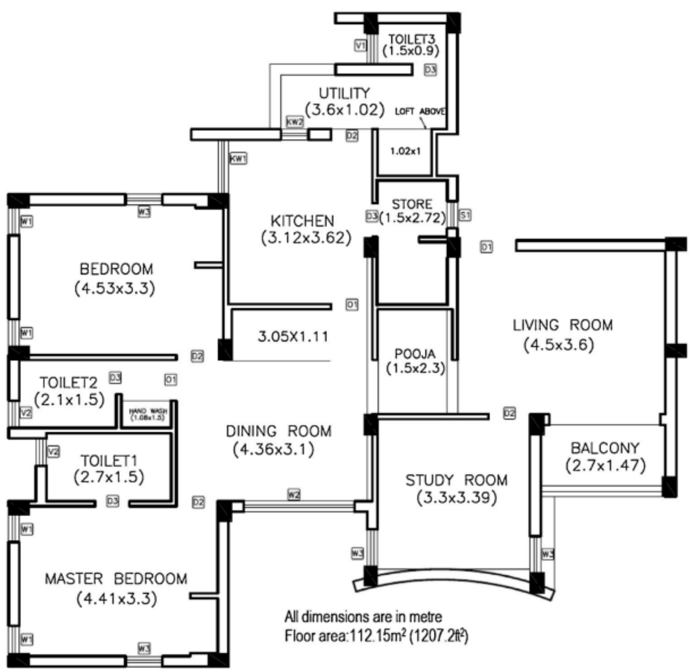

Figure 1 - Layout of a typical 2 BHK apartment

Table 1- Materials considered for LCA

Component/Service	Materials/Appliances
Structural Frame: Foundation, Columns, & Beams	Cement, Sand, Lime, Coarse Aggregate, Rebar
Building Envelope	AAC blocks, Cement, Sand, Aggregate
Finishes: Plastering, painting and tiling	Cement, Sand, Ceramic Tile, Granite, Putty, Primer, Paint
Doors and Windows	Wood, Iron, Steel, Stainless Steel, Brass, Nylon
Sanitary Installations	Iron, PVC, Porcelain, Glass
Pipes and Accessories	Iron, Stainless steel, PVC, Brass
HVAC appliances	Top mounted AC, Exhaust Fan, Ceiling fan

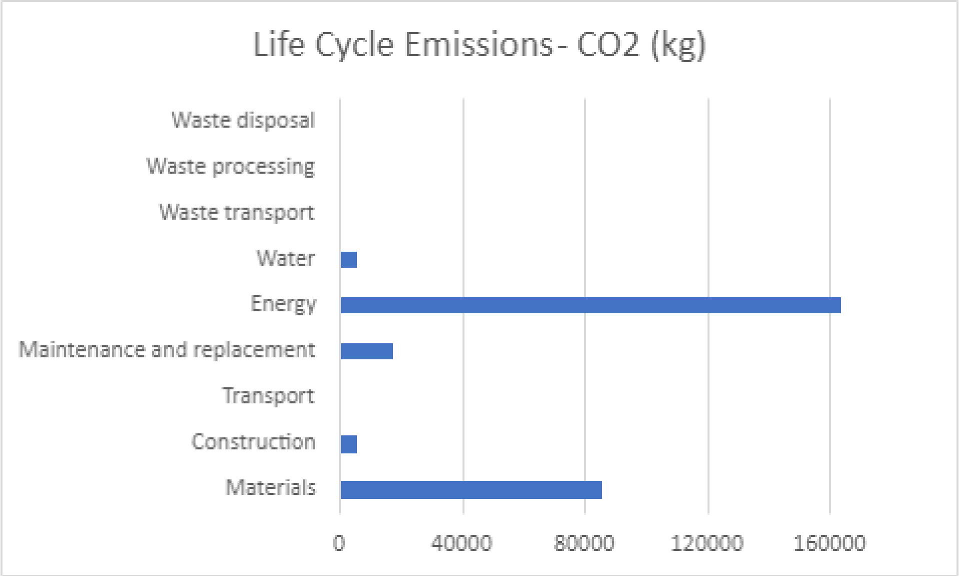

Figure 2 - The life cycle CO2 emissions of a conventional house distributed among different categories

While conducting a life cycle assessment (cradle-to-grave), we observed that CO_2 emissions are high during the material production phase. The import of electricity contributed the most to the total energy consumption of the building and thus the CO_2 emissions. Using solar PV for electricity generation has decreased our grid imports. As a result, to reduce environmental impacts, we have focused on selecting construction materials that are recycled and locally sourced. We ensured that the materials also help with passive systems, which make the design more energy efficient than conventional buildings.

Improving Over the Standards

We have focused on balancing efficiency, performance, and environmental impact while selecting materials and systems for the house. For each building material we chose, we conducted a preliminary analysis comparing the embodied CO2 and energy footprint of different market-available materials for the same house layout. These values were sourced from the report "India Construction Materials Database of Embodied Energy and Global Warming Potential" by International Finance Corporation. To better the performance of the design with the design constraints, we chose the following materials and systems for the reasons described.

Apart from just the reduction of upfront materials embodied carbon in the design process, we have also considered the trade-offs of employing techniques that add to the initial emissions but significantly cut down the emissions during house operation life and thereby reduce the emissions in the long run. For example, installing and replacing solar panels for electricity generation adds to the initial emissions but decreases the import from the grid, reducing emissions. Similarly, with the insulation, the upfront embodied CO2 increases by a minimal amount but reduces the load on the HVAC system by maintaining thermal comfort in the house.

Steel Structural Frame

Steel structures have a higher circularity and recycling value than RCC (Reinforced Cement Concrete) structures. According to a study by the Steel Recycling Institute, steel is the most recycled material in the world, with a recycling rate of around 88%, in contrast to RCC, with a rate of 5-10%. Additionally, the embodied energy of steel is much lower than RCC's. According to a study by the World Steel Association, the embodied energy of a typical steel structure is around 18 GJ/tonne, while that of RCC is about 90-120 GJ/tonne. This means that producing steel requires less energy than producing RCC, leading to lower greenhouse gas emissions.

Wall Assembly for Envelope

Various options we considered for enclosing the envelope of the house are listed in the Table 2 . This preliminary comparison assumes the emissions from the adhesive agent of each assembly are equivalent.

Table 2 - Envelope Material GWP comparison

Wall type	Composition Materials	Expected Emissions*
Blocks (Conventional building)	AAC blocks	1

Sandwich Wall Assembly (selected for Project Vivaan)	Fiber Cement boards, Ecoboard Wall Panels, Glass wool Insulation	0.32
Sandwich Wall Assembly	Hollowcore Concrete Panels, Mineral wool insulation, Fibercement boards	0.56
Sandwich Wall Assembly	Fibercement boards, Polyurethane foam	1.95

* Expressed as a fraction of conventional materials

Ecoboard

These panels are made from agricultural waste materials, such as rice straw or bagasse, which would otherwise be burned or left to decompose, releasing methane and other greenhouse gases. Using these materials to make wall panels reduces the amount of waste sent to landfills and the amount of CO_2 released during manufacturing. Additionally, agro-waste-based wall panels have a lower embodied energy than conventional building materials like concrete or brick, reducing CO_2 emissions. They are also lighter, which lowers transportation emissions during shipping and installation. Finally, recycled agro waste-based wall panels can be recycled at the end of their useful life, reducing their environmental impact. Using recycled agro-waste-based wall panels can significantly reduce CO_2 emissions and make homes more sustainable in the long run.

Glass Wool

It is used to create a barrier between the interior and exterior of a building, reducing heat transfer and keeping the interior cooler. This provides a layer of insulation that can help reduce the heat that passes through the walls. By reducing heat transfer, glass wool helps keep the interior cooler without needing mechanical cooling systems.

Liquid Desiccant based Dehumidifier System

This is a more sustainable alternative to air conditioners for reducing CO_2 emissions. They can be up to 50% more energy-efficient, and waste heat from the dehumidification process is recovered to reduce the energy needed for heating or cooling. They use natural refrigerants like water instead of potent greenhouse gases in air conditioners. Liquid desiccant-based dehumidifiers also require less maintenance than air conditioners, reducing the energy and resources needed for servicing and repair. By reducing moisture levels, they can improve indoor air quality, reducing the need for air conditioning and lowering CO_2 emissions.

Water Savings

Efficient water fixtures can significantly reduce water consumption in households. For instance, low-flow showerheads can reduce water usage by up to 40% compared to conventional showerheads. Similarly, water-efficient faucets and toilets can reduce water usage by up to 30%. Also, the grey water recycling systems would help us reuse the water in the bathrooms, decreasing fresh water consumption. These are the methods we have followed to reduce fresh water consumption and its emissions.

Project Vivaan

The life cycle assessment of Project Vivaan's G+1 structure, a 2 BHK house designed for a family of four with a total floor area of 120 sqm, was conducted after selecting the construction, materials, HVAC systems, and electrical appliances. The

Table 3 details the materials, systems, and appliances utilized in the project.

Table 3 - Assessment components of Project Vivaan

Component/Service	Materials/Appliances
Structural Frame: Foundation, Columns, Beams	Cement, Sand, Lime, Coarse aggregate, Rebar, Mild Steel (Fe 410), Silica plastic blocks
Building Envelope	Fiber Cement boards, Glasswool, Ecoboard Wall Panels, Moisture barrier, Cement, Sand, Aggregate
Finishes: Plastering, Painting and Tiling	Cement, Sand, Ceramic Tiles, Granite, Putty, Primer, Paint
Doors and Windows	Iron, Stainless Steel, u-PVC double glazed windows
Sanitary Installations	Iron, PVC, Porcelain, Glass
Pipes and Accessories	Iron, Stainless Steel, PVC, Brass, Tanks
HVAC appliances	Exhaust Fans, Ceiling Fans, Liquid Desiccant based Dehumidifier, Air Conditioners
Electricity generation	Solar PV panels, Lead-acid batteries, Inverters

Project Vivaan has upfront emissions (materials, construction and transportation) of nearly 60,800 kg. In the operational phase, the house produces an average of 2120 kg per year (averaging out the material replacement throughout the life cycle). We export around 2716 kwh/ year accounting to nearly 2845 kg CO_2/ year savings and this way we are offsetting around 85% of the total emissions of the house during the life cycle period of 50 years.

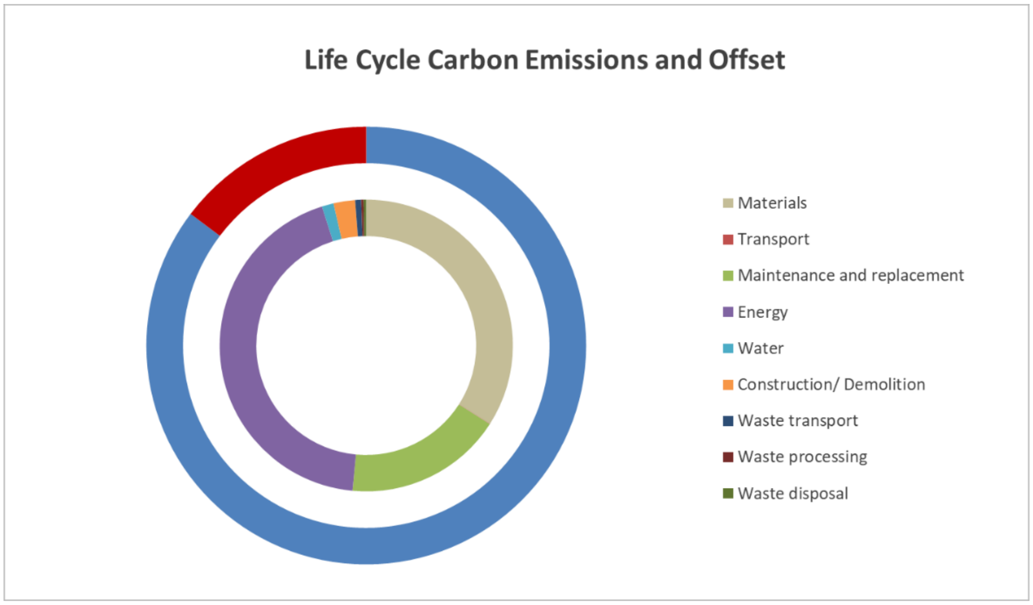

Figure 3 - The life cycle CO2 emissions of Project Vivaan distributed among different categories

Comparison of Embodied Environmental Impact

After performing the life cycle assessment of Project Vivaan, we have compared the environmental impacts of carbon dioxide emissions with the conventional house. The analysis is done across different life cycle phases and years for both buildings. This comparison would help us comprehend if the design decisions we have taken to achieve an energy-efficient building fare in contrast to the conventional structure we expected.

Figure 4 shows the graph of the carbon dioxide emissions distributed annually throughout the life cycle. In both the upfront phase of material production and construction and the operational phase, Project Vivaan performs better than a typical 2 BHK house. The occasional spikes in the graph are attributed to the replacement of Solar PV panels at the end of 30 years and the miscellaneous material replacements in the house.

In the above graph, we can see the comparison of the life cycle impacts by the phase. Our house has 40% fewer emissions overall than a conventional house of similar aspects. Project Vivaan has considerably lower emissions due to electrical energy usage. The intake from the grid is reduced by 60%. And the export of electricity to the grid offsets up to 85% of the total emissions in the project's life cycle. The materials selection has fostered a reduction of 34%. The efficient water fixtures of our house reduce the intake from 668 litres per day to 395 litres per day for the four-person house. And the grey water recycling system saves around 60 litres daily that could be reused in the toilets. This reduction in water consumption caused a 61% reduction in the CO_2 emissions from the water supply and consumption.

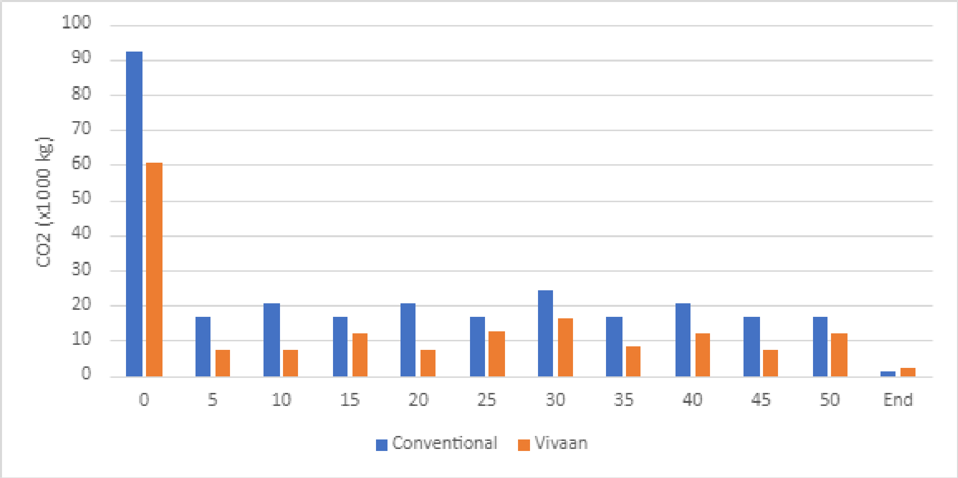

Figure 4 - Project Vivaan vs. Conventional house's annual impacts comparison

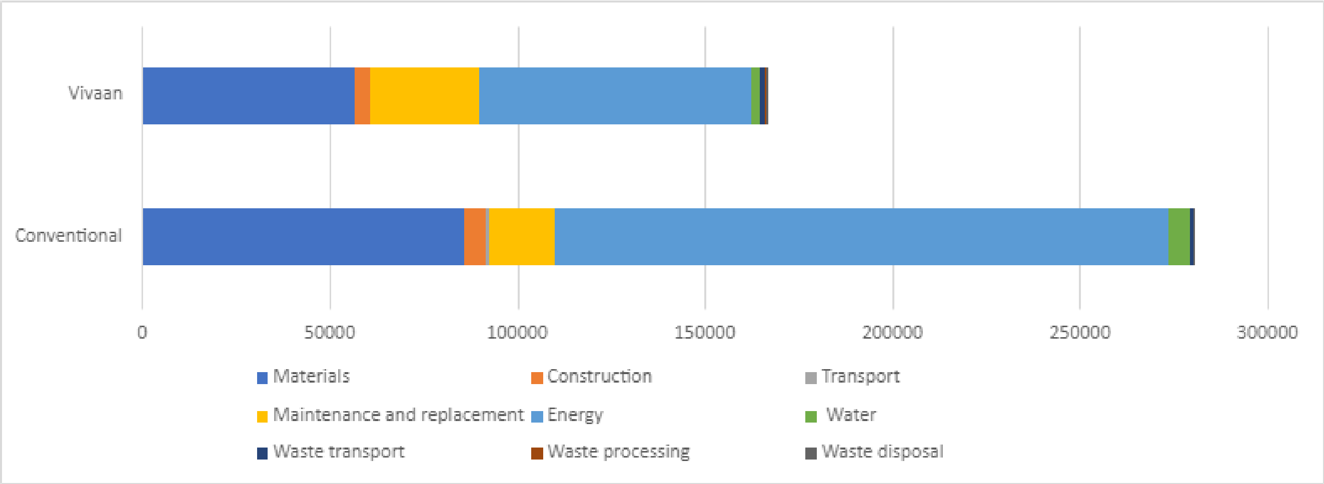

Figure 5 - Project Vivaan vs. Conventional house total emissions stacked

In conclusion, Project Vivaan fares very well compared to a conventional building concerning its design philosophies and elements. We considered the environmental impacts at every decision-making phase for selecting our materials and systems for the design of the house.

We at Team SHUNYA aimed for our Project to be a Net Zero Carbon house. We offset around 85% of our CO2 emissions by exporting electricity. We plan to cover the rest of the emissions by tree plantation to achieve a Net Zero Carbon house.

References

1. India Construction Materials Database of Embodied Energy and Global Warming Potential, International Finance Corporation (IFC), 2011.

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3. Energy Efficiency Labels for Residential Buildings - Bureau of Energy Efficiency, India
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