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Life Cycle Assessment of Residential Building

Author: Ar. Z. S. Pirjade Co- Author: Ar. Medha Naik
Department of Architecture,
Jawaharlal Neharu Engineering College, Chh. Sambhajinagar,(Mahatma Gandhi Mission University)

Abstract:

The building sector consumes a significant amount of energy due to various factors such as the building facade, floor area, energy resource demand, temperature variations, and construction and usage practices. The efficiency of building energy demand and equipment during construction also contribute to increased energy consumption. There is a wide range of materials available for construction, each with its own environmental impacts. The objective of this research is to establish a decision-making framework for the selection of appropriate buildingmaterials.

The main focus of this paper is to conduct a comprehensive life-cycle assessment (LCA) for two building systems in Indian cities, spanning a period of 60 years. The assessment takes into account various factors that influence the life cycle of residential buildings, including the construction, maintenance, and operational aspects of the systems. Evaluating the performance of buildings is crucial in order to reduce residential energy consumption and optimize the quality of materials using LCA methodologies. The research outlines a systematic and thorough approach to selecting building materials, offering valuable insights for decision-making related tomaterials that offer maximum efficiency in residential construction.

Introduction:

The building includes walls, roofs, windows, doors, and insulation, forming the physical barrier between the interior and exterior environment of a building. It plays a pivotal role in determining energy consumption, thermal comfort, indoor air quality, and the overall environmental impact of residential buildings throughout their life cycle.

Life Cycle Assessment (LCA) is a valuable methodology for assessing the environmental impacts of building materials, systems, and components throughout their entire life cycle. LCA evaluates factors such as energy use, greenhouse gas emissions, resource depletion, water consumption, waste generation, and potential environmental pollution. It enables a comprehensive evaluation of the environmental performance of residential buildings, from raw material extraction to end-of-life disposal.

Objectives of the Study:

- Evaluating the most environmentally friendly alternative for residential building.

Scope and Limitations

- The study specifically examines building elements such as walls, roof, floors,windows, and doors.
- The LCA analysis includes the production stage, construction process, maintenance and replacement in the use phase, and end-of-life stage of the mentioned building components.

Life Cycle Assessment (LCA) Methodologies:

Methodology:

The LCA methodology is used in this paper, from a cradle to site approach, which means that environmental impacts analysis includes the production (extraction and processing of raw materials, transport to manufacturer and manufacturing), transport to the building site and the installation in the building. The software One Click LCA has been used.

Overview of LCA:

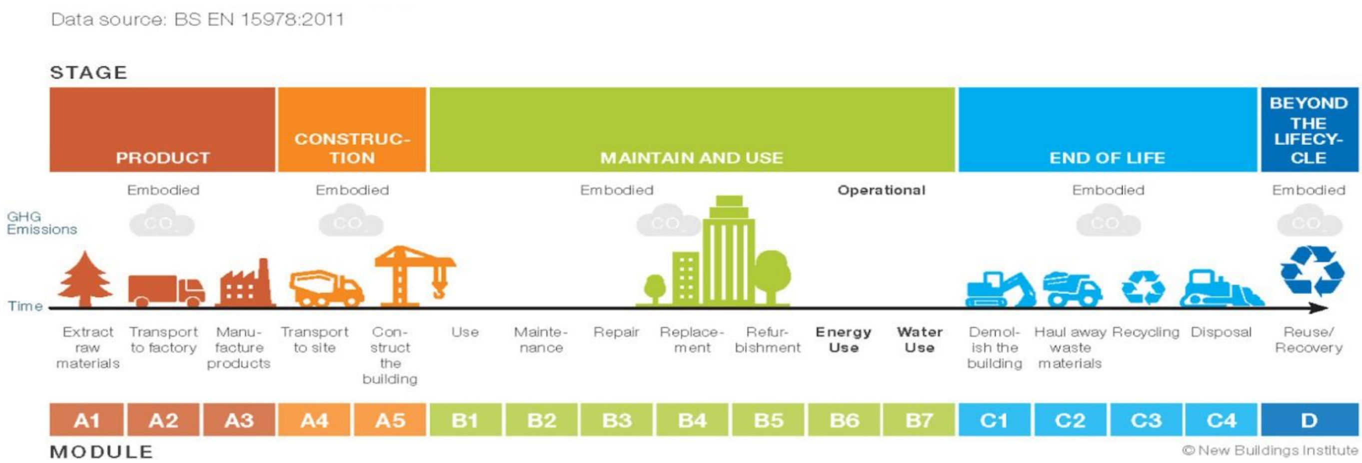
Life Cycle Assessment (LCA) evaluates the environmental impact of a product or system throughout its life cycle. In building, LCA assesses materials, construction techniques, and maintenance processes. It considers extraction, manufacturing, transportation, installation, use, and disposal/recycling. Factors include energy consumption, emissions, water usage, waste generation, and environmental degradation.

LCA aims to enhance sustainability and reduce the construction industry's environmental footprint. By comparing materials, designs, and methods, it guides informed decisions prioritizing environmental performance.

LCA identifies hotspots in building life cycles, revealing improvement opportunities. This involves choosing low-embodied energy materials, optimizing insulation and air sealing, promoting energy efficiency, and considering end-of- life scenarios. LCA aids architects, engineers, and developers in assessing environmental impact, guiding sustainable design choices, and fostering eco-friendly buildings.

Environmental Impacts:

Emissions, such as greenhouse gases, harm the environment and humans. They are released into the air, water, or soil as waste. Greenhouse gases contributeto global warming by trapping heat in the atmosphere, leading to rising temperatures worldwide. This has negative effects on ecosystems, people, and economies. Impact categories are used to measure the effects of substances and gases on the environment, quantifying human actions. In a building life cycle assessment (LCA), material and process quantities are combined to calculate the environmental impacts. Overall, emissions have significant consequences for our planet.

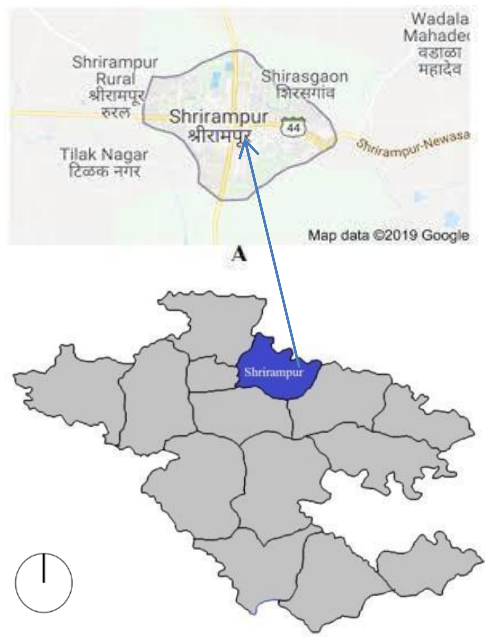


Environmental Impact Categories:

The impact categories included in this study, are global warming potential (GWP), acidification potential (AP).

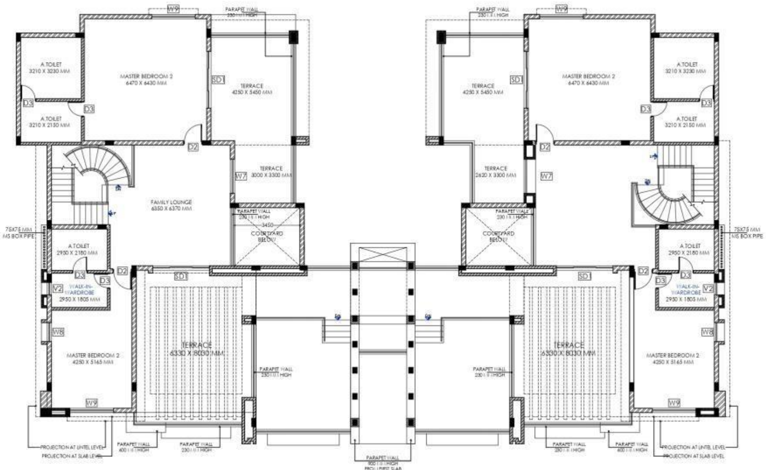
Case Study:

In this study, a residential building located in Shrirampur, Dist. Ahmednagar, Maharashtra, is used as a case study to demonstrate the mechanism of this research method. Shrirampur has a tropical wet and dry climate.

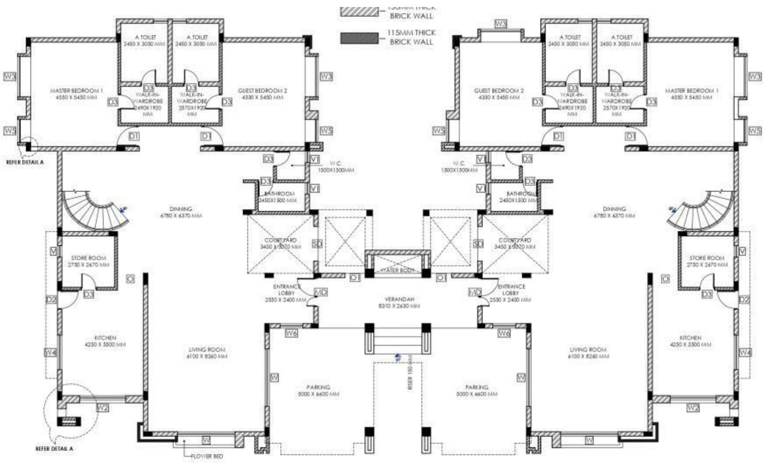


The residence comprises two floors. Table I provides the type and quantity of construction materials have been estimated through direct observations, drawings from architects, and expert consultation.

Ground Floor Plan



First Floor Plan



(Table 1)

MATERIAL QUANTITY			
Element	**Material**	**Quantity**	**Unit**
oundations and substructure	Excavation works	243	Cu. Mt
	Cement	52100	Kg
	Reinforcement steel	14050	Kg
	Sand	36	Cu. Mt
	Aggregate	71	Cu. Mt
	Clay bricks	180	Sq. Mt
al structures and facade	Cement	21350	Kg
	Reinforcement steel	10650	Kg
	Sand	15	Cu. Mt
	Aggregate	29	Cu. Mt
	Clay bricks 230 mm thick	600	Sq. Mt
	Clay bricks 150 mm thick	600	Sq. Mt
	Exterior Plaster mortar	1790	Sq. Mt
	Exterior paint	1790	Sq. Mt
	Interior plaster	2735	Sq. Mt
	Interior paint	2735	Sq. Mt
Horizontal structures: beams, floors and roofs	Cement	96550	Kg
	Reinforcement steel	25450	Kg
	Sand	66	Cu. Mt
	Aggregate	132	Cu. Mt
	Floor and wall tiles	1705	Sq. Mt
r structures and materials	Door with frame	125	Sq. Mt
	Window with frame	100	Sq. Mt

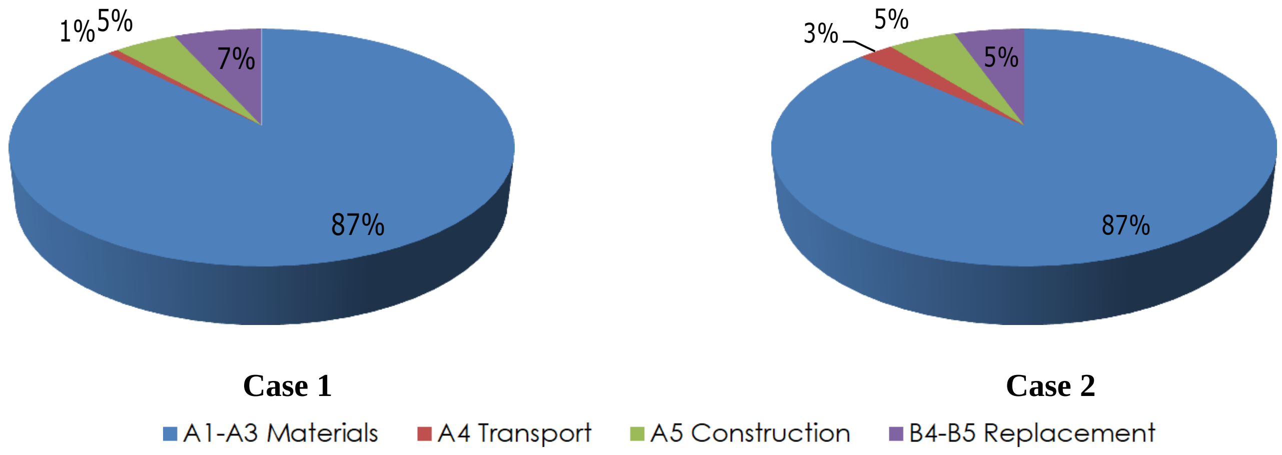
(Figure 1) Contributing building material types for global warming potential (GWP) by One Click LCA.

CASE 1	
Material	**pal warmingkg CO2e**
Excavation works	340
Portland cement	175000
Reinforcement steel (rebar), 0% recycled content	169000
Sand	560
Recycled concrete aggregate (RCA), fine or coarse	64000
Clay bricks	176000
Plaster mortar	27000
Gypsum plaster	27000
Ceramic floor and wall tiles	60000
Wooden door with wooden frame	26000
Aluminium frame window, anodized	24000
Low VOC, high gloss paint with polyurethane finish	1500
Acryclic paint	150

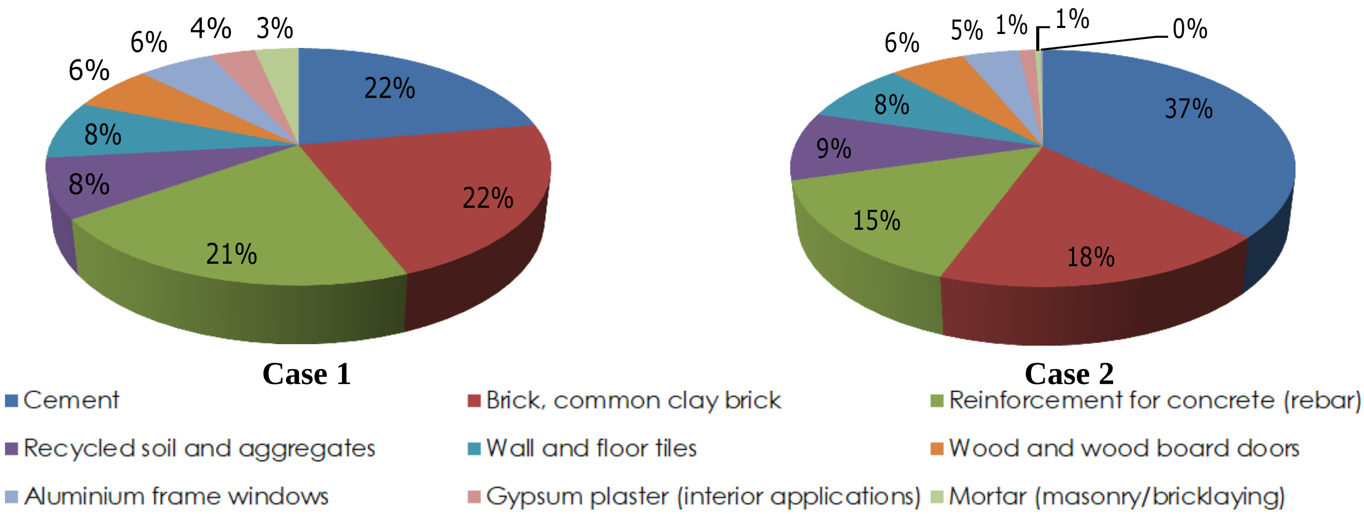
(Figure 2) Contributing building material types for global warming potential (GWP)by One Click LCA.

CASE 2	
Material	**Global warmingkg CO2e**
Excavation works,	340
Blast furnace cement	77000.00
Reinforcement steel (rebar) 100% recycled content	38000.00
Non-cohesive soil	3.8
Crushed natural stone aggregates	1800.00
Extruded raw earth brick	16000.00
Dry mortar	31000.00
Gypsum plaster	27000.00
Porcelain glazed tile	19000.00
Laminated plywood, waterproof	920.00
Double-glazed PVC frame window	6400.00
Emulsion facade paint	490.00
Acrylic emulsion paint	83

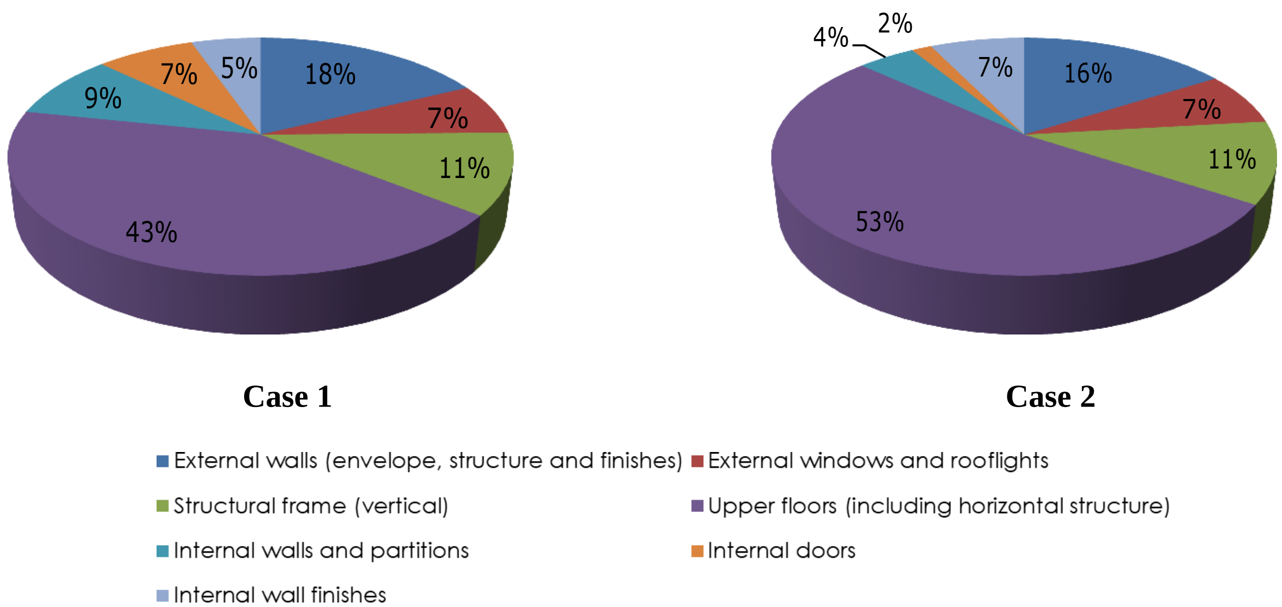
(Figure 3) Global warming kg CO2e - Life-cycle stages



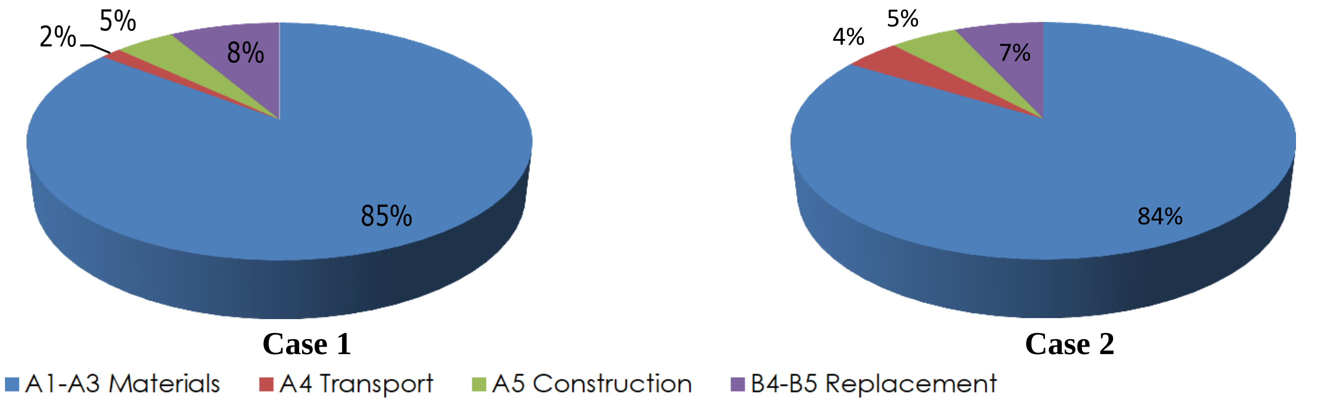
(Figure 4) Global warming kg CO2e - Resource types



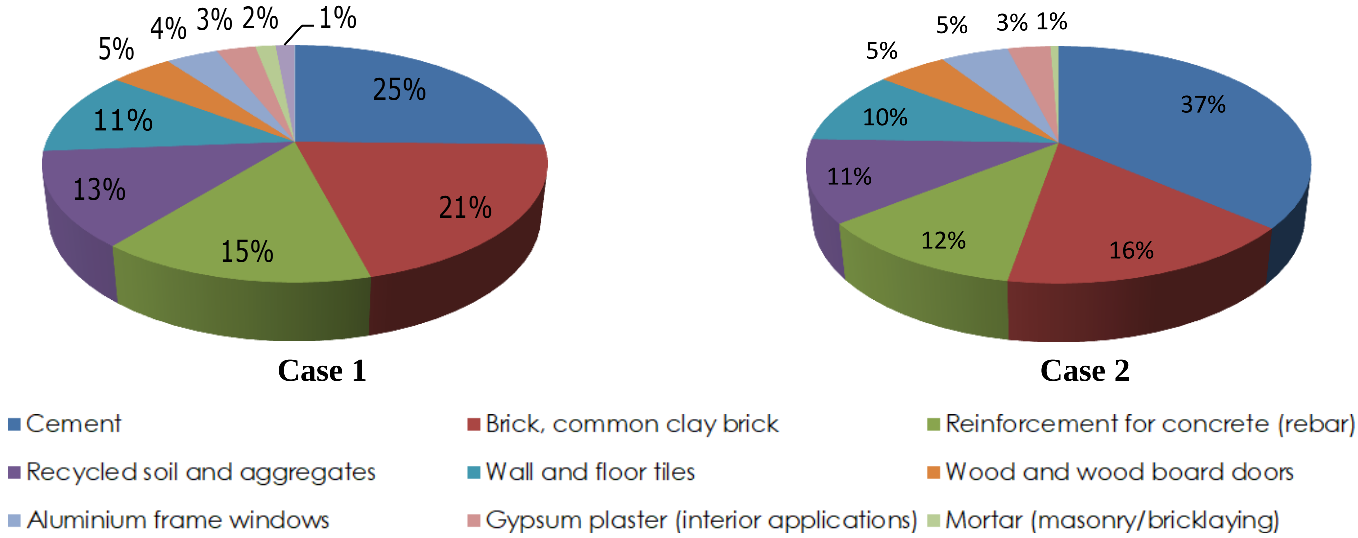
(Figure 5) Global warming kg CO2e - Classifications



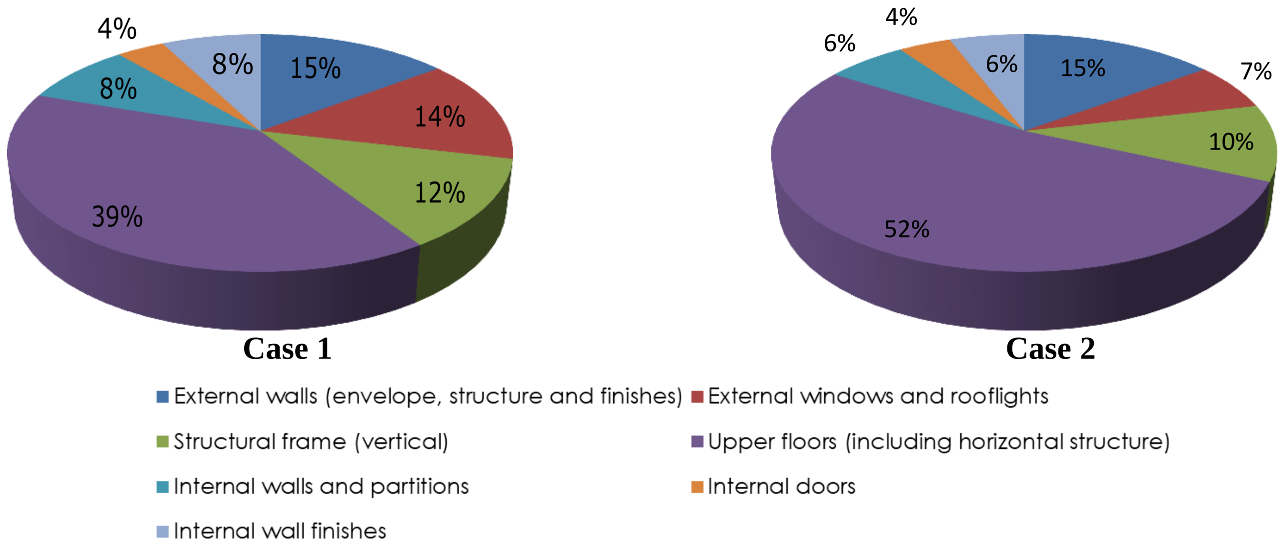
(Figure 6) Acidification kg SO2e - Life-cycle stages



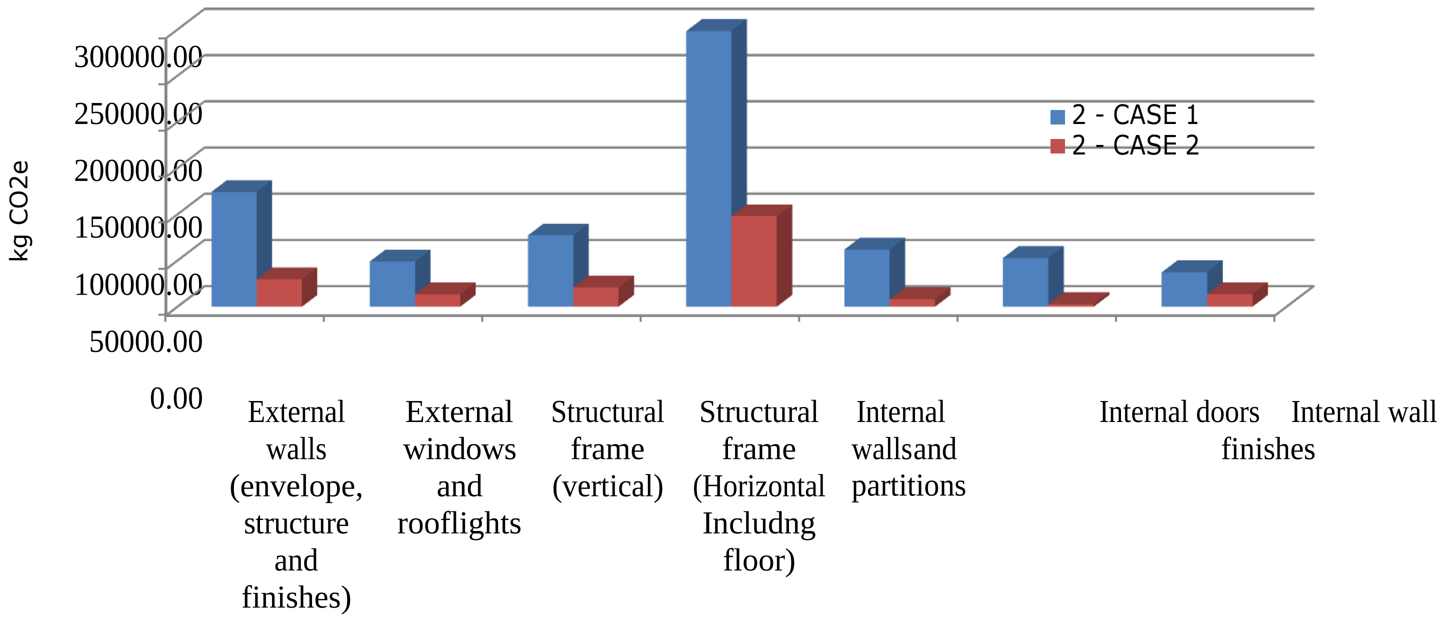
(Figure 7) Acidification kg SO2e - Resource types



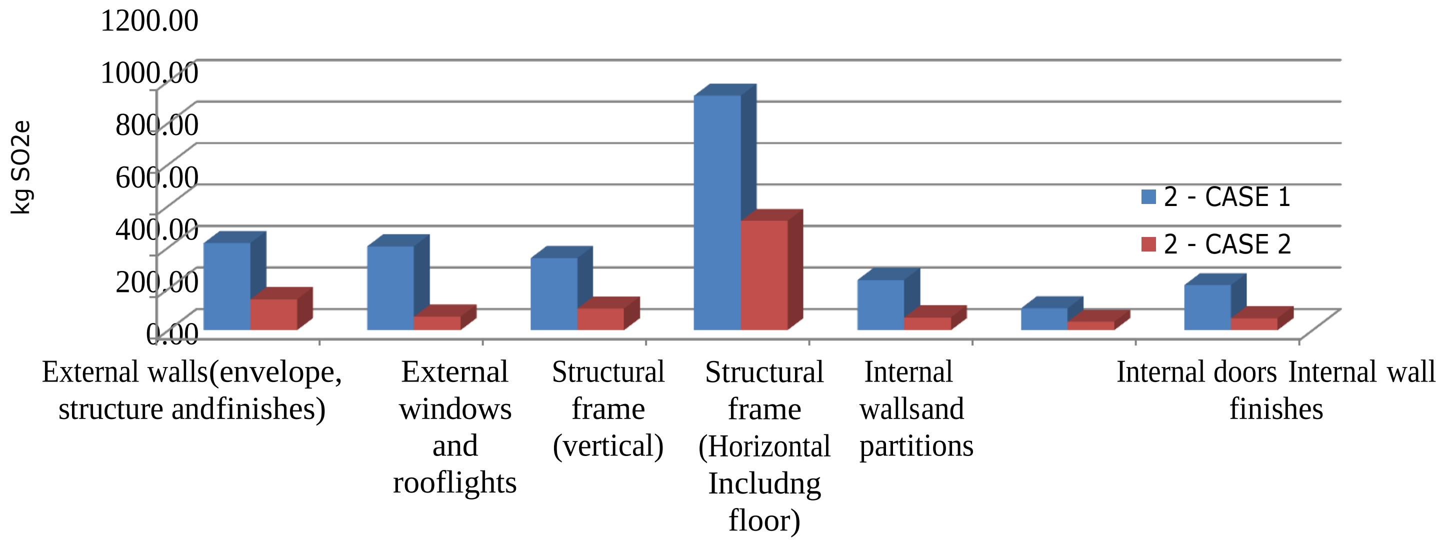
(Figure 8) Acidification kg SO2e - Classifications



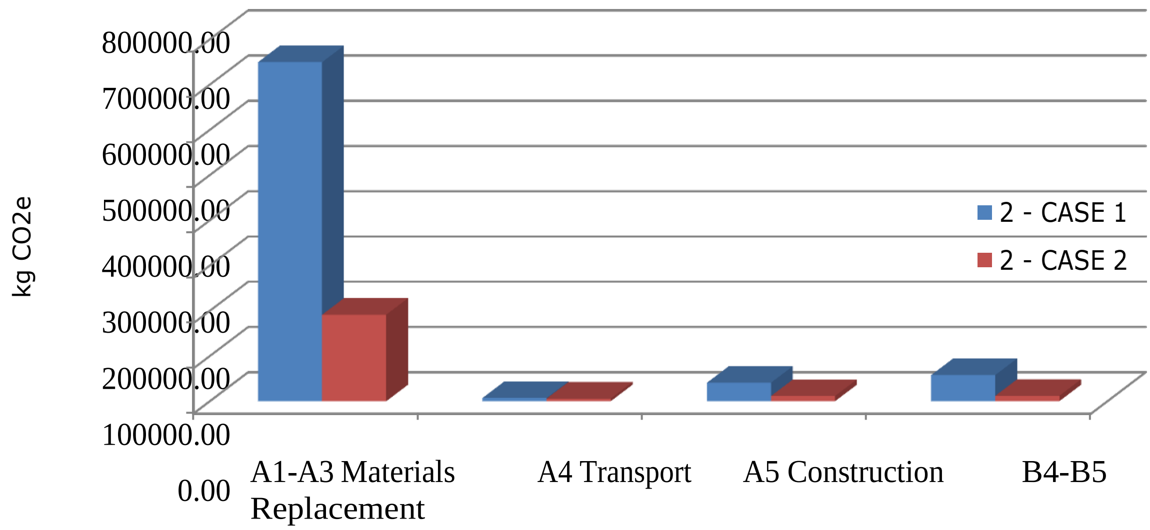
(Figure 9) **Global warming, kg CO_2e - Compare elements**



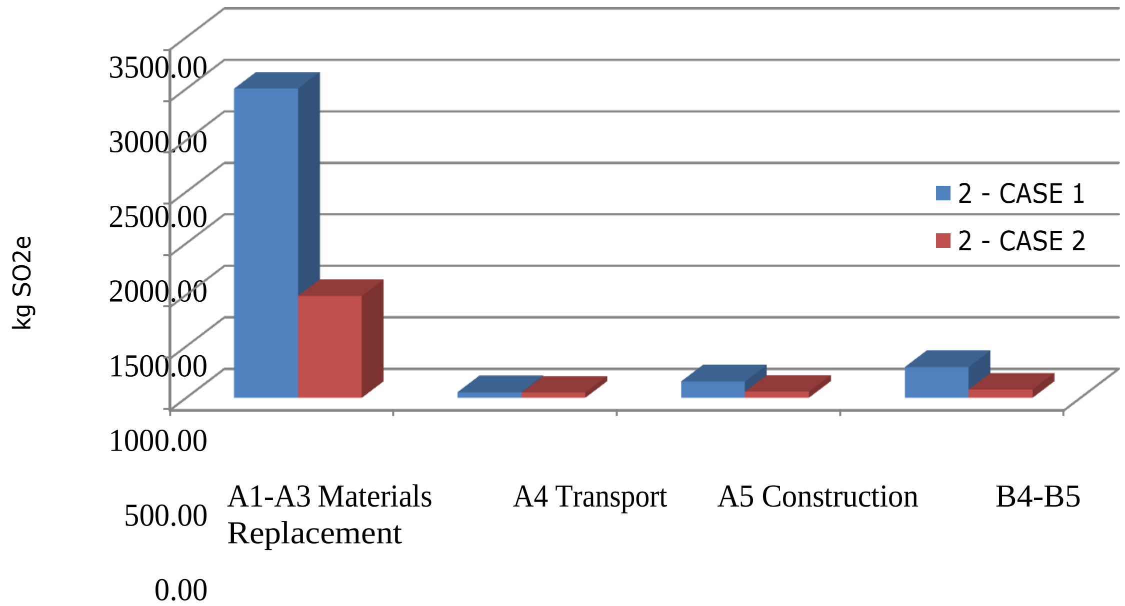
(Figure 10) **Acidification, kg SO2e - Compare elements**



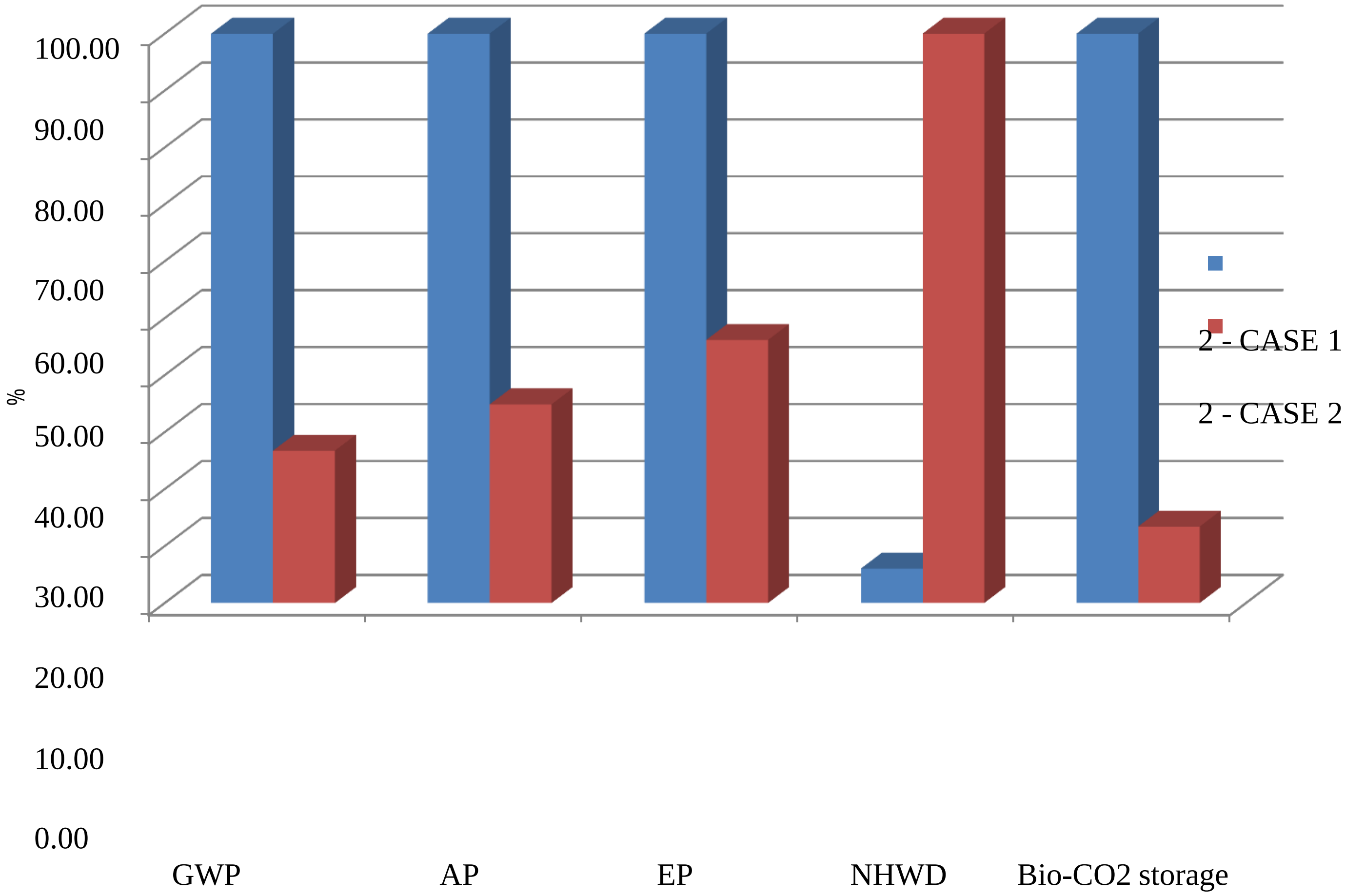
(Figure 11) **Global warming, kg CO_2e - Life-cycle stages**



(Figure 12) **Acidification, kg SO2e - Life-cycle stages**



(Figure 13) **All impact categories**



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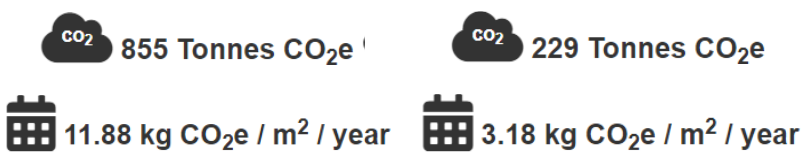
(Figure 14) **All impact categories**

		CASE 1		CASE 2	
Category		**Global warmingkg CO2e**	**cidificationkg SO2e**	**Global warmingkg CO2e**	**Acidification kg SO2e**
Life Cycle Stage	**A1-A3 Materials**	749469.84	3002.43	191273.08	988.53
	A4 Transport	7112.96	55.45	5951.46	50.14
	A5 Construction	40780.71	158.97	11423.91	60.92
	B4-B5 Replacement	57763.56	298.10	11883.59	80.86
Element Classification	**External walls (envelope, structure and finishes)**	124289.43	419.62	29808.11	149.22
	External windows and roof lights	48849.58	403.96	13320.24	65.19
	Structural frame (vertical)	77201.64	347.17	20698.54	104.30
	Structural frame (Horizontal Including floor)	298307.90	1130.30	97969.44	526.28
	Internal walls and partitions	61979.34	242.08	8200.88	61.49
	Internal doors	52760.74	105.31	2860.76	40.27
	Internal wall finishes	37251.45	216.81	13481.38	57.79



Results and Discussion:

Figures 1, 2, 4, and 7 showcase the building materials that contribute, while Figures 3, 6, 11, and 12 demonstrate the life cycle stages that contribute the most to the carbon footprint. Figures 5, 8, 9, and 10 on the other hand, display the building elements that have the greatest impact. Together, these figures provide a comparative analysis of the Global Warming Potential and acidification Potential between Cases 1 and 2, serving as an indicator for the carbon footprint, which refers to the release of carbon dioxide and other greenhouse gases into the atmosphere.

In the software, One Click LCA, building elements include foundations and substructures, vertical structures and facades, horizontal structures, and other structures and materials.

In Case 1, the building's total impact of all life-cycle stages discharges about 855 tons of CO2e for a study period of 60 years, which is equal to 11.88 kg of CO2e per m2/year. In Case 1, During the life cycle stages, A1–A3, building elements such as the structural frame, specifically the horizontal component, along with building materials like Portland cement, reinforcement steel, and clay bricks exhibit the highest rates of kilograms of carbon dioxide equivalent (kg CO2e). The transportation stage (A4) and replacement stage (B4-B5) has shown the lowest contribution.

Figure 13 presents the results of all impact categories at building life-cycle stages. Global Warming Potential describes changes in temperatures caused by increased GHG in the atmosphere. Acidification Potential shows the effects of some acid substances(SO2e)in the environment. Eutrophication Potential describes effectsof added nutrients (phosphorus and nitrogen)to soil or water.

In Case 2, the results show that, over a 60-year study period, the building's total environmental impact remains about 229 tons of carbon dioxide equivalent (CO2e) after replacing high-impact components with low-impact substitutes. Nevertheless, how this impact is distributed changes over the course of a building's existence. The outcome also states that the impact is equivalent to 3.18 kg of CO2e per square meter per year on average. This number represents the annual emissions per squaremeter of the building's footprint.

Conclusion:

This paper presents evaluation of environmental impacts for building materials for residential building. These results provide important insights into the building's carbon footprint and its contribution to climate change. The LCA allows stakeholders to assess and compare the environmental performance of different buildings, identify areas for improvement, and make informed decisions regarding sustainable design, materials, and construction practices.

It's worth noting that the LCA results mentioned here specifically focus on the greenhouse gas emissions (represented as CO2e) associated with the building's life cycle. Other environmental indicators, such as water consumption, resource depletion, and toxicity, may be evaluated in a comprehensive LCA to provide a moreholistic understanding of the building's overall sustainability performance.

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