Environmental Impact Assessments Using Vernacular Materials for Sustainable Developments: Insights from an Eco-Sensitive Resort in India

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Abstract

It is known that quantification of embodied carbon and associated carbon emissions of different building types gives indications of the environmental impact of a structure during its construction, operation, and demolition stages and the various levels of boundary conditions within the framework of life cycle analysis (LCA). In this context, this study examines an eco-sensitive resort, located in a warm and humid climate. It conducts a comparative assessment of embodied carbon and resultant carbon emission by using conventional and alternative vernacular construction materials for foundation, superstructure, walling, roofing, flooring, joinery, finishing details, and site-work.

The research method includes calculation of total quantum of materials used in the selected eco-sensitive resort project with one case scenario of using conventional construction materials and another case scenario of using their vernacular alternatives for all the different blocks with MS Excel© tool. The resultant values of their embodied carbon and carbon emission are calculated by using the globally recognized database and other calibrated LCA tools.

The results show that in the high-end cottages with conventional brick and RCC construction systems, the superstructure and finishing cause the major amount of energy consumption during the construction stage. Using alternative vernacular materials like bamboo in the super structure, local tandoor stones in flooring reduce the embodied energy and carbon emission level significantly. The assessment shows that a 38.8% reduction can be achieved in embodied energy. The carbon emissions decrease by 1680 MT if vernacular materials are used.

This finding is useful for building owners and designers in selecting holistic and environmentally sustainable building materials to produce sustainable buildings.

Keywords: Eco-sensitive resort, Embodied energy, Carbon footprint, Comparative analysis, Vernacular materials

Introduction

Many have shown the implications on resultant carbon footprint and embodied energy while using different kinds of vernacular and modern building materials especially in the residential sector (Debnath, Singh and Singh, 1995; Chani and Kaushik, 2000; Chani, Najmuddin and Kaushik, 2003; Reddy and Jagdish, 2003; Rossano, 2009; Kumar et al., 2012; Kumar, Chani and Deolia, 2015; Kumar et al., 2021). In fact, they have revealed that judicious selection of appropriate building construction materials can reduce the overall energy footprint and carbon emission of any project.

As known, this is the need of the hour considering the limited energy resources available globally and particularly in India. Many have explained the definition, process, and analytical framework regarding the assessment of environmental impact in terms of embodied energy and carbon footprint (Yohanis and Norton, 2002; Cleveland and Morris, 2009; Densley and Davison, 2011; Praseeda, Reddy and Mani, 2015; ICE, 2024). Many have also calculated the proportional contribution of different vernacular and modern construction materials used in residential buildings towards the overall energy footprint of the building project (Debnath, Singh and Singh, 1995; Chani, Najmuddin and Kaushik, 2003; Reddy and Jagdish, 2003; Kumar et al., 2012; Kumar at al., 2021). At the same time, given the pressing need to develop low-carbon societies, countries worldwide are implementing policies to promote sustainable construction practices (NWAP, 2002; UNWTO, 2004; Keenan, 2015).

In this context, India has implemented an eco-sensitive resort project aiming to contribute to sustainable tourism development by promoting the cohesive synthesis of vernacular and modern environmentally appropriate building materials and construction practices without disturbing local flora and fauna. This study examines this building and the phenomenon of environmental performance based on the use of materials.

The scope encompasses the assessment of environmental impact, in terms of embodied energy and carbon footprint of the building. It compares the present day construction practices incorporating modern materials with proposed alternative vernacular construction materials. It argues that this will minimize ecological disturbances while maximizing sustainability. The project provides all the necessary facilities in an eco-friendly manner, ensuring that the natural habitat is preserved. The study aims to serve as a benchmark for future construction projects in ecologically sensitive areas, demonstrating the feasibility and benefits of sustainable tourism and low-carbon building practices by using vernacular materials.

By integrating sustainable design principles with a focus on reducing embodied energy and carbon footprint, this research highlights the importance of environmentally conscious construction practices that can be achieved by adopting suitable vernacular materials.

Review of Literature

Many have studied this phenomenon. For example, Bansal and Nandy (2010) and Bansal, Singh and Sawhney (2014) in the Indian context have examined the embodied energy in residential units with plinth areas up to 60 m². They have compared the embodied energy values (EEV) of different construction materials and have found that, in comparison to brick masonry, EEV can be reduced to the tune of 38% by using hollow concrete blocks, 37% by using aerated autoclaved concrete (AAC) blocks, 34% by using Fal-G blocks, 32% by using fly-ash bricks, 29% by using stabilized-earth-blocks, 28% by using solid concrete block, and 4% by using rat-trap bond in normal brick masonry. They have also found that hollow concrete blocks are marginally cheaper than the normal bricks, but walls with AAC blocks, fly-ash blocks, and soil-cement blocks are costlier than walls with normal burnt bricks.

In comparison, Moncaster and Symons (2013) Bansal, Singh and Sawhney (2014) have observed that in the Indian context, the embodied energy value of the residential sector is higher than its operational energy requirement. However, in the UK, the operational energy footprint of domestic sector is much higher in relation to its embodied energy considering a building life-span of 50 - 60 years.

Simultaneously, Filimonau et al. (2011) Liu et al. (2022) Liu and Leng (2022) Zhao, Liu and Miao (2023) have also explored innovative materials and construction techniques to mitigate embodied energy and associated carbon footprint. For instance, Chang et al. (2018) has done life-cycle analysis (LCA) of products made from bamboo to demonstrate that bamboo, a vernacular and rapidly renewable resource, possesses substantially lower embodied energy compared to modern conventional construction materials.

These research show that there is ample opportunity to employ vernacular building materials to achieve environmental sustainability.

Research Methodology

In this study an eco-sensitive resort located in Visakhapatnam, India was assessed using LCA method to compare the carbon footprints and embodied energy values of conventional versus alternative vernacular building materials. In this, a detailed carbon footprint assessment is conducted, employing a trial-and-error approach to determine the most effective materials and construction techniques for reducing carbon emissions.

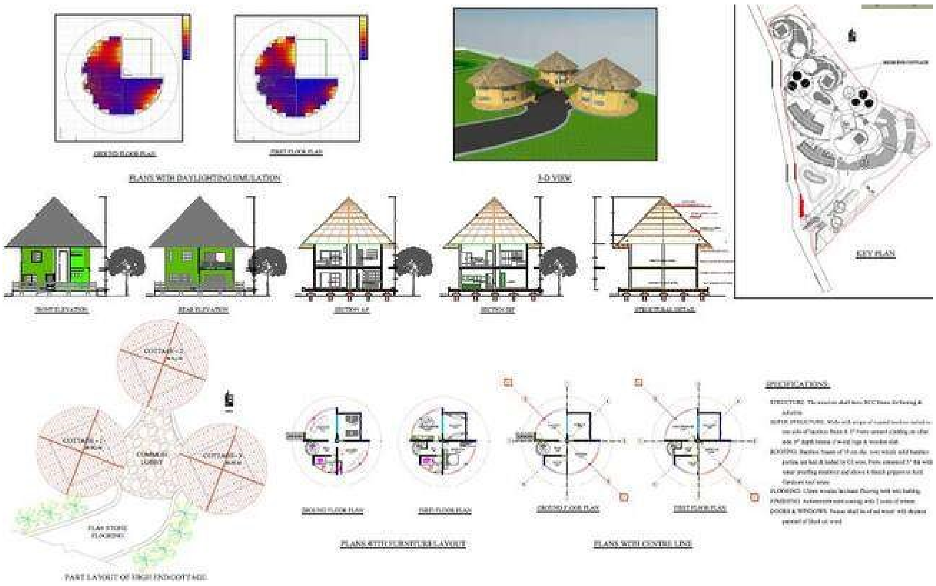
Detailed data for each material and process are collected and expressed in units of energy (MJ) or mass (kg). For instance, the embodied energy of concrete or steel reinforcement is calculated based on the volume or weight used, multiplied by the respective energy intensity of these materials. Similarly, emissions data are obtained, often from databases or specific studies, to determine the CO2 emissions per unit of energy consumed.

The energy use and emissions of each stage are then summed to provide a total figure for the embodied carbon of the architectural project. The methodology ensures that each process's contribution to the overall environmental impact is accounted for, providing a comprehensive picture of the building's carbon footprint.

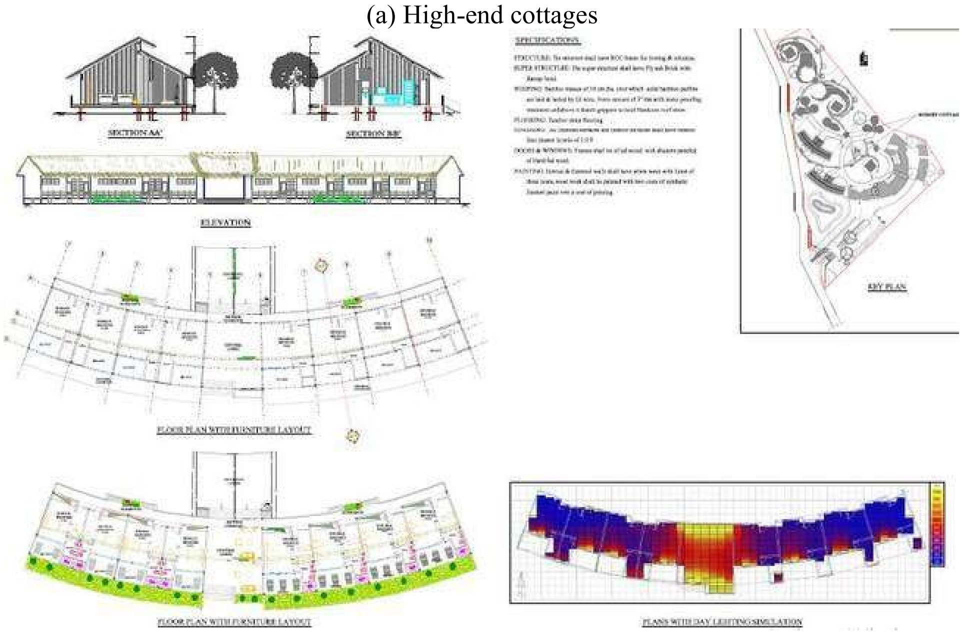
In practice, this method is highly detailed and requires substantial data collection and analysis, making it suitable for assessing specific projects rather than larger-scale analyses like those at the national or city level. The process method provides a granular understanding of the environmental impact, enabling the identification of the most carbon-intensive stages and materials. This detailed insight allows for more targeted strategies to reduce carbon emissions, such as selecting alternative, low-carbon vernacular materials or optimizing construction processes to enhance energy efficiency. This method was employed in the study to compare conventional building materials with vernacular alternative, eco-friendly options for constructing an eco-sensitive resort in Visakhapatnam, India, to fulfil the aim of the research to assess the possibility of reduction of the energy footprint of the whole project within the geoclimatic context.

Details of the Selected Project: Eco-Sensitive Resort

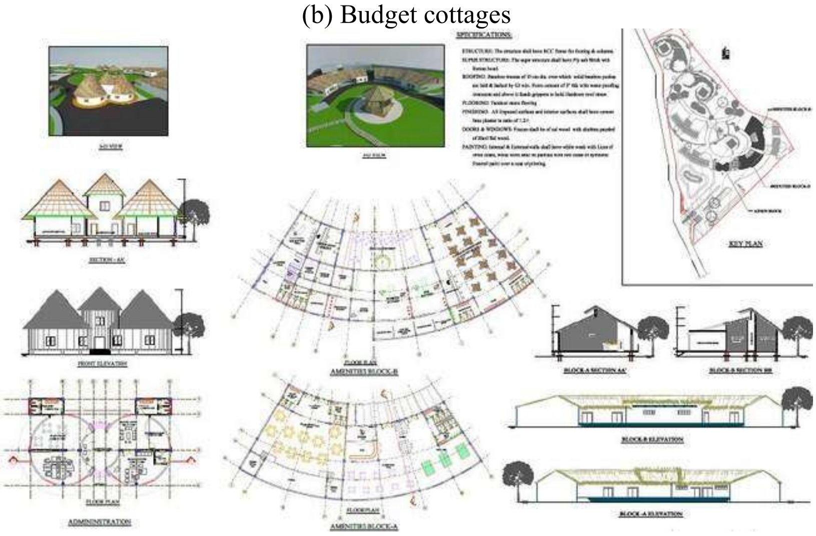
The Eco-Sensitive Resort project in Visakhapatnam, Andhra Pradesh, India (17.69°N Lat, 83.23°E Long) is envisioned as a harmonious blend of sustainable construction and eco-tourism, set within the lush Kambalakonda Reserve Forest. This beautiful forest, part of the Eastern Ghats, is characterized by its dry evergreen flora and diverse wildlife, including leopards, panthers, and various species of deer and birds. Located on the northern side of Vishakhapatnam, the resort spans approximately 10 acres, surrounded by forest on three sides and by sea (the Bay of Bengal) on east side. The terrain is hilly, with steep slopes and a lake adjacent to the site, providing an ideal backdrop for an eco-sensitive tourism experience. The architectural details and specifications of the selected eco-sensitive resort are shown in fig. 1 (Chadalavada, 2016).



(a) High-end cottages



(b) Budget cottages



(c) Admin and amenities block

Fig. 1: Architectural details of the selected eco-sensitive resort
Source: Author

The construction of the resort involves several key elements, each designed with both conventional and alternative materials to assess their sustainability. For the foundation, the conventional approach uses cement and steel, while the alternative option can incorporate rammed earth and recycled steel. The superstructure in the conventional design relies on reinforced concrete and bricks, whereas the alternative method can employ bamboo and timber framing. For the walls, the conventional materials are burnt bricks, concrete blocks and plaster, contrasted with the alternative's use of fly-ash bricks and lime plaster. Roofing in the conventional scenario consists of concrete slabs, while the alternative employs thatched roofs made from local materials. Flooring, typically done with tiles and cement in the conventional method, is replaced with wooden planks and natural stone in the alternative approach. The material-specifications for different blocks and site-works used in the assessments are presented in the following tables 1 to 3.

Table 1: Material specifications of high-end cottage
Source: Author

Materials	**Option-1 (Conventional materials)**	**Option-2 (Alternative materials including vernacular materials)**
Foundation	The structure shall have RCC for footings and columns	The structure shall have RCC for footings and columns
Super-structure	230mm panel wall shall be of I class brick work 1:6 cement, sand and mortar. The beams and lintels are RCC style with cement plastering of 20mm and 12mm on external and internal surfaces respectively.	Walls with strips of treated bamboo nailed on one side of bamboo frame and 3" ferro cement cladding on other side. 9" depth beams of wood logs and wooden slab.
Roofing	RCC sloped roof with Terracotta tile roofing.	Bamboo trusses of 10 cm dia. over which solid bamboo purlins are laid and lashed by GI wire. Ferro cement of 3" thick with water proofing treatment and above it thatch-grippers to hold hard-core roof straw.
Flooring	Kota stone flooring.	Tandoor stone flooring (locally available).
Joinery	Class I teak wood framing for doors and windows with shutters paneled of teak wood.	Sal wood framing for doors and windows with shutters paneled of hard sal wood.
Finishing	3 coats of white wash with lime on internal and external surfaces with a coat of synthetic enamel paint over priming on doors and windows.	3 coats of white wash with lime on internal and external surfaces with a coat of synthetic enamel paint over priming on doors and windows.

Table 2: Material specifications of budget cottage, admin., and amenities block
Source: Author

Materials	**Option-1 (Conventional materials)**	**Option-2 (Alternative materials including vernacular materials)**
Foundation	The structure shall have RCC for footings and columns	The structure shall have RCC for footings and columns
Super-structure	230mm panel wall shall be of I class brick work 1:6 cement, sand and mortar. The beams and lintels are RCC style with cement plastering of 20mm and 12mm on external and internal surfaces respectively.	230mm panel wall of fly ash brick with rat-rap bond masonry. The beams and lintels are RCC style with cement-lime plastering of 20mm and 12mm on external and internal surfaces respectively.
Roofing	RCC sloped roof with Terracotta tile roofing.	Bamboo trusses of 10 cm dia. over which solid bamboo purlins are laid and lashed by GI wire. Ferro cement of 3" thick with water proofing treatment and above it thatch-grippers to hold hard-core roof straw.

Flooring	Kota stone flooring.	Tandoor stone flooring (locally available).
Joinery	Class I teak wood framing for doors and windows with shutters paneled of teak wood.	Sal wood framing for doors and windows with shutters paneled of hard sal wood.
Finishing	3 coats of white wash with lime on internal and external surfaces with a coat of synthetic enamel paint over priming on joinery and steel work.	3 coats of white wash with lime on internal and external surfaces with a coat of synthetic enamel paint over priming on joinery and steel work.

Table 3: Material specifications of site-works
Source: Author

Materials	**Option-1 (Conventional materials)**	**Option-2 (Alternative materials including vernacular materials)**
Curb	Pre-cast curb	Fly-ash brick curb
Pathways	Inter-locking pavers	Flag stone flooring
Entrance	Brick work entrance plaza	Bamboo entrance plaza
Road	Cement concrete road	Bitumen road
Bench	Cement concrete bench	Wooden bench
Recreational Huts	Brick masonry with terracotta roof tiling and cobble stone flooring	Bamboo pitched roof framing with hard-core roof straw and random rubble stone flooring

The site layout and topography of the resort play a crucial role in its design. The site, oriented towards the north, has an irregular shape and contours that tilt towards the southeast. This natural slope, combined with the proximity to the lake and the dense forest surroundings, offers numerous vantage points for scenic views and eco-tourism activities. The resort is designed to minimize environmental impact, preserving the existing flora and fauna during and after construction (Chadalavada, 2016). To enhance sustainability, air conditioners are not provided, relying instead on natural ventilation and cooling methods.

The project's inferences and outcomes highlight the adaptability of different construction typologies within the eco-sensitive area. The resort's design aims to promote eco-tourism while conserving the local wildlife. Various blocks within the resort are planned according to functionality and sustainability criteria, integrating local materials and their embodied energies into the design. The overall theme focuses on eco-tourism and wildlife conservation, utilizing the lake for recreational activities and ensuring that the construction does not disturb the natural habitat.

Data Sources and Analytical Tools

The data collection for this study focuses on acquiring comprehensive details on materials, construction processes, and energy consumption for different building components in both conventional and alternative construction methods. The primary data sources include technical specifications, supplier data sheets, construction industry reports, and databases (ICE, 2024). Additionally, field data from ongoing construction projects were collected to validate the accuracy of the theoretical data.

Life Cycle Assessment (LCA) software, such as SimaPro© and GaBi©, was utilized to analyze the environmental impact of each material and process involved in the construction. Energy consumption and carbon emission calculations were based on the embodied energy values (MJ/cu.m or MJ/sq.m or MJ/kg) and standardized conversion factors for CO2 emissions. The data were systematically organized in spreadsheets for detailed comparison and analysis.

Analysis

The assessment of conventional and alternative construction methods including the vernacular materials employed several key criteria to determine their environmental impact. Total embodied energy (MJ) considers the cumulative energy required throughout the material life cycle, encompassing production, transportation, and assembly. To facilitate comparisons between buildings of varying sizes and types, embodied energy per square meter (MJ/sq.m) normalizes energy consumption based on floor area. Furthermore, by converting embodied energy into kilowatt-hours (kWh), Energy Consumption in kWh translates this data into a more readily understandable unit for assessing the overall energy footprint. Finally, CO2 emissions (MT) quantify the total carbon dioxide released due to embodied energy, providing a direct measure of the environmental impact. To assess the effectiveness of alternative materials and methods, the percentage reduction in energy and carbon footprint highlights the associated efficiency and sustainability gains.

High-End Cottage: Conventional vs. Alternative Materials

The conventional approach uses materials like cement, steel, and bricks, while the alternative approach integrates sustainable materials such as bamboo and wood, emphasizing low embodied energy and local availability. For Option 1, the total embodied energy was 1,243,637 MJ, with an embodied energy per square meter of 10,721.01 MJ/sq.m; energy consumption was 348,219 kWh, and CO2 emission was 265 MT. For Option 2, the total embodied energy was 706,431.2 MJ, with an embodied energy per square meter of 6,089.92 MJ/sq.m; energy consumption was 197,865 kWh, and CO2 emission was 150 MT. The analysis revealed a total carbon footprint reduction of 115 MT and a 43% reduction in energy consumption when using alternative materials for the high-end cottage (Fig. 2). The embodied energy associated with the different components of the high-end cottage is shown in the chart given in Fig. 3.

HIGH END COTTAGE OPTION I (CONVENTIONAL MATERIALS)					
S.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)
	EXCAVATION				
1	Excavation of earth	25.50	cu.m	0.00	0.00
2	Earth work filling in plinth	40.50	cu.m	0.00	0.00
	FOUNDATION				
4	Cement concrete in foundation	6.00	cu.m	3890.00	23340.00
5	Steel reinforcement in slab & beams	2	quintal	3500	7000.00
	SUPER STRUCTURE				
6	RCC in 1:2:4 slab and beams	12.5	cu m	3180	39750.00
7	Steel reinforcement in slab & beams	15	quintal	3500	52500.00
8	RCC columns and lintals	3.45	cu m	3180	10971.00
9	Steel reinforcement columns and lintels	1.5	quintal	3500	5250.00
10	Brick work in 1:6 cement mortar	64.23	cu.m	2700	173421.00
11	Half brick masonry in 1:3 cement mortar	75.00	sq.m	720.00	54000.00
12	12mm cement plaster in 1:6	450.00	sq.m	1521	684450.00
	ROOFING				
13	Roof terracing of R.C.C	12.20	cu.m	3500	42700.00
	FLOORING				
14	Terrozo flooring	125.00	sq.m	113	14125.00
	JOINERY(Teak wood)			0	
15	Teak wood frames	3.00	cu.m	388.00	1164.00
16	Door shutters	3.00	cu.m	388.00	1164.00
17	window glazed shutters	0.25	sq.m	37550.00	9387.50
18	Iron work	5.60	quintals	1590.00	8904.00
	FINISHINGS				
19	white washing with lime in 3 coats	540.00	sq.m	0.58	310.50
20	Synthetic enamel paint	90.00	sq.m	1280.00	115200.00
					1243637.0
Total Embodied Energy		MJ			1243637.0
Embodied Energy Per Square Meter		MJ/Sq.m			10721.01
Energy Consumption in kWh (1MJ=0.28kWh)					348219kWh
CO_2 Emissions (MT)					265MT

HIGH END COTTAGE OPTION 2 (ALTERNATIVE MATERIALS)					
S.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)
	EXCAVATION			MJ	
1	Excavation of earth	25.50	cu.m	0.00	0.00
2	Earth work filling in plinth	40.50	cu.m	0.00	0.00
	FOUNDATION				
3	Cement concrete in foundation	6.00	cu.m	3890.00	23340.00
4	Steel reinforcement in slab & beams	2	quintal	3500	7000.00
	SUPER STRUCTURE				
5	RCC columns	3.45	cu m	3180	10971.00
6	Steel reinforcement columns and lintels	5.17	quintal	3500	18095.00
7	Wooden Slabs and beams	25	cu.m	388	9700.00
8	Outer wall with Bambusa Tulda	64.23	cu.m	450	28903.50
9	Inner Wall Melacanna baccifera	11.25	cu.m	450.00	5062.50
10	12mm cement plaster in 1:6	372.00	sq..m	1521	565812.00
	ROOFING				
11	3"Ferro cement plaster	6.00	cu.m	800	4800.00
12	Bamboo pitched Roof Framing	12.20	cu.m	388	4733.60
13	Hard core Roof Straw	12.20	cu.m	30.5	372.10
	FLOORING				
14	Wood flooring	125.00	sq.m	58	7250.00
	JOINERY(Sal wood)				
15	Door shutters	3.00	cu.m	350.00	1050.00
16	window glazed shutters	0.25	sq.m	37550.00	9387.50
17	Iron work	5.60	quintals	1590.00	8904.00
18	Salwood frames	3.00	cu.m	350.00	1050.00
	FINISHINGS				
19	white washing with lime in 3 coats	540.00	sq.m	0.58	310.50
20	Thinner Coat	300.00	sq.m	1280.00	384000.00
					706431.20
Total Embodied Energy		MJ			706431.20
Embodied Energy Per Square Meter		MJ/Sq.m			6089.92
Energy Consumption in kWh (1MJ=0.28kWh)					197865kWh
CO_2 Emissions (MT)					150MT

Total Carbon Footprint Reduction is 115MT
Embodied Energy Reduced is 43%

Fig. 2: Comparison of energy footprint of high-end cottages
Source: Author

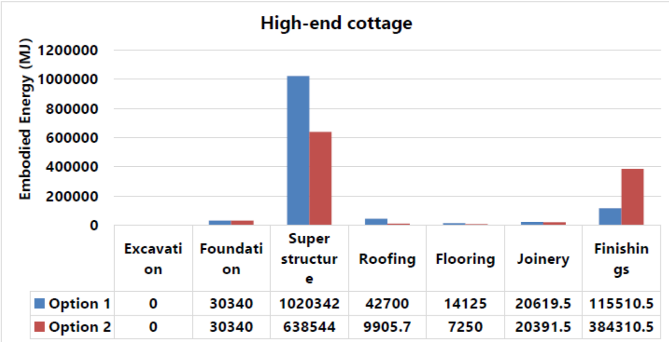


Fig. 3: High-end cottage – embodied energy details
Source: Author

Fig. 3 shows that in the high-end cottage the super structure and finishing take the major amount of embodied energy compared to the others. The bamboo super structure reduces most of energy compared to RCC construction. In case of finishing, the thinner coat application to the bamboo after the construction causes the maximum amount of embodied energy.

Budget Cottage: Conventional vs. Alternative Materials

As per the detailed calculations given in Fig. 4, in Option 1 the total embodied energy was 5,086,693 MJ, with an embodied energy per square meter of 8,023.18 MJ/sq.m; energy consumption was 1,424,275 kWh, and CO2 emission was 1,085 MT. In Option 2, the total embodied energy was 2,761,913 MJ, with an embodied energy per square meter of 4,356.33 MJ/sq.m; energy consumption was 779,995 kWh, and CO2 emission was 590 MT. The alternative materials approach led to a 490 MT reduction in CO2 emission and a 45% decrease in energy consumption for the budget cottage. The embodied energy associated with the different components of the budget cottage is shown in the chart given in Fig. 5.

BUDGET COTTAGE OPTION-1 (CONVENTIONAL MATERIAS)						BUDGET COTTAGE OPTION 2 (ALTERNATIVE MATERIALS)					
S.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)	S.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)
	EXCAVATION						EXCAVATION				
1	Excavation of earth	54.5	cu.m	0	0.00	1	Excavation of earth	54.5	cu.m	0	0.00
2	Earth work filling Excavation	23.76	cu.m	0	0.00	2	Earth work filling	23.76	cu.m	0	0.00
	FOUNDATION						**FOUNDATION**				
3	Cement concrete in foundation	13.27	cu.m	3890	51620.30	3	Cement concrete in foundation	13.27	cu.m	3890	51620.30
4	Steel reinforcement in slab & beams	3	quintal	3500	10500.00	4	Steel reinforcement in slab & beams	3	quintal	3500	10500.00
	SUPER STRUCTURE						**SUPER STRUCTURE**				
5	RCC in 1:2:4 slab and beams	157.35	cu.m	3180	500373.00	5	RCC in 1:2:4 slab and beams	157.35	cu.m	3180	500373.00
6	Steel reinforcement in slab & beams	24	quintal	3500	84000.00	6	Steel reinforcement in slab & beams	24	quintal	3500	84000.00
7	RCC columns and lintals	5.23	cu.m	3180	16631.40	7	RCC columns and lintals	5.23	cu.m	3180	16631.40
8	Steel reinforcement columns and lintels	1.5	quintal	3500	5250.00	8	Steel reinforcement columns and lintels	1.5	quintal	3500	5250.00
9	Brick work in 1:6 cement mortar	155.4	cu.m	2700	419580.00	9	Fly Ash Brick with Ratrap Bond	155.4	cu.m	1101	171095.4
10	12mm cement plaster 1:6	450	sq.m	1521	684450.00	10	12mm cement lime plaster 1:2:9	450	sq.m	290	130500.0
11	20mm cement plaster in 1:4	850	sq.m	1521	1292850.0	11	15mm cement lime plaster in 1:2:9	850	sq.m	310	263500.0
	ROOFING						**ROOFING**				
12	R.C.C roofing	157	cu.m	3180	499260.00	12	Bamboo pitched Roof Framing	157	cu.m	450	70650.00
13	Terracota Tile Terracing	157	cu.m	242	37994.00	13	Hard core Roof Straw	157	cu.m	30.5	4788.50
	Flooring				0.00		Flooring				
14	Kota Stone flooring	140	sq.m	335	46900.00	14	Tandoor stone flooring	140	sq.m	115	16100.00
	Joinery						Joinery			0	
15	Teak Wood work in frames of doors & windows	5	cu.m	388	1940.00	15	Sal Wood work in frames of doors & windows	5	cu.m	350	1750.00
16	Door shutters	5.00	cu.m	388.00	1940.00	16	Door shutters	5.00	cu.m	350.00	1750.00
17	window glazed shutters	35	sq.m	37550	1314250	17	window glazed shutters	35	sq.m	37550	1314250
18	MS bars for windows	5	quintal	3200	16000.00	18	MS bars for windows	5	quintal	3200	16000.00
	FINISHINGS						**FINISHINGS**				
19	white wash with lime in three coats	1300	sq.m	0.58	754.00	19	white wash with lime in three coats	1300	sq.m	0.58	754.00
20	Painting with synthetic enamel of two coats over joinery and steel work	80	sq.m	1280	102400.00	20	Painting with synthetic enamel of two coats over joinery and steel work	80	sq.m	1280	102400.00
					5086692.7						2761912
	Total Embodied Energy	**MJ**			**5086693.0**		**Total Embodied Energy**	**MJ**			**2761913**
	Embodied Energy Per Square Meter	**MJ/sq.m**			**8023.18**		**Embodied Energy Per Square Meter**	**MJ/sq.m**			**4356.33**
Energy Consumption in kWh (1MJ=0.28kWh)					**1424275kWh**	**Energy Consumption in kWh (1MJ=0.28kWh)**					**779995kWh**
CO_2 Emissions (MT)					**1085MT**	**CO_2 Emissions (MT)**					**590MT**
Total Carbon Footprint Reduction is 490MT											
Embodied Energy Reduction is 45%											

Fig. 4: Comparison of energy footprint of budget cottages
Source: Author

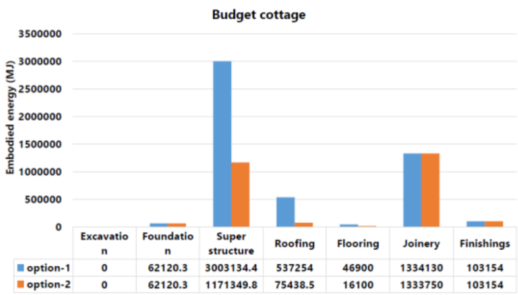


Fig. 5: Budget cottage – embodied energy details
Source: Author

Fig. 5 shows that in the budget cottage the super structure and finishing take the major amount of embodied energy compared to the others. The bamboo super structure reduces most of energy compared to RCC construction. Bamboo cottage has highest area and accommodates many rooms so the joinery also causes the major amount of embodied energy share.

Admin Block: Conventional vs. Alternative Materials

The administration block's construction was evaluated similarly, highlighting the benefits of using sustainable construction techniques. For Option 1, the total embodied energy was 1,817,310 MJ, with an embodied energy per square meter of 8,041.19 MJ/sq.m; energy consumption was 508,845 kWh, and CO2 emission was 390 MT. For Option 2, the total embodied energy was 1,255,965 MJ, with an embodied energy per square meter of 5,557.37 MJ/sq.m; energy consumption was 351,669 kWh, and CO2 emission was 270 MT. The adoption of alternative materials reduced CO2 emission by 120 MT and energy consumption by 30% for the admin block of the resort (Fig. 6). The embodied energy associated with the different components of the administration block is shown in Fig. 7.

Admin Block option I (Conventional materials)						Admin Block option 2(Alternative materials)					
S.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)	s.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/cu.m or MJ/sq.m or MJ/kg)	Total energy (MJ)
	EXCAVATION						EXCAVATION				
1	Excavation of earth	30	cu.m	0	0.00	1	Excavation of earth	30	cu.m	0	0.00
2	Earth work filling Excavation	18	cu.m	0	0.00	2	Earth work filling	18	cu.m	0	0.00
	FOUNDATION						FOUNDATION				
3	Cement concrete in foundation	23	cu.m	3890	89470.00	3	Cement concrete in foundation	23	cu.m	3890	89470.00
4	Steel reinforcement in slab & beams	2.3	quintal	3500	8050.00	4	Steel reinforcement in slab & beams	2.3	quintal	3500	8050.00
	SUPER STRUCTURE						SUPER STRUCTURE				
5	RCC in 1:2:4 slab and beams	33	cu m	3180	104940.00	5	RCC in 1:2:4 slab and beams	33	cu m	3180	104940.00
6	Steel reinforcement in slab & beams	3	quintal	3500	10500.00	6	Steel reinforcement in slab & beams	3	quintal	3500	10500.00
7	RCC columns and lintels	4.2	cu m	3180	13356.00	7	RCC columns and lintels	4.2	cu m	3180	13356.00
8	Steel reinforcement columns and lintels	1	quintal	3500	3500.00	8	Steel reinforcement columns and lintels	1	quintal	3500	3500.00
9	Brick work in 1:6 cement mortar	75	cu.m	2700	202500.00	9	Fly Ash Brick with Ratrap Bond	75	cu.m	1101	82575.00
10	12mm cement plaster 1:6	160	sq.m	1521	243360.00	10	12mm cement lime plaster 1:2:9	160	sq.m	290	46400.00
11	20mm cement plaster in 1:4	120	sq.m	1521	182520.00	11	15mm cement lime plaster in 1:2:9	120	sq.m	310	37200.00
	ROOFING						ROOFING				
12	R.C.C roofing	33	cu.m	3180	104940.00	12	Bamboo pitched Roof Framing	33	cu.m	450	14850.00
13	Terracota Tile Terracing	33	cu.m	242	7986.00	13	Hard core Roof Straw	33	cu.m	30.5	1006.50
	FLOORING						FLOORING				
14	Kota Stone flooring	8.38	sq.m	335	2807.30	14	Tandoor stone flooring	8.38	sq.m	115	963.70
	JOINERY						JOINERY				
15	Teak Wood work in frames of doors & windows	3	cu.m	388	1164.00	15	Sal Wood work in frames of doors & windows	3	cu.m	350	1050.00
16	Door shutters	3.00	cu.m	388.00	1164.00	16	Door shutters	3.00	cu.m	350.00	1050.00
17	window glazed shutters	15	sq.m	37550	563250.00	17	window glazed shutters	22	sq.m	37550	563250.00
18	MS bars for windows	3	quintal	3200	9600.00	18	MS bars for windows	3	quintal	3200	9600.00
	FINISHINGS						FINISHINGS				
19	white wash with lime in three coats	400	sq.m	0.58	232.00	19	white wash with lime in three coats	400	sq.m	0.58	232.00
20	Painting with synthetic enamel of two coats over joinery and steel work	4	sq.m	1280	5120.00	20	Colour wash with base coat two coats over joinery and steel work	4	sq.m	1280	5120.00
	Total Embodied Energy	MJ			1817310		Total Embodied Energy	MJ			1255965
Embodied Energy Per Square Meter MJ/sq.m					8041.19	Embodied Energy Per Square Meter MJ/sq.m					5557.37
Energy Consumption in kWh (1MJ=0.28kWh)					508845kWh	Energy Consumption in kWh (1MJ=0.28kWh)					351669kWh
CO_2 Emissions (MT)					390MT	CO_2 Emissions (MT)					270MT
Total Carbon Footprint Reduction is 120MT											
Embodied Energy Reduction is 30%											

Fig. 6: Evaluation of energy footprint of admin block
Source: Author

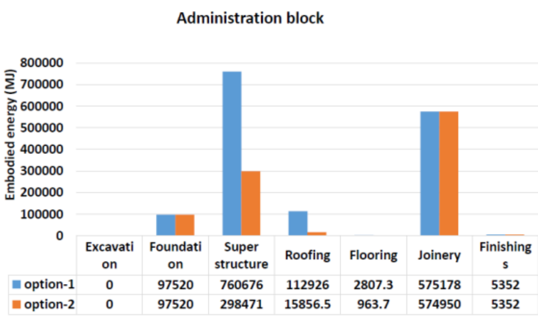


Fig. 7: Admin block – embodied energy details
Source: Author

As per Fig. 7, in the administration block the super structure and finishing result the major amount of embodied energy compared to the others. The bamboo super structure reduces most of energy compared to RCC construction. Due to the number of openings in the administration block joinery takes major share and sal wood reduces embodied energy compared to teak.

Amenities Block: Conventional vs. Alternative Materials

The amenities block's analysis further emphasized the environmental advantages of sustainable construction methods. In Option 1, the total embodied energy was 7,613,819 MJ, with an embodied energy per square meter of 5,403.7 MJ/sq.m; energy consumption was 2,474,431 kWh, and CO2 emission was 1,620 MT. In Option 2, the total embodied energy was 5,139,388 MJ, with an embodied energy per square meter of 3,647.54 MJ/sq.m; energy consumption was 1,439,030 kWh, and CO2 emission was 1,093 MT. The transition to alternative materials achieved a 530 MT reduction in CO2 emission and a 32% reduction in energy consumption for the amenities block (Fig. 8). The embodied energy associated with the different components of the amenities block is shown in the chart given in Fig. 9.

Amenities Block option I (Conventional materials)						Amenities Block option 2 (Alternative materials)					
s.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/cu.m or MJ/ sq.m or MJ/kg)	Total energy (MJ)	s.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/cu.m or MJ/ sq.m or MJ/kg)	Total energy (MJ)
	EXCAVATION						EXCAVATION				
1	Excavation of earth	131	cu.m	0	0.00	1	Excavation of earth	131	cu.m	0	0.00
2	Earth work filling Excavation	90	cu.m	0	0.00	2	Earth work filling	90	cu.m	0	0.00
	FOUNDATION						FOUNDATION				
3	Cement concrete in foundation	40	cu.m	3890	155600.00	3	Cement concrete in foundation	40	cu.m	3890	155600.00
4	Steel reinforcement in slab & beams	2.3	quintal	3500	8050.00	4	Steel reinforcement in slab & beams	2.3	quintal	3500	8050.00
	SUPER STRUCTURE						SUPER STRUCTURE				
5	RCC in 1:2:4 slab and beams	210	cu.m	3180	667800.00	5	RCC in 1:2:4 slab and beams	210	cu.m	3180	667800.00
6	Steel reinforcement in slab & beams	21	quintal	3500	73500.00	6	Steel reinforcement in slab & beams	21	quintal	3500	73500.00
7	RCC columns and lintals	25.15	cu.m	3180	79977.00	7	RCC columns and lintals	25.15	cu.m	3180	79977.00
8	Steel reinforcement columns and lintels	4	quintal	3500	14000.00	8	Steel reinforcement columns and lintels	4	quintal	3500	14000.00
9	Brick work in 1:6 cement mortar	520	cu.m	2700	1404000.00	9	Fly Ash Brick with Ratrap Bond	520	cu.m	1101	572520.00
10	12mm cement plaster 1:6	300	sq.m	1521	456300.00	10	12mm cement lime plaster 1:2:9	300	sq.m	290	87000.00
11	20mm cement plaster in 1:4	540	sq.m	1521	821340.00	11	15mm cement lime plaster in 1:2:9	540	sq.m	310	167400.00
	ROOFING						ROOFING				
12	R.C.C roofing	210	cu.m	3180	667800.00	12	Bamboo pitched Roof Framing	210	cu.m	450	94500.00
13	Terracota Tile Terracing	70	cu.m	242	16940.00	13	Hard core Roof Straw	70	cu.m	30.5	2135.00
	Flooring				0.00		Flooring				0.00
14	Kota Stone flooring	140.9	sq.m	335	47201.50	14	Tandoor stone flooring	140.9	sq.m	115	16203.50
	JOINERY						JOINERY				
15	Teak Wood work in frames of doors & windows	8	cu.m	388	3104.00	15	Sal Wood work in frames of doors & windows	8	cu.m	350	2800.00
16	Door shutters	8.00	cu.m	388.00	3104.00	16	Door shutters	8.00	cu.m	350.00	2800.00
17	window glazed shutters	78	sq.m	37550	2928900.00	17	window glazed shutters	78	sq.m	37550	2928900.00
18	MS bars for windows	3	quintal	3200	9600.00	18	MS bars for windows	3	quintal	3200	9600.00
	FINISHINGS						FINISHINGS				
19	white wash with lime in three coats	1040	sq.m	0.58	603.20	19	white wash with lime in three coats	1040	sq.m	0.58	603.20
20	Painting with synthetic enamel of two coats over joinery and steel work	200	sq.m	1280	256000.00	20	Colour wash with base coat two coats over joinery and steel work	200	sq.m	1280	256000.00
	Total Embodied Energy	MJ			7613819		Total Embodied Energy	MJ			5139388.
	Embodied Energy Per Square Meter	MJ/sq.m			5403.70		Embodied Energy Per Square Meter	MJ/sq.m			3647.54
Energy Consumption in kWh (1MJ=0.28kWh)					2474431kWh	Energy Consumption in kWh (1MJ=0.28kWh)					1439030kWh
CO_2 Emissions (MT)					1620MT	CO_2 Emissions (MT)					1093MT
Total Carbon Footprint Reduction is 530MT											
Embodied Energy Reduction is 32%											

Fig. 8: Evaluation of energy footprint of amenities block
Source: Author

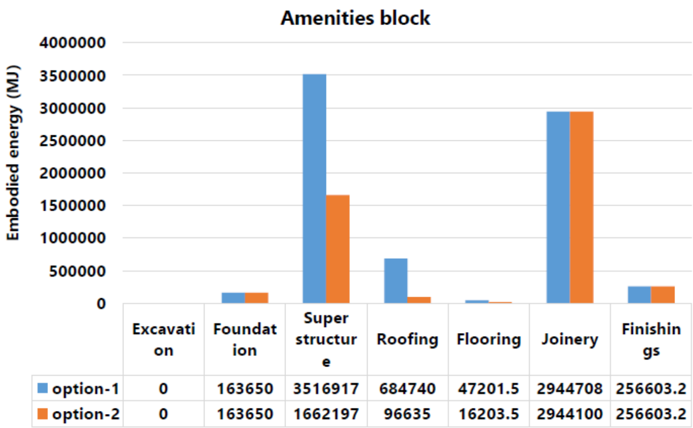


Fig. 9: Amenities block – embodied energy details
Source: Author

Site-Works: Conventional vs. Alternative Materials

The site-work component also demonstrated significant environmental benefits from using sustainable materials. For Option 1, the total embodied energy was 761,381.9 MJ, with an embodied energy per square meter of 5,403.7 MJ/sq.m; energy consumption was 247,443.1 kWh, and CO2 emission was 162 MT. For Option 2, the total embodied energy was 513,938.8 MJ, with an embodied energy per square meter of 3,647.54 MJ/sq.m; energy consumption was 143,903.0 kWh, and CO2 emission was 109 MT. The use of alternative materials for site work reduced the carbon footprint by 530 MT and decreased energy consumption by 32% (Fig. 10). The embodied energy associated with the different components of the site-works is shown in the chart given in Fig. 11.

Site Work option I (Conventional materials)						Site Work option 2 (Alternative materials)					
s.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/ sq.m or MJ/ kg)	Total energy (MJ)	s.no	Description of quantities	Quantity	Unit	Embodied energy (MJ/ cu.m or MJ/ sq.m or MJ/ kg)	Total energy (MJ)
	CURB						**CURB**				
1	Excavation of earth	115	cu.m	0	0.00	1	Excavation of earth	115	cu.m	0	0.00
2	Pre cast Kerb	115	cu.m	3890	447350.00	2	Fly Ash Brick Kerb	115	cu.m	1521	174915.00
	PATHWAY						**PATHWAY**				
3	Inter locking Pavers	2100	sq.m	247	518700.00	3	Flag Stone Flooring	2100	sq.m	120	252000.00
	entrance plaza						entrance plaza				
4	Brick work in 1:6 cement mortar	4	cu.m	2700	10800.00	4	Bamboo Entrance	4	cu.m	450	1800.00
5	12mm cement plaster 1:6	2	sq.m	613	1226.00	5	Thinner Coat	2	sq.m	290	580.00
	ROAD						**ROAD**				
6	Cement Concrete Road	6120	sq.m	247	1511640.00	6	Bitumen Road	6120	sq.m	150	918000.00
	DIVIDER						**DIVIDER**				
7	Brick work in 1:6 cement mortar	13.2	cu.m	2700	35640.00	7	R.R Masonary Wall	13.2	cu.m	1200	15840.00
	BENCH						**BENCH**				
8	Cement Concrete Bench	20	cu.m	3890	77800.00	8	Wooden Bench	20	cu.m	350	7000.00
	RECREATIONAL HUTS						**RECREATIONAL HUTS**				
9	Brick Masonary	216	sq.m	613	132408.00	9	Bamboo Wall	216	sq.m	350	75600.00
10	Terra coata Tile Roofing	216	sq.m	120	25920.00	10	Hark core Roof Straw	216	sq.m	30	6480.00
11	Cobble Stone Flooring	1360	sq.m	620		11	R.R Flooring	1360	sq.m	320	
Total Embodied Energy		**MJ**			**2314134.00**	**Total Embodied Energy**		**MJ**			**1277300.00**
Embodied Energy Per Square Meter		**MJ/sq.m**			**65.56**	**Embodied Energy Per Square Meter**		**MJ/sq.m**			**36.19**
Energy Consumption in kWh (1MJ=0.28kWh)					**647957kWh**	**Energy Consumption in kWh (1MJ=0.28kWh)**					**1277300kWh**
CO_2 Emissions (MT)					**492MT**	**CO_2 Emissions (MT)**					**272MT**
Total Carbon Footprint Reduction is 220MT											
Total Embodied Energy Reduction is 44%											

Fig. 10: Comparison of energy footprint of site-works
Source: Author

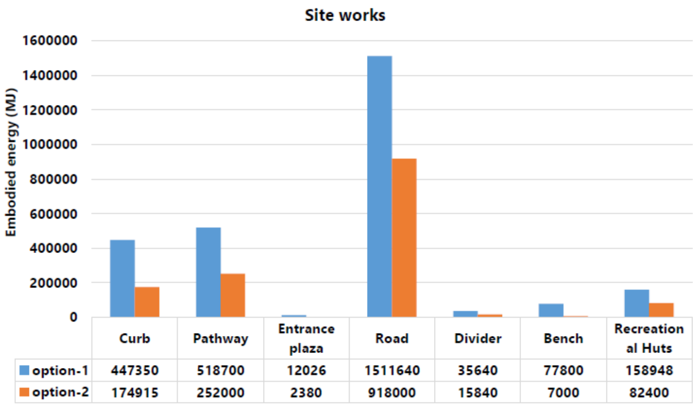


Fig. 11: Amenities block – embodied energy details
Source: Author

Fig. 11 shows that in the site-level works the road takes the highest embodied energy with pathways and curbs follows the road. The bitumen road in the parking areas gives average energy values compared to cement road. Concrete works in overall site plays a major role in embodied energy share; 44% reduction is achieved in carbon levels in the overall site comparison using alternative materials including local materials.

Results and Discussions

This comprehensive data collections and analyses underscore the substantial benefits of using alternative locally available vernacular sustainable materials in construction. By choosing materials with lower embodied energy and integrating them into construction projects, considerable strides can be made to reduce the energy and associated carbon footprint of the concerned architectural project.

The comparative analysis of energy footprint regarding foundation, superstructure, walling, roofing, flooring, joinery, finishing details, and site-work, reveals significant differences between option-1 with conventional materials and option-2 with alternative materials including vernacular materials. All the different major blocks of the eco-sensitive resort were evaluated based on their embodied energy values and carbon emission values. The analysis shows that the use of alternative building materials including the vernacular materials leads to substantial reductions in both metrics. Specifically, the budget cottage, which has the highest area and accommodates more rooms, achieved a 45% reduction in embodied energy. High-end cottages showed a 43% reduction in energy, while the amenities and admin blocks, due to their extensive services, exhibited reductions of 32% and 30%, respectively. The site-works also demonstrated a 44% reduction in energy use. The major findings from the analysis are presented in table 4.

The total carbon emission for the construction of the eco-sensitive resort was calculated by summing the emission of individual blocks. For example, the resort comprises six high-end cottages and two budget cottages. By using the conventional building materials, the total carbon emission was calculated to be 6262 metric tons (MT), and the total embodied energy was 29.38 terajoules (TJ). Whereas, by adopting the alternate building materials, the total carbon emission was found to be 4582 metric tons (MT), and the total embodied energy was 17.45 terajoules (TJ). The difference in embodied energy between conventional and alternative materials amounted to about 12 TJ, while the carbon emission difference was 1680 MT. Overall, a 38.8% reduction in embodied energy was achieved when using alternative materials including the vernacular options compared to conventional materials. The embodied energy per square meter across the whole eco-sensitive resort project was calculated to be 427.8 MJ/sq.m.

Table 4: Material specifications of site-works
Source: Author

Blocks Analyzed	Option-1		Option-2		Reduced Carbon Emission	% Energy Reduction
	Embodied Energy	Carbon Emission	Embodied Energy	Carbon Emission		
High-End cottage	243637 MJ	265 MT	706431 MJ	150 MT	115 MT	43 %
Budget cottage	5086693 MJ	1085 MT	2761915 MJ	590 MT	495 MT	45 %
Admin Block	1817310 MJ	390 MT	1255965 MJ	270 MT	120 MT	30 %
Amenities block	7613819 MJ	1620 MT	5139388 MJ	1093 MT	530 MT	32%
Site-level work	2314134 MJ	492 MT	1277300 MJ	272 MT	220 MT	44%
Total Project	29.38 TJ	6262 MT	17.43 TJ	4582 MT	1680 MT	39%

The chart in fig. 12 shows the comparison of embodied energy value calculated for whole of the eco-sensitive resort project considering the conventional materials and alternative materials with vernacular options. The analysis reveals that the super structure plays the major role in embodied energy. Joinery also causes equal share since the teak wood and sal wood are used in this project. The roofing is generally major part that results more energy share but due to usage of bamboo and straw their embodied energy share as a whole is very less. However, the embodied energy associated with the finishing in alternative materials are higher due to usage of thinner for bamboo construction.

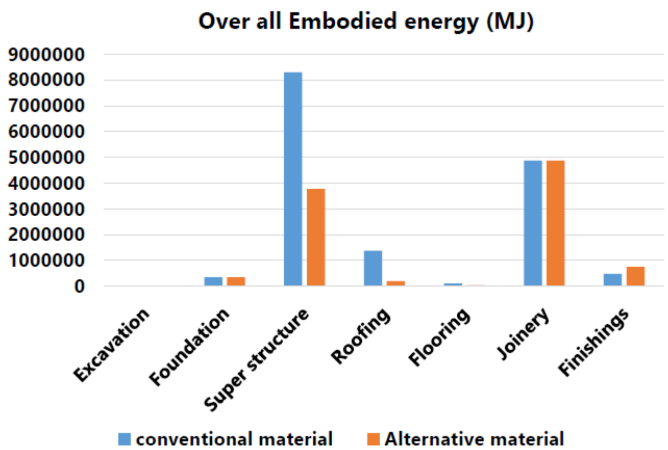


Fig. 12: Embodied energy details of all blocks of the eco-sensitive resort
Source: Author

The present research has highlighted the environmental benefits that can be achieved by using alternative building materials including the vernacular options wherever possible in the construction of an eco-sensitive resort. The significant reductions in embodied energy and carbon emissions across various blocks of the resort highlight the potential for sustainable construction practices by using vernacular materials. The budget cottage, with its highest area and number of rooms, shows the most considerable energy reduction at 45%, emphasizing the importance of material choice in large-scale constructions. High-end cottages and other blocks also demonstrate noteworthy reductions, indicating that alternative materials are effective across different types of structures.

The implications for design and construction are profound. The findings suggest that selecting alternative materials such as bamboo for the superstructure and local Tandoor stone for flooring can lead to substantial environmental benefits. These materials not only reduce the embodied energy and carbon footprint but also contribute to a more sustainable building lifecycle. This study provides valuable insights for building owners, designers, and stakeholders, encouraging them to consider holistic and environmentally sustainable building materials for future projects.

Conclusions

Due to varying occupancy levels in the resort, this study focused solely on embodied energy, including raw material extraction and material manufacturing. Further study will be done by including the operational energy of the buildings.

In construction, the superstructure and roofing are the primary areas of energy consumption. Using bamboo pitched roof framing with roof straw significantly reduces roofing energy. This research emphasizes the reduction of the carbon footprint, starting from the design stage by creating less intrusive footprints, increasing soil percolation by elevating blocks from the ground, preserving undisturbed site areas, adding plantations, and avoiding the removal of existing trees. Form, orientation, shape, and wind movement also play critical roles in reducing carbon levels. Since, buildings contribute to about 45% of carbon emissions, selection of appropriate material and its application is a crucial factor to achieve the goals of sustainability in the project. Promoting alternative building materials is essential for reducing carbon footprints and ensuring the well-being of eco-sensitive areas and surrounding environments.

This research underscores the effectiveness of the process method in achieving detailed insights and significant carbon-emission reductions, promoting sustainability in the construction industry (Chadalavada, 2016). By applying these methodologies, substantial progress can be made in the reduction of the carbon footprints of buildings and contributing to global efforts against adverse effects of climate change by adopting vernacular building materials.

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