Vernacular Construction Techniques of the Kangra Region of Himachal Pradesh, India

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Abstract

The architecture of a specific place is always an outcome of geography, availability of materials and resources, climate, socio-economic conditions, and most importantly, culture. Considering the harsh conditions, indigenous architecture forms the spine of its social and cultural setup. In indigenous architecture, inhabitants do the construction primarily by hand and sometimes with the help of other inhabitants from the village. Knowledge of construction is empirically passed down from generation to generation, mainly through oral narratives or years of apprenticeship.

A notable indigenous architecture exists in India's Kangra region of the Himachal Pradesh. This research examines the indigenous architecture of this region. Residential buildings consume significant energy and produce large amounts of emissions and waste. There is substantial potential to save energy in the residential building sector, which should be evaluated over the course of a building's life cycle.

Life Cycle Assessment (LCA) has examined the primary energy use and associated environmental impacts of different residential building stages (such as product manufacturing and construction). This study used two types of houses - a traditional vernacular house made of dry stone and a modern contemporary house - to calculate the total embodied energy. The transportation of raw materials to the factory and finished products to the end-user was also included in the embodied energy calculation. When comparing the vernacular house to the contemporary house, it was found that the total energy value was 2% of the total energy of the contemporary house, making it a more environmentally friendly option.

Keywords: Stone, Himachal Pradesh, Vernacular Architecture, Aesthetics, Indigenous architecture

1 Introduction

In Himachal Pradesh, more notably in the villages of the districts of Chamba, Shimla, Kullu, and Kinnaur, there are many structures of dry-stone constructions. Due to the abundant supply of river stones and the dearth of wood, people have been forced to abandon their conventional building methods, such as Kath-kunni (cator-and-cribbage). Instead, they have adopted this dry-stone masonry version. This form of buildings has no common local name; instead, it is referred to as "pattharkemakan" (houses of stone). The intricate use of interlocked joints without nails is the hallmark of indigenous construction. With changing times, as a society, knowledge, construction and values continuously transform, while all the newly introduced modern materials replacing the old do not have any relevance and contextual hold over the region.

Housing, water and food, medical facilities, transportation, and waste management are just a few demands that an expanding urban population must meet. These services significantly impact the use of resources and energy and other environmental effects such as waste production, emissions, and wastewater generation (Cuéllar-Franca and Azapagic, 2012). Residential buildings are a crucial contributor to energy and environmental problems since they account for a sizable amount of land use and house the most significant number of people. The building industry consumes about 39% of all primary energy: 38% of carbon emissions, and 40% of raw materials annually in the United States and Canada. (van Ooteghem and Xu, 2012). Due to these effects, the sector has embraced ways for more effective, ecologically friendly designs and building methods (Ganjidoost and Alkass, 2012).

Sustainability places an increased emphasis on environmental concerns. Therefore, a building's environmental evaluation is crucial for reaching sustainability objectives. The building industry frequently uses the Life-Cycle Assessment (LCA) technique to assess and quantify a structure's environmental effects throughout its entire life cycle, including the extraction of raw materials, construction, usage, and end of life. (Asif, Muneer and Kelley, 2007). Many LCA studies have been done in the construction industry, with many of them concentrating on residential constructions.

This study explicitly examines the embodied energy of two distinct construction types: traditional construction and vernacular construction. In order to better understand the full life-cycle effects of residential buildings in Himachal Pradesh, this study compares two distinct house styles from the same region: vernacular construction and contemporary construction. The principal objective of this study is to assess and analyze, using LCA ideas, the primary energy use related to these two types of residential buildings. It considers the embodied energy of structures exclusively in the Himachal Pradesh province of Kangra. This study aims to compare the embodied energy of a modern house in India and a low-cost residential structure of the vernacular construction while considering current building techniques.

Its objectives are:

- Documentation of architectural aspects of selected houses of different construction types.
- Estimation of quantities associated with the construction of the selected houses.
- Perform the building energy simulation on Design Builder software to identify the buildings' operational energy.

A wide range of stakeholders, and researchers, including planners, engineers, developers, and politicians, are anticipated to find value in the findings of the study.

2 Literature Review

A life cycle approach is advised for assessing the usage of resources in the building industry, energy use, and environmental implications. This approach considers whole lifecycle of a building, from its construction and use to its decommissioning and disposal. It is possible to find chances for increasing energy efficiency and minimizing the environmental effect of the building sector by taking these elements into account throughout the lifecycle of a building (Bekker, 1982).

There have been several studies on the embodied energy of different types of buildings, with a focus on the construction phase. Suzuki, Oka, and Okada (1995) has found that steel-reinforced concrete buildings had the highest embodied energy at 8-10 GJ/m2, followed by light-weight steel buildings at 4.5 GJ/m2, and wooden buildings at 3 GJ/m2. Debnath, Singh, and Singh (1995) has found that steel, cement, and brick were the major contributors to the embodied energy of a single-story house with load-bearing walls, accounting for 9%, 33%, and 41%, respectively, of the total embodied energy. Adalberth (1997a, 2000) has studied seven buildings in Sweden and has found that the construction phase accounts for 14-15% of the total life cycle energy use, while the operation of the buildings accounted for 84-85% and transportation and erection and demolition accounted for 1%. Pullen (2000) has studied 25 Australian homes and has found that on-site construction energy accounted for 6.5% of the total initial embodied energy, while the operating energy was four times greater than the construction energy. The transportation and equipment use in the on-site construction phase accounted for 69% and 28%, respectively, of the total on-site construction energy use, and the construction phase accounted for 20% of the total life cycle energy use. These studies highlight the importance of considering the embodied energy of buildings, particularly in the construction phase, in order to identify opportunities for energy efficiency and sustainability.

Several studies have investigated the embodied energy of different types of buildings and the impact of various factors on this energy. For example, a study of a residential structure in Hong Kong has found that using recycled materials during the construction could reduce embodied energy by 50% (Chen, Burnett & Chau, 2001). A life cycle assessment study of a semi-detached house in Scotland has found that concrete accounted for 65% of the total embodied energy (Asif, Muneer and Kelley, 2007). A study of a 55 m2 single-landed house in Indonesia has found that embodied energy contributed 9-14% of life cycle energy and that the building envelope was a significant source of embodied energy (Utama and Gheewala, 2008). Another study found a 50% reduction in the embodied energy when a low-energy house was compared to an ordinary concrete building (Shukla, Tiwari and Sodha, 2009). A study of two houses in Spain and Columbia has found that consumption patterns, climatic variations, technological factors, cultural and socio-economic differences all have an impact on energy use and emissions throughout a building's lifetime (OrtizRodrguez, Castells & Sonnemann, 2010). Similarly, Kua and Wong (2012) has found that building operation, on-site construction, and material manufacture accounted for 13.17%, 0.96%, and 86.10%, respectively of the total life cycle energy.

Research Methodology

The study compares two buildings located in Kangra village, Himachal Pradesh. One building is a traditional, single-family residential structure made of vernacular materials and constructed in 1930. It has two rooms, a storage area, and a veranda, and has a usable floor area of 85.5m2. The other building is a contemporary structure with five rooms and a veranda, and is made of modern materials such as reinforced concrete (RCC) for the roof, concrete for the floor, and clay bricks for the walls. The contemporary building has windows with a 20% window-to-wall ratio and single-pane, clear glass with a solar heat gain coefficient (SHGC) of 0.86, fitted in wooden frames. In contrast, the traditional building has a sloping slate roof, a mud floor, and walls made of slate with mud plaster, and windows with a 20% window-to-wall ratio fitted with wooden panels in wooden frames.

This study involves estimating the energy demand for the production (embodied energy) of the two buildings from a primary energy perspective. It is assumed that the energy used for any renovation of the buildings will be relatively small and is included in the embodied energy (EBE) calculation for the buildings. The embodied energy coefficients for the building materials are taken from the literature.

Several case studies are conducted, for generating data and following steps are used to achieve the goals:

- A physical survey to identify the contextual issues and setting. It is intended to understand the typology, architectural style, construction techniques, and materials within the case study of the vernacular architecture of Kangra region, i.e., dry stone construction houses.
- A document survey to study the context and the rationale behind the construction techniques practiced.
- Analysis and inferences derived from the case studies categorized into two aspects i.e., architectural aspect and life cycle energy aspect.

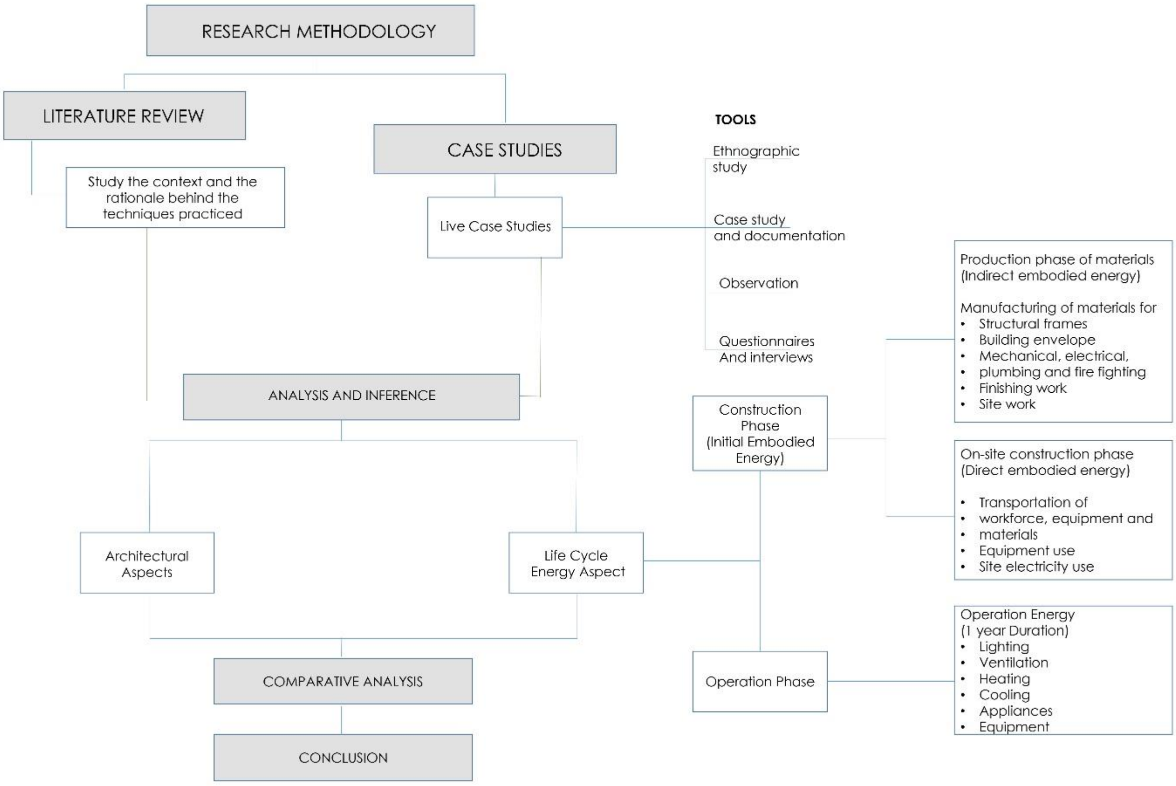


Fig. 1: Life Cycle Energy Aspect- For the calculation of total Embodied Energy, only Embodied Energy Initial (i.e., manufacturing) and Embodied Energy on-site is considered, and no recurrent and end-life embodied energy is considered.
Source: Author

3 Introduction to the Site: Kangra (Himachal Pradesh)

3.1 Understanding the context of Kangra Valley

3.1.1 Physiography of Kangra

The latitude and longitude of the Kangra district are 31° 21 to 32° 59N and 75° 47 to 77° 45E, respectively. It is situated along the Himalayan range on the southern ridge (Uniyal, Sharma, and Jamwal, 2011). Shiwalik and Dhauladhar navigate from South East to North West in the Kangra district. While the height of this region is considered from the mean sea level, it varies from 500 meters to 5000 meters.

3.1.2 The Topography of Kangra

Kangra, a region located in the mountains of Himachal Pradesh, India, is known for its high and undulating landforms, with a terrain that ranges from 500 meters to 5,000 meters above the mean sea level. The mountainous portion of Kangra is characterized by deep valleys that lie between ranges of varying altitudes. To better understand and classify the diverse terrain of Kangra, the region is divided into three zones based on altitude: low hills and valleys, mid hills, and high hills (Uniyal, Sharma and Jamwal, 2011). The low hills and valleys extend up to an elevation of 900 meters above the mean sea level and cover 49% of the Kangra district. The mid hills, ranging from 900 to 1,500 meters above the mean sea level, occupy 16% of the Kangra district. Finally, the high hills, which extend from 1,500 meters to 5,000 meters above the mean sea level, cover 35% of the area of the Kangra district. These three zones, each with its own unique characteristics, provide a range of ecological environments that support a variety of plant and animal species. Understanding the altitude-based zoning of Kangra can help inform land use planning and management decisions and facilitate the conservation of the region's diverse ecosystems.

3.1.3 The Climate of Kangra

The climate of the Kangra district varies with the altitude. As a result, the high hills have a mild climate, the middle hills are sub-humid and the low hills and valleys have a sub-tropical climate. The average rainfall of this region is about 205 cm. However, in the southern parts, it is 100 cm and goes up to 250 cm in the northern parts. The region receives about 80% precipitation from June to September.

The table below shows the average annual rainfall from 2005 to 2015.

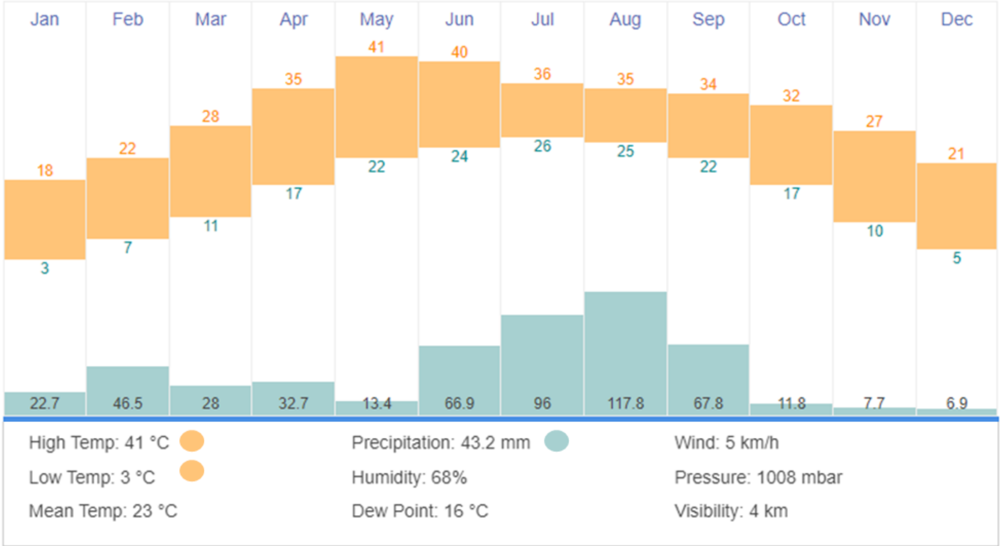


Fig. 2: Annual Rainfall in Kangra and the Himachal Pradesh
Source: https://www.timeanddate.com/weather/@1268083/climate

3.1.4 Forest Resources of Kangra

The forest cover in the Kangra region is spread over 284.18 thousand hectares, more than 49% of the total geographical area. However, only 143.3 thousand hectares occupy one-fourth of the total geographical area as an existing forest resource. The four main types of forest divisions in the Kangra district are Nurpur, Palampur, Dehra, and Dharamsala. In addition to these four, there are two more forest blocks under the Una Forest Division (Ramprasad, Joglekar and Fleischman, 2020). These forests have been further divided into seven broad categories. The state of Himachal Pradesh in India is home to a diverse range of forest types, each with its own unique characteristics and plant species. The dry alpine forests found in the Baijnath region's Bara Bhangal and Chhota Bhangal are characterized by xerophytic vegetation, such as Lonicera, Juniper, Cotoneaster, and Artemesia. The moist chain scrub forests, found above the tree line and below the snow line, are dominated by Viburnum, Lonicera, and Salix. Sub-alpine forests, found at elevations up to 3,500 meters are characterized by Kharsu and Betula utilis trees. The Himalayan moist temperate forests, found in the Kangra region above 1,500 meters in elevation are home to the expensive Cedrus deodara species. The wet temperate forests found in Kangra, Dharamsala, and Palampur are characterized by Kail, Deodar, and Chil trees, and also contain bamboo groves on the western slopes. The sub-tropical pine forests found at the mean sea levels between 1,000 and 2,200 meters in the Dehra, Nurpur, and Kangra areas are dominated by the Himalayan chil trees. Finally, the sub-tropical broad-leaved hill forests found below 1,000 meters in the sub-tropical areas of Kangra, such as Indora, Pragpur, and Dehra are characterized by albizia, Khair, kachnar, tun, bamboo, and beul trees. Overall, the forests of Himachal Pradesh are diverse and support a wide range of plant and animal species.

4 Slate as a Building Material

Slate is a type of metamorphic rock that is finely grated and imitative from sedimentary rock shale, made from clay or volcanic ash through the rigorous process of regional metamorphism. Among the category of metamorphic rocks, it is the best-grained foliated. Moreover, in this case, foliation corresponds to planes in the direction perpendicular to metamorphic compression, not the original sedimentary layering (Lee and Kim, 2021; Bogdanowitsch, Sousa and Siegesmund, 2022).

The most protuberant roofing material used in the Himachal Pradesh is Slate. These come mainly from Thatri, Kareti, Khaniara, Narwana, and Bhagsunath. Nevertheless, this process of mining slates goes back to the 1880s. Earlier, these quarries were handled and controlled by the local contractors with mining rights, but recently the government has taken over these, making this a lot more systematic (Encyclopedia, 2013;Kant and Kumari, 2021).

Fig. 3: Stone Quarry at Khanyara, Kangra
Source: Author

5 Dry Stone Construction in Himachal Pradesh

The Kangra region is well known for its dry-stone construction as slates are abundant here. However, the Kinnaur region also carries out this construction style as the excellent quality of stone is quarried there. This whole process is carried out without the use of any mortar. Stones of different sizes are kept over each other and compacted; after regular intervals, they are used through the stone. One key point to notice here is that the interlocking of stones is done to achieve a more robust bond instead of throwing the smaller stones in the gaps. Mud plastering of interior surfaces is preferred. Structural walls of stone masonry are made for lateral and gravity load, which efficiently distribute the load uniformly in orthogonal directions (Kant and Kumari, 2021).

Fig. 4: A House with Dry Stone Construction
Source: Author

6 Case Studies

This research uses a case study approach to provide detailed descriptions of the cases and their users in the right context. This helps in structuring a systematic analysis resulting in detailed answers to the research questions.

6.1 Case Study 1: The Vernacular House of Kangra- VH1

The residential vernacular house is about 92 years old (built in 1930), belongs to Ram Karan Rana and is located in the Khaniyara village (Fig.5) on the outskirts of district Kangra with adjoining residential buildings made of dry stones. The built up area is 106 sq.m on the ground floor and is used for residing purposes whereas the upper floor is used as a storage area accessed by a stone staircase. The typical rectangular plan of dimensions 12.5m X 8.5m is divided into 4 areas, as a veranda, a storage area and 2 rooms (Fig. 6 and 7).

Fig. 5: Isometric View of the House
Kant and Kumari, 2021

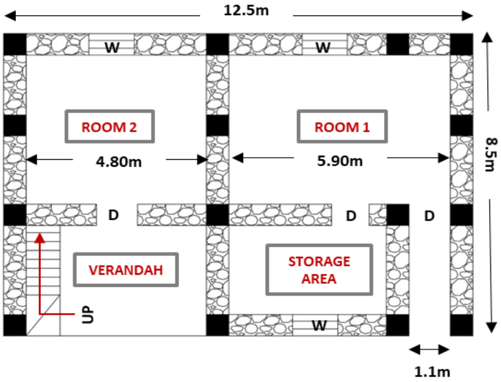


Fig. 6: Ground Floor Plan of the House
Source: Author

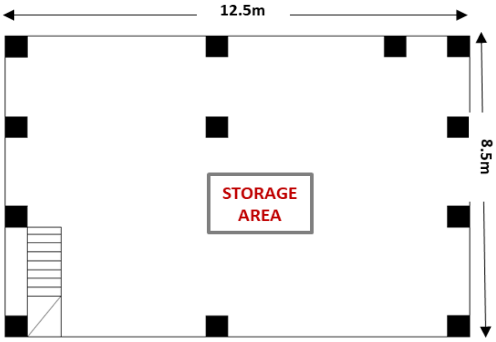


Fig. 7: First Floor Plan of the House
Source: Author

6.1.1 Inferences: Architectural Aspects

6.1.1.1 Siting

These buildings are typically located on hilly or sloping areas. Although there are no shared walls between them and the next buildings, there may be as little as 30 cm or 3 metres between them (typical street width). In almost all cases, the available land is contoured.

As a result, a flat base platform is created using one of the two methods, depending on the slope of the site.

- A dry-stone gravity retaining wall is built across the steeply sloping terrain to produce usable flat land before the dwelling is built.
- Using the cut and fill approach, which allows for a smaller usable space (used for storage) on the bottom level and a bigger usable area on the top level, this construction is possible on a site with a relatively mild slope.

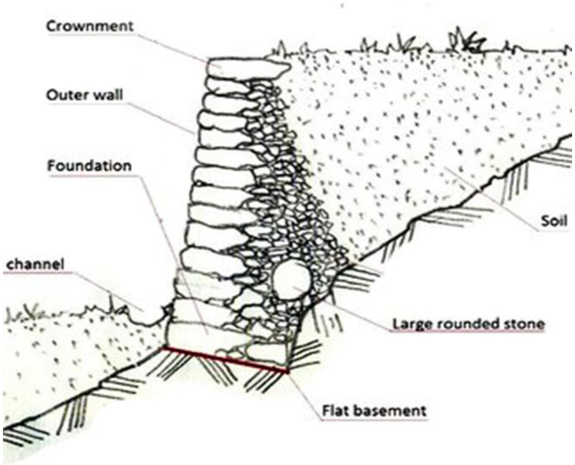


Fig. 8: Dry Stone Gravity wall system
Source: Bragança dos Santos, 2018

Configuration of the Building

The houses often have a front veranda and a rectangular shaped plan. A two-story house is typical. Ventilation is frequently provided through large apertures in the walls. Because a single brick wall is substantially thinner than a dry stone wall, small niches are left in the wall, and bricks are placed there to create spaces inside the wall. Horizontal walls are built using wooden planks or RC slabs within the niche that has been created.

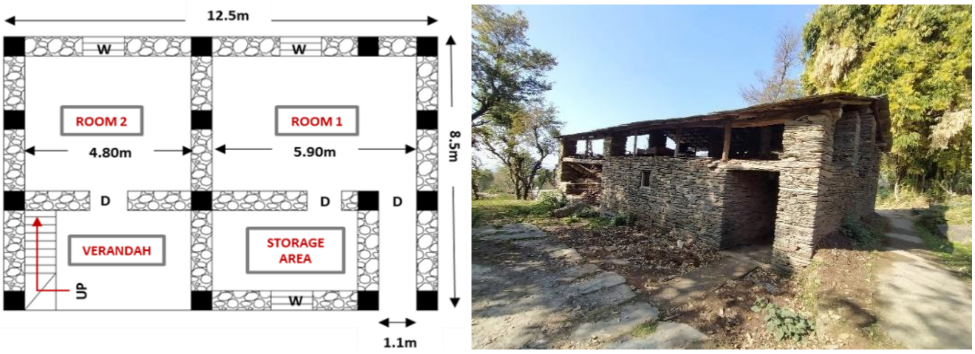


Fig. 9: Typical Rectangular Floor Plan with openings in walls for ventilation
Source: Kant and Kumari, 2021

6.1.1.2 Modifications to the Building

The buildings in question are frequently built in accordance with the original blueprints, with no significant adjustments to older buildings. In some situations, the structure is built with RCC columns, slabs, and stone walls.

Fig. 10: Stone wall with RCC columns, slabs and concrete band
Source: Author

6.1.1.3 Gravity & Lateral Load-Resisting System

Stone masonry walls serve as a vertical load-bearing system. The most frequent roof style is a slanted wooden roof with slate stone. The gravity force is transferred to the 450-600 mm thick walls constructed of undressed slate stones without mortar by the floors and roof. In some circumstances, RC columns support beams with larger spans (Encyclopedia, 2013; Singh and Sharma, 2019; Kant and Kumari, 2021).

In contrast, these supportive RCC columns are non-engineered parts of the structure, and the mason's judgment determines their proportions and reinforcing detailing. The high axial stresses and bearing capacity of the RCC columns are known to masons; hence, they commonly utilise very thin columns (with cross-sections of 200-250 mm). These columns, like the dry stone walls are equally vulnerable to earthquake loads because of their slenderness, lack of reinforcement, and poor joint details.

Fig. 11: 600mm Stone Column (left) and RC Column to support larger span (Right)
Source: Author

Walls consisting of stone masonry make up the system for resisting lateral loads. The same dry-stone walls, which may be up to 600 mm thick and are composed of undressed river stones without cement supply all of the building's lateral load resistance (Singh and Sharma, 2019).

6.1.1.4 Building Dimensions

Standard plan dimensions of these structures are lengths of 8 to 15 meters and widths of 5 to 8 meters. There are two to three levels in the structure. In these structures, the standard story height is 2.5 meters. Walls of the structures often have a density of more than 20%. (i.e., the proportion of the floor area to the total area of walls facing both directions).

6.1.1.5 Roofing System

With rafters, GI sheets, or wood shingles for cladding, roofs are frequently tilted. Stone slates are also utilized for roof cladding, depending on local availability. The lack of cross-bracing and ties on sloping roofs makes them vulnerable to damage during an earthquake. Due to the dry-stone construction of walls, the connection of walls to the roof is often not seen. Some structures have flat RC roofs, which, because of their in-plane stiffness and favorable bearing on the walls, are supposed to slightly enhance a building's seismic behaviour.

6.1.1.6 Foundation

Without any mortar, the foundations are made of hand-packed stones of various shapes and sizes. For loose soil, the foundation depth up to the ground level is 900 mm; for hard strata, it is 200 mm. The foundation typically has the same width as the wall described earlier (i.e., 450 to 600 mm). The plinth is approximately 300 mm above the ground level. Sometimes backfill is supported by dry stone retaining walls, or a flat platform for the construction is made.

6.1.2 Inferences: Life Cycle Energy Analysis Aspect

In LCEA, the energy embodied in a structure and the energy used to operate it are calculated throughout the anticipated lifespan of the structure (LCEA)(Fay, Treloar and Iyer-Raniga, 2000).

6.1.2.1 Embodied Energy Analysis Method

The energy required to collect, transport, and refine raw materials, manufacture component parts, and assemble the product is included in the energy contained in the product (Fay, Treloar and Iyer-Raniga, 2000)

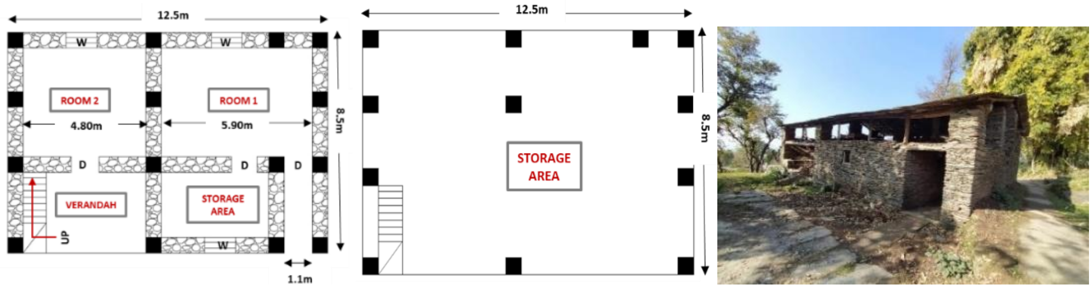


Fig. 12: (1) Ground Floor Plan, (2) First Floor Plan (Source: Author) and Perspective View (3) Source: Kant and Kumari, 2021

Table 1: Bill of Quantities of Vernacular House
Source: Author

Building Components	Building Material	Unit	Quantity
Foundation	Slate Stone	m^3	28.30
	Mud	m^3	9.42
Walls	Slate Stone	m^3	78.50
Floor	Slate Stone	m^3	6.03
Roof	Slate Stone	m^3	8.10
Wood Work	Timber	m^3	10.21

Table 2: Embodied Energy of Construction Materials
Source: Reddy and Jagadish, 2003

S. No	Item	Embodied Energy (GJ/m^3)	
		Indian Data(BMTPC,1995; Reddy & Jagadish,2003; Shukla et al.,2009)	Inventory of carbon and energy (ICE) (Hammond & Jones, 2011)
1	Cement	5.9–7.8 (avg. 6.85)	4.5
2	Fine aggregate/ Sand	0.1–0.2 (avg. 0.15)	0.083
3	Coarse aggregate/gravel	0.4	0.083
4	Reinforcement/ steel rebar	28.2–42 (avg. 35.1)	17.4
5	Bricks	1.8	3
6	Painting (lime)	5.65	5.3
7	Woodworks	7.2	10
8	Copper wire	110	36
9	PVC conduit	104–108 (avg. 106)	67.5
10	Slate Stone	_	_
11	Mud	_	_

Table 3: Embodied Energy Calculation for House
Source: Author

Building Components	Building Material	Unit	Quantity	Energy Intensity(GJ/unit)	Embodied Energy (GJ)
Foundation	Slate Stone	m^3	28.30	_	_
	Mud	m^3	9.42	_	_
Walls	Slate Stone	m^3	78.50	_	_
Floor	Slate Stone	m^3	6.03	_	_
Roof	Slate Stone	m^3	8.10	_	_
Wood Work	Timber	m^3	10.21	7.2	73.4994
Total					73.4994

In India, natural construction stones have been used to construct several structures. The hard natural stone is often chopped into workable sizes to produce slate blocks. The sizing activities of slate stone is done by manual labor. Detonators are occasionally used to break apart large, extremely hard stones into smaller pieces for easier handling during manual processing. Consequently, very little thermal energy is used to produce desired size stones. (Reddy and Jagadish, 2003)

6.1.2.2 Operational Energy Analysis Method

The study of operational energy is based on the consumption of electricity for the residence. The value of operational energy of the residence calculated in the design builder is 12.63 kWh/m^2 (0.045468 GJ).

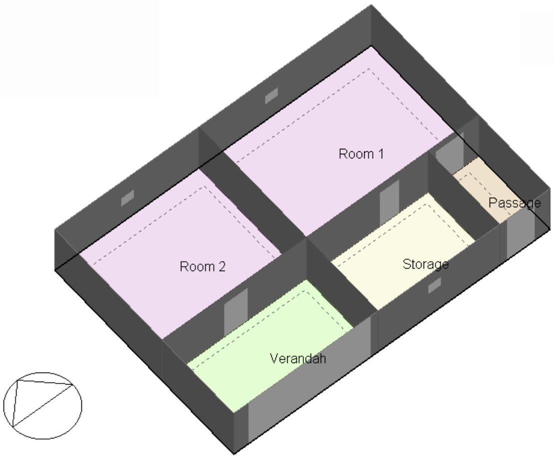


Fig. 13: Isometric Plan of Vernacular House from Design Builder V4.0
Source: Author

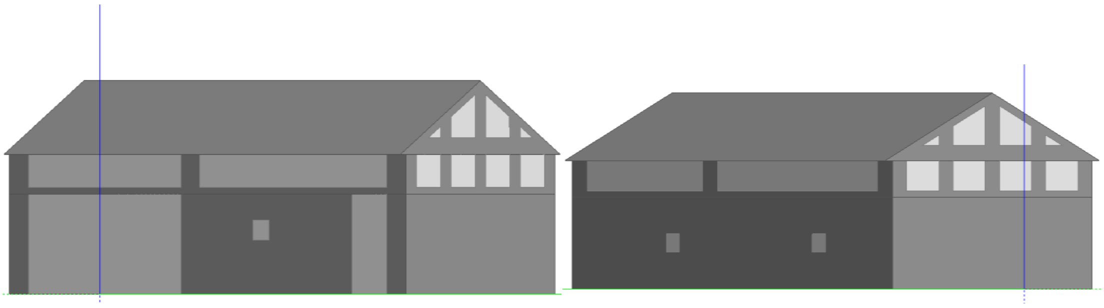


Fig. 14: Front (Left) and Rear (Rear) Elevation of Building from Design Builder V4.0
Source: Author

6.1.2.3 Life cycle Energy Analysis of Vernacular House

Life-cycle energy (LCE) is a measure of the energy required to operate a building, as well as the initial and ongoing embodied energy throughout the course of its anticipated lifetime. To calculate the LCE, the following equation is used: LCE = Initial Embodied Energy of Building + (Annual Recurrent Embodied Energy + Annual Operational Energy) x Building lifespan. According to this equation, the total LCE of the vernacular house is 73.535 GJ. This includes the initial embodied energy of the building, as well as the annual recurrent embodied energy and annual operational energy required to maintain and operate the building over its lifespan. The LCE is an important consideration in the design and construction of a building, as it helps to identify opportunities for reducing energy consumption and improving overall sustainability.

6.2 Case Study 2: Contemporary House

The contemporary residential house is about seven years old (built in 2015), belongs to Dile Ram Thakur and is located in the Khaniyara village (Fig. 15) on the outskirts of district Kangra. The adjoining residential buildings are also made of modern materials. The built up area is 106 sq.m on the ground floor and are used for residential purposes whereas the upper floor is used as a storage area accessed by a concrete staircase. The typical rectangular plan is 12.5m X 8.5m and is divided into six areas, as a veranda, and 5 rooms.

Fig. 15: Front View of Contemporary House
Source: Author

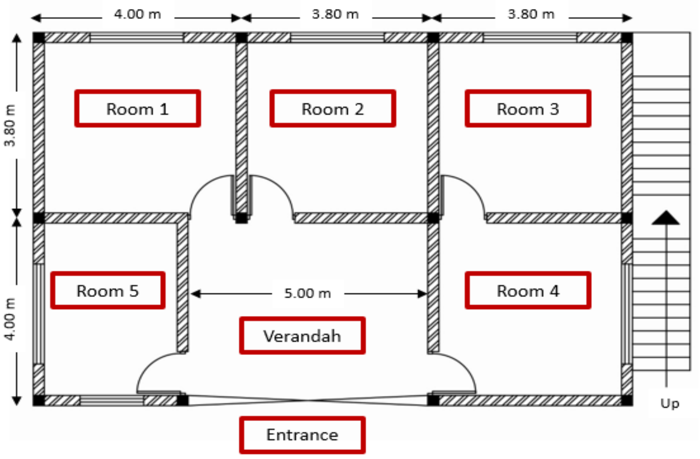


Fig. 16: Ground Floor Plan
Source: Author

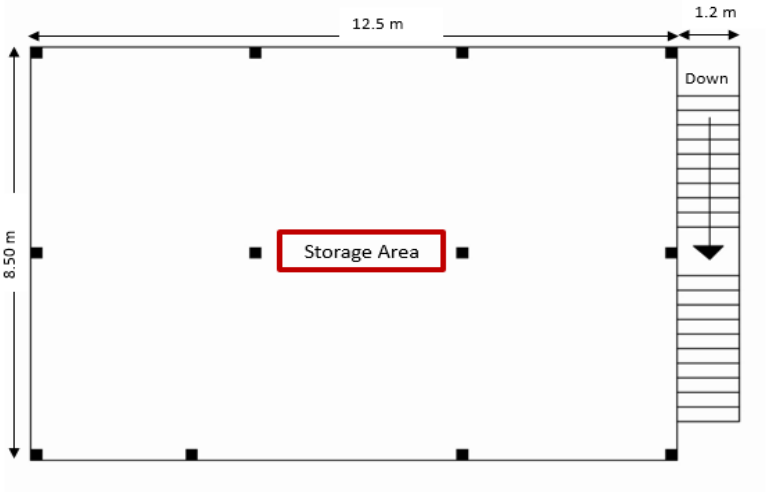


Fig. 17: First Floor Plan
Source: Author

6.2.1 Inferences: Architectural Aspects

The contemporary house boasts a number of impressive architectural features, starting with its foundation. The step foundation is laid in a trench at a depth of 1.5m, providing a strong and stable base for the rest of the building. The concrete plinth beam, measuring 0.3m in height, serves as a support for the walls and helps to distribute the load of the building. The flooring is made of 12mm ceramic tiles, which are durable and easy to maintain. The RCC sill, located at a height of 0.9m, serves as a base for the placement of windows. The windows and doors of the house have timber frames and there is a collapsible steel gate at the entrance for added security. An RCC lintel slab is placed over the doors and windows, providing structural support and helping to distribute the load of the building above it. The ceiling of the house is finished with a ceiling slab made of reinforcement bars and concrete, topped with POP (plaster of Paris) from the inside. This creates a smooth and seamless finish and adds to the overall aesthetic of the house. Overall, these various architectural features work together to create a strong, stable, and visually appealing contemporary house.

6.2.2 Inferences: Life Cycle Energy Analysis Aspect

In LCEA, the energy embodied in a structure and the energy used to operate it are calculated throughout the anticipated lifespan of the structure (LCEA)(Fay, Treloar and Iyer-Raniga, 2000).

6.2.2.1 Embodied Energy Analysis Method

The energy required to collect, transport and refine the raw materials, manufacture of component parts and assembly of the product is included in the energy contained in the product (Fay, Treloar and Iyer-Raniga, 2000)

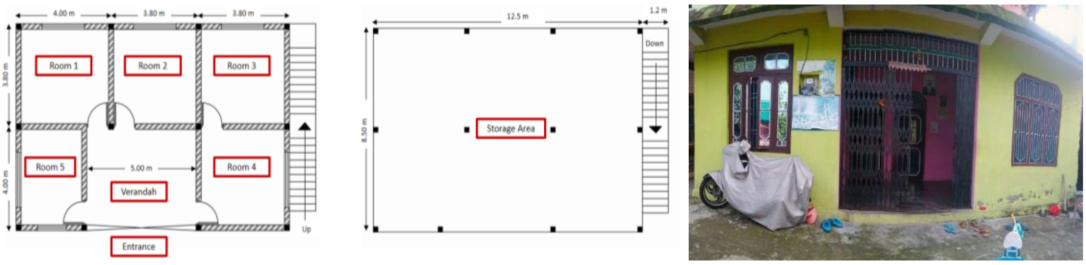


Fig. 18: (1) Ground Floor Plan, (2) First Floor Plan and (3) Front View of House
Source: Author

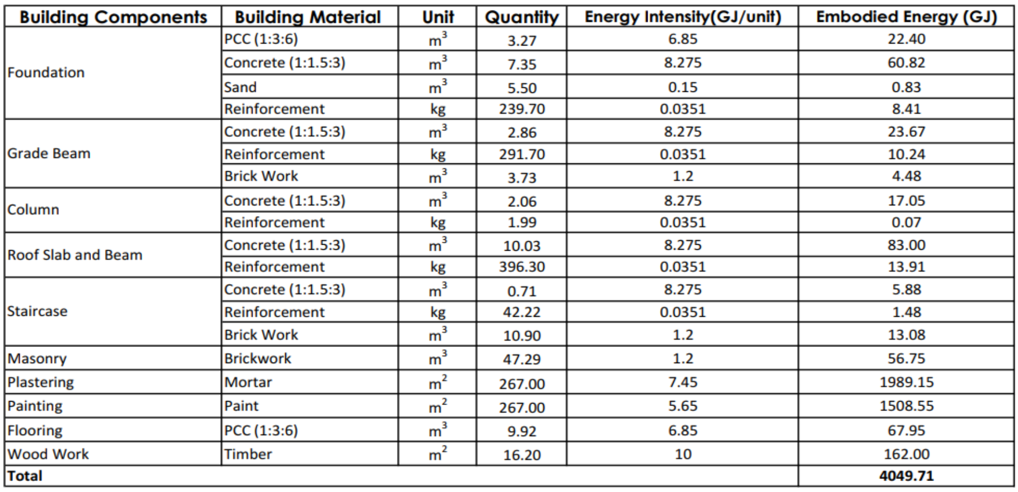
Table 4: Bills of Quantities of the Contemporary House
Source: Author

Building Components	Building Material	Unit	Quantity
Foundation	PCC (1:3:6)	m^3	3.27
	Concrete (1:1.5:3)	m^3	7.35
	Sand	m^3	5.50
	Reinforcement	kg	239.70
Grade Beam	Concrete (1:1.5:3)	m^3	2.86
	Reinforcement	kg	291.70
	Brick Work	m^3	3.73
Column	Concrete (1:1.5:3)	m^3	2.06
	Reinforcement	kg	1.99
Roof Slab and Beam	Concrete (1:1.5:3)	m^3	10.03
	Reinforcement	kg	396.30
Staircase	Concrete (1:1.5:3)	m^3	0.71
	Reinforcement	kg	42.22
	Brick Work	m^3	10.90
Masonry	Brickwork	m^3	47.29
Plastering	Mortar	m^2	267.00
Painting	Paint	m^2	267.00
Flooring	PCC (1:3:6)	m^3	9.92
Wood Work	Timber	m^2	16.20

Table 5: Embodied Energy of Construction Materials
Source: Reddy and Jagadish, 2003

S. No	Item	Embodied Energy (GJ/m^3)	
		Indian Data(BMTPC,1995; Reddy & Jagadish,2003; Shukla et al.,2009)	Inventory of carbon and energy (ICE) (Hammond & Jones, 2011)
1	Cement	5.9–7.8 (avg. 6.85)	4.5
2	Fine aggregate/ Sand	0.1–0.2 (avg. 0.15)	0.083
3	Coarse aggregate/gravel	0.4	0.083
4	Reinforcement/ steel rebar	28.2–42 (avg. 35.1)	17.4
5	Bricks	1.8	3
6	Painting (lime)	5.65	5.3
7	Woodworks	7.2	10
8	Copper wire	110	36
9	PVC conduit	104–108 (avg. 106)	67.5
10	Slate Stone	_	_
11	Mud	_	_

Table 6: Embodied Energy Calculation for House
Source: Author



Building Components	Building Material	Unit	Quantity	Energy Intensity(GJ/unit)	Embodied Energy (GJ)
Foundation	PCC (1:3:6)	m^3	3.27	6.85	22.40
	Concrete (1:1.5:3)	m^3	7.35	8.275	60.82
	Sand	m^3	5.50	0.15	0.83
	Reinforcement	kg	239.70	0.0351	8.41
Grade Beam	Concrete (1:1.5:3)	m^3	2.86	8.275	23.67
	Reinforcement	kg	291.70	0.0351	10.24
	Brick Work	m^3	3.73	1.2	4.48
Column	Concrete (1:1.5:3)	m^3	2.06	8.275	17.05
	Reinforcement	kg	1.99	0.0351	0.07
Roof Slab and Beam	Concrete (1:1.5:3)	m^3	10.03	8.275	83.00
	Reinforcement	kg	396.30	0.0351	13.91
Staircase	Concrete (1:1.5:3)	m^3	0.71	8.275	5.88
	Reinforcement	kg	42.22	0.0351	1.48
	Brick Work	m^3	10.90	1.2	13.08
Masonry	Brickwork	m^3	47.29	1.2	56.75
Plastering	Mortar	m^2	267.00	7.45	1989.15
Painting	Paint	m^2	267.00	5.65	1508.55
Flooring	PCC (1:3:6)	m^3	9.92	6.85	67.95
Wood Work	Timber	m^2	16.20	10	162.00
Total					**4049.71**

6.2.2.2 Operational Energy Analysis Method

The study of the operational energy is based upon the consumption of electricity for the residence. The value of operational energy is calculated by the Design Builder is 45.29 kWh/m^2 (0.16 GJ).

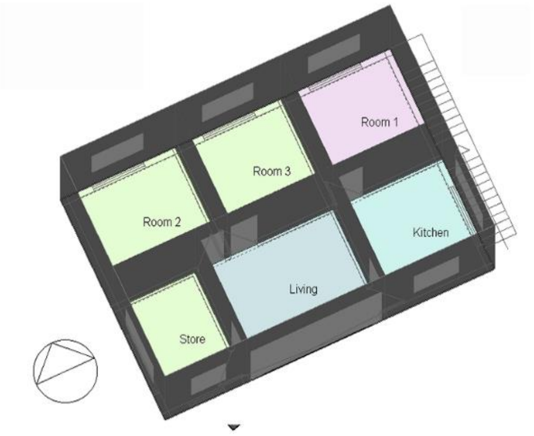


Fig. 19: Isometric Plan of Vernacular House from Design Builder V4.0
Source: Author

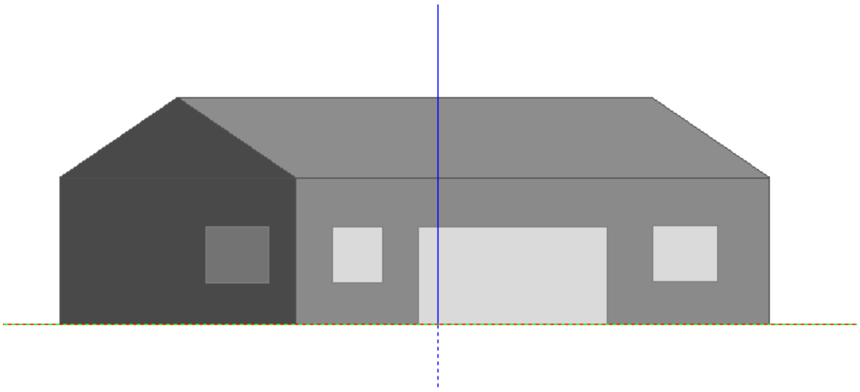


Fig. 20: Front Elevation of Building from Design Builder V4.0
Source: Author

6.2.2.3 LCEA of Contemporary House

The building's operating energy as well as the initial and ongoing embodied energy throughout the course of its anticipated lifetime comprises life-cycle energy. To calculate the LCE, the following equation is used:

LCE = Initial Embodied Energy of Building **+** **(**Annual Recurrent Embodied Energy
+ Annual Operational Energy**)** x Building lifespan

Thus, the total Life Cycle Energy of the contemporary house is *4049.87 GJ.*

The contemporary house has a relatively high LCE compared to other types of buildings, which may be due to its size, materials, and other factors. However, there are various strategies that can be implemented to reduce the LCE of a building, such as using energy-efficient appliances and systems, and incorporating renewable energy sources.

7 Comparative Analysis (LCEA Aspect)

Comparison of the results of the vernacular house to that of the contemporary house is presented in the Table 7. The floor area of a house is limited to 107 m2. Vernacular houses in the Kangra region have significantly less embodied energy than the modern houses in the same area. The embodied energy in both cases varies from 73 to 4050 GJ. The vast difference in embodied energy is due to the materials used. The material palette for the vernacular house is slate stone, mud and timber and as slate (natural occurring material) is available in the region, very little thermal energy is used to produce the desired size stones. This leads to little embodied energy. On the other hand, the material palette for the contemporary house is cement, fine aggregate/sand, brick, coarse aggregate, reinforcement bars, lime, timber, PVC, and copper wire. All these materials used in the construction of the contemporary houses are of high thermal energy consumption. The operational energy of the building per year ranges from 0.04 to 0.16 GJ. The difference of 0.12 GJ in the operational energy of houses with the same area is because of the materials used. The combination of mud and slate in the vernacular house creates a natural insulation thus keeping the internal area of houses cool in the summer and warm in the winters.

In the contemporary house with modern materials, mechanical ventilation is required to achieve and maintain the ambient temperature which is achieved naturally in case of the vernacular house due to different thermal properties of vernacular and contemporary materials.

Table 7: Comparison of Energy use for the Vernacular and the Contemporary houses
Source: Author

Type of Construction	Location	Floor Area	Type of House	Embodied Energy (GJ)	Operational Energy (GJ)	Life Cycle Energy (GJ)
Vernacular	Kangra, HP	107 m^2	Residential	73.50	0.045	73.54
Contemporary	Kangra, HP	107 m^2	Residential	4049.71	0.16	4049.87

8 Discussion and the Conclusion

This study concludes that the dry-stone construction is an outcome of all the indigenous techniques of the mountains. Although it is greatly affected by the availability of materials, there have been drastic changes over time.

A few key features of this construction style are thick walls and the placement of slates on the roof without any braces. However, in recent times, people have started opting for newer construction techniques for many reasons, like providing safety from seismic activity, covering less space on the ground, and having more lay-people available for building them. With such continuous changes in lifestyles, people are opting for new styles and materials, resulting in the changes that this construction style might not survive for long.

Even though it is clear how the vernacular construction style is comparatively better in terms of budget, embodied energy and operational energy and is a more sustainable architectural practice with cultural linkages, people are more inclined towards modern constructions. This is inevitable. Thus, with this study, attempts are made to document and investigate the traditional techniques, which may soon disappear.

However, there is scope to evolve these traditional construction techniques with modem materials as an alternative to be employed in the region as a sustainable construction technique. Further research can be carried out for the various safety features in these alternate techniques while testing them for sustainability.

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