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Comparison of energy requirements for space heating in traditional and modern housing in the hills

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1. Abstract

The project aims at comparing the energy requirements for maintaining a comfortable temperature inside houses built using different construction materials. The vernacular construction techniques used in Himachal Pradesh were studied to find the traditional construction materials used. These materials were compared with modern brick and cement based on the energy consumed for heating a house. The test case was designed to be a small room, and the energy requirements were calculated for different wall materials. Furthermore, the advantages/disadvantages of the traditional and modern construction materials were studied. The various factors that are causing a shift from traditional to modern settlements in the hills have also been discussed.

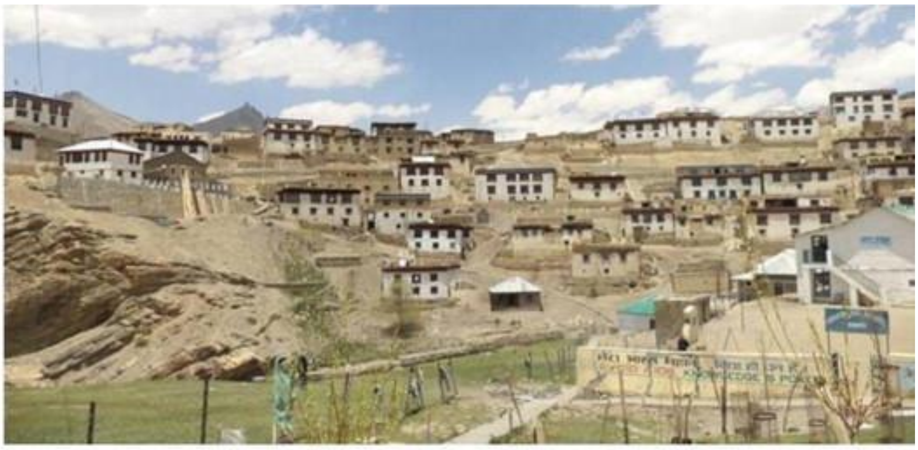
2. Background

Several factors (difficult topography, steep gradient, harsh climatic conditions, rich flora and vulnerability to natural hazards) make planning and designing buildings in the hills an extremely challenging task (Pushplata and Kumar, 2014) [1]. Numerous vernacular techniques have been developed over the centuries to satisfy the necessities of native folks within the Himalayan region of north India [1]. These vernacular practises have been developed for the folks, by the folks, and without any technical/professional coaching [1]. They make use of locally available and eco-friendly construction materials [1]. These conventional practises have been developed over generations with the aim of providing protection from the adverse climate and natural hazards [1]. They supply best solutions for practical utility and liveability [1]. Ritual beliefs, customs, culture, social system, professions, and economic standing are usually mirrored in vernacular structures through their type, size, scale, materials, colours and facades [1].

2.1 Characteristics of Traditional Settlements

1. Conventional hill settlements in India are typically developed on comparatively flatter grounds than the surrounding areas. This is because flat grounds are believed to be more stable and less vulnerable to landslides [1].
2. Houses are located on the south-facing slopes to permit sufficient sunlight throughout the day and protection from freezing northern breeze. This helps in achieving comfortable living conditions with nominal energy consumption [1].

3. Proximity to surface water supply is a vital criterion for choosing settlement site in the mountainous regions. This is because of low ground water table, specifically in new ridges and main land area [1].
4. Buildings are typically constructed along the contours to decrease site development work (cutting and filling of slopes) [1].
5. Conventional buildings in the mountainous regions are usually rectangular in shape. Locally available materials are used for construction because they provide good climatic response. The floor to ceiling height is typically between eight and nine feet, which is less compared to new building standards used in contemporary construction. The small symmetrical openings in the walls permit daylight and ventilation. The buildings are observed to have low lighting levels indoors, but a better response to earthquakes in comparison to most contemporary buildings constructed using modern materials [1].



(a) Settlement in Upper Himalayan Region

(b) Settlement in Middle Himalayan Region

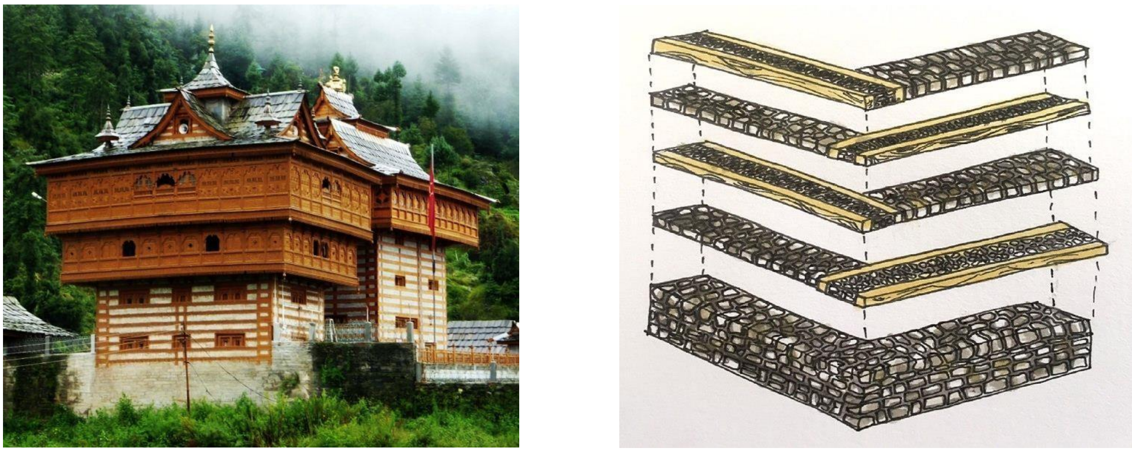
Figure 1: Settlements in Himachal Pradesh [1]

2.2 Traditional Construction Techniques

Non-engineered indigenous construction techniques utilise locally available materials [1]. They have good climatic response, very good response against earthquakes and maintain indoor comfort [1]. Traditional construction techniques adopted in the Himalayan region are as follows:

2.2.1 Kath-Kuni Architecture

Kath-Kuni construction technique is prevalent in the isolated hills of norther India [2]. It is found in Kullu, Mandi, parts of Shimla and Solan districts [3]. It has been orally transmitted over the generations [2]. The main construction materials used are stone, wood and slate [2]. Specifically, long and well-dressed flat stones are used in construction [3]. The walls are constructed by laying timber logs and stones in alternate with each other, without using any mortar [3]. A pair of wooden beams runs along the entire length of wall, and another pair of wooden beams in alternate direction placed perpendicular to each other [3]. The space between the wooden beams is then filled with dry stones [3]. Absence of vertical members is another considerable feature of this construction technique [3]. The thickness of walls ranges from 400 nm to 1000 nm in some cases, which provides insulation from both cold and hot climate (Yogita and Sandeep, 2019) [3].



(a) (b)

Figure 2: (a) Bhimkali temple, built in Kath-Kuni style of architecture [2] (b) Kath-Kuni architecture [2]

2.2.2 Dhajji-Diwari Construction

Dhajji-Diwari construction can be seen in the hills of Shimla, Kangra and Kashmir [3]. It is a combination of wood, stone and mud [3]. The main feature of this construction is a braced timber framing, full of brick or stone layers with mud or lime mortar [3]. The vertical and horizontal members with diagonal bracing are joined with the help of steel bolts and iron hook [3]. The triangular spaces are filled with stone or bricks with the help of binding material, and plastered from both sides to make the whole wall act as one large piece [3]. Thickness of wooden members varies from 450 mm to 600 mm [3]. The time lag of 8-9 hours allows the house to be cooler in summers and warmer in winters [3].

Figure 3: Dhajji-Diwari Construction [3]

2.2.3 Dry Stone Construction

Dry stone construction can be seen commonly in Kangra and Kinnaur [3]. Different sizes of stones are often used in construction [3]. No mortar or wood is used in this technique, and the stones solely provide strength and stability [3]. It is similar to the kath-kuni construction technique, with the absence of wooden beams [3]. The inner and outer stone walls have same thickness of about 600 mm each [3].

2.2.4 Mud Construction

The main construction materials are mud and wood. The walls are made primarily of mud, and the floor slabs are laid using wooden/timber beams [3]. There are two types of mud construction: rammed earth construction and sun-dried brick construction [3]. The walls are 600 mm to 900 mm thick, made with sun-dried bricks and plastered with mud [3]. To prevent erosion due to rains, the walls are raised over stones up to 600 mm and 900 mm from the plinth, and are plastered [3].

Figure 4: Dry stone construction [4]

Figure 5: Mud Construction [5]

2.2.5 Overview of various Techniques

Construction Technique	Materials Used	Area	Characteristics
Kath-Kuni	Stone and timber	Shimla, Kullu, Kinnaur, Garhwal and Kumaun regions	Good seismic and thermal response, good aesthetic value
Dhajji-Dewari	Timber, stone and mud	Kashmir and Chamba	Good seismic and thermal response
Stone houses	Natural stone	Kashmir, Jammu, Himachal, Uttarakhand	Good thermal response
Wooden houses	Timber	Kashmir, Himachal, Uttarakhand	Good seismic and thermal response
Mud houses	Mud	Leh, Ladkah, Lahaul Spiti	Good thermal and climatic response
Sun dried bricks	Earth	Outer Himalayan regions	Good thermal and climatic response

Table 1 : Wall construction techniques used in different hilly regions [1]

3. Methodology and Calculations

The construction technique, construction materials, size of the house, internal layout, number of occupants, materials used inside the house, doors and windows are some of the factors that influence the heating/cooling requirements of a house at a given location. The objective of this project is to compare the heating requirements of traditional and modern houses, primarily based on the different construction materials used. This has been done by calculating the energy consumption for different construction materials. To eliminate the variation caused by factors other than the construction materials, we have designed a test case.

The test case is empty house consisting of a single room with dimensions: 15 ft (length), 12 ft (breadth) and 10 ft (height). There is one door with dimensions: 7 ft (length) and 3 ft (breadth). There are 3 windows covering a total area of 50 square feet. The 3D model of the room (Figure 6) has been designed using HeatCAD 2011 software. The floor has been constructed using 8'' sand gravel and aggregate. The windows are made of single pane glass, and the door is made of 1'' wood. In a practical scenario, these materials and specifications may not be suitable for all types of houses; but these have been kept constant so that nothing but the walls affect heating requirements of the house. Furthermore, the walls are assumed to be made of only one material, not a combination of materials as in real life. This has been done so that the construction materials can be compared with each other easily.

The traditional materials used are wood, mud and stone. The modern materials used are brick and concrete. The standard thickness (without mortar or plaster) of a common brick external wall is 9 inches and RCC roof is 4.5 inches [6]. The thickness of a wood external wall is just over 5 inches [7]. We have taken nearby wall thickness for the calculations. The wall thickness of all materials (except timber) has been kept nearly the same as a brick wall because: they don't have any standard thickness, and to remove the influence of wall thickness from energy consumption calculations.

The calculations have been performed using an online calculator [8]. The calculator requires inputs: component (wall, roof, floor, door, window), dimensions and R-Value. The R-Value is characteristic of a material; it is the building industry term for thermal resistance per unit area [9]. It is a measure of how well a barrier, such as layer of insulation resists the conductive flow of heat [9]. Table 2 contains R-Values of the different materials used in our analysis. Another input is ACPH – air changes per hour. ACPH is a measure of the air volume added to, or removed from a space (a room or house) divided by the volume of space [10]. It can be understood as a measure of ventilation in the room. It will vary in the scenario of analysing a material in different weather conditions. Windy conditions will mean more ACPH whereas hot dry day will mean low ACPH. In our analysis, since we have to compare only the wall materials, the ACPH has been kept as any constant value. We have done the calculations for inside temperature = 25 °C and varying outside temperatures (-5°C, 0°C, 5°C, 10°C, 15°C, 20°C). The calculator outputs energy required for heating the house for the given temperature difference, and the given construction materials. We have used these results to compare the chosen construction materials.

Material	**Thickness**	**R-Value**
Common Brick	1’’	0.2
Concrete Block	4’’	0.80
Concrete Block	8’’	1.11
Granite	1’’	0.05
Mortar	1’’	0.2
Sand gravel aggregate	8’’	1.11
Sandstone / Limestone	1’’	0.08
Single Pane Glass	-	0.88
Soil	1’’	0.25
Stone	1’’	0.08
Wood	1’’	1.56
Wood	2’’	2.33

Table 2: R-values of materials

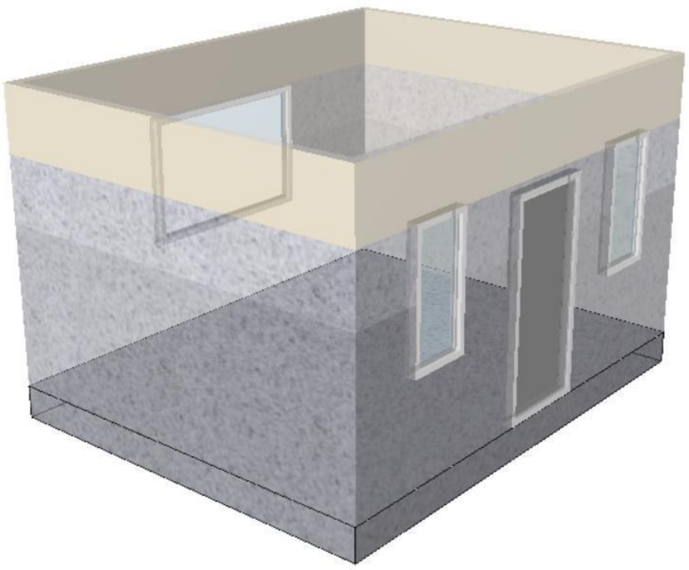


Figure 6: 3-D model of test house

Length	15 ft
Width	12 ft
Height	10 ft
Area	180 sq. ft
Volume	1800 cu. ft
Windows	50 sq. ft
Door	21 sq. ft

Table 3 (a): Room dimensions

Air Changes Per Hour (ACPH)	4
Inside Temperature	25 °C / 77 °F

Table 3 (b): Room Atmosphere

Item	**Material**	**Area (sq. ft)**	**R-factor**	**BTU/Hr/Degrees F**
Windows	Single Pane Glass	50	0.88	56.8181
Doors	1’’ Wood	21	1.56	13.4615
Floor	8’’ Sand and gravel aggregate	180	1.11	162.1621

Table 4: Heat loss calculations for room components

Item	**Material**	**Area (sq. ft)**	**R-factor**	**BTU/Hr/Degrees F**
Net Walls	6’’ Wood	540	6.99	77.2532
Roof	6 ‘’ Wood	180	6.99	25.7510

Table 5 (a): Heat loss calculations for timber house

Outside Temperature °C / °F	**Energy Watts per hour**

-5 / 23	7474.0015
0 / 32	6228.3346
5 / 41	4982.6677
10 / 50	3737.0007
15 / 59	2491.3338
20 / 68	1245.6669

Table 5 (b): Energy consumption for timber house

Item	**Material**	**Area (sq. ft)**	**R-factor**	**BTU/Hr/Degrees F**
Net Walls	8’’ Stone	540	0.64	843.75
Roof	5’’ Stone	180	0.401	450

Table 6 (a): Heat loss calculations for stone house

Outside Temperature °C / °F	**Energy Watts per hour**
-5 / 23	26319.3322
0 / 32	21932.7768
5 / 41	17546.2215
10 / 50	13159.6661
15 / 59	8773.1107
20 / 68	4386.5553

Table 6 (b): Energy consumption for stone house

Item	**Material**	**Area (sq. ft)**	**R-factor**	**BTU/Hr/Degrees F**
Net Walls	10’’ Soil	540	2.5	216
Roof	10’’ Soil	180	2.5	72

Table 7 (a): Heat loss calculations for mud house

Outside Temperature °C / °F	**Energy Watts per hour**
-5 / 23	10401.8351
0 / 32	8668.1959
5 / 41	6934.5567

10 / 50	5200.9175
15 / 59	3467.2783
20 / 68	1733.6391

Table 7 (b): Energy Consumption for mud house

Item	Material	Area (sq. ft)	R-factor	BTU/Hr/Degrees F
Net Walls	8’’ Concrete Blocks + 2’’ mortar	540	1.11 + 0.4 = 1.51	357.6158
Roof	4’’ Concrete Blocks + 2’’ mortar	180	0.80 + 0.4 = 1.2	150

Table 8 (a): Heat loss calculations for modern house – common brick

Outside Temperature °C / °F	Energy Watts per hour
-5 / 23	13877.5849
0 / 32	11564.6541
5 / 41	9251.7233
10 / 50	6938.7924
15 / 59	4625.8616
20 / 68	2312.9308

Table 8 (b): Energy Consumption for modern house – common brick

Item	Material	Area (sq. ft)	R-factor	BTU/Hr/Degrees F
Net Walls	8’’ Common Brick + 2’’ mortar	540	1.6 + 0.4 = 2	270
Roof	4’’ Common Brick + 2’’ mortar	180	0.8 + 0.4 = 1.2	150

Table 9 (a): Heat loss calculations for modern house – concrete

Outside Temperature °C / °F	Energy Watts per hour
-5 / 23	12490.9324
0 / 32	10409.1104
5 / 41	8327.2883
10 / 50	6245.4662
15 / 59	4163.6441
20 / 68	2081.8220

Table 9 (b): Energy Consumption for modern house – concrete

House	Energy Watts per hour
Timber house	6228.3346
Mud house	8668.1959
Modern house – common brick	10409.1104
Modern house – concrete	11564.6541
Stone house	21932.7768

Table 10: Energy consumption for all houses at outside temperature 0° Celsius

4. Result and Discussion

4.1 Comparison of traditional and modern construction materials

The result section contains the energy calculations for traditional and modern construction materials. Table 10 shows the energy consumption for all construction materials at an outside temperature of 0° Celsius. It can be seen that the timber house requires the least energy, followed by the mud house. The stone house has maximum energy consumption, almost double to that of the modern houses made of brick and concrete.

The wood house requires the least energy for heating because wood is a natural insulator [11]. It contains tiny air pockets at a cellular level [11]. Wood has a low coefficient of thermal conductivity and high specific heat [12]. High specific heat means that 1 kilogram of wood requires a high amount of energy to decrease/increase its temperature by 1 unit [12]. Stone and concrete require almost half of the heat energy required by wood, and steel requires only one-third [12]. Timber is hygroscopic in nature, which means that it can exchange moisture with the environment [11]. Therefore, it can act as a buffer during short-term changes in temperature and humidity [11].

Wood houses are attractive and don't need special decorative finishes. Moreover, they are quick and relatively inexpensive to build. However, wood houses are vulnerable to air leaks [11]. Air-dried wood can still contain 15-20% moisture when it is used in house construction [11]. But over the years, it can dry and shrink to create air gaps [11]. These gaps cause air leakage, and eventually increase the energy consumption for heating/cooling [11]. Timber is a natural material, and it is vulnerable to various biotic and abiotic forces: termites, woodworms, wood ants, water, fire, sun, etc. [12]. Sound travels more easily through wood walls and there are issues with shower units like leakage of water into the main frame.

The mud houses also require less energy for heating because mud walls are able to absorb the sun's heat during the day, and slowly radiate that heat back into the house during the night [13]. The walls are able to release all the stored heat during the span of the night [13]. The cycle continues during the day when the walls again absorb heat release freshness into the house [13]. Mud houses are easy and inexpensive to build [14]. However, they are vulnerable to catching fungus [14]. They can be easily attacked by rodents, termites and burglars [14]. They can be eroded easily by water and have low tensile strength [14]. Also, mud houses have a foul odour when they are newly built [14]. It is not easy to build framed doors and windows, because the grip between earth and wood is weak [14]. Mud houses are not fire proof, and they require regular upkeep [14].

Modern houses made of brick/concrete require more energy consumption for heating because brick and concrete are not natural insulators. However, they have many advantages over conventional materials. Masonry materials (stone, brick and concrete) are non-combustible, and they are highly resistant to rotting, pests and harsh weather conditions [15]. They are more durable, have longer lifespans and require little maintenance [15]. Construction of brick houses does no requires highly skilled labour because the size of bricks is uniform [15]. Bricks offer more advantages like low weight, less cost than concrete, easy transportation and handling [15]. Walls made of bricks are thin, and the bricks can be sticked together using various types of mortar based on the construction requirements [15]. Openings for doors and windows can be built easily and with lower cost because of thinner joints [15]. However, brick houses are vulnerable to earthquakes because of low resistance to loads [15]. Also, they have less strength and durability as compared to stone/concrete walls [15].

Concrete is economical and widely available, and concrete units can be manufactured to fulfil specific project requirements [15]. Coating and painting are not required to protect concrete walls from harsh weather [15]. However, transportation and handling concrete blocks is difficult because of their heavy weight [15]. Both concrete and brick have low R values. Therefore, the primary source of insulation is thickness of the walls.

Stone houses require high energy consumption for heating because stone does not trap heat effectively. Stones decrease the floor space, because they are thick [15]. Stone walls have low strength, and are vulnerable to earthquakes [15]. Construction of stone houses is tedious and difficult because the house cannot be altered, repaired or relocated easily [15]. Also, the construction and installation must be done carefully for the safety of the occupants [15]. Hence, highly skilled labour is required [15].

4.2 Causes of increasing modern settlements in the hills

Several years ago, it was a common practise for the village people to build their houses themselves [16]. This was much before the roads and cement-and-brick buildings found their way to the remote villages [16]. These structures were able to endure the harsh weathers for hundreds of years [16]. The structures were built using locally available materials (wood, mud and stone) and basic tools (tools to dig ground, chisel rocks, and shape wood) [16]. Even the huge temples were constructed using the same techniques, which had been developed and evolved over generations [16]. These conventionally built structures were eco-friendly, comfortable, strong, earthquake resistant, had low energy consumption as added advantage, and they required only locally available materials to withstand the harsh climate of the Himalayas [16].

Modernisation made even the remotest villages of Himachal Pradesh accessible to roads and cement-and-brick buildings [16]. The villages have lost much of their indigenous character, and this continues to happen [16]. There are many reasons behind this. The locals have begun to find kath-kuni houses uncomfortable: they have less space due to thick walls, and it is difficult for older people to climb up the steep stairs [16]. Also, kath-kuni houses are catalyst to the flames in an event of fire break [16]. Traditional resources: stone and timber are difficult to find; there are rules and regulations for cutting trees and quarrying of stone [16]. The local people find modern RCC structures much better and cleaner [16]. Government buildings are also RCC structures, which sets a bar of what is best and people get inspired to make similar houses [16]. The new construction techniques are workable, better, fast and can be easily understood [1]. Other factors that promote modern structures are: improved economic status, improved living conditions, increasing need of multi storeyed buildings, and increasing construction services [1].

4.3 Spreading awareness about Traditional Settlement through Surveys

As the hill folks of Himachal are continuously moving towards a more modern housing architecture, it is essential to make them aware about certain advantages of the traditional style of architecture, especially from the point of view of 'low energy consumption' and eco-friendliness of the resources that go hand-in-hand for establishing a 'Kath-Kuni' or Dhajji-Dewari dwelling, such as timber, mud and sun-dried bricks. This would make them better equipped with the knowledge that would ultimately help them weigh their options better when building their house in future.

An important step towards this goal is conducting area-wide surveys. Unfortunately, due to Covid'19 that was rendered impossible. However, we had prepared a draft questionnaire that would help the survey conductor interact with the villagers well and also gain an insight to their needs and likewise, opinion of traditional housing.

The questions would be based on their financial status, average age and number of family members, local weather, etc. and these are some examples-

a.) What is the number of elderly and children below 13 in your family?

b.) How often do you have hail/snow/heavy rains in your area during the season?

c.) Are you aware of the fact that adding elements of traditional architecture such as mud, timber, etc., can help regulate the indoors temperature better?

d.) What kind of methods would you say, you employ to maintain the room temperature, that consume mainly electricity? Certain examples- fans, room heaters, air conditioner, cooler, etc.

e.) How would you rank from lowest to highest in terms of annual/monthly cost the following- Electricity bill, food and groceries, medicine and healthcare, weather related reconstructions?

f.) Based on the above answers- how would you rank the following, from highest to lowest priority when investing in a house- Fresh air and ventilation, indoors mobility, eco-friendliness?

5. Conclusion

In this project, we have understood that the traditional construction techniques of Himachal Pradesh are the outcome of its typical climatic conditions, landscapes, availability of raw materials and other natural resources. These techniques provide thermally comfortable shelter by giving due consideration to local climatic conditions. Main advantages of these constructions are reusable resources, sustainability and design efficiency. The thermal comfort aspect is supported by the energy consumption calculations done in this project. It has been observed that the sample house consumed less energy when the walls and roof were made of wood or mud, as compared to brick or concrete. However, people in the hills are now shifting to modern housing techniques and materials. Factors like liveability, comfort, maintainability, security, protection from biotic/abiotic forces make modern cement-and-brick houses more desirable than traditional houses. Other factors like unavailability of traditional materials and lack of people who can build those houses also play a role. The hills are losing their indigenous structures and becoming more like the cities – concrete and dull.

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