Alliance for an Energy Efficient Economy | energise 2023
Lifestyle, Energy Efficiency, and Climate Action

Cite this article
Mattu, A., Prasad, A. K. (2024). Hybrid Solution for Solar Passive Architecture in the High-Altitude Cold Climate of Leh. In Proceedings of Energise 2023- Lifestyle, Energy Efficiency, and Climate Action, pp 99–108, Alliance for an Energy Efficient Economy.
https://doi.org/10.62576/LGBD5265

Energise 2023 Conference | Goa, 1-4 November 2023

Hybrid Solution for Solar Passive Architecture in the High-Altitude Cold Climate of Leh

Amandeep Mattu
Chandigarh College of Architecture, Chandigarh, India
(Corresponding Author: ar.mattu.cca@gmail.com)

Anup Kumar Prasad
CSIR-Central Building Research Institute, Roorkee, India

Highlights

- Climate Responsive Hybrid Technology for High Altitude Cold Climate
- Nil-to-very less carbon footprint
- Improvised thermal performance

Abstract

The study aims to establish a research directory of passive techniques in the field of building construction. It would provide local practitioners the necessary skills to improve and innovate building construction technology for Leh's harsh, high-altitude cold climates. The research focuses on understanding the cold highland climate of Ladakh, integrating cultural elements into the built environment, and identifying the latest innovative construction technologies. It will help to determine the existing architectural or structural development issues. The study extends to finding possible solutions to the non-renewable indigenous approach and gathering the new trends in the building environment or modern building techniques. Further, the research proposes adapting modern technology that efficiently works in high-altitude, cold climates. It aims to improve indoor environmental quality in harsh climatic conditions by using local materials and developing hybrid solutions. Passive solar techniques can take advantage of the available energy source.

Keywords: Solar-passive, High-altitude, Hybrid Construction Technique, Thermal comfort, Vernacular Architecture

Introduction

Human civilization has evolved and survived throughout history by integrating with the surrounding environment and relying on preserving nature. Each region developed distinct features that distinguished it from other places over time and via the diverse interaction of evolution and human adaptation to the ambient environment, which is unique [1]. Vernacular architecture has always been a way of building locally in response to a region's cultural, social, and microclimate [2]. It is indigenous to an area and contributes to the community's and environment's long-term viability. With the shifting approach to the built environment, understanding the state of vernacular sustainability is more important than ever [3]. Sustainability is an essential component of vernacular architecture, which has grown over time by using local materials and technologies to create a harmonious relationship between humans and their surroundings.

This paper aims to propose suitable indices for assessing the long-term viability of vernacular architecture in Ladakh, a region in northern India known to be the world's highest and coldest region that humans have continually inhabited. The communities are known for their monasteries and palaces, which testify to the indigenous people's outstanding building ability despite the harsh environment and topography [4]. Aside from its unique and rich cultural history, any study of architecture and settlement studies is fascinated by human survival in difficult weather conditions, with temperatures as low as - 30°C, posing a threat to human survival and other life forms. Ladakh's residents have harnessed the sun's energy through traditional architecture incorporating climate-controlling passive techniques [4]. Apart from using native building materials such as mud bricks, quartzite stones, poplar, grass, timber, etc., and construction techniques, the buildings have a distinctive spatial arrangement to deal with the climatic circumstances.

Most of the building components used in technology come at a cost to the environment or our immediate surroundings. In addition to using a lot of energy and natural resources, construction operations generate many by-products. It indicates that the world's resources are being used up far more quickly than they are being restored. Similarly, producing tons of by-products causes the environment to be further harmed by releasing undesired elements. Numerous problems exist in the modern world, such as resource shortages and pollution (including air, water, land, and noise). Everything here emphasizes how crucial it is to protect the environment and keep it that way for future generations and how essential it is to use sustainable building and architectural practices.

Hence, their study focuses on understanding the cold highland climate and identifying the latest innovative construction and technologies. To create a directory of indigenous architectural technologies and identify existing architectural and structural development issues. This study aims to find a possible solution to the non-renewable indigenous approach. This study aims to find a possible solution to the non-renewable indigenous approach.

Methodology

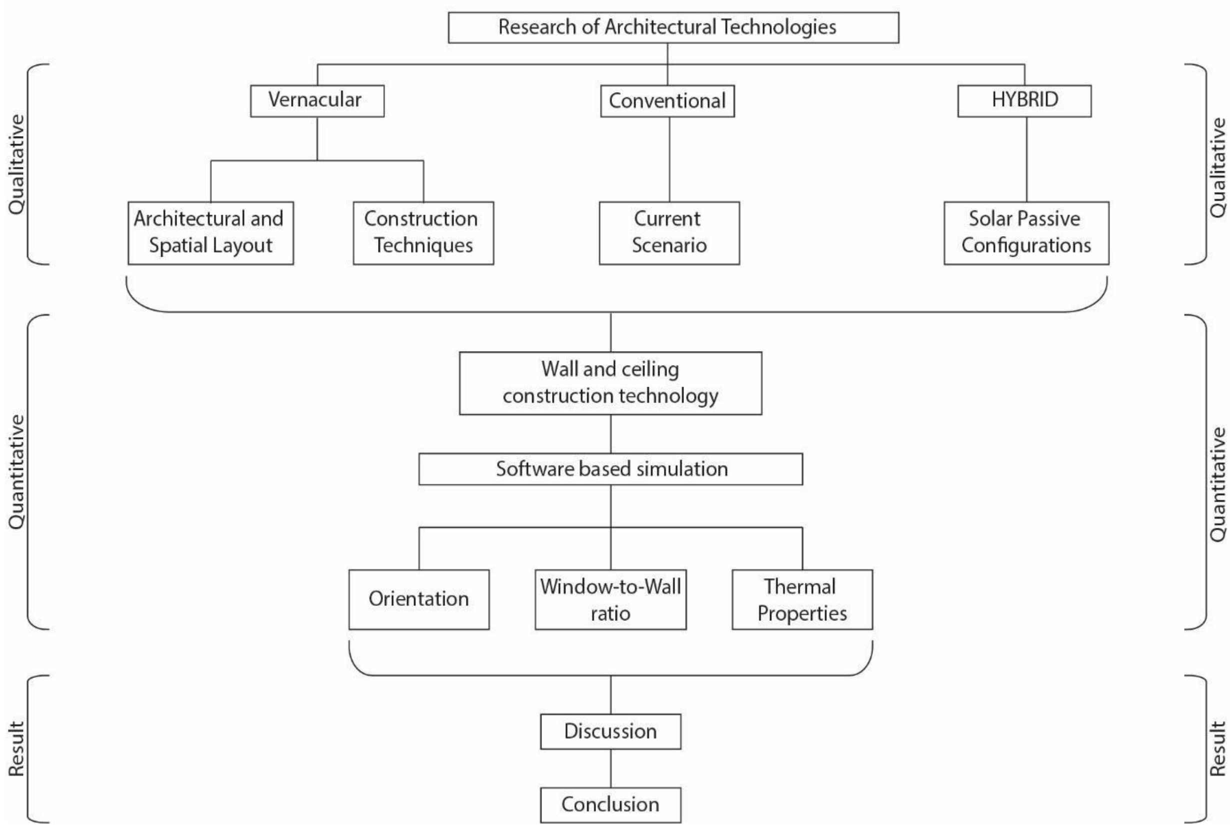


Figure 1: Methodology of the Research

This methodology provides a structured approach to researching solar passive techniques and fusion technologies in high-altitude regions. It involves gathering information from multiple sources, analyzing data, proposing solutions, and validating findings through simulations and real-world tests.

Ladakh: The Study of Context

After the removal of section 370 in 2019, Ladakh became UT. It occupies the largest area of this region, even if it is the least populated one. Ladakh is surrounded on the east by the Tibet Autonomous Region, on the south by the Indian state of Himachal Pradesh, and on the west by Pakistan's Gilgit-Baltistan. It also stretches southward from the Siachen Glacier to the main Great Himalayas.

Ladakh is a high-altitude desert with extremely little vegetation for the most part due to a lack of precipitation. Natural vegetation thrives along waterways and higher elevations, with more snowfall and lower summer temperatures.

Traditional buildings in Ladakh, like those in Tibet, are made of stones, timbers, and mud in various forms, such as sun-dried mud bricks and rammed earth for floor and roof plastering. The structures

reflect the people's way of life, with cow pens on the ground floor and Buddhist altar chambers on the top [5].

Climate of Ladakh

Temperature variation is substantial both diurnally and seasonally, with temperatures ranging from 35°C in the summer to -35°C in the winter. The annual average rainfall in Leh is 100 mm, most falling between May and September, and snowfall in the winter (November to March) is typical. The harsh climatic conditions of India's cold desert region are characterized by dry and cold weather, heavy snowfall, and low temperatures, reaching as low as -30°C in the late evenings. During the summer, the average temperature can get + 30°C in the afternoon [6]. According to a 35-year analysis of meteorological data, the minimum temperature at Leh has been rising by roughly 1 degree Celsius in the winter and 0.5 degrees Celsius in the summer [7]. Rising temperatures and more precipitation have transformed this harsh and dry Himalayan desert into a warmer and wetter environment with shorter winters and pleasant summers over the last few years [8].

Architectural Technologies - Vernacular, Conventional, and Hybrid

Vernacular technologies of the High-Altitude Cold Climate of Leh district

Vernacular architecture is the constructed environment (city, architecture, and interior spaces) created to meet the demands of civilization. It is constructed by the natural environment (geography, terrain, site, climate, local building materials, labor experience, and construction techniques), ensuring that people's physical, economic, social, and cultural needs are met.

Due to transportation constraints, vernacular architecture relied on local materials, which helped to save resources while also giving each region's architecture a distinct personality [9]. Each material had its own physical and aesthetic properties, which governed the architectural technology that was appropriate for it.

Earth and Timber, are the oldest and most often used materials in dry places like Ladakh, necessitating specific technologies due to their shape, size, and durability. The proportions of most sun-dried earth blocks are designed to fit the palm of a human's hand; this was useful for constructing walls and piers, as the thickness of these vertical elements varied depending on their constructional location, height, and structural loads. Builders had to construct new forms by the physical qualities of brick to solve the roofing problem; the trunk of native poplar trees as beams was the creative solution. These innovative forms were both aesthetically and functionally compatible with the surrounding environment and climate. These structural materials received symbolic importance beyond functionality and aesthetics over time, and they formed part of the "culture memory." In terms of aesthetics, the long sunny days in scorching dry locations complemented the brick's particular charm. Through the juxtaposition of shade and shadow, the sun and clear sky highlighted the aesthetics of mud bricks. Even though some of these forms were designed for structural and practical reasons, the aesthetic and creative aspects were not overlooked [1].

Architectural and Spatial Layouts

Typical residences are two-story structures. Larger homes are built around a courtyard, whereas smaller homes are not. The Ground Floor is usually a dwarf floor that is not intended for human use. It serves as a holding area for cattle, as well as a storage facility and a collection point for lavatory waste [4]. (Refer Figures 2 and 3) The top levels have lavatories, whereas the lower stories have a chamber where the excreta are collected and composted. Since the kitchen and sleeping areas are adjacent, the heat generated during cooking contributes to the overall warmth of the interior during the night [4]. In addition, the main hall is carpeted and equipped with a furnace and a smoke stack for warmth in the winter. The upper floor is used for residential purposes and includes a prayer room, store, and toilet, and a relatively big space as a drawing room, kitchen, and bedroom [10]. A typical timber decorative Ladakhi post in the center of the main room serves as a focal point.

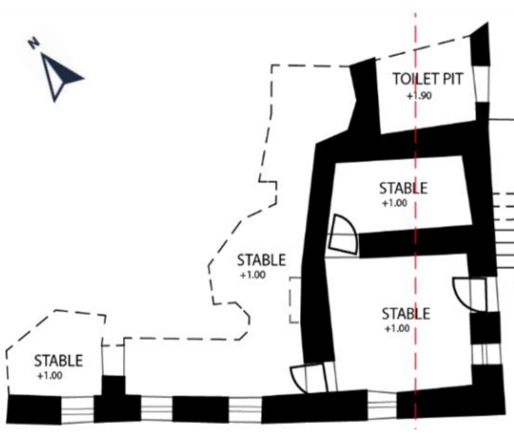


Figure 2: Typical Ground Floor Layout [11]

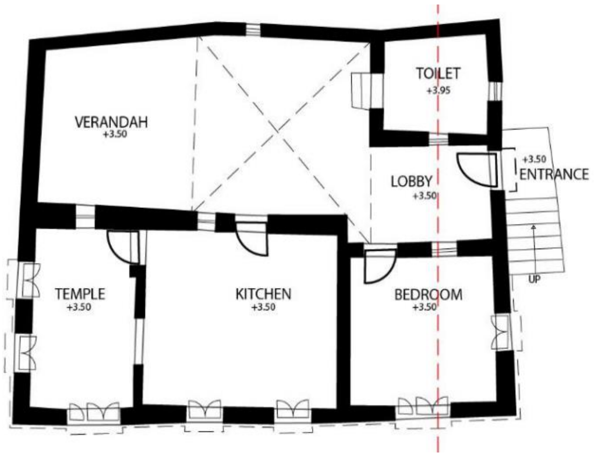


Figure 3: Typical First Floor Layout [11]

The terrace is used for family meetings and drying items. The main living area has a large window facing the sun. Dry materials like grass, straw, and sticks are stored on the roof for insulation. Other rooms typically have less volume, keeping the interior warm and comfortable. Larger rooms tend to cool off quickly, and smaller windows in rooms not exposed to the sun help maintain heat [12] [13] [14] [4].

Construction Techniques and Technology

The fundamental unit of a masonry building is sun-dried earth blocks (Figure 6a). They are used to construct 300 or 450-mm thick walls, usually 300 x 150 x 150 mm. Alluvial material along the banks of the Indus River was used to create these earth bricks. Most earth blocks are manufactured in Shey, which is around 15 kilometers from Leh [15].

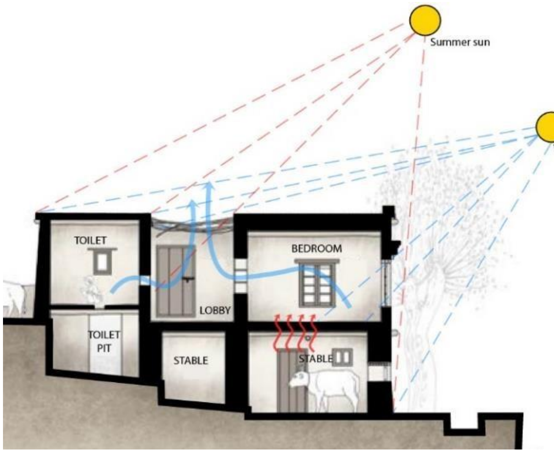


Figure 4: Typical section [11]

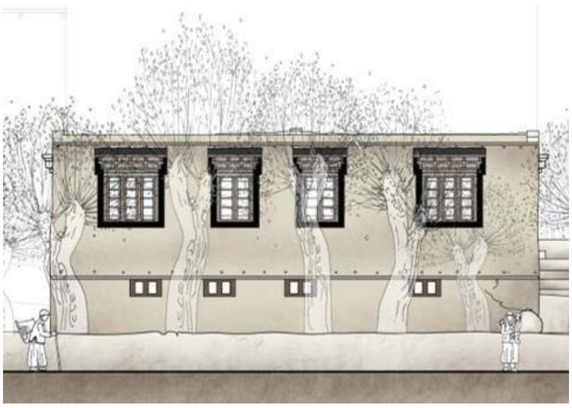


Figure 5: Typical Elevation [11]

Stone blocks are sometimes used in the lower courses of walls for extra strength and water resistance, especially in low-lying areas. Finally, mud plaster is used to complete the wall. Roofs are built with flat spans utilizing the trunks of native poplar trees as beams, spaced 50-60cm apart. The trunks have an average diameter of 15 centimeters and a length of 3 to 4 meters [15]. Poplar willows spread in the other direction are used to cover these timbers. Willows usually have a thickness of 20 to 30 mm. Over the layer of willows, a 15 to 20-cm layer of dried grass, hay, etc., is laid and finished with clayey mud plaster.

Figure 6 (a): Traditional Façade (b) Sun-dried Earth Block (c) Traditional ceiling [23]

The bottom story on the ground has mud floors, while the upper level has timber floors. Along with outfitting rugs, timber flooring provides improved thermal comfort [16]. Timber from Kashmir is used for the doors and windows. The lintels of the doors and windows are ornately corbelled elements. The plaster band, which is commonly red or black in color, articulates the sills and jambs. The distinctive features of Ladakhi architecture are the timber lintels and plaster bands. Their growth, however, is not solely for symbolic or aesthetic purposes [17].

Shift from traditional to modern architecture - Conventional building techniques

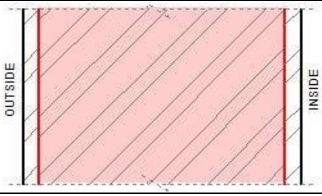
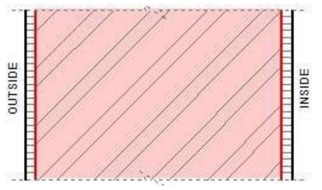
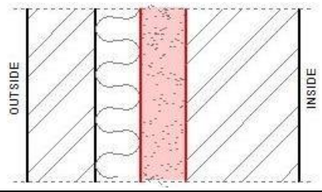
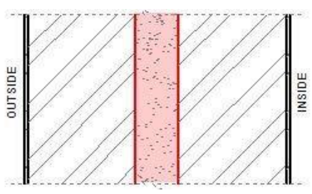
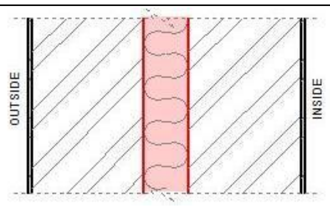
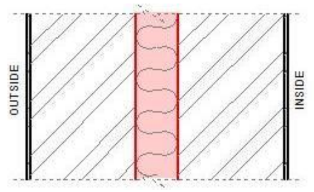
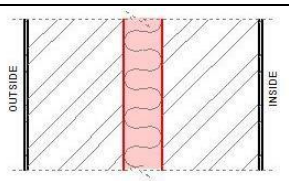
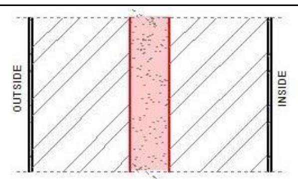
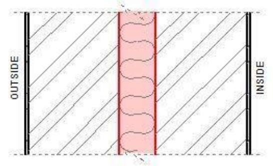
After releasing the movie 3 Idiots, starring Aamir Khan, in 2009, Leh experienced a boom in national tourism. The city's floating population increased multiple folds, and many guest houses started being built to accommodate such a high number of tourists. Due to the absence of a city master plan, the growth was never planned, leading to building encroachment on roads and traffic congestion. Almost everyone had a home in Leh where they stayed during the summer and a home in their nearby village where they spent the off-season. After the major floods of 2010, a misbelief rose among the locals that traditional mud construction is not stronger than concrete.

Identifying the features that attracted people to move towards brick and concrete houses was essential. After studying traditional earth homes and modern brick homes, it was inferred that users found brick construction faster, more durable for rain, cheaper, and easier to maintain. Brick houses were also found to be a status symbol. Users also pointed out that villagers themselves traditionally built an earth home. However, modern-day lifestyles do not allow people to pursue the construction of their homes. In this regard, it is easy to find a contractor to construct a conventional home rather than an earth building. With this perception in mind, the focus of the research was to rethink the technique of designing and executing earth homes to make them more palatable to present-day user needs, both aesthetically and economically [16].

Climate Responsive Hybrid Architecture using Passive Solar techniques

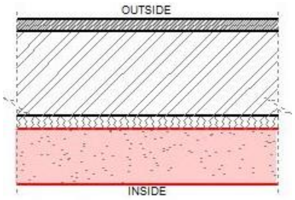
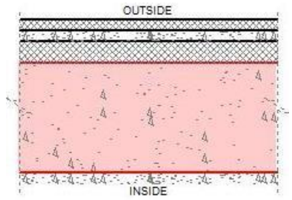
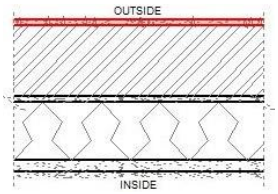
Combining traditional knowledge with modern technologies is essential to arrive at an environmentally friendly solution that uses local resources and harvests indoor thermal comfort through passive means. Climate-responsive hybrid architecture using solar passive techniques could be the answer to the sustainable architecture approach in Ladakh's harsh, arid climatic conditions.

Table 1: Wall Design (The thermal conductivity for each material is referred from AutodeskEcotect, and λ value is cross-checked by the CBRI material list)

1. **Traditional Wall (TW)** 320mm thick	2. **Contemporary Wall (CW)** 250mm thick	**3. Hybrid Wall Option 1 (HWO1)** 600mm thick
		
Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.3 m, λ = 0.75 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)	Cement Plaster (l = 0.01 m, λ = 0.9 W/m.K) + Brick (l = 0.23 m, λ = 0.7 W/m.K) + Cement Plaster (l = 0.01 m, λ = 0.9 W/m.K)	Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.15 m,) + λ = 0.75 W/m.K) + Wool (l= 0.1m, λ = 0.03 W/m.K)) + Sawdust (l= 0.1m, λ = 0.05 W/m.K) + Mud Brick (l = 0.25 m, λ = 0.75 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)
U-Value = 1.685 W/m²K	**U-Value = 2.038 W/m²K**	**U-Value = 0.163 W/m²K**
4. Hybrid Wall Option 2 (HWO2) 620mm thick	**5. Hybrid Wall Option 3 (HWO3)** - 620mm thick	**6. Hybrid Wall Option 4 (HWO4)** - 620mm thick
		
Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.15 m,) + λ = 0.75 W/m.K) + Sawdust (l= 0.1m, λ = 0.05 W/m.K) + Mud Brick (l = 0.25 m, λ = 0.75 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)	Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.15 m,) + λ = 0.75 W/m.K) + Wool (l= 0.1m, λ = 0.03 W/m.K)) + Mud Brick (l = 0.25 m, λ = 0.75 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)	Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.15 m,) + λ = 0.75 W/m.K) + Straw (l= 0.1m, λ = 0.07 W/m.K) + Mud Brick (l = 0.25 m, λ = 0.75 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)
U-Value = 0.355 W/m²K	**U-Value = 0.241 W/m²K**	**U-Value = 0.445 W/m²K**
7. Hybrid Wall Option 5 (HWO5) - 620mm thick	**8. Hybrid Wall Option 6 (HWO6)** - 620mm thick	**9. Hybrid Wall Option 7 (HWO7)** - 620mm thick
		

Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Rammed Earth (l = 0.25 m,) + λ = 1.8 W/m.K) + Wool (l= 0.1m, λ = 0.03 W/m.K)) + Rammed Earth (l = 0.25 m, λ = 1.8 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)	Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Rammed Earth (l = 0.25 m, λ = 1.8 W/m.K) + Sawdust (l= 0.1m, λ = 0.05 W/m.K)) + Rammed Earth (l = 0.25 m, λ = 1.8 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)	Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K) + Rammed Earth (l = 0.25 m,) + λ = 1.8 W/m.K) + Straw (l= 0.1m, λ = 0.07 W/m.K)) + Rammed Earth (l = 0.25 m, λ = 1.8 W/m.K) + Mud Plaster (l = 0.01 m, λ = 0.75 W/m.K)
U-Value = 0.265 W/m²K	**U-Value = 0.399 W/m²K**	**U-Value = 0.516 W/m²K**

Table 2: Ceiling Design (The thermal conductivity for each material is referred from AutodeskEcotect))

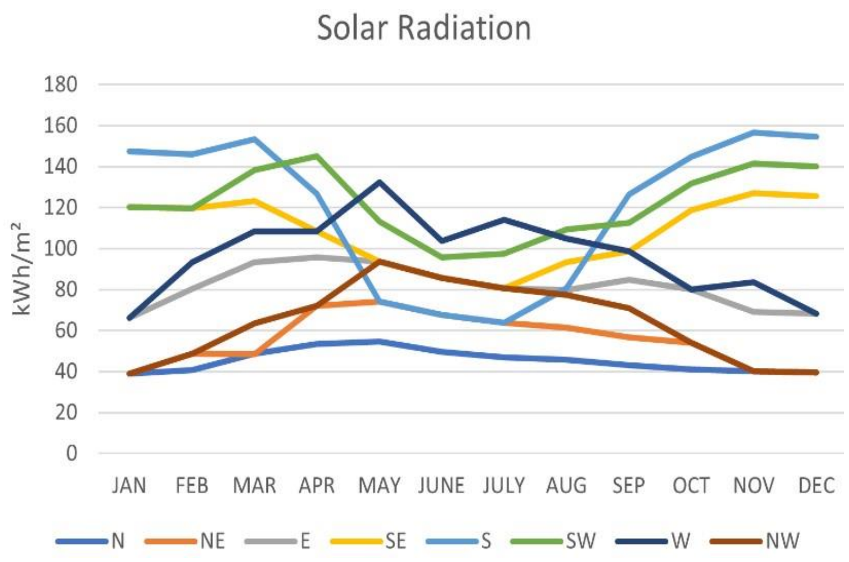
1. Traditional Roof (TR)	2. Contemporary Roof (CR)	3. Hybrid Roof (HR)
		
Mud Plaster (l = 0.03 m, λ = 0.75 W/m.K) + Rammed Earth (l = 0.25 m,) + λ = 1.8 W/m.K) + Straw (l= 0.3m, λ = 0.07 W/m.K)) + Timber (l = 0.13 m, λ = 1.4 W/m.K)	Tile (l = 0.01 m, λ = 1.2 W/m.K) + Cement motar (l = 0.1 m, λ = 0.14 W/m.K) + RCC Slab (l= 0.1m, λ = 0.8 W/m.K)) + Cement Plaster (l = 0.01 m, λ = 0.9 W/m.K)	Mud Plaster (l = 0.03 m, λ = 0.75 W/m.K) + Mud Brick (l = 0.3 m,) + λ = 1.8 W/m.K) + Wood batten (l= 0.025m, λ = 0.14 W/m.K)) + Insulation (l = 0.25 m, λ = 0.03 W/m.K) + Wood batten (l= 0.025m, λ = 0.14 W/m.K))
U-Value = 0.607 W/m²K	**U-Value = 2.810 W/m²K**	**U-Value = 0.108 W/m²K**

For cold climates, a passive solar building is a building in which the various components are arranged to maximize the collection of solar heat. It is then stored and finally distributed into the space without any expenditure of conventional energy [17]. The two primary types of solar heating systems, active and passive, can be distinguished by how they retain heat after it has been produced from sunshine. Active systems use an additional energy source to pump a liquid or blow air over the absorber. The passive system has absorbers that also store heat but require no other energy source [18]. Instead of being purchased as a finished good, passive solar systems are carefully measured and sized before being planned, produced, and manufactured. This section discusses the use of sunlight for home heating in cold climates and describes several passive solar heating systems.

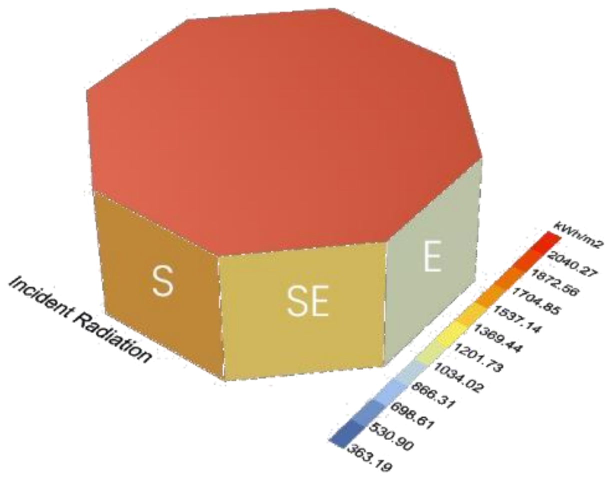
Passive Solar Building Configurations

Layout, Orientation, Shape, and Opening

Knowledge of the sun's path and the intensity of global solar radiation falling on rooves and different walls at different times of the day at a particular location is essential for determining the location and orientation of the building. The building should be located where adjacent buildings or tree cover do not impose shade on it. As explained earlier, the roof and the south-facing wall receive maximum solar radiation in the northern hemisphere during winter. Therefore, the plan of the building should be rectangular, with its length running east-west to allow for maximum opening on the south face. [19]. The surface and roof area of the building should be at a minimum to reduce heat loss and also the location from which snow will have to be removed. For example, double-storied structures are preferable to single-storied ones. The emphasis should be given to minimizing internal volume, i.e., the height between the floor and ceiling should be as little as possible to lessen the heating load. It is also desirable to identify heated (kitchen), unheated (staircase, store, bathrooms), and transition zones (bedrooms) and locate them to maximize thermal comfort and minimize heat loss [20,21,22]. Windows should be on the south-facing walls, and the percentage of opening required for floor area depends on the outside temperature during winter. Windows on the north side should be kept to a minimum.[19]



(a)



(b)

Figure 7: (a) Graph showing solar radiation of 8 sides in a monthly period (b) visual of Octagon with annual solar radiation data (Data and visual from Rhino with Grasshopper and Ladybug)

Traditional, Contemporary, and Hybrid Technologies

Inferences: Due to their lower u values, which equate to lower thermal conductivity, hybrid wall and ceiling designs function more effectively.

Performance analysis – Based on software analysis

Orientation of Building

An octagon shape (3 m in length and 2.4 m in height) with eight radiation sides is modeled in Rhino software. With the help of Grasshopper and Ladybug, solar radiation on different facades is derived for performance analysis based on orientation.

Inferences: One needs maximum radiation in winter to harvest maximum heat and minimize radiation in winter to maintain a comfortable temperature. Figure 7 indicates that the south façade of any building gets the maximum exposure to radiation (Minimum to the north). The south wall gets maximum radiation in winter (Oct, Nov, Dec, Jan, Feb) and minimum radiation in peak months of summer (May, June, July).

Fenestration Design

One of the significant factors affecting solar radiation to promote solar heat gain or loss is the window-to-wall ratio. A matrix for Performance efficiency analysis with variable orientation and window-to-wall ratio with the deciding factors are Direct Radiation and diffuse radiation for performance analysis. Data were taken for the entire year, from 8 AM to 6 PM, for a size 5m x 5 m room. The variable for WWR is 5% (0.7 m x 1 m), 10% (1.3 m x 1 m), 15% (1.8 m x 1 m).

Table 3: Matrix for Energy efficiency analysis with variable orientation and window-to-wall ratio. The deciding factors are Direct, Diffuse, and Total radiation (Simulation done in Ecotect)

Orientation ▼	Window-To-Wall ratio ▼	Direct Radiation (kWh)	Diffuse Radiation (kWh)	Total Radiation (kWh)
North	5%	0.123	111.1	112
	10%	0.2	116.1	116.4
	15%	0.28	119.7	120
North-East	5%	2.6	111.8	114.5
	10%	4.9	116.1	121.1
	15%	6.7	119.7	126.5
East	5%	12.9	111.8	124
	10%	24.1	116.1	140.3
	15%	33.2	119.7	153
South-East	5%	21.4	111.8	133.3
	10%	39.1	116.1	153.3
	15%	54.2	119.7	174
South	5%	23.6	111.8	135.5
	10%	43.3	116.1	159.5
	15%	59.5	119.7	179.3
South-West	5%	17	111.8	128.9
	10%	32.1	116.1	148.3
	15%	44.3	119.7	164
West	5%	10.7	111.8	122.6
	10%	19.6	116.1	135.8
	15%	27.1	119.7	146
North-West	5%	3.4	111.8	115.3
	10%	6.4	116.1	122.6
	15%	8.8	119.7	128.6

Inferences: From the matrix, cross-referenced from various orientations, WWR to Direct, Diffuse, and total radiation infer that building WWR 15% gives the best performance in high altitude climatic conditions. It also suggests that a longer wall oriented towards the south is best regarding Direct and Diffuse Radiation. (Avoid the north side window.)

Thermal Performance

Further, to compare the thermal performance based on the insulation in Vernacular, Conventional, and Hybrid building envelope, modelling and simulation was done in Ecotect software. The deciding factor is the temperature difference between outside and indoors. (Ecotect)

Inferences: Conventional Walls/Roofs are efficient for summer seasons. The kitchen is a good source of heat. Hybrid Wall (HR) and Traditional Roof (TR) or Hybrid Wall (HW) and Hybrid Roof (HR) are performing efficiently.

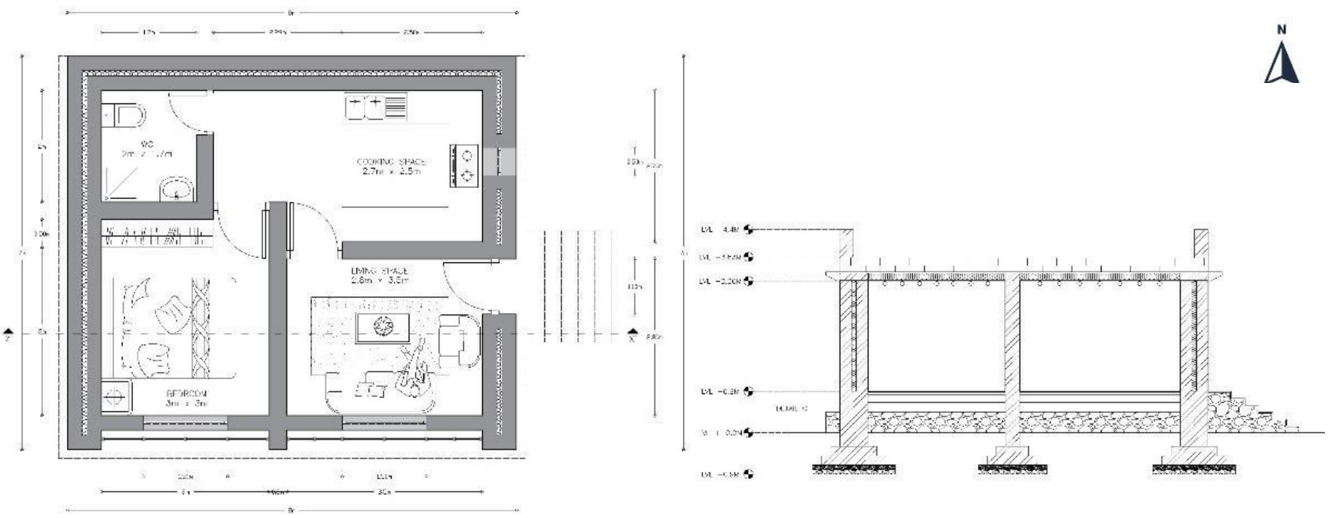


Figure 8: (a) Plan (1 BHK 8m x 7m) (b) Section AA

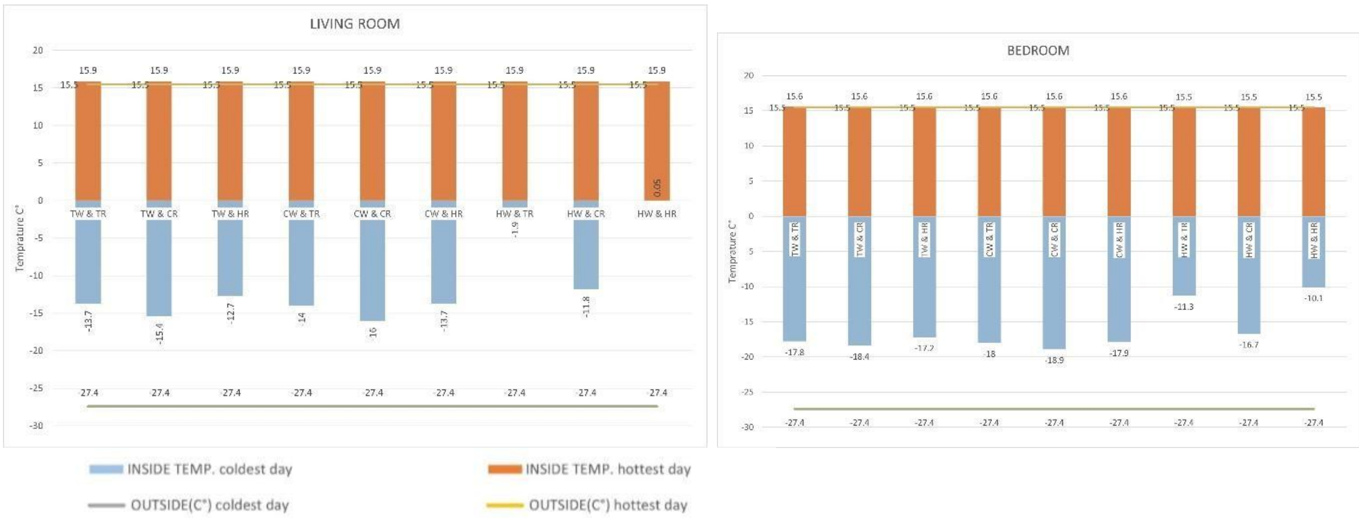


Figure 9: (a) Living room (b) Bedroom

Discussion

- For climate efficient design in high altitude climate., one needs maximum radiation in winter to harvest maximum heat and minimize radiation in winter to maintain a comfortable temperature. The south wall gets maximum radiation in winter (Oct, Nov, Dec, Jan, Feb) and minimum radiation in peak months of summer (May, June, July).
- To get maximum solar radiation in summer, the building with WWR 15% gives the best performance in high altitude climatic conditions. It also suggests that a longer wall oriented towards the south is best regarding Direct and Diffuse Radiation. (Avoid the north side window.)
- Conventional Walls/Roofs are efficient for summer seasons. The kitchen is a good source of heat. Hybrid Wall (HR) and Traditional Roof (TR) or Hybrid Wall (HW) and Hybrid Roof (HR) are performing efficient discussion.

Conclusion

- After completing the studies mentioned above, we learned about the architectural practices used in Ladakh. Based on this knowledge, the contemporary architectural style is inappropriate for that environment due to resource constraints, lack of water, and the growing carbon footprint of moving construction materials. While 80% fewer carbon emissions are produced during construction, the hybrid has 80-90% local materials and vernacular techniques.
- In 2009, comparing costs between conventional construction and passive solar earth homes, TPDS mentor Sonam Wanchuk found that while conventional construction costs Rs.750 per square foot, earth homes only cost Rs.500 [16].
- Passive solar technology is advantageous in areas like Ladakh, where thermal radiation is more abundant and can generate more heat in cold climates.
- After comparing u-values, hybrid walls and ceilings with a lower u-value have less thermal conductivity, which is beneficial for maintaining internal comfort in a climate like Ladakh. In a hybrid wall, the u-value is five times traditional and seven times contemporary. The hybrid ceiling is six times lower than the traditional one and 28 times lower than the modern one.
- Due to the need to maintain heat in the winter, the sun is naturally at a 30-degree angle, allowing the most sunlight and heat to enter the room. In contrast, the sun is at an 85-degree angle in the summer, preventing sunlight from entering the room and resulting in lower summer radiation on the south wall. As opposed to this, 15% WWR will operate effectively in the south, 5% in the east, 5% in the west, and 5% in the north, which is only optional for ventilation after simulating the three analyses.

References

[1] O. Nasir and M. Kamal, "Vernacular Architecture as a Design Paradigm for Sustainability and Identity: The Case of Ladakh, India," American Journal of Civil Engineering and Architecture, vol. 9, no. 6, Dec. 2021. https://doi.org/10.12691/ajcea-9-6-2

[2] W. Yousuf, "The challenge of sustainability in developing countries and the adaptation of heritage-inspired architecture in context," Archnet-IJAR, vol. 5, no. 2, pp. 1938-7806, July 2011.

[3] R. Dayaratne, "Toward sustainable development: Lessons from vernacular settlements of Sri Lanka," Front. Arch. Res., vol. 7, no. 3, Apr. 2018. https://doi.org/10.1016/j.foar.2018.04.002

[4] N. Khan, "Vernacular Architecture and Climatic Control in the extreme conditions of Ladakh ASPIRE-2013," National Conference

[5] J. F. McLennan, The Philosophy of Sustainable Design, MO EcoTone, Kansas City, 2006.

[6] B. Singh, and S. K. Dwivedi, Climate change in cold arid region: Horticulture to Horti-business, New - Delhi publishers, New Delhi, 2011.

[7] IPCC, The Science of Climate Change, Cambridge University Press, Cambridge, 1995.

[8] Jina, Prem Singh, The Cultural Heritage of Ladakh, Indus Publishing Company, New Delhi, 2003.

[9] H. Fathy, Architecture for the Poor, University of Chicago Press, Chicago, 1976.

[10] S. Paul, Climate Change in Ladakh, In Ladakh Studies, edited by Kim Gutschow, vol. 25: 3-6. Kargil and Leh: IALS. 2010.

[11] S. K. Desai, A. Bhate and A. Varma, "Decoding the Vernacular Practices of The Cold-Dry Climate of The Phyang Village in Leh-Ladakh,".

[12] S. S. Sagwal, “Specifications of Ladakh: Ecology and Environment,” Ashish Publishers, 1997.

[13] A. Cunningham, Ladakh, Gulshan Books Publications, Srinagar, 1997.

[14] M. V. Beek, K. B. Bertelsen, and P. Pedersen, 1999, "Ladakh: culture, history, and development between Himalaya and Karokaram" Oxford Publication House.

[15] Jan·Osmaczyk, Edmund; Osmańczyk, Edmund Jan (2003), Encyclopedia of the United Nations and International Agreements: G to M, Taylor & Francis, 2003, 1191.

[16] N. Joshi, "Efforts to Resurrect and Adapt Earth Building and Passive Solar Techniques in Ladakh, India," Oct. 2013. https://doi.org/10.1201/b15685-106

[17] C. Flavin, "Energy and Architecture: The Solar and Conservation Potential," Worldwatch Paper 40, Nov. 1980,

[18] B. Schepp and S. M. Hastie, "The Complete Passive Solar Home Book," University of Minnesota, Tab Books, 1985.

[19] K. Rijal and N.K. Bansal, "Passive Solar Building Technology: Potentials for Application in Mountain Areas".

[20] H. J. Moore, "Making use of the heat of the Sun," Unesdoc.unesco.org, https://unesdoc.unesco.org/ark:/48223/pf0000077448

[21] B. Erat, Manual: Passive Solar Energy in Bhutan. National Urban Development Corporation, NUDC/005/1985. Bhutan: Royal Government of Bhutan, 1985.

[22] P. Gut, and D. Ackerknecht, “Climate Responsive Building,” 1996. In Regional Workshop on Passive Solar Architecture. Guwahati, Assam: Energy Division, Assam Science Technology and Environment Council/Ministry of Non-Conventional Energy Sources.