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STUDY OF VERNACULAR SOLAR PASSIVE DESIGN TECHNIQUES FOR COLD AND DRY CLIMATE LADAKH

Ashish Gautam [1], Dr. Sonal Atreya [1], Dr. Anil Kumar K [2]

[1] Department of Architecture and Planning, Indian Institute of Technology Roorkee, Roorkee, Uttarakhand India
[2] ICFAI School of Architecture ICFAI Foundation for Higher Education, Hyderabad, Telangana India

Corresponding Author
Ashish Gautam, agautam1@ar.iitr.ac.in

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ABSTRACT

Ladakh, one of the remote regions in the Himalayas, has been an example of a self-sustainable ecosystem with its unique socio-economic and cultural characteristics since time immemorial. Primarily a rural agrarian economy, all social activities and basic life processes were sustainably interlinked in a cordial community setup. The current study focuses on the vernacular passive design techniques of the dwelling units in Ladakh's cold and dry climate.

The study aims to explore the vernacular passive design techniques of the Ladakh region by examining aspects related to spatial design, thermal mass, material usage, insulation, and other concepts that may be crucial for designing conventional buildings. Traditional dwelling units within the Ladakh region have been selected for the study purpose, and analysis has been conducted through qualitative methods like an observational approach, photographic analysis, and quantitative analysis. Along with the analysis, different construction elements of the dwelling units have been studied with respect to their performance. The study concludes with an overview of the revival strategies for vernacular passive design techniques that can be amalgamated into appropriate interventions on materials and passive design aspects in the contemporary scenario. The study thus adds to the existing knowledge base towards reviving vernacular architecture through an amalgamation of the vernacular and contemporary knowledge, which will be beneficial to building a sustainable environment.

Keywords: Vernacular Architecture, Passive Design, Thermal Performance, Dwellings, Construction Technique

1. INTRODUCTION

Vernacular architecture was developed throughout history, mirroring an area's environmental, cultural, technological, and historical circumstances (Nguyen & Reiter, 2017). Leveraging the benefits of the surrounding environment, including sunlight, while mitigating the adverse impacts of the local climate, such as low night-time temperatures (in cold climates), on the building's comfort level is known as passive solar architecture (Williams College, n.d.). In the cold and deserted regions of the Himalayas, biomass fuels are generally the energy source for heat, including dried animal dung, wood, and bushes. Due to rapid urbanization and increased demand, these fuels are getting harder to locate in several areas, including Ladakh. In the vernacular architecture of this region, passive techniques were used to capture the heat coming from the sun to reduce the load on fossil fuels (Stauffer & Hooper, 2000).

The Ladakh region, situated in the high-altitude Trans-Himalayas of northern India, experiences a cold desert climate characterized by long, harsh winters and short, mild summers. With temperatures dropping below –20°C in winter and limited annual rainfall of less than 100 mm, the region remains arid and dry. High solar radiation, strong winds, low humidity, and significant diurnal temperature variations further define its harsh environment. These climatic extremes have profoundly influenced the region's architectural practices, resulting in built forms that prioritize thermal insulation, solar gain, and protection from the elements.

There are four key aspects/categories to consider in solar passive design techniques in cold climates (Bansal & Rijal, 2000). They are optimizing solar gain, reducing heat losses, increasing heat retention capacity, and controlling heat flow (for hotter times of the year). As per Rosenlund (Rosenlund H, 1995), Layout, Orientation, shape of building, and fenestrations are key factors that influence solar heat gain in buildings. Schepp et al (Schepp & Hastie, 1985) suggests reducing heat loss by trapping the gained heat through proper insulation and ventilation control. Along with Schepp, other authors, including Erat (Erat B, 1985) and Bansal and Minke (Bansal & Minke, 1995) suggests increasing the thermal mass of the walls and other building components to increase the heat retention in the building. Controlling heat flow can be done by providing shade to control overheating in summer.

This research critically evaluates a couple of old vernacular residential structures (one is a 105-year-old structure and the other is a 75-year-old structure) in the Ladakh region, which are currently in use, using the four categories of solar passive techniques mentioned above. This research reveals how these structures incorporate various solar passive design techniques vernacularly and also suggests where recent technological advancements can complement vernacular architecture to improve solar passive design performance.

2. METHODOLOGY

This study employs a comparative case study approach to assess the passive design strategies found in two vernacular Ladakhi houses. The selection of cases was influenced by criteria such as location, altitude, terrain, orientation, and the utilization of local construction materials, ensuring they are contextually similar. A thorough field study was conducted to capture the physical characteristics, architectural features, and the buildings' adaptations to Ladakh's harsh climatic conditions. The key passive design elements like orientation, thermal mass, built form, infiltration, insulation techniques, daylighting, ventilation, and building envelope properties are the focus of the study. For the purpose to determine each house ability to maintain indoor thermal comfort with minimal to no dependence on mechanical systems.

Study design

A mixed-methods approach was utilized to obtain quantitative and qualitative data, which allows for a better understanding of solar passive design performance of both the houses.Quantitative standard included space planning, dimensions, material properties, insulation techniques, and solar gain by houses. These details were enhanced by qualitative data collected through user interviews and observations, living experiences, adaptability, and cultural effects on building usage. This two approach enabled the study to appraise both human and technical elements affecting the efficacy of solar passive design in cold climates.

Site selection and data collection

For case study two vernacular houses from different location in Ladakh regions were selected. These selected case study houses provide as examples of various building types, passive design elements, and needs of users. For each location, thorough documentation was completed, including drawings, floor plans, materials use for construction, insulating material, and shading mass devices. Each of these elements cooperated to enhance temperature regulation across the year was the primary concern.

The finding give a framework for consider the importance of vernacular solar designed building practices in the present and identifying opportunities for blending them with contemporary design technologies.

Comparative Analysis

Two vernacular passive-designed houses were compared based on their building design plans and thermal qualities to identify connections between architectural elements and solar passive design performance. This comparative investigation aimed to pinpoint best practices in local material selection and vernacular passive design strategies that enhance solar passive design techniques in cold climates.

3. SURVEY RESULTS AND ANALYSIS

Table 1 Location of case study sites

		Case study -1	Case study-2
a)	**Latitude/Longitude**	34.145,77.644	34.128,77.624
b)	**House Owner name**	Jamspal George	Chhering Yangor
c)	**Hamlet Name**	Saboo	Saboo
d)	**Distance from Leh**	9.5 km	9km
e)	**Altitude**	3513m	3496m
f)	**Climate Condition**	Cold and dry	Cold and dry

Table 2 Topology

		Case study -1	Case study-2
a)	**Age of House**	105 year old	75 year old
b)	**Context**	Open space	Open space
c)	**Terrain**	Contour	Contour
d)	**Connectivity**	Metal road	Kucha road
e)	**Occupancy (pax)**	7	3
f)	**Water resource distance**	5m	5m
g)	**Distance for farmland**	10 m	10 m
h)	**Soil condition**	Fertile	Fertile
i)	**Vegetation**	Fruits plants ,willow trees	Fruits plants ,willow trees
j)	**Power source**	Grid supply	Grid supply

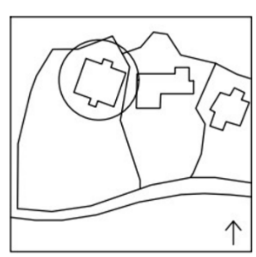
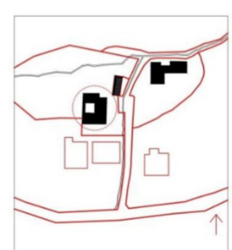
4. SOLAR PASSIVE DESIGN TECHNIQUES

Optimizing solar gain

Site and Context for the building

When choosing a site, two primary factors are considered: natural hazards and the presence of both natural and man-made elements that affect the shading of the proposed structure. In the study context, neither house has any structures in the immediate vicinity, avoiding shade on the building and maximizing the Solar Gain.

Table 3 Context

Context Both houses are free from surrounding built mass, which led to no obstruction for sunlight.		

5. FORM AND ORIENTATION

A solar passive design building aims to harness solar energy to heat the interior by absorbing as much sunlight as possible during the day (in winter). The south-facing walls of passive solar buildings are enlarged to keep the maximum surface area towards the sun along an east-west axis, to optimize the amount of radiation received (Bansal & Rijal, 2000). The overall form of a structure plays a vital role in influencing its heat exchange with the outside environment. Compact buildings with multiple storeys are usually more efficient in this regard, as they present a lower area/volume ratio (Zachar, 1982). The rooms that need heat are placed on the south face of the building, as it is the area most exposed to the sun. The least-used rooms, like the storage areas and toilets, are shaded on the north side.

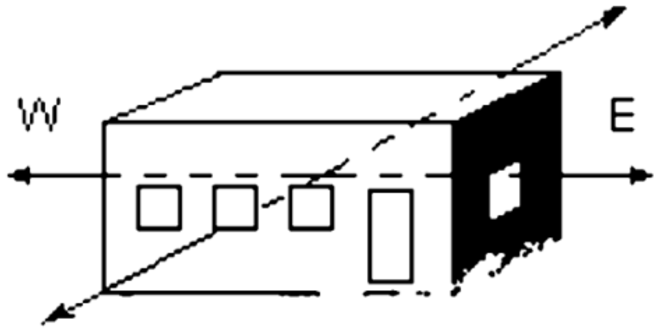


Figure 1 Longer façade facing south along east-west axis
Source Author

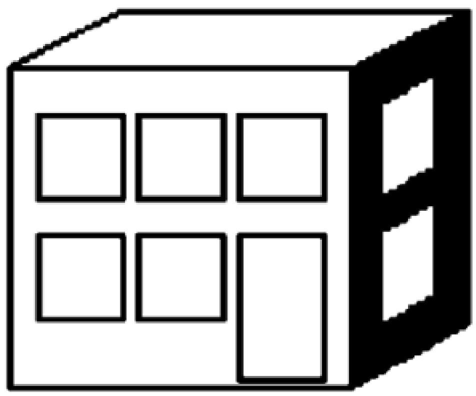
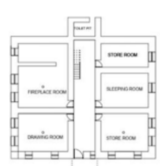
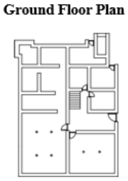
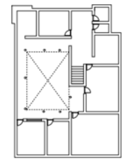


Figure 2 Minimum area to volume
Source Author Table-4 Analyses

Table 4 Analyses

Analyses	Case study -1	Case study-2
Orientation Case 1 house is southwest oriented for maximum heat gain from the sun. Case 2 house is east and south oriented for heat gain from the sun.	**South-West** 	**East** 
Built Form Both houses have linear space planning, and the area/volume ratio is minimal to limit heat loss.	**Ground Floor Plan** 	**Ground Floor Plan** 

Built Form Compact buildings with multiple storeys are more efficient in regulating heat loss and heat gain	**First Floor Plan** 	**First Floor Plan** 
Façade Case 1: The Longest façade of the house is towards the southwest to gain maximum sunlight. Case 2 The Second longest façade of the house is towards the south to gain maximum sunlight.	**South-west** 	**South** 

Zoning / Space Planning

Buildings were planned so that the internal heat generated through the stable can be shared with the living and sleeping spaces during cold winters.

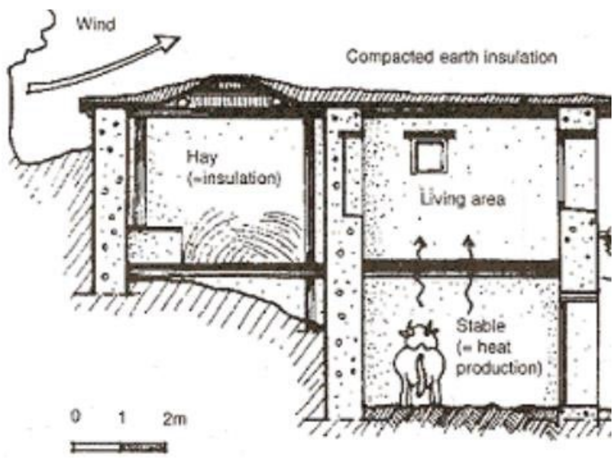
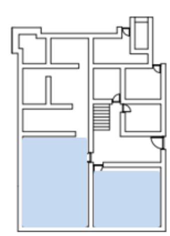


Figure 3 Additional heating in the dwelling is provided through the stable on the ground floor

Source https://lib.icimod.org

Stable In both cases, the shaded areas are stable. Stable are located below the living and sleeping areas to gain the heat that is radiated by the cattle. Stable inside the house is only used in the winter.	**Ground Floor** 	**Ground Floor** 

Shading

Huge impediments like mountains, trees, hills and nearby buildings generally become a reason of restricting the amount of sunlight which a building should otherwise receive. Additionally, the quantity of diffuse sunlight (indirect sun) which reaches the building can be decreased by the nearby structures or impediments, even those situated in the north of the site. Windows shading masses, such as overhangs, louvers, and exterior screens, are essential passive design techniques that intercept and reduce direct solar radiation before it enters the building's interior spaces. In the context of architectural design for structures in Ladakh, reduced parapet height emerges as a significant characteristic for enhancing heat gain.

Shading mass In both cases, the shading masses are small (15 to 20 cm), which allows more heat gain for the building		

Reducing heat losses

Reduction of heat loss is done through two mechanisms; one is insulation and the other is reducing Infiltration through windows and doors. Insulation is specifically for the outer walls. This Insulation also improves heat retention capacity. One of the vernacular methods for controlling infiltration is to provide buffer zones.

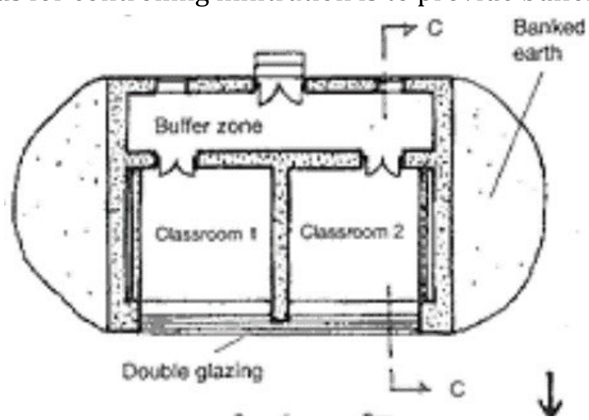


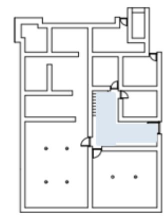
Figure 4 Providing buffer zones to reduce infiltration

Source https://lib.icimod.org

Infiltration

The unintentional air exchange between the inner and outer sides of a building may be called infiltration. When cool outer air enters a room, it displaces the warm interior air, lowering the room's inner temperature. Cold air infiltration can occur through doors, as well as through the frames of doors and windows. However, a building that is hermetically sealed cannot retain sufficient fresh, oxygen-rich air, which makes its inhabitants uncomfortable.

The extent of loss from air replacement is greatly influenced by user behavior, such as leaving a door partially open, which leads to rapid reductions in the inner temperature. Users generally lack awareness of this issue, which, along with the rapid deterioration of doors and windows, results in relatively large infiltration deficits in passive solar structures in the Himalayas. The effectiveness of fittings like doors and windows directly affects the infiltration rate. The quality of building and the behavior of the residents (frequent opening of doors) in Ladakh allow heat losses due to air infiltration to play a significant role in the structure's temperature.

Infiltration Buffer zone, which is shaded. Buffer zone reduce the air exchange of the building and maintain the temperature of the rooms		

Glazing

Windows are considered one of the most substantial sources of heat loss if a building is not insulated. The window coverings (curtains or blinds) are used as insulation at night. Double glazing is considered a possible solution to reduce heat loss through infiltration.

6. INCREASING HEAT RETENTION CAPACITY

Thermal Properties

Passive solar buildings consist of two different types of material:

- Dense materials that can conduct and store heat such as brick and stone
- Low–density or lightweight materials that are neither good conductors nor can store heat.

The materials that permit energy transfer solely through conduction are known as opaque materials. Examples of such materials include stone, brick, and straw. A material's conductivity, or its capacity to transmit heat, increases with its density, which measures weight per unit of volume.

In construction, dense materials can carry the load of walls and roofs, making them load-bearing materials. Generally, denser materials can support greater loads than less dense ones. However, heat conduction is faster in dense materials. An informed choice can be made regarding the most appropriate materials for passive solar buildings because we understand that denser materials are effective heat conductors. For instance, we know that stone buildings are less warm than mud-brick ones since mud brick is less dense than stone, allowing heat to be transmitted through stone quickly and re-radiated into the outer atmosphere rapidly (Johra, 2021).

It requires a precise duration for heat to be transferred from one face of a wall to the other, which is referred to as the lag time. For instance, to transfer heat through a 35 cm thick mud-brick wall, a duration of 12 hours is required. Thus, the lag time here is 12 hours. The fact that the inside rooms absorb heat during the day and the cold of the night is retained by the inside rooms during the day makes mud-bricks an epitome of passive solar buildings. This can be explained in either way: as the walls are heated by the sun, the heat of the day is stored in them, and the interior is thus exposed to this heat at night (Bansal et al., 1994).

Transparent materials transfer solar radiation, allowing it to pass through. These materials are distinguished by their transparency. The transmission (τ) of glass is 0.9, representing the amount of incident radiation transferred, i.e., the quantity of light that travels through a translucent substance. When the sun is perpendicular (or at an angle of about 30 °), the transmittance is intense, but it drops sharply when the angle exceeds 50 °.

Insulation

To increase a building's internal temperature, simply expanding the solar collection area is not enough. Theoretically, this should provide ample heat storage within the walls, enabling a sustained inner temperature. However, this notion is misleading due to the behavior of materials. Heat continually escapes from the building to the exterior through conduction and convection. To minimize these losses, insulation becomes crucial, particularly on overcast days or during nighttime. Insulation helps keep warm air inside by reducing heat loss. The main culprits for these losses are conduction through windows or walls and air infiltration between the interior and exterior of the building, which leads to heat loss via convection. To counteract heat loss, it's essential to prevent air infiltration and properly insulate the walls and ceiling.

Wall – Materials, Design and Insulation

Low-density materials, such as straw, are the best insulation materials. Ladakh have some very potential insulation materials such as: Barley and wheat straw, mustard straw and husks, Wild bushes Yagzee, Sawdust and wood shavings Among these materials, some are already employed as animal fodder. One must beforehand determine if these can be used for construction without disrupting the system for providing animal feed. Since each of these materials is organic, getting them moist will cause them to rot.

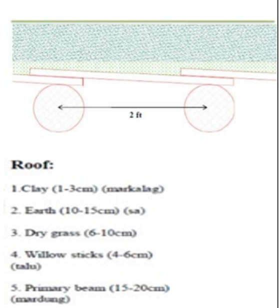
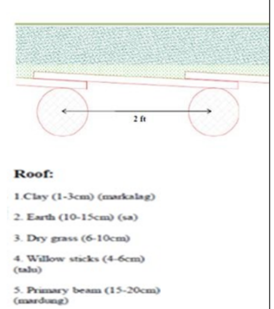
Table 5 wall design

Wall Design Random rubble stone wall design used with mud mortar. Header bond use for mud brick wall with mud mortar.	Ground floor – 3ft Stone wall First floor - 2ft Sun dried mud brick wall	Ground floor – 2ft Stone wall First floor - 1ft Sun dried mud brick wall
Wall material Local materials are used for the construction of walls.	Ground floor- Stone wall with mud mortar Frist floor – Sun dried mud brick	Ground floor- Stone wall with mud mortar Frist floor – Sun dried mud brick
Wall Insulation A thick stone wall absorbs heat during the day and radiates at night. Sun-dried mud brick reduces heat and cold transfer in the building	Ground floor Stone wall thickness is around 3ft First floor sun-dried mud brick wall thickness is 2ft	Ground floor Stone wall thickness is around 2ft First floor sun-dried mud brick wall thickness is 1ft

7. ROOF – MATERIALS, DESIGN, AND INSULATION

A traditional roof is composed of beams, local hardwood rounds (talboo or bailes), dry straw or insulation material , earth, and a clay covering for waterproofing, parapet along the periphery. For structures used during the day, the insulation layer should be 10 cm thick; for structures utilized at night, it should be 20 cm thick. The layer of earth is at least 15 centimeters thick. There are apertures in the north parapet every 1.5 meters because the stratum is slightly inclined to the backside to let rainwater drain away. To prevent water intrusion and damage to the insulating material and building interior, a 1-inch clay coating is applied to the earth's layer.

Table 6 Roof design

Roof Design 1st layer of clay to prevent water percolation. 2nd layer of earth for insulation. 3rd layer of grass to stop dust. 4th layer of willow sticks for load distribution. The 5th layer of the beam gives structural support.		
Roof materials Local materials are used for the construction of the roof.	Wooden beam, wooden sticks, Grass, Earth and Clay	Wooden beam, wooden sticks, Grass, Earth and Clay
Roof Insulation Earth and grass reduce the conduction.	Thickness of roof is around 50 cm with beam without beam around 30 cm.	Thickness of roof is around 50 cm with beam without beam around 30 cm.

Controlling heat flow

Table 7 Other Elements of Design – Parapet, and Main Entrance Portico

Main Entrance Case 1 The portico is added 20 year back it will reduce heat gain of the building. Case 2 Entrance without portico	**South Entrance** 	**East Entrance** 
Parapet The height of parapet is very less (20to 30cm) in both cases that will reduce shadow casting on the terrace which led to more heat gain		

During the day, the sides of buildings that are exposed to the sun absorb heat, whilst the opposite sides that are in the shadow lose heat (Stauffer & Hooper, 2000). This provides an aid in preventing overheating during the summer.

8. DISCUSSION

The two vernacular houses under comparison are situated in the cold and dry climate of Ladakh, with one house being approximately 100 years old and the other 75 years old. Both dwelling units are constructed using local materials, including stone, mud, and timber, reflecting the vernacular building techniques adapted to the harsh environmental conditions of the region. The case study houses exhibit a thoughtful amalgamation of vernacular passive design approach focus on improving thermal comfort in the harsh cold and dry climate, ensuring heat retention in winter, and maintaining thermal comfort temperature throughout the year.

The orientation of the house plays an important role in enhance solar radiation heat gain. House one is oriented southwest, while house two is oriented eastward, both thoughtfully positioned to capture maximum solar heat gain. This orientation allows direct solar heat radiation to enter the house during winter months, thereby increasing passive solar heating. Both houses are located in open spaces free from surrounding building structures, ensuring no obstruction to solar radiation. This unhampered exposure is important for supporting internal thermal comfort in winter season.

Both case study houses show a linear spatial planning, with a minimum area-to-volume ratio to reduce heat loss, a important factor in cold climate conditions. This compactness of the building volume enhance energy efficiency by decreasing the surface area exposed to the outside environment, which reduce heat loss to the surrounding. The configuration of both houses increase their ability to regulate heat gain and loss, as the vertical volumes give better thermal insulation through parallel ceilings and shared walls. House one has its longest façade facing towards southwest, which is thoughtfully designed to capture the solar radiation. The southwest-facing façade is fitted with a higher number of windows, maximizing solar heat gain. In contrast, the second-largest façade of house two faces south, promote the intake of solar radiation. Additional openings and the corner window are integrated on this façade, further increasing the house's capacity to absorb solar radiation.

The ground coverage of both case study houses reflects their compact nature, with house one occupying 15% of the total area and house two covering 7.5% ground coverage of the total site. This nominally low ground coverage helps minimize the heat loss generally associated with larger building footprints. The compactness of the buildings reduces exposure to the cold and harsh climate, promoting more efficient thermal regulation. In terms shading, both houses consist small shading masses, which allow for more heat gain through solar radiation. However, house one includes a portico added 20 years ago, which reduce heat gain on the southwest façade, somewhat reducing the solar benefits it might otherwise receive. House two, by contrast, has no such shading masses on enter, allowing for increased solar gain. The parapets in both houses are primarily low, which contributes to decrease the shadow casting on the terraces, thereby elevating additional heat gain on the roof surfaces. This design technique is particularly helpful for winter heating, as it enhance the amount of sunlight that received by the building's surfaces. Both houses also integrated a stable for cattle under the living and sleeping areas,that allows for the harnessing of heat produced by the animals it is an important design feature . This space is primarily used during the winter months, where the body heat of the cattle helps to warm the rooms above.

Local building construction materials include local stone, mud, wood and locally produced sun dried bricks, which are excellent thermal mass. The ground floor thick stone walls of both houses retain heat during the day and release it slowly during the nights, providing a appropriate interior temperatures. Additionally, the use of sun dried mud bricks in the walls reduces the rate of heat transfer, insulating the inner part from the outside temperature. The materials for roofs constructed are timber beams, willow sticks and covered with a mixture of earth, clay, and locally available materials, contributing to both insulation and stability. The random rubble stone walls, built with mud mortar, further enhance the thermal performance of the structures, as the solid, thick walls act as buffers, absorbing and releasing heat gradually. In both houses, air infiltration is minimized through well-designed buffer zones and tightly sealed doorways and windows. This reduces air exchange with the outside environment, helping to maintain a stable indoor temperature. These passive design features, combined with local materials and traditional building techniques, make these vernacular houses well-suited to Ladakh's cold, dry climate, offering a sustainable and energy-efficient solution for thermal comfort in the region.

9. RECOMMENDATIONS TO DESIGN A VERNACULAR PASSIVE SOLAR BUILDING

The recommendations for a passive solar building are determined at the initial stage of the design process the intended purpose of the building determines the building's specification. These specifications are actually the physical criteria which can not only affect the passive solar structures but also the design of any structure. They comprise of:

- Recommended number of rooms
- Desired area of each room
- Number of doors and windows

Although the phrase explicitly refers to the anticipated use of the building the proposed usage of the building which includes:

- The building's intended use i.e. for domestic residence, office, storeroom etc.
- Whether it will be used in summer, winter or throughout the year.
- Whether it will be used in day, night or whole day.
- The total number of residents about to use the building.

The following design recommendations for multi-story buildings should be followed:

- Cattle and other livestock should be kept on the ground floor.
- Rooms that are primarily used in the winters should be located on the first floor.
- Accommodations that are utilized primarily in the summers should be located on the second floor.
- In order to create a buffer zone, storerooms and other infrequently used spaces should be placed on the north facing side.
- The rooms which are more frequently used such as kitchen, living room and the bedroom should be kept on the south facing direction.
- The areas mostly used in the mornings should be positioned in the east facing direction.
- The areas used primarily at night should be located in the west-facing direction

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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