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Climate Responsive Strategies in Vernacular Architecture: A Comparative Analysis at Various Latitude

Laura Estrada D'amato[1], Sunanda Kapoor[2]*

[1]Chalmers University of Technology, Sweden, [2]Manipal University Jaipur, India. *Corresponding Author's Email: sunanda.kapoor@jaipur.manipal.edu

Abstract

Climatic responsive strategies represent a systematic approach that meticulously considers climatic and environmental parameters during the architectural design phase, aiming to achieve optimal thermal comfort while minimizing energy consumption. Across the globe, millenary cultures and civilizations have learned to read their local climate to adapt their constructions to the natural habitat, using available resources in the immediate environment, developing unique vernacular architectures in each corner of the world. The current study highlights the pivotal role of climate responsive strategies in the design of vernacular architecture across diverse latitudinal contexts, identifying techniques and methods that can help us today to build more comfortable spaces using local resources, less energy demand, and decreasing the overall carbon footprint of the constructions. This approach leads to sustainable architecture and can be a great tool to rescue local traditions and cultural heritage as a relevant technology on a globalized world. This study reveals a spectrum of passive strategies actively explored and implemented within the realm of vernacular architecture in four distinct cultural and environmental contexts, such as India, Colombia, Sweden, and South Africa. The climatic responsive strategies of vernacular buildings at these locations have been analysed with the help of case study and Mahoney table. The research findings affirm that climate responsive architecture, through the judicious application of passive measures, presents itself as an efficacious strategy to overcome unfavourable climatic conditions.

Keywords: Climate-Responsive Architecture, Passive Strategies, Thermal Comfort, Vernacular Architecture.

Introduction

Climate responsive design is to plan for maximum comfort with the least amount of energy use by considering the climate and environmental conditions (1). This research is based upon the query "In what ways the thermal comfort of the occupants was enhanced by the solar passive strategies employed in vernacular architecture?" Research findings by Chandel *et al.,* (2016) have demonstrated that a considerable proportion of energy consumption within residential settings is dedicated solely to the preservation of indoor thermal comfort (2). Thus, this is the responsibility on architects/ designers to sensitively incorporate the passive strategies in the contemporary architecture. The observation at various historic cities underlines the thrust behind the research, which seeks to examine the intricate interplay between thermal comfort, energy efficiency, and the intrinsic passive environmental control techniques inherent in traditional vernacular architecture. The behaviour of buildings and the comfort of their occupants are profoundly impacted by climatic conditions, with solar radiation, temperature, wind, humidity, and sky conditions standing out as pivotal determinants (3). In this article, these factors have been subjected to meticulous analysis across various latitudes to gain comprehensive insights into their influence on the broader architectural design of vernacular architecture. Four distinct global locations, Barichari Columbia [Latitude: 6.39˚N], Jaipur, India [Latitude: 26.9˚N], Gothenburg, Sweden [Latitude: 57.7˚N] and Cape town, South Africa [Latitude: 33.55˚S] have been identified for analysis. In these locations, case examples of vernacular buildings have been taken up to understand Climate responsive strategies.

The comprehensive review undertaken in this paper has given the opportunity to draw conclusions about climatic responsive architectural strategies, which have been successfully applied in various regions and exhibit

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the potential for adoption in areas with similar climatic conditions. These passive strategies tailored to the unique demands of their respective climates have demonstrated their efficacy in addressing solar protection, humidity regulation, and temperature control which have yielded substantial energy savings. This study further highlights that the incorporation of Climate responsive strategies not only yields substantial energy savings in the heating and cooling of buildings but also facilitates the creation of a comfortable indoor environment. These features stimulate a consistent, gentle airflow within structures, resulting in a harmonized equilibrium of temperature and humidity irrespective of external climatic variations. This paper comprehends documentation of climate responsive design principles and its relationship with vernacular architectural, within the distinct geographic contexts of Jaipur, Barichara, Gothenburg, and Cape town, with the objective of acknowledging passive strategies which are demonstrated in the vernacular buildings and can be further translated into contemporary construction.

These particular latitudes: 6.39˚N, 26.9˚N, 57.7˚N, and 33.55˚S has been chosen with care to ensure a thorough investigation of how vernacular architecture adapts to various climatic circumstances and environmental difficulties. Traditional architectural solutions created in response to different environmental elements can be broadly compared because each latitude indicates a different climatic zone. The equatorial region at 6.39˚N, for instance, sees hot, humid weather all year round, which encourages the use of lightweight, well-ventilated structures that promote airflow and reduce heat accumulation. The 26.9˚N latitude, on the other hand, which includes desert and subtropical areas, offers a chance to experiment with design features that combat high heat and dryness, such as thick walls, shaded courtyards, and water-efficient systems. Comparably, the latitude of 57.7˚N is located in a cold temperate to subarctic climate, where vernacular architecture places a premium on compact forms, steep roofs, and thermal insulation to control heavy snowfall and maintain warmth throughout the long winter months. Finally, the addition of 33.55˚S reflects the architectural responses of temperate or Mediterranean regions, where the need to balance hot summers and chilly winters has prompted the adoption of high thermal mass materials, cross-ventilation techniques, and shaded patios.

Literature study for Climate responsive strategies in vernacular architecture has been conducted to gain valuable insights into the sustainable and climate-responsive design principles that have been developed and practiced over centuries in various regions around the world. Extensive literature exists within the realm of thermal comfort, climate adaptability, and Climate responsive design. The concept of Climate responsive architecture is deeply rooted in architectural science, particularly architectural energetics. It advocates for the elimination of energy-inefficient and dehumanizing environments, challenging the prevalent use of glass-clad structures and towering mechanical skyscrapers (4). Vernacular architecture, developed over several generations, necessarily includes elements or functions that ensure a comfortable microclimatic indoor environment, effectively using natural ventilation and solar energy (5). T Esfehankalateh *et al.,* 2022 (6) has clearly stated that throughout history, strategies tailored to the unique characteristics of individual climates have demonstrated enduring efficacy and reliability in the creation of habitable environments that cater to the needs and comfort of their occupants. According to Hassan Fathy 1986 (7), different architectural forms in the various climates have developed naturally from ideas that are supported by science to highlight the benefits of a variety of locally accessible construction materials and conventional building techniques. Victor Olgay, 2015 (8) in his book titled ‘Design with Climate’ discussed about the challenges of unifying climate control and building functionality for securing a managed environment within a natural setting and combating the harsh forces of wind, water, and sun. Amon Rapoport,1999 (9) has elaborated the study of vernacular design and emphasized upon its necessity to be so structured as to contribute to the development of an explanatory theory of environment. Paul Oliver, 2006 (10) clearly stated that by the application of vernacular architecture, there can be less wasteful in energy for heating and cooling appliances. Based on a comprehensive review of the literature, the study has ascertained that climate exerts a substantial influence on the behaviour of buildings and the overall well-being of their occupants. Notably, solar radiation, temperature, wind patterns, humidity levels, and sky conditions emerge as the foremost determinants significantly impacting human comfort within both outdoor and indoor environments.

Methodology

The primary objective of this study is to highlight the significance of Climate responsive strategies in the context of vernacular architecture design. The research has been structured into the following sequential steps (Figure 1):

- **Literature studies:** Review of studies based upon Climate responsive strategies. Understanding of climate responsive architecture of vernacular buildings with reference to the main six elements of climate: Radiation, temperature, winds, precipitation, humidity, and sky condition. For better understanding comparative analysis of tropical climate, hot-dry, warm-humid and composite climate has been carried out w.r.t. elements of climate.
- **Selection of Case Study:** Vernacular buildings from four locations with distinct climatic features have been chosen to be compared for different strategies of adaptation to the environment. The selection criteria included the scale and use of the building. The cultural and environmental diversity of the locations has also been taken into consideration.
- **Discussion on the influence of climate on the architecture features**: For this step, each case study has been analysed using solar charts and climate data. The incidence of solar radiation on the buildings has been graphically analysed. This analysis explained the main requirements and challenges at each location.
- **Understanding Solar Passive Strategies:** Illustrate strategies implemented in each study case to overcome environmental struggles and the efficient utilization of natural resources, to provide comfort conditions to their inhabitants.
- **Comparative Analysis:** Compare differences and similarities between the four locations and draw conclusions about relevant strategies that can be used nowadays as references for contemporary challenges and possible adaptations, considering current technologies and materials.

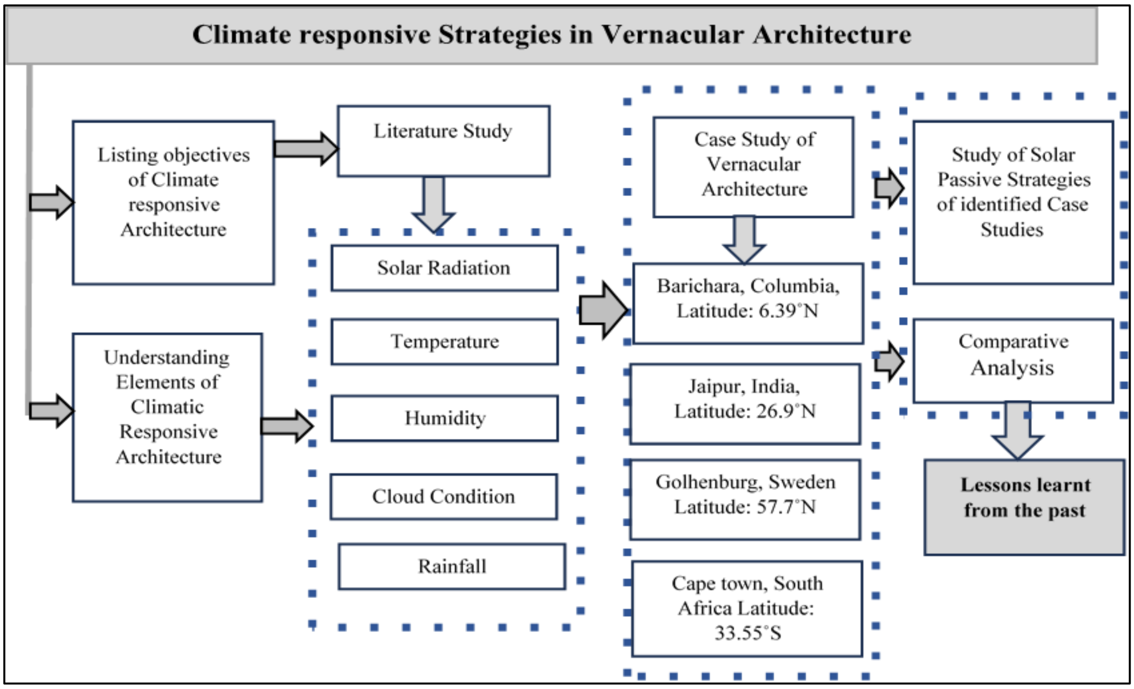

Figure 1: Methodology for Research

Throughout history, vernacular architecture has skilfully employed the prevalent solar passive techniques to creäte unique traditional buildings (11-13). This ingenious utilization of environmental conditions has been pivotal in enhancing thermal comfort in buildings. These architectural achievements stand as symbolic indexes of cultural identity and sources of pride for locals. The following section will present a comprehensive exploration of the diverse strategies employed at various latitudes to adapt resourcefully to their natural surroundings, with a specific focus on the utilization of locally available materials.

Understanding Climatic Characteristics of Tropical Climate

Climate influences buildings' behaviour and their inhabitants' wellbeing. The tropical climate has been broadly classified into three categories: hot-dry, warm-humid, and composite climate. To understand the characteristics of tropical climate, comparative analysis has been demonstrated with relation to the elements of climate, solar radiation, temperature, wind, humidity, and sky condition (Figure 2).

- **Solar Radiation:** The solar altitude angle is the angle between the sun and the horizontal plane at a specific location and time. The altitude angle can be calculated using trigonometric functions and the latitude of the location, the solar declination angle, and the hour angle. The formula for calculating the solar altitude angle (α) is as follows (14):

$\sin(\alpha)=\sin(\varphi).\ \sin(\delta)+\cos(\varphi).\ \cos(\delta).\ \cos(H)$

where, α is the solar altitude angle; φ is the latitude of the location; δ is the latitude of the location. H is the hour angle, which represents the time of day and is measured in degrees.

  - The solar altitude angle serves as a critical determinant in establishing the appropriate balance between solid and void relationship of wall, as well as in the design of shading devices. This strategic consideration aims to mitigate the impact of the summer sun while facilitating the entry of the winter sun into indoor spaces.
  - **Air temperature:** Air temperature varies significantly in different climates. For instance, in a hot and dry climate like India (26°N), there's a wide diurnal temperature range, with winter lows around 8°C and summer highs reaching approximately 45°C (16). In contrast, the tropical upland climate of the in Colombia sees temperature variations according to altitude, ranging from over 24°C at sea level to below 6°C at altitudes above 4000m (17). Meanwhile, the warm and humid climate of Congo maintains relatively stable temperatures year-round with minor fluctuations between day and night and between dry and wet seasons (18).
- **Wind:** In Colombia, the ITCZ movements create dry, windy conditions (December–April), a transitional phase (May–July), and a rainy season (August–November), subject to variations influenced by the American monsoon system, proximity to the Caribbean Sea, low-level atmospheric winds, and 'El Niño' and 'La Niña' phenomena (19). In India, the Thar Desert's heating leads to ocean-to-land winds from June to September. In Congo, the rainy season spans April to October, followed by a dry season from November to March.
- **Humidity:** Humidity is the amount of moist present in the air, it depends both on the air temperature and the actual amount of water vapour present in the air, it also indicates the evaporation potential, or the amount of moisture the air can hold. It directly affects the thermal sensation of the place. In warm-humid climates like Congo the humidity remains high at about 75% for most of the time while in monsoon climates like Jaipur it varies from 20-55% during dry periods to 55-95% during rainy seasons; for the tropical upland climates, the humidity varies from 45% and 95% (20).
- **Precipitation:** Both in warm-humid and upland climates, rain is high through the year, with more intense months from May to October in the example of Santa Marta, Colombia and the opposite moths in Kinshasa, Congo; on the other hand, in monsoon climates, precipitation varies much more between dry and wet seasons.
- **Sky Conditions:** Sky condition can affect the amount of radiation that get to the surface, and with this, the temperature and natural light on the site, it is usually described in terms of clouds presence. In hot-dry climates sky conditions are normally clear or with a few clouds due to the low humidity. On the other hand, in more humid climates, the cloudy conditions, filter only some of the solar radiation during the day but also trap the residual heat during the nights, which can explain the lower temperature shifts in these regions.

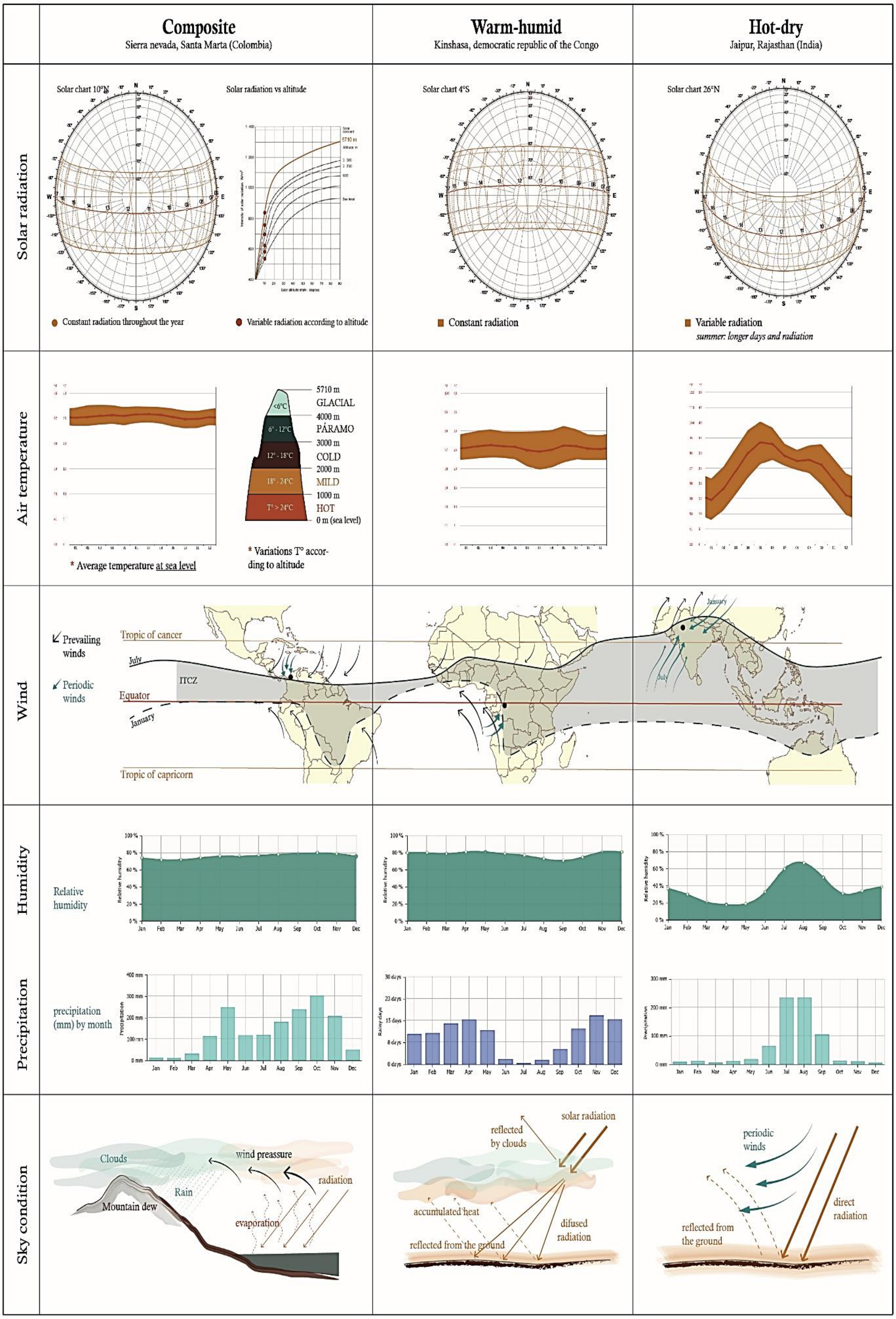

Figure 2: Climatic Characteristics of Tropical Climate (15)

In the next section the discussion on how the impact of climatic condition of a location plays a crucial role in designing buildings. Vernacular architecture refers to traditional building practices and designs that have developed over time in response to specific environmental and climatic conditions.

Case Study

Vernacular architecture is deeply shaped by the interplay of cultural influences, climatic conditions, and the local availability of resources. To offer a comprehensive perspective on instances where these factors manifest prominently, this study has meticulously chosen four distinct locations based on the following criteria: cultural attributes (encompassing ethnicities, religions, heritage, etc.), geographical characteristics (including latitude, elevation, and continental positioning), and natural environmental conditions (specifically climate and the availability of resources) (Figure 3). This classification methodology aligns with the framework employed by Zhiqiang and Previtali published in 2009. Consequently, the study has designated the following regions as its focal points, the tropical equatorial climate of the Colombian mountains, the arid-hot, semi-arid climate prevalent in Rajasthan, the subpolar conditions characterizing Sweden, and the temperate, Mediterranean climate found within the South African savannah (Figure 4).

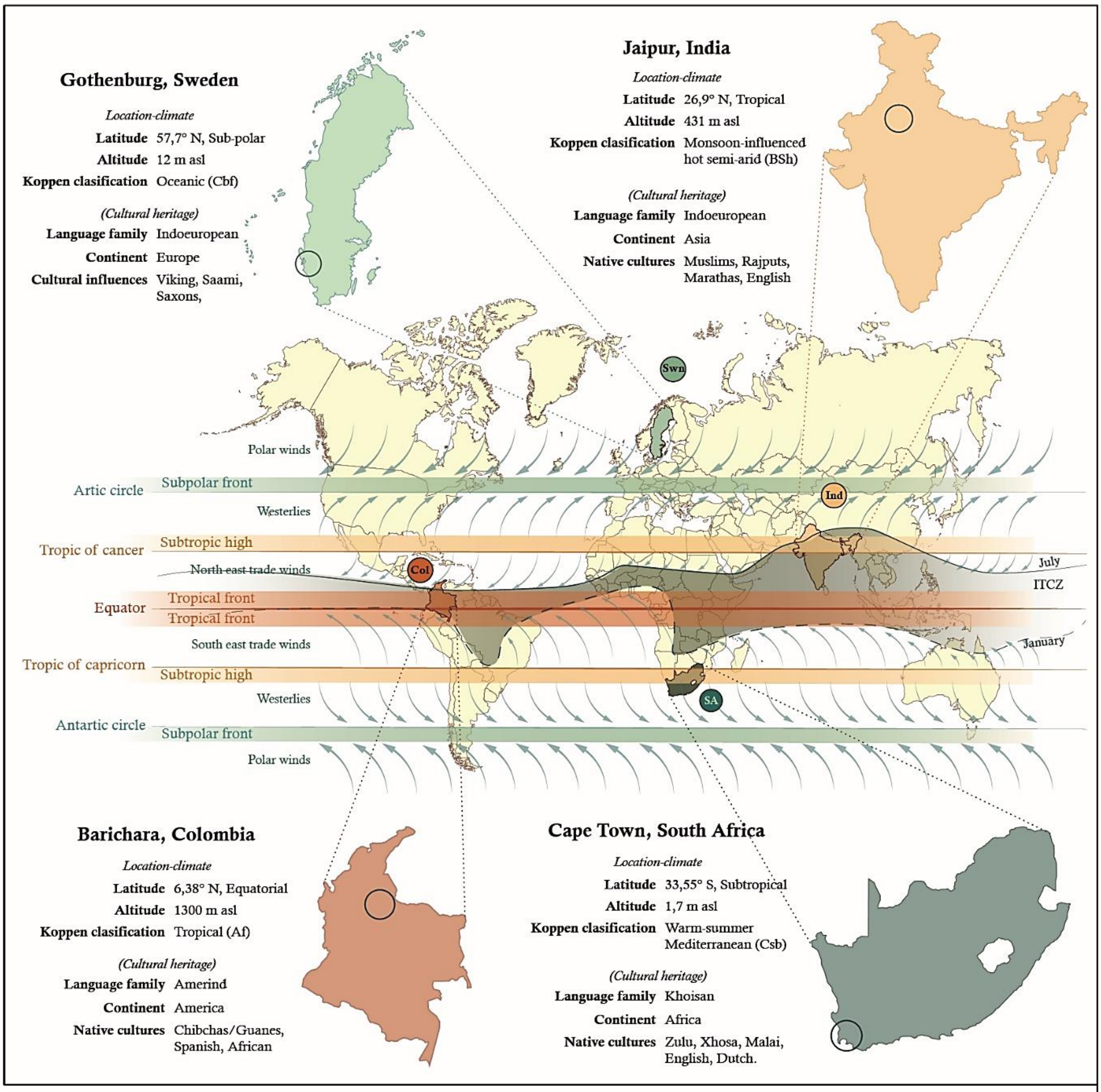

Figure 3: Location of Identified Case Studies for Analysis (21)

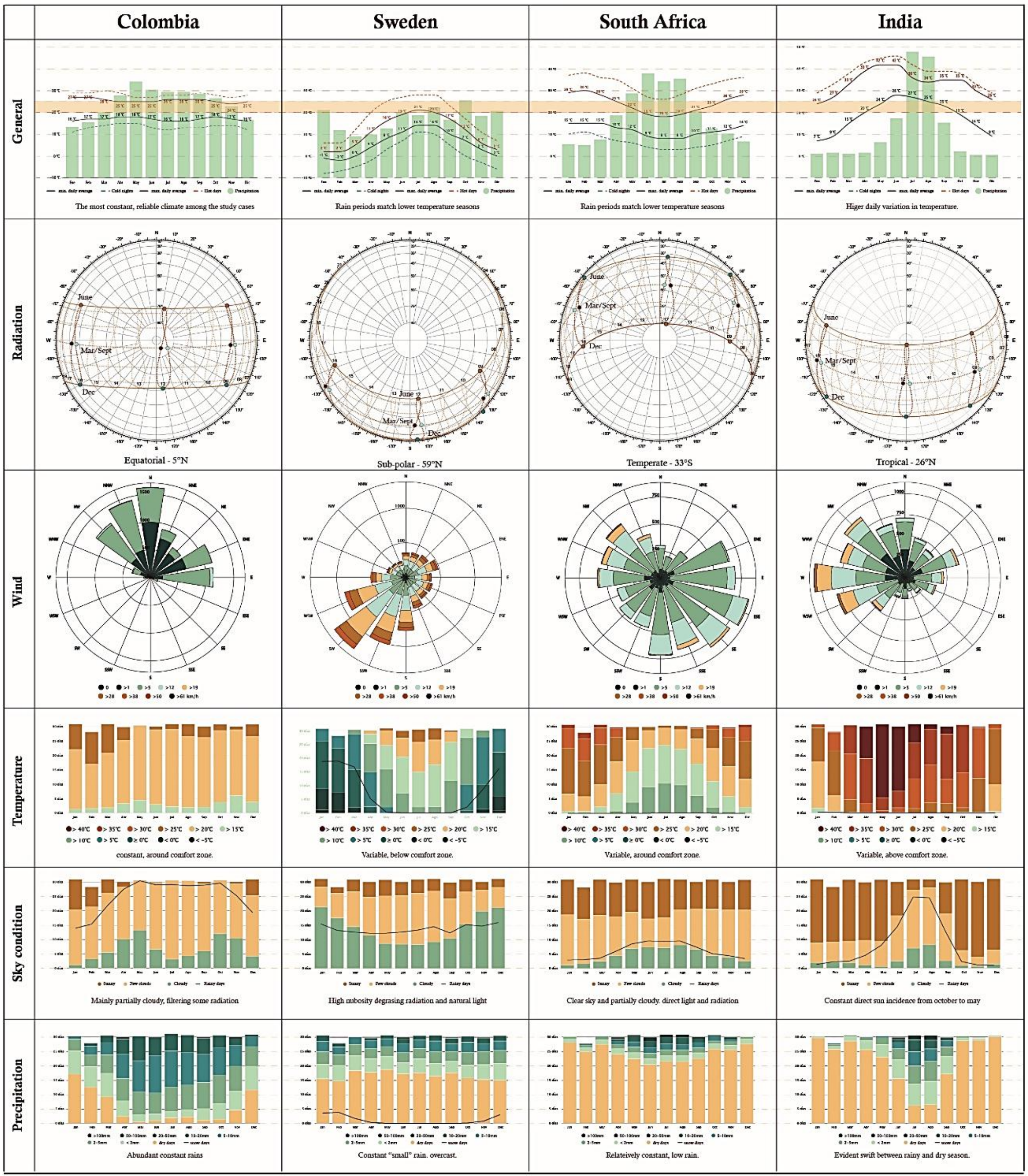

Figure 4: Comparative Analysis of Climate at Four Identified Locations (22)

These diverse locales have been selected to provide rich insights into the nuanced relationship between vernacular architecture and the multifaceted contexts in which it thrives.

The Vernacular architecture of identified case studies have been analysed under following headings:

- **Climate Adaptation:** Designers of vernacular buildings considered climate to design that can naturally maintain comfortable indoor temperatures through passive means. For example, buildings in hot climates may incorporate features like thick walls, shading devices, and natural ventilation to minimize heat gain and maximize cooling.
- **Material Selection:** Vernacular architecture often relies on locally sourced materials that have specific thermal properties. Understanding the thermal behaviour of these materials and their interaction with the surrounding environment is crucial for designing energy-efficient buildings. The thermal balance equation helps in assessing

how different materials affect the heat transfer within a structure.

- **Passive Heating and Cooling:** Vernacular architecture often leverages passive heating and cooling strategies to minimize the need for mechanical HVAC systems. These strategies may involve orienting buildings to maximize solar gain in cold climates or designing for natural ventilation and shading in hot climates.
- **Thermal Mass:** Many vernacular buildings incorporate thermal mass, such as adobe or rammed earth, to store and release heat slowly, helping to stabilize indoor temperatures. The thermal balance equation can be used to analyse how thermal mass impacts the energy performance of a building.
- **Energy Efficiency:** Vernacular architecture aims to reduce energy consumption by optimizing building design and layout. The thermal balance equation is a tool for evaluating and improving the energy efficiency of these buildings.

Barichara, Columbia: Latitude 6.39˚N

Columbia, South Carolina, is known for its warm and humid subtropical climate. Vernacular buildings in this region historically have architectural features that respond to the local climate. Barichara, located in Colombia, is known for its well-preserved colonial architecture and vernacular building styles that have evolved over the centuries. The identified vernacular building from the region is a residential building built in 1920 (23). The building features central courtyard and compressed mud construction (Figure 5). The thickness of the walls is approximately 700mm which increases the thermal mass, increases the time-lag and helps in keeping the indoors cool.

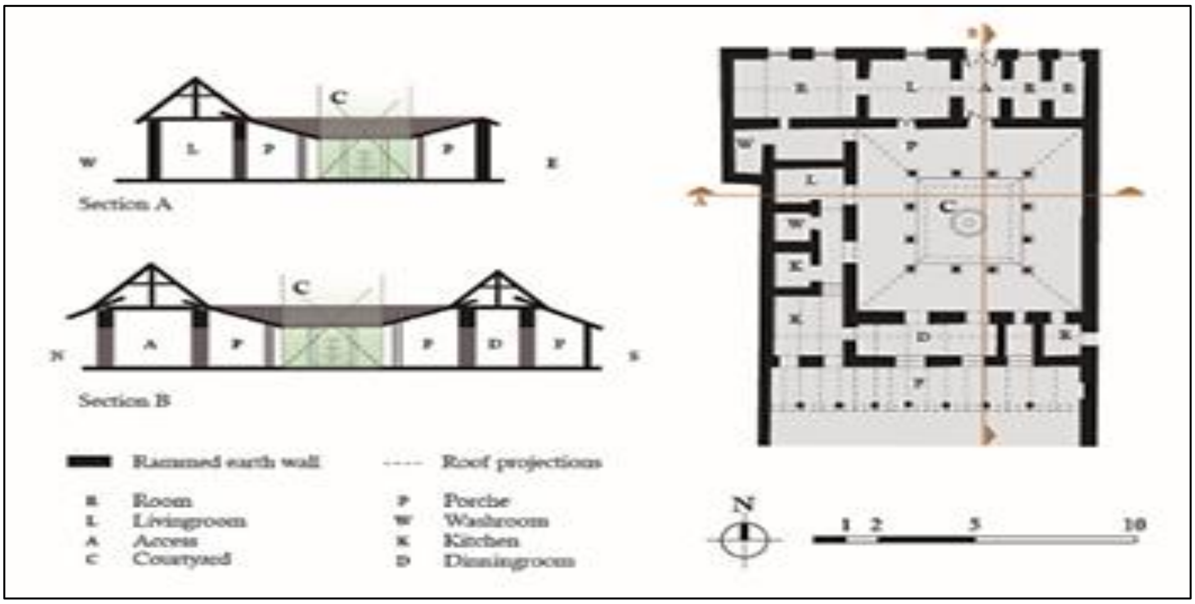

Figure 5: Plan and Section of Vernacular Building at Latitude 6.39˚N (23)

Figure 6: Visuals of Identified Vernacular Building at Latitude 6.39˚N (23)

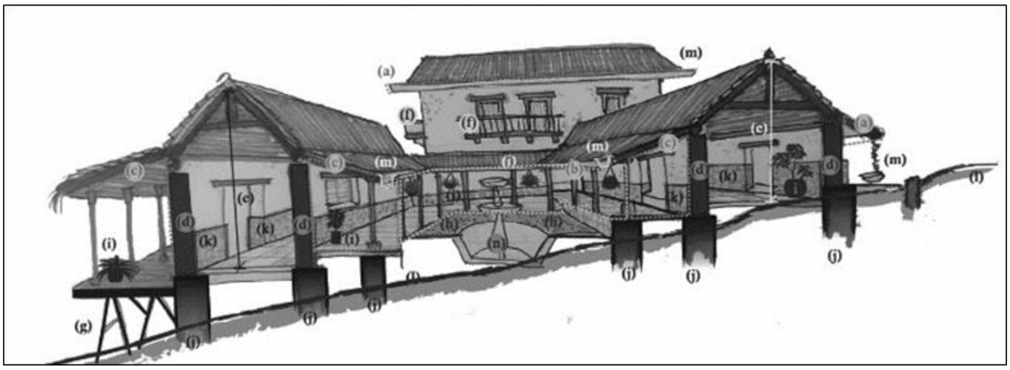

Figure 7: Climate Responsive Strategies at Vernacular Architecture in Colombia

Table 1: Architecture of Vernacular Building in Response to the Local Climatic Condition of Columbia

Climatic condition		Need	Climate response
Radiation	High, constant, vertical incidence	Protection mainly on horizontal planes as sun is usually at high angles	Roof overhangs (a), patio/courtyard (b) and corridor (c). (sun buffer)
Temperature	Warm throughout year	Cool down during day hours, preserve heat at night	High thermal mass (d), interior spaces height (e), fountains (n)
Wind	Slow (1-12km/h)	Maximize wind currents	Cross ventilation through patios (b) balconies (f), external corridors (c), Elevated constructions (g)
Humidity	Relatively high and constant (76%-86%)	Maintain as low as possible	Internal gardens (h) and plants to catch humidity (i)
Precipitation	High throughout the year mainly from April-oct.	Protect buildings from direct rain incidence. Protect public space from flooding	Foundations (j) elevation (g), plinth (k), sloped terrain adaptation (I), rain catcher(m)
Sky	Usually clouds	Avoid direct sunlight	Stone foundations (j), Patios (e)

Table 2: Solar Altitude angle at Latitude 6.39˚N [Barichara]

Month	Time in hrs						
	07:00	08:00	10:00	12:00	14:00	16:00	17:00
Jan	8	21	44	60	52	31	16
Feb	6	19	45	65	58	32	20
March	6	22	53	74	66	44	21
April	11	25	55	85	65	36	21
May	13	28	56	80	62	34	19
June	12	26	53	90	60	33	19
July	13	28	56	80	62	34	19
Aug	11	25	55	85	65	36	21
Sept	6	22	53	74	66	44	21
Oct	6	19	45	65	58	32	16
Nov	8	21	44	60	52	31	16
Dec	10	24	48	62	49	26	12

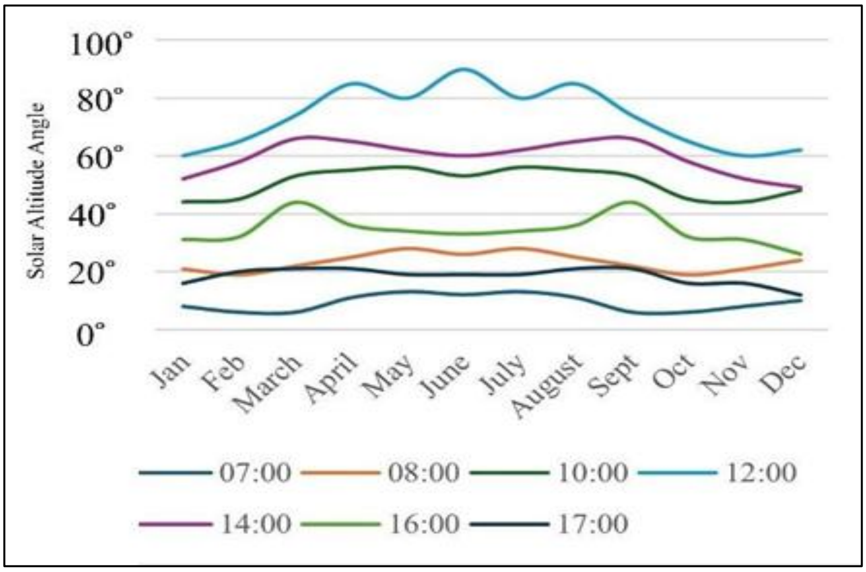

Figure 8: Solar Altitude Angle at Latitude 6.39˚N

The response of the vernacular building to the local climatic conditions have been listed and demonstrated in Table 1 and Figure 7. The relationship between solar altitude angles (Table 2 and Figure 8) and vernacular architecture in Barichara, as in many other regions, is significant due to its influence on architectural design, comfort, and energy efficiency.

This can be observed from Figure 9, that the solar altitude angle is high during summer months which can easily be protected by horizontal overhangs.

The courtyard is also playing important role in the protection from solar radiation during summer. As seen in Figure 6, solar altitude angle of sun is high in the afternoon i.e. 70˚, 86˚ and 61˚. Here are some climate-responsive aspects found in these vernacular buildings in Columbia, South Carolina:

- **Wide Porches and Overhangs**: To provide shade and protection from the sun and rain, vernacular buildings often feature wide porches and roof overhangs. These architectural elements help keep the interiors cooler and more comfortable.
- **Cross-Ventilation:** As the region is dominated with high humidity, house has been typically designed with cross-ventilation in mind. Multiple windows and doors on opposite sides of a building can be opened to create airflow and reduce the need for mechanical cooling.
- **Tall Ceilings:** High ceiling has been observed in historic vernacular buildings. This feature is based upon the stack effect which allows hot air to rise, keeping the living spaces cooler, and it also provides better air circulation.
- **Materials:** The building materials include wood and brick. These materials have insulating properties that help regulate indoor temperatures. Vernacular architecture often emphasizes the use of local and natural materials, which can have lower embodied energy and environmental impact compared to modern construction materials.
- **Louvered Shutters**: There are louvered shutters that can be adjusted to control the amount of sunlight and airflow entering the building.
- **Landscaping**: Landscaping with native plants and shade trees can further help with temperature regulation by providing natural shade and reducing the heat island effect.

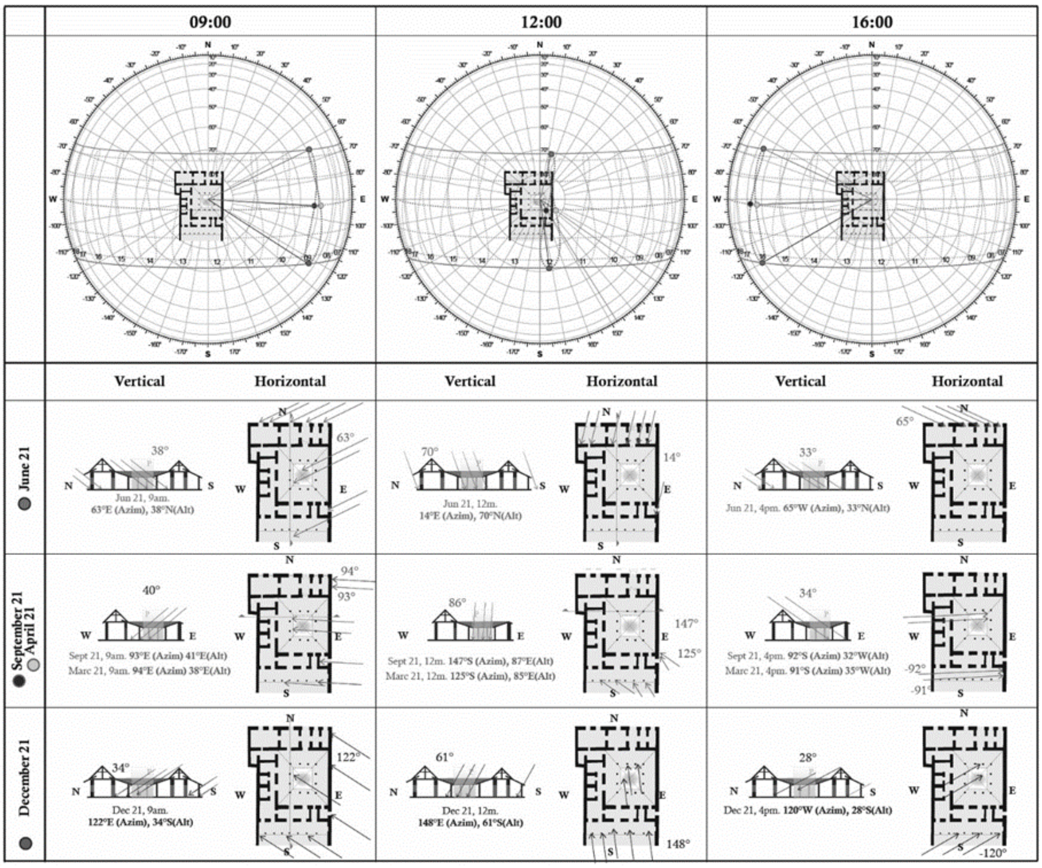

Figure 9: Incidence of Solar Radiation on Identified Building at Specific Time and Month

Jaipur, India: Latitude 26.9°N

Jaipur, situated in the Aravali foothills, is bounded by hills to the north and east and plains to the west and south. It marks the eastern edge of the Thar desert, with an altitude of about 400 meters above sea level. Intense summer solar radiation in Jaipur primarily comes from the south. Local architecture addresses the challenge of creating comfort in high temperatures, intense sunlight, and variable humidity. Vernacular architecture in Jaipur focuses on shielding interior spaces from direct sunlight and maintaining air temperature. The Tatiwali Haveli, located in Jaipur's walled city, is a 300-year-old example of this architectural tradition which is still in use has been taken for analysis (Figure 10 and 11).

Climate-responsive architecture in Jaipur, like in many parts of India, is influenced by the region's hot and dry climate. Climate responsive strategies adopted in vernacular architecture of Rajasthan have been listed in Table 3 and Figure 12.

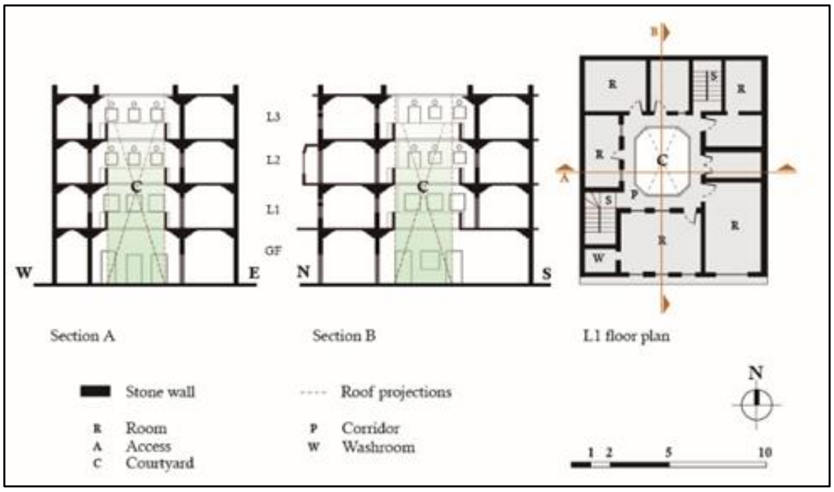

Figure 10: Plan and Section of Identified Vernacular Building, Tatiwali havali at Latitude 26.9°N

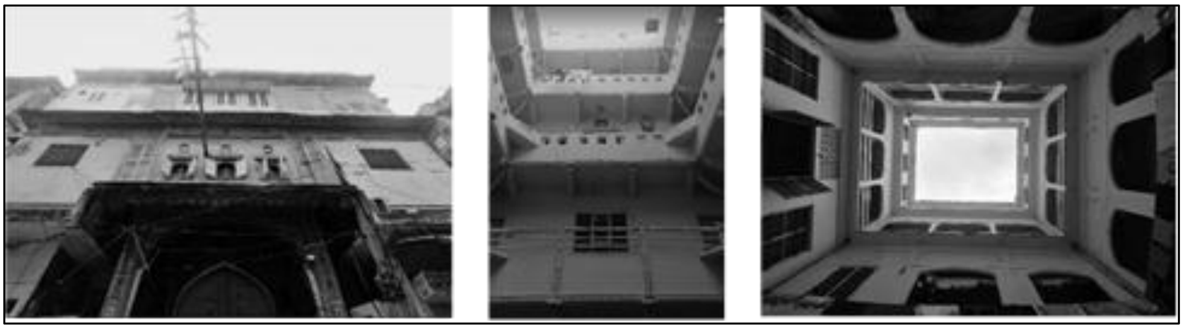

Figure 11: Visuals of Tatiwali havali at Latitude 26.9°N

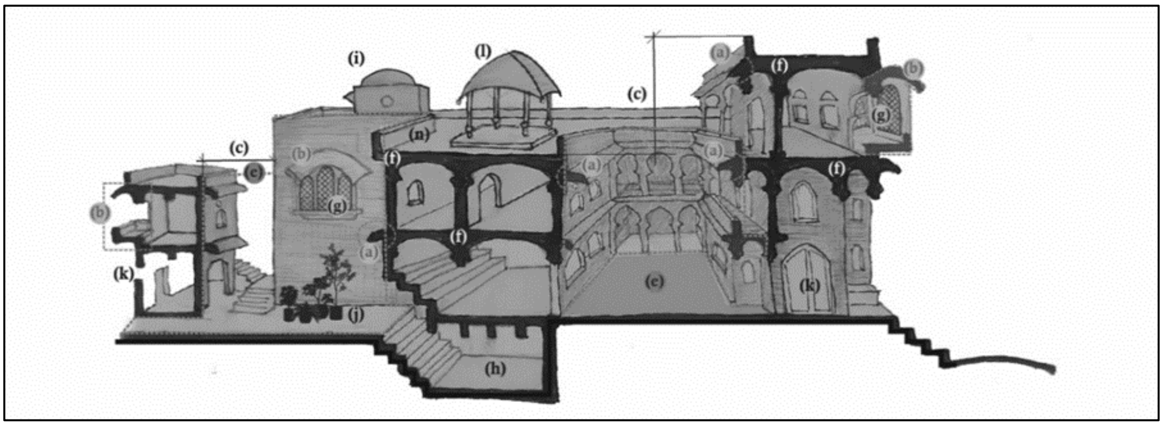

Figure 12: Climatic Responsive Strategies of Vernacular Architecture of Rajasthan

Table 3: Architecture of Vernacular Building in Response to the Local Climatic of Jaipur

Climatic condition		Need	Climate response
Radiation	High, semi variable	Avoid direct solar incidence. Protection on horizontal and vertical planes.	Overhangs (a), jharokas/ balconies (b), height differences (c), dense clustering (d), courtyard (e)
Temperature	Hot, Strong yearly variation	Cool down most of the year	Solar orientation, High thermal mass (f), solar filters (jaalis) (g), basements (h)
Wind	Moderate (5-19km/h)	Using existing wind currents	Courtyards (e) wind traps (i), jaalis (g), interconnected vertical shafts (not in sketch)
Humidity	Relatively low and vary (approx21% apr-76% aug)	Humidify in dry summer season to refresh environment	Wind chimneys with ‘humidifiers’ (not in sketch), aromatic gardens (j)
Precipitation	Demarked dry and rainy season	During rainy season, save water for dry periods. Protect from dust during dry seasons.	Stepwells and foundations for dry season (not in sketch), indirect entrances (k), humidifiers
Sky	Relatively constant clear sky, except rainy season	Preserve heat after sun hours (decrease ‘I’, difference between day & night)	Jaalis (g), chhatris (I) and Jharokas (b)

The solar altitude angle significantly influences the design and orientation of vernacular architecture in Jaipur. Ancient designers leverage their knowledge of the sun's path to create climate-responsive and sustainable buildings suited to the region's conditions. As per solar chart, the solar altitude angle is high during summer months and low during winter months (Table 4 and Figure 13). The influence of same can be seen in the design of vernacular architecture. In the Figure 14, it can be seen that the courtyard of the haveli is in shade during most of the time as high-altitude solar radiations during summer months are being screened by the building mass on other side.

Table 4: Solar Altitude Angle at Latitude 26.9°N [Jaipur], India

Month	Time in hrs						
	06:00	08:00	10:00	12:00	14:00	16:00	18:00
Jan		18	31	40	32	15	
Feb		21	40	50	41	20	
March	4	28	48	60	49	28	4
April	9	33	56	70	55	32	8
May	13	36	58	80	60	38	11
June	14	38	60	88	61	42	13
July	13	39	58	80	60	38	11
Aug	9	33	56	70	55	32	8
Sept	4	28	48	60	49	28	4
Oct		20	40	50	41	20	
Nov		15	31	40	32	15	
Dec		12	29	35	30	13	

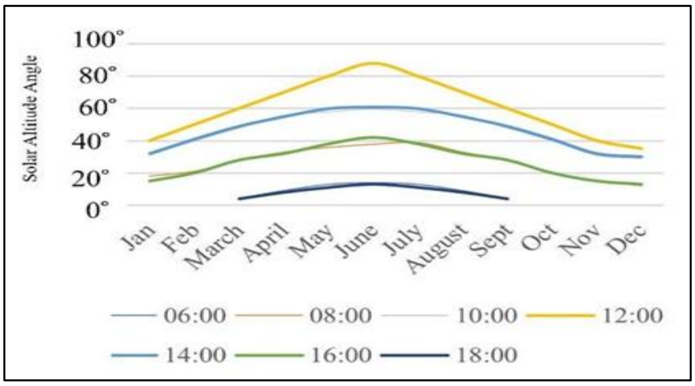

Figure 13: Solar Altitude Angle at Latitude 26.9°N

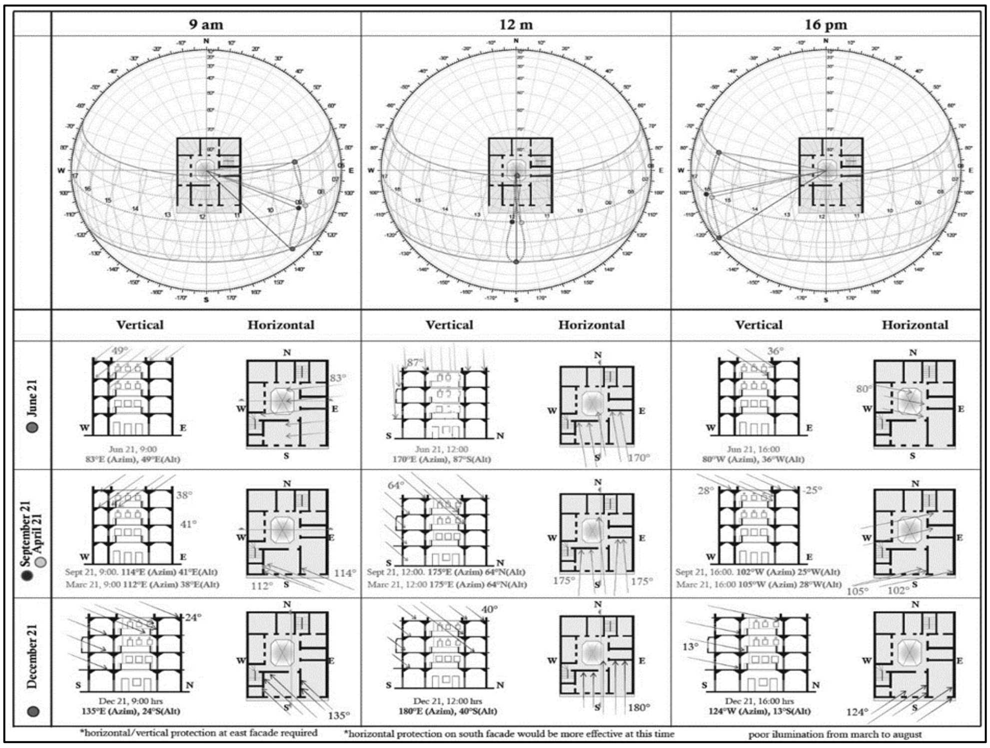

Figure 14: Incidence of Solar Radiation on Identified Building at Specific Time and Month

Vernacular architecture in Jaipur incorporates traditional building techniques, materials, and design principles that help to naturally cool and ventilate buildings while providing shade and protection from the harsh sun. Here are some key features of climate-responsive vernacular architecture in Jaipur:

- **Orientation and Layout**
  - Buildings are typically oriented in a way that minimizes direct exposure to the sun during the hottest part of the day. North-south orientation is common to maximize shading on the longer sides of the building.
  - Courtyards are often incorporated into the layout to facilitate cross-ventilation and provide a cool, shaded spaces.
- **Thermal Mass**

Thick walls made from locally available materials like stone, clay, or adobe are used to provide thermal mass. These materials absorb heat during the day and release it slowly at night, helping to maintain a more stable indoor temperature.

- **Jaali**

Jaali screens made from stone or wood are used on windows and walls to filter and diffuse sunlight. They allow for natural light and ventilation while reducing direct solar gain and providing privacy.

- **Roof Design**
  - Flat roof has been provided to protect against the sun. Rooftop terraces are also used for outdoor living during cooler evenings.
  - Traditional techniques like lime plaster and waterproofing with materials like terracotta tiles are used to keep roofs cool.
- **Shading Devices**
  - Overhanging eaves, pergolas, and verandas provide shade to windows and walls, preventing direct sunlight from entering the interior spaces.
  - Traditional *chajjas* (projections) are used to shade openings and maintain comfort inside.
- **Ventilation**

Most of the ventilation to the indoors is happening from courtyard. There are very small windows on the exterior façade with wooden shutters, which are kept closed during the daytime.

- **Use of Indigenous Materials**

Local stone has been applied for the construction, as they are readily available and adapted to the climate. These materials have the advantage of thermal mass and insulation properties.

Gothenburg, Sweden: Latitude 57.7˚N

Climate-responsive architecture in Gothenburg, Sweden, is influenced by the city's unique climate conditions, which include cold winters, mild summers, and significant rainfall throughout the year. The below mentioned residential vernacular building (Figure 15 and 16) from this region has been take for understanding the climate responsive practices.

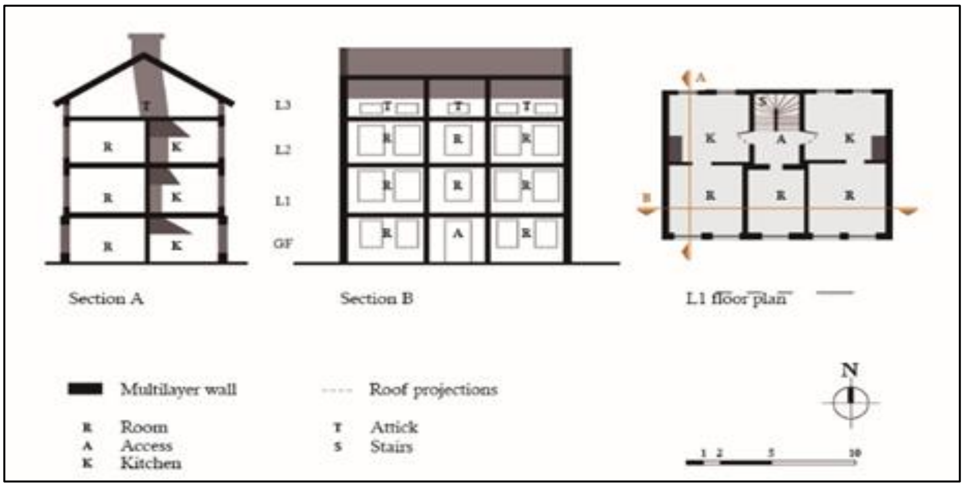

Figure 15: Plan and Section of Identified Vernacular Building at Latitude 57.7˚N (24)

Figure 16: Visuals of identified vernacular building at Latitude 57.7° (24)

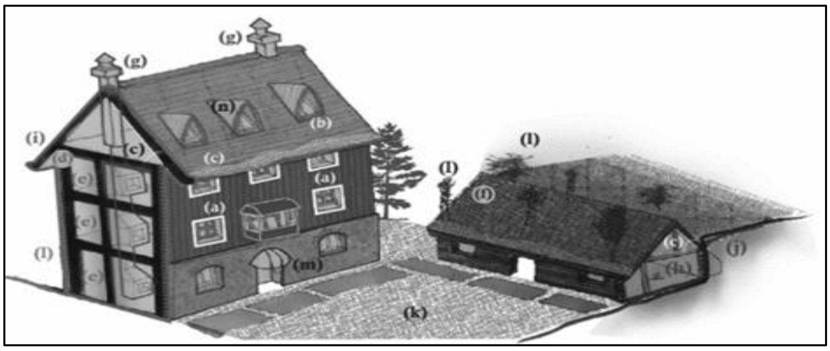

Figure 17: Climate Responsive Strategies in Scandinavian Vernacular Architecture

As per climatic data, for most parts of the year outdoor thermal comfort is poor due to low air temperature, strong winds and low solar radiation. Overall compact planning has been observed. The objective of the typology of architecture is to reduce the heat loss. The larger windows on southern façade have been observed which helps in trapping solar radiation to the indoors which helps in making the comfortable indoors. Outside walls are made up of stone and turf pieces. When building a wall with these components, the turf or stone might be simply coursing one type of turf or a composite coursing of several types of turf blocks or turf and stone (25).

The climatic responsive strategies in scandinavian vernacular architecture have been listed in Table 5 and Figure 17.

Table 5: Architecture of Vernacular Building in Response to the Local Climatic Condition of Sweden

Climatic condition		Need	Climate response
Radiation	High, very variable	Gain as much solar radiation as possible	Long facades and windows orientation to south (a), slopped roofs to south (b), roof pitch (c)
Temperature	Low and variable, below comfort	Preserve interior heat and distribute it accordingly to habituated spaces	Thermal mass (d), room distribution €, turf walls & roofs (f), saunas, badstofa/ chimneys (g), indoor fire (h)
Wind	Fast speed and cold	Protect from high-speed winds	Closed layout (i), underground portion of construction (dune formation) (j), common courtyards (k), rooftrees (f)
Humidity	Relatively high (70% -88%)	Maintain as low as possible	Saunas (not in sketch), interal fires (h), chimeneys (c), multilayer walls (I)
Precipitation	Constant light rain throughout the year	Protect from snow and accumulated moist on ground	Stone base protecting structural wood (m), Roof pitch and slope for snow (c)
Sky	Clear due to constant nubosity	Maximum natural light from fall to spring. Reduce natural sunlight on summer nights	Skylights (n), small windows

Table 6: Solar Altitude Angle at Latitude 57.7°N [Gothenburg]

	Time in hrs						
	06:00	**08:00**	**10:00**	**12:00**	**14:00**	**16:00**	**18:00**
Jan	22	7	5	10	7	2	16
Feb	17	2	9	16	14	4	10
March	9	5	18	25	23	13	2
April	2	16	30	37	34	22	7
May	11	26	41	48	43	31	14
June	16	33	47	55	50	37	20
July	11	26	41	48	43	31	14
Aug	2	16	30	37	34	22	7
Sept	9	5	18	25	23	13	2
Oct	17	2	9	16	14	4	10
Nov	22	7	5	10	7	2	16
Dec.	19	4	7	11	8	3	17

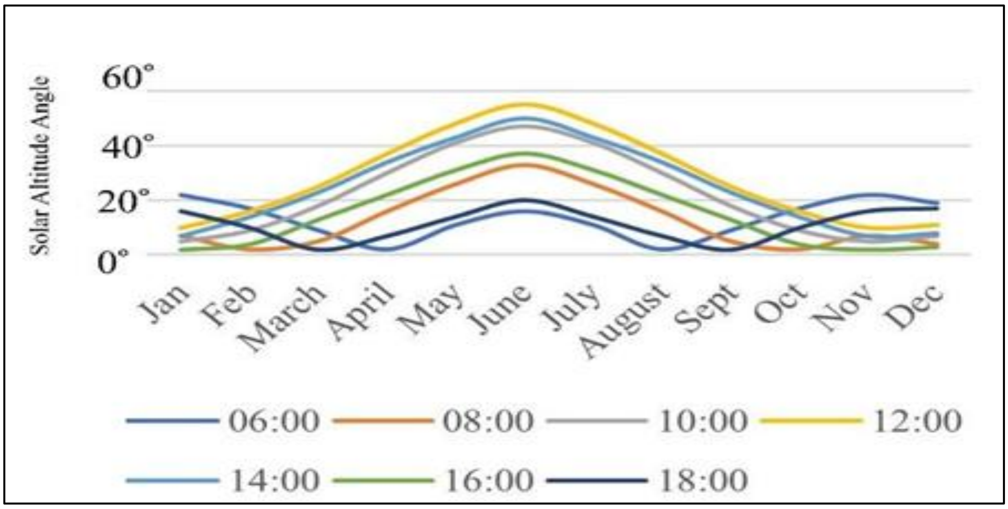

Figure 18: Solar Altitude Angle at Latitude 57.7°N

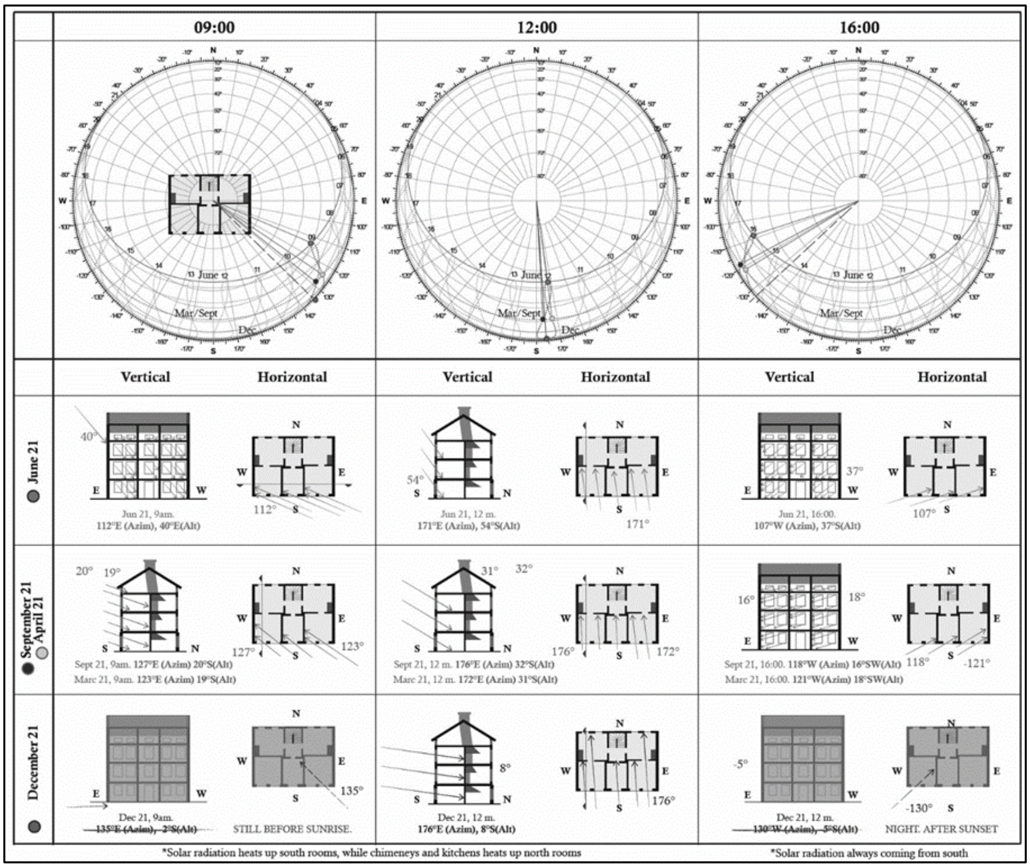

Figure 19: Incidence of Solar Radiation on Identified Building of Sweden at Specific Time and Month

The impact of solar radiation on the designing of vernacular architecture has been analysed in the next section (Table 6, Figure 18 and 19).

Vernacular architecture in this region has evolved over centuries to adapt to these environmental conditions. Here are some key features of climate-responsive architecture in Gothenburg:

- **Orientation:** Traditional buildings in Gothenburg are often oriented to maximize solar gain during the cold winter months. South-facing facades with large windows allow for passive solar heating, helping to keep the interiors warm and comfortable.
- **Insulation:** To cope with the cold winters, vernacular buildings typically feature thick walls and roofs with excellent insulation properties. Traditional materials like timber and clay are used to provide thermal mass, which helps regulate indoor temperatures.
- **Pitched Roofs:** Pitched roofs with overhangs are common in Gothenburg's architecture. The steep angle helps shed snow and rain, while the overhangs protect the building's walls and foundation from excessive moisture.
- **Ventilation:** Traditional buildings normally feature operable windows and chimneys to facilitate natural ventilation.

Cape town, South Africa: Latitude 33.55˚S

Climate-responsive architecture in Cape Town, as in many other regions, draws inspiration from vernacular building practices. The identified building for analysis is Grootfontein, which was constructed in 1883 (Figure 20 and 21).

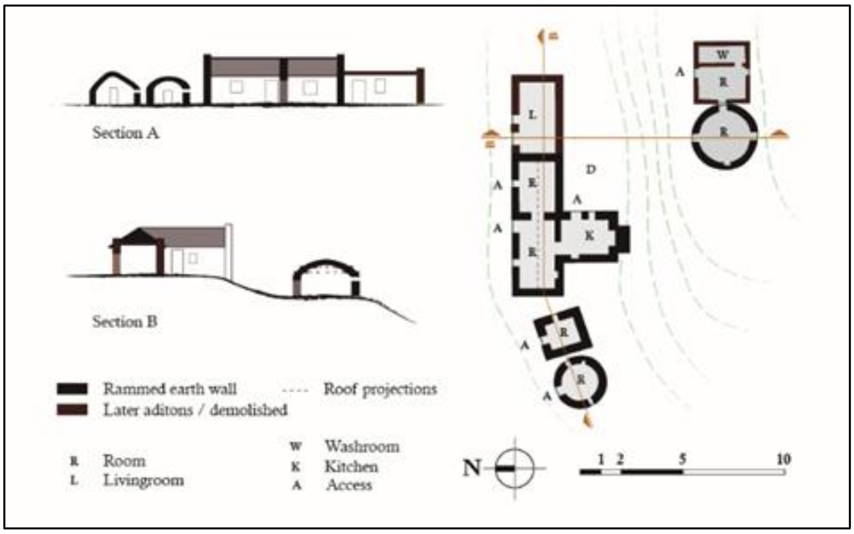

Figure 20: Plan and Section of identified Vernacular Building at Latitude 33. 6˚S (26)

Figure 21: Visuals of Identified Vernacular Building at Latitude 33.6˚S (26)

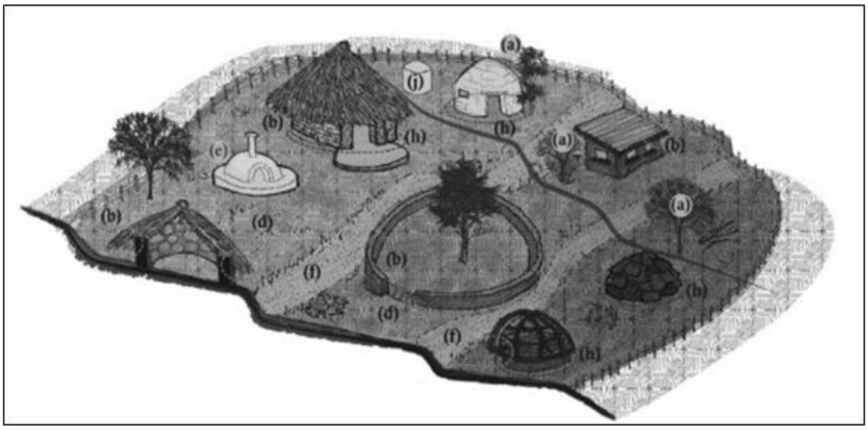

Figure 22: Climate Responsive Strategies of Vernacular Architecture of Zulu and Xhosa

Table 7: Architecture of Vernacular Building in Response to the Local Climatic Condition of Cape town

Climatic condition		Need	Climate response
Radiation	High, semi variable	Protection from direct radiation on horizontal and vertical planes	Location next to tree shades (a), roof overhangs (b)
Temperature	Warm and semi variable and below comfort level	Heat up at night, keep fresh during day	Round building geometry (c), high thermal mass (d), exterior kitchen (e)
Wind	Variable direction (unpredictable) medium speed	Use wind currents for ventilation	Disperesed layout (d), external kitchens (e), terraces with slope protection (f)

Humidity	Relatively high (72% -80%)	Maintain as low as possible, waterproof spaces	Drainage channels (g), round geometry (h), slope terrain terraces (f)
Precipitation	Low rain throughout the year	Harvesting water, find subsistence resources	Nomad structures (i), flat roofs, wells, water tanks (j)
Sky	Clear skies and few clouds	Using natural sunlight	External rooms, 'stable doors'

The corbelled building had a rectangular stone room added to it, although this room lacked an interleading door. An additional rectangular space with an interleading door was attached to this room. The building's side was expanded to include a kitchen or hearth in addition to more internal space. This became significant accommodation with the addition of a dining room, an indoor kitchen, and several additional rooms. The family stayed in this complex until the early 1950s, at which point they moved to a new home that was situated a short distance from the complex of corbelled buildings.

The longer side of the building block is facing north-south directions. To avoid the direct penetration of solar radiation in the indoors, the smaller sized windows are seen on the northern side and openings are avoided on the southern side. The small openings on the northern side are being protected by small horizontal overhang. The climatic responsive strategies at cape town have been listed in Table 7 and Figure 22.

The impact of solar radiation on the designing of vernacular architecture has been analysed in the next section (Table 8, Figure 23 and 24).

Table 8: Solar Altitude Angle at Latitude 33.55˚S [Cape town]

Month	Time in hrs						
	06:00	**08:00**	**10:00**	**12:00**	**14:00**	**16:00**	**18:00**
Jan		22	39	48	39	22	
Feb		27	45	55	52	33	15
Mar	10	35	53	68	58	35	10
April	15	41	65	78	65	41	15
May	22	55	70	87	70	45	21
June	23	52	72	89	72	53	23
July	22	55	70	87	70	45	21
Aug	15	41	65	78	65	41	15
Sept.	10	35	53	68	58	35	10
Oct.		27	53	55	52	33	15
Nov.		22	39	48	39	22	
Dec		20	37	43	36	20	

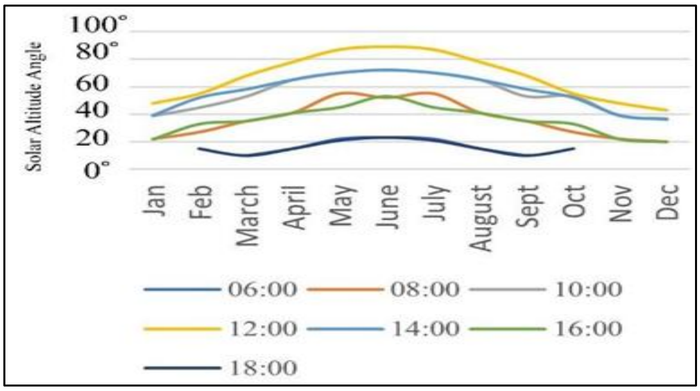

Figure 23: Solar Altitude Angle at Latitude 33.55˚S

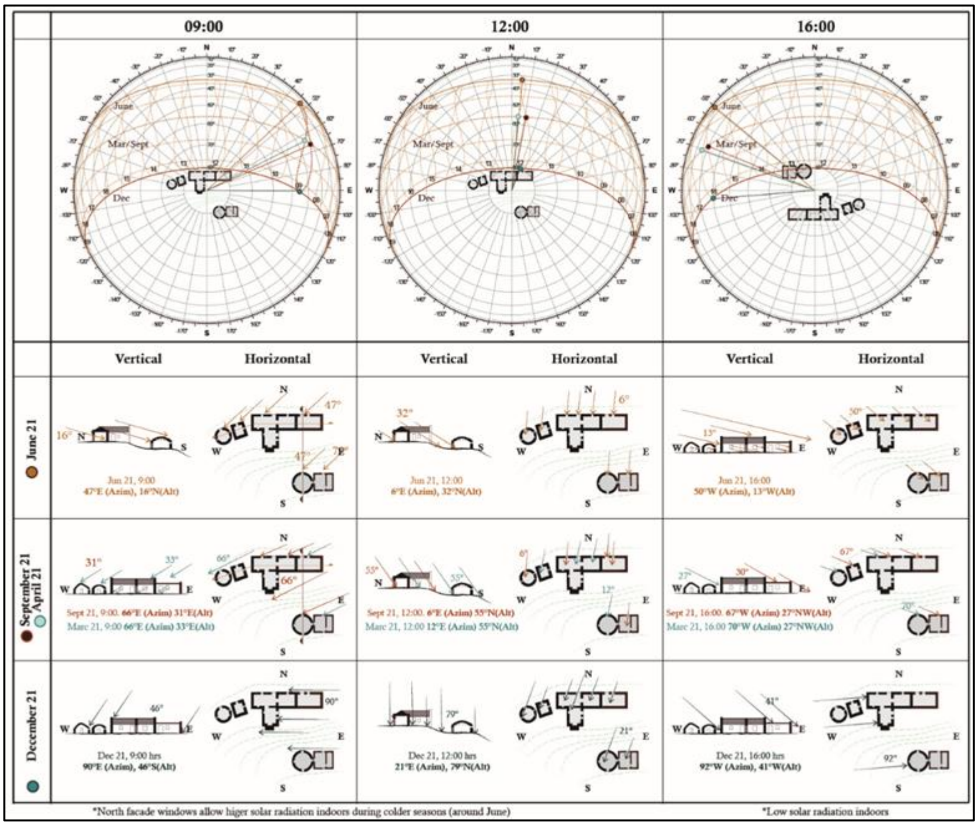

Figure 24: Incidence of Solar Radiation on Identified Building at Specific Time and Month

Vernacular architecture is rooted in local traditions, materials, and climate-responsive design principles. In Cape Town, a city with a diverse climate ranging from Mediterranean to semi-arid, the vernacular architecture incorporates several features and strategies to adapt to the local climate. Here are some key elements of climate-responsive vernacular architecture in Cape town.

- **Orientation:** Vernacular buildings in Cape Town often have their long facades facing north and south to minimize direct sun exposure during the summer and maximize solar gain during the winter months. This helps to maintain comfortable indoor temperatures throughout the year.
- **Thermal Mass:** Buildings incorporate materials with high thermal mass like stone, brick, or mud. These materials absorb heat during the day and release it slowly at night, helping to regulate indoor temperatures.
- **Shading Devices:** To protect against harsh summer sun, buildings often have wide overhangs, pergolas, or shading devices that block direct sunlight from entering windows and overheating interior spaces.
- **Roof Design:** In areas with high rainfall, roofs may have a steep pitch to efficiently shed water.
- **Use of Local Materials**
- **Modularity and Adaptability:** Many vernacular buildings are designed with flexibility in mind, allowing residents to adapt spaces according to changing weather conditions.
- **Local Craftsmanship:** Traditional building methods and craftsmanship are valued, as they often result in structures that are well-suited to the local climate and culture.
- **Cultural Sensitivity:** Vernacular architecture in Cape Town often respects the cultural and historical significance of local building styles, blending modern comfort with traditional aesthetics.

Discussion

As per studies, predominantly, vernacular architecture of Jaipur, Cape town and Barichara exhibit a north-south orientation. This orientation strategy is underpinned by several advantageous considerations. It is aligned with the trajectory of the sun, which typically occupies the southern hemisphere with a relatively higher solar altitude angle for a significant portion of the day.

Consequently, this alignment is conducive to mitigate solar exposure. On the other hand, the planning strategies at Gothenburg, Sweden are about capturing the solar radiation. Furthermore, respondents during survey indicated the integration of compact horizontal shading devices on the southern side, facilitate solar control. Conversely, the orientation limits openings on the western side, recognizing the lower solar angle on that axis and the associated challenges in solar control. It's worth noting that while historic vernacular buildings in Columbia exhibit many of these climate-responsive features, i.e sloping roof, wide porches and overhangs etc.

Regarding the selection of construction materials, sandstone emerges as a preferred choice among Jaipur residents due to its exceptional resilience in the face of the arduous desert climate. The application of stone in both load-bearing structural elements and ornamental embellishments was commonly observed. Of notable significance is the prevalent incorporation of intricately carved wooden screens and *jharokhas* (overhanging enclosed balconies) in the architectural composition of havelis, a distinctive hallmark of Rajasthan's architectural heritage. In summary, the climate responsive aspect is a fundamental concept in the design and analysis of vernacular architecture.

Conclusion

This article has shed light on the implementation of innovative climate responsive architectural strategies within the context of vernacular architecture. The integration of these climate responsive principles into modern building practices holds the promise of significantly mitigating energy consumption. Understanding how heat is gained, lost, and stored within a building is essential for creating structures that are well-suited to their specific climate and can provide comfortable living conditions with minimal energy input. Vernacular architecture often embodies these principles by incorporating traditional knowledge and practices that align with the thermal balance equation.

Contemporary construction practices have evolved, and newer buildings may incorporate modern energy-efficient systems, insulation, and sustainable design principles to address the challenges of the local climate while reducing energy consumption and environmental impact. Additionally, building codes and regulations may require specific measures to ensure safety and energy efficiency in new buildings.

It's important to note that while vernacular architecture has traditionally been shaped by the local climate, contemporary architects are also incorporating innovative sustainable design principles and technologies to create buildings that are even more environmentally friendly and energy efficient.

The vernacular principles, like natural ventilation, shading, and thermal mass, can be applied in contemporary buildings to reduce energy consumption. Vernacular architecture often involves the local community in the construction process. Contemporary architects can adopt a similar approach, engaging with local communities to create a sense of ownership and inclusion in the design and construction process. Contemporary buildings often incorporate energy-efficient technologies, such as solar panels, and energy-efficient lighting, to reduce energy consumption and environmental impact. In recent years, green roofs have gained popularity in Gothenburg as they provide insulation, reduce stormwater runoff, and support biodiversity. They can also help regulate indoor temperatures and improve air quality.

In summary, incorporating vernacular architecture strategies in contemporary architecture can result in buildings that are not only sustainable but also culturally and contextually sensitive. This approach can lead to architecture that respects the environment, embraces local culture, and contributes to the well-being of the community.

Abbreviation

Nil.

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Author Contributions

Dr. Sunanda Kapoor and Ar. Laura Estrada D'amato contributed equally to the conceptualization, methodology, data analysis, and writing of this article.

Conflict of Interest

The authors declare no conflict of interest.

Ethics Approval

Not applicable.

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