

Exploring Courtyards as Climate Responsive Solutions in Vernacular Architecture

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Abstract

A courtyard typically refers to an open space enclosed by the walls of a house or a group of houses. Throughout history, courtyards have been an integral element in many distinct styles of architecture and cultures. In most of the regions, courtyards are essential component of the overall architectural style of vernacular homes. Courtyards can have a variety of uses, depending on the local and cultural environment. They can be utilised for family activities, parties, gardening, or just as a peaceful place to unwind. The study highlights the courtyard's role as a climate friendly feature and as an essential attribute for social interaction. The study has been conducted by analysing the courtyards of vernacular houses at three different latitudes representing different climates. A case study methodological research approach has been adopted to generate an in-depth understanding of application of 'courtyard' in vernacular architecture. Examples from tropical and temperate zones are specifically included in the study. These zones are located at latitudes 6.1603° S, 26.9124° N, and 37.8882° N, and they reflect different climate types. Over the period, designers have ignored the scientific relevance of courtyards. Article demonstrates the climatic & cultural relevance of courtyard so that it can be adopted in contemporary times. A case study methodological research approach has been adopted. Comparative Analysis of Courtyards at identified latitudes have been conducted. By computing the values of P/A ratio, aspect ratio, degree of sky exposure from the courtyard and wall height of adjoining surfaces of courtyards at identified latitudes, study has demonstrated the relevance of courtyards w.r.t the climatic conditions of place. The study has been carried out in various stages from understanding of climatic characteristics of three different latitudes and then analysing climatic significance of courtyards with the help of solar chart. The findings of research demonstrate the best possible orientation of courtyard buildings with respect to sun & prevailing wind and the most preferred proportion of void (courtyard) to solid (the building).

1.0 INTRODUCTION

Oxford Dictionary defines a courtyard as "an unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or large house." Moreover, the Cambridge Dictionary defines a courtyard as "an area of flat ground outside which is partly or completely surrounded by the walls of a building". Courtyard plays very important role in attaining the functionality at residential buildings of vernacular architecture¹. The significance and architectural form of courtyard varies according to global location. In addition to other semi-open areas like verandas and overhangs, courtyards are crucial for reducing the effects of outdoor temperature swings (Hao *et. al.* 2019). Normally used as open areas inside buildings, courtyards facilitate natural ventilation and help cool a building by allowing air to circulate more easily throughout it in hotter months. In cold regions, the courtyards are best suited in order to maximise sunshine exposure inside the building and provide a natural heating source. The courtyard in vernacular architecture is a flexible feature that fulfils functional demands and addresses the cultural milieu of a specific area. Courtyard represents important piece of vernacular architectural heritage because of the way it was built and serves the community's customs. In traditional homes, the courtyard served as the main gathering place and almost all the rooms of house were directly connected to the courtyard (Sthapak and Bandyopadhyay, 2014). Courtyards are unique spaces that are mostly within in the dwelling, exposed to the sky and encircled by rooms. The courtyard serves as a conduit and filter for light, dark, wind, rain, and sound, and it is closely connected to the rooms that encircle it. In courtyards, people can regularly engage with nature.

Furthermore, a building's courtyard is sometimes its most exquisite feature. In addition to bringing nature inside a structure, courtyards also help temper the extremes of nature. They are rarely as hot in the middle of summer as it is in the countryside, or even on the street outside, or as cold right before dawn (Hinrichs, 1989). Craig Hinrichs (2016) makes a valid point when he says that man needs a space of solitude, meditation, and tranquilly in his everyday existence. Al-Zamil (2018) has explained courtyard as a 'room without a roof'. Courtyard has been interpreted as a peaceful conduit to the universe, the well of heaven, or protected court garden, connected several separate but interconnected ancient societies (Lehrman, 1980). Three main factors in the climatic function of a courtyard building: sun, wind, and humidity (Taleghani, *et. al.* 2012). Courtyards represent outstanding examples of the Vitruvian trio of "firmness, commodity, and delight" because they seamlessly blend aesthetics, social relevance, and thermal comfort (Reynolds and Lowry, 1996). The courtyard is the primary contributor of light and air to the building; thus, it plays a major role in optimizing the building's energy consumption and in its thermal comfort (Tabadkani *et. al.*, 2022).

The article is about the analysis of a courtyard for various aspects i.e. design, functionality & cultural significance. The authors have compared vernacular houses at three different latitudes to assess its functionality w.r.t local climate and cultural & symbolic aspects which has influenced in shaping courtyard's design. User experience has been gauged in terms of perception, comfort, and privacy through documentation. This systematic research methodology provides a holistic approach to analyse courtyards and their multifaceted contributions to the built environment. The broader aim of the study is to demonstrate the significant role of courtyard in the vernacular architecture. The corresponding objectives of the study can be listed as below:

- To study the significance of courtyards w.r.t local climate.
- To understand the best possible orientation of courtyard w.r.t sun and prevailing wind with the help of solar chart.
- To analyse courtyards of different latitudes for the most preferred proportion of void (courtyard) to solid (the building)
- To understand the relevance of courtyard as cultural & symbolic feature in vernacular architecture.

¹ The term 'vernacular architecture' describes the customary, native architecture of a certain area, influenced by the environment, local resources, and cultural norms.

2.0 LITERATURE REVIEW

2.1 Courtyard in History



Figure 1. Types and Historical evolution of Courtyards

Source: Abass et. al (2016)

Courtyards have been an essential part of architecture for centuries. Homes were constructed with multiple rooms encircling compact courtyards. The city-state of Ur in Mesopotamia (c. 2000 BCE) had two-story brick houses with a courtyard in the middle of the living space. Chinese siheyuan houses from the 1000s BCE onward frequently had inner courtyards with gardens or water features. The domus house plans of ancient Rome (c. 800 BCE) had an open roof section in the living room that allowed rainfall to drain into a pool below (Pérez Ordóñez, 2009).

There are different types of courtyards that serve specific purposes and are closely connected to adjoining spaces in vernacular dwellings. Here are several types of courtyards commonly found in vernacular dwellings, each with its unique relationship to the surrounding spaces; central courtyard (Fig 1;a,c & e) is positioned at the centre of the dwelling and is surrounded by various rooms; entrance courtyard (Fig. 1;b,d), positioned at the entrance of the dwelling serves as a welcoming space and an initial transition from the exterior to the interior; garden courtyard designed primarily to have serene atmosphere.

These kinds of courtyards in traditional homes highlight the variety of styles and purposes while highlighting the interdependent relationship between the courtyards and the surrounding areas. They are essential elements of vernacular architecture, representing regional requirements, climate factors, and cultural customs.

2.2 Defining the Research Gap through Literature review

Lot of researchers have explored the climate responsiveness of vernacular architecture and role of courtyard in particular. Referring to the ANZSRC 2020, the majority of the publications in this field falls under the category of 'built environment & design' followed by 'history', 'heritage' & 'archaeology and human society' The courtyard served as a crucial space for social interaction and as a regulated microclimate inside the units. Additionally, it draws attention to its bioclimatic relevance in boosting the way that natural components are incorporated into the dwelling's design and overall architectural idea (Philokyprou and Michael, 2016). Leng J *et. al.* (2020) has discussed about the role of courtyards in controlling the air borne diseases. Vernacular architecture is the design of buildings created by craftsmen without official training who employed native materials and had a thorough awareness of the climate conditions in the area. This method provided low-cost solutions for concerns related to building, materials, energy, and climate. Passive internal climate regulation techniques were frequently used to create comfortable building interiors, and they may hold the answer to fixing some of the contemporary world's problems (Purushothaman, 2021). Further bibliometric search on the topic has been carried out using ai tool 'dimensions' [Fig. 2]. The quantity of academic publications that have been published on this topic is a reliable indicator of the validity of that field of study.

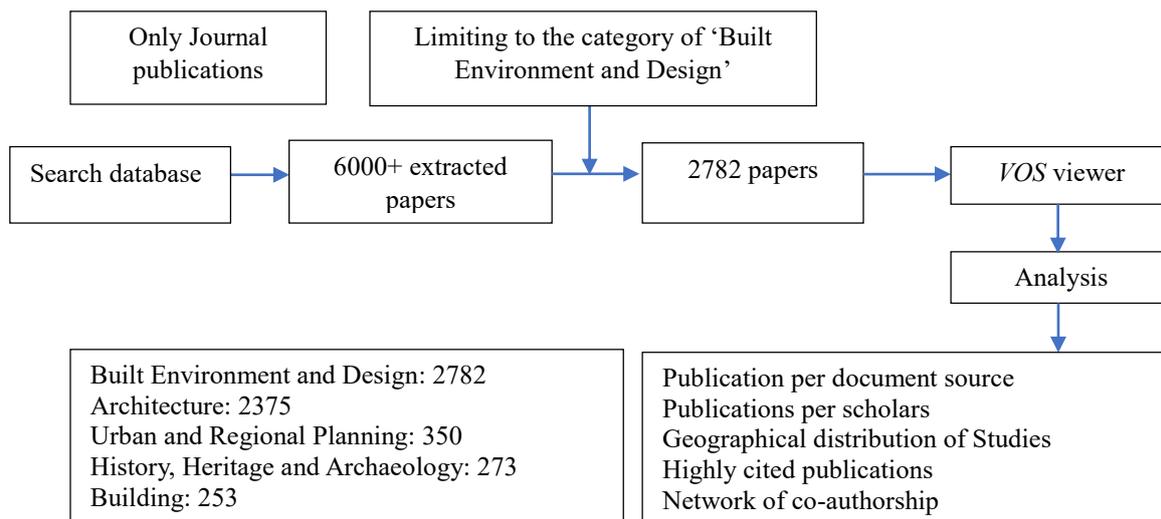


Figure 2. Publication details on the role of courtyards in vernacular architecture

In order to gain important insights about the most influential research in a particular topic, it is imperative to evaluate the extracted documents in order to discover highly cited papers and comprehend their focus areas. Furthermore, by examining these publications, it has been possible to pinpoint areas which are understudied or research gaps that need to be filled. This procedure helped the authors to focus on research by bringing it in line with areas that have substantial academic and practical value. It also assured that this study is expansion upon previously published work.

Table 1. Top ten productive journals having the aligned publication using ai tool ‘dimensions’

Sources	Publications	Citations	Citations mean
Journal of Architectural Education	168	196	1.17
Sustainability	150	150	150
Buildings	120	750	6.25
Journal of the Society of Architectural Historians	86	317	3.69
Building and Environment	83	4,000	48.19
The Journal of Architecture	79	300	3.80
Journal of Asian Architecture and Building Engineering	70	231	3.30
Urban History	57	72	1.26
Energy and Buildings	51	1,971	38.65
Architectural Research Quarterly	48	82	1.71

In Table: 1, the ‘Publications’ stands for the number of publications related to the topic in the mentioned journal. ‘Citations’ is the number of times a particular publication has been cited by other publications in the database. The ‘Citation mean’ of a citation typically refers to the average number of times a particular article has been cited in a year.

Further, it was essential to perform a comprehensive analysis of the most referenced works in the field in order to define research gaps. Studies that receive a lot of citations, indicate important contributions that have influenced upon the understanding of an area of study. Finding gaps in the literature is made easier with the use of this comparative technique, whether the gaps are due to underdeveloped theoretical perspectives, overlooked populations or contexts, or missing variables. Top ten most cited authors in the field are listed below Table 2.

Table 2. Top ten most cited authors in the field using ai tool ‘dimensions’

Researcher	Organization, Country	Publications	Citations	Citations mean
Raffaello Furlan	Qatar University, Qatar	13	129	9.92
Maria Philokyprou	University of Cyprus, Cyprus	11	242	22.00
Mohammed Abdullah Eben	King Saud University, Saudi Arabia	11	123	11.18
Aimilios G Michael	University of Cyprus, Cyprus	10	365	36.50
Carmen Galán-Marín	University of Seville, Spain	9	193	21.44
Victoria Patricia López-Cabeza	University of Seville, Spain	8	147	18.38
Carlos Alberto Rivera-Gómez	University of Seville, Spain	8	160	20.00
Charlie Qiuli Xue	City University of Hong Kong, China	8	50	6.25
Hiroatsu Fukuda	The University of Kitakyushu, Japan	8	28	3.50
Eduardo María Diz-Mellado	University of Seville, Spain	8	160	20.00

AL-Mohannadi (2023) talked on how women's spaces are seen spatially in Qatari households, taking into account societal elements like gender segregation and privacy. The social and environmental characteristics of courtyards in Cypriot vernacular homes were examined by Maria and Aimilios (2016) who emphasised the role courtyard as social hubs and microclimate regulators. Mohammed Abdullah Eben Saleh (2001) highlighted the importance of traditional architecture & harmony between social and physical elements. While Guanghui et. al. (2019) concentrated on Chinese vernacular architecture, Diz-Mellado *et.al.* (2023) investigated passive conditioning in the courtyards of communal housing in Seville and also studied the possible advantages of courtyard layouts, while Zhang *et.al.* (2021) studied their thermal performance.

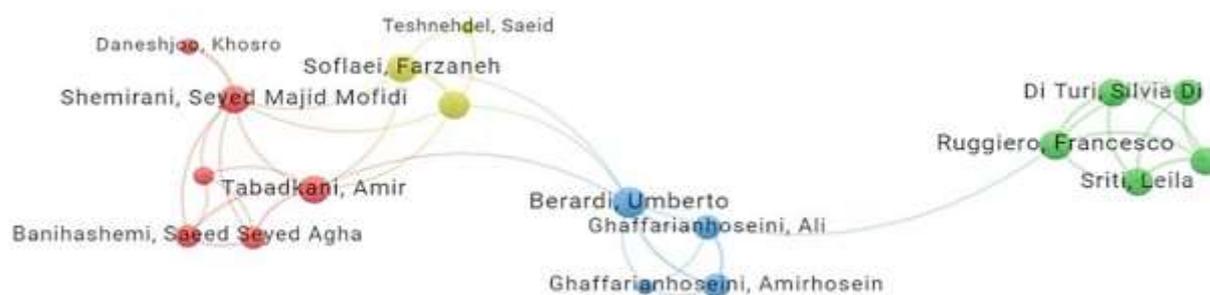


Figure 3. Co-authorship network
 Source: generated from Vos viewer

A total of sixty-six authors including all corresponding authors and co-authors has been reflected in the database. It is important to establish a cluster that emphasises the concentration area in order to represent the focus of this study. Four clusters with eighteen researchers, sixty-five co-authorships, and thirty-eight co-authorship linkages were found in VOSviewer. Utilising VOSviewer's co-authorship analysis, Figure 3 displays knowledge domain maps of the major research groups. Each node in this graphic represents a researcher, and its size indicates how many articles that researcher has published. There are several co-authorship groups: the red group is led by Shemirani, Seyed Majid Mofidi, while the blue group is centred around Berardi, Umberto. Figure 3 shows an example of the network visualisation. The relatedness of the research is approximately indicated by the distance between nodes and clusters in this visualisation. In general, the stronger the link between two nodes, the closer they are.

The literature review reveals that a great deal of research has been done on vernacular architecture. Although a few studies touch on courtyards in brief, none have offered a thorough examination that addresses all aspects of courtyards or examined their functions across different latitudes. This study is an attempt to provide the focused research upon the role of courtyard in vernacular architecture in various latitudes.

3.0 METHODOLOGY

The main aim of the study is to demonstrate the significant role of courtyard in the vernacular architecture. A case study methodological research approach has been adopted to generate an in-depth understanding of application of 'courtyard' in vernacular architecture. For researchers who are primarily interested in answering "how," "why," and "what" questions, the case study approach is an especially useful tool. These kinds of enquiries frequently seek to investigate intricate phenomena in authentic settings where factors are difficult to control or change (Robert, 2009).

A thorough analysis of several courtyard design parameters has been made possible by the selected case studies of vernacular architecture of different latitudes. Researchers have tried to understand the underlying mechanisms and relationship between courtyards and climate & social setting by concentrating on the subtleties and intricacies of certain case studies. This approach proves to be particularly advantageous in situations where comprehension of not just the end result but also the underlying dynamics and contextual elements is required. The sequence of study has been put on view in figure 4.

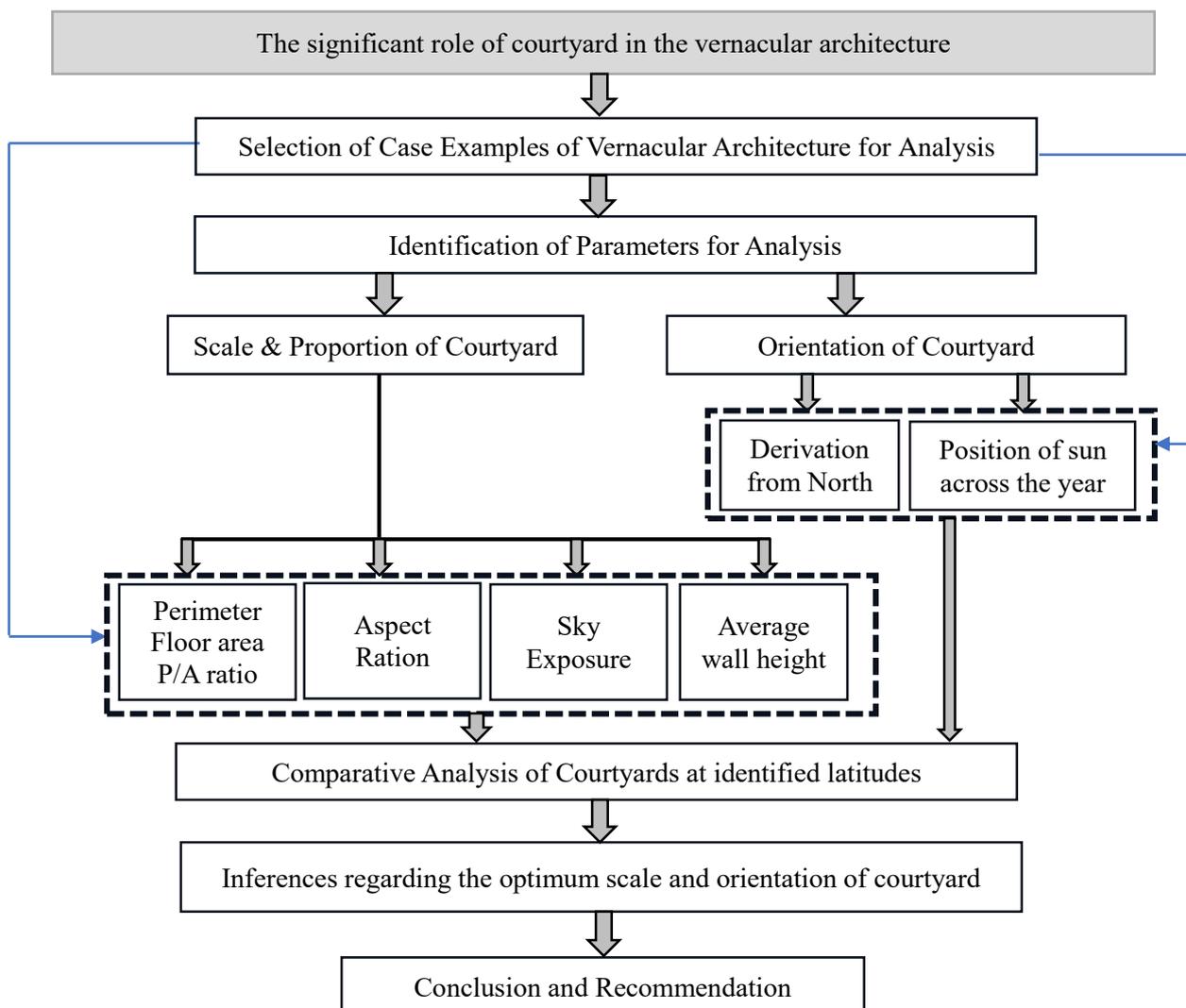


Figure 4. Methodology of Research.

Source: Authors

4.0 ABOUT CASE STUDIES

In order to attain a thorough comprehension of the functioning of courtyards in various geographical contexts, this research looks at case studies from three different latitudes. This allows the research to capture a wide range of climatic and environmental circumstances, as courtyards from both the northern and southern hemispheres are chosen. Examples from tropical and temperate zones are specifically included in the study. These zones are located at latitudes 6.1603° S, 26.9124° N, and 37.8882° N, and they reflect different climate types. The purpose of choosing such broadly dispersed case studies is to study how courtyards respond to various climates and how variables like sun exposure, wind, and temperature affect their design. The research intends to identify the design approaches and architectural enhancements that maximise thermal comfort, natural ventilation, and energy efficiency by comparing courtyards in areas with distinct climates. This method demonstrates how vernacular architecture adapts to local environmental conditions, providing insightful information for sustainable design across a range of climate zones.

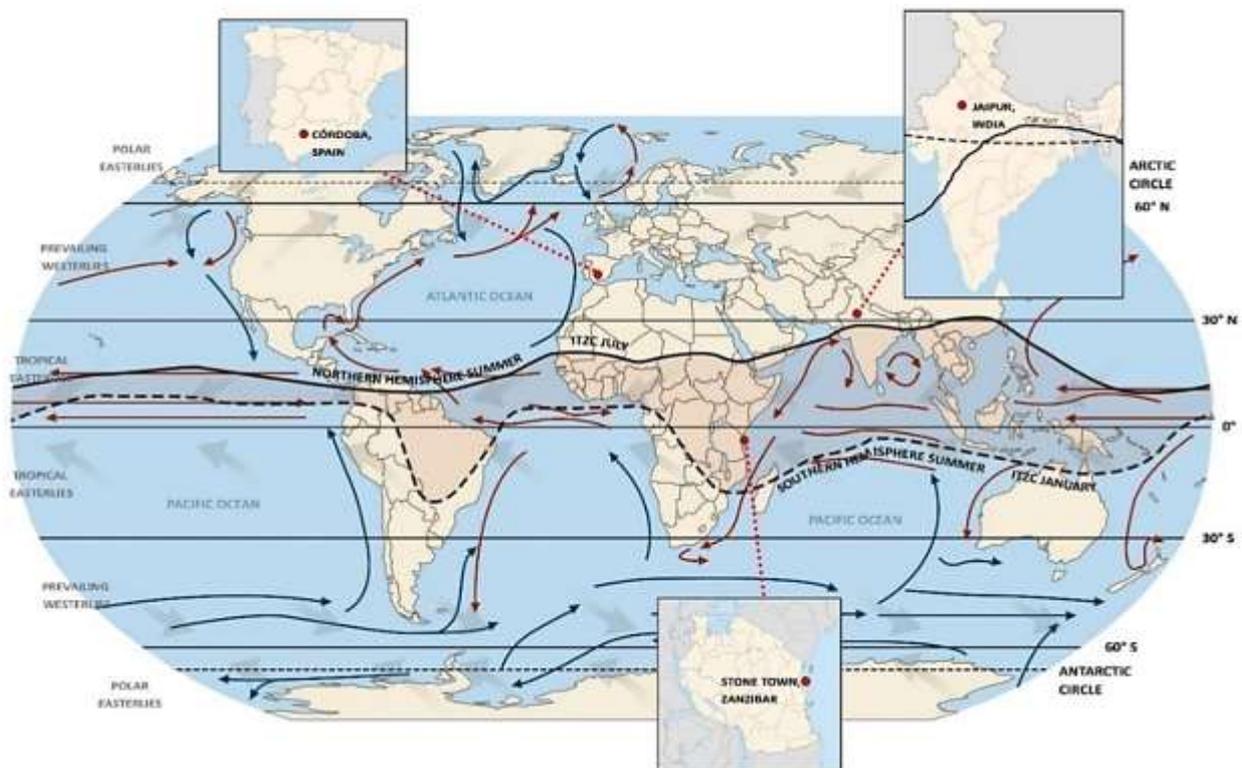


Figure 5. Location of case studies w.r.t World Map

Source: Base map from World Map Blank.svg

https://es.m.wikipedia.org/wiki/Archivo:A_large_blank_world_map_with_oceans_marked_in_blue.svg

Details of location of identified case examples [Fig. 5] has been listed below:

- **Latitude 37.8882° N – Cordoba, Spain**

At latitude 37.8882° N, the city of Cordoba, Spain. Located in the southernmost region of the Iberian Peninsula, Andalusia, Cordoba experiences a Mediterranean climate, characterized by hot, dry summers and mild, wet winters. With an average annual temperature of around 20°C (68°F), temperatures higher than 40°C (104°F) are common during the hottest summer months (Angulo-Romero *et. al.*, 1999) (Fig. 6(a)). This location represents a northern latitude and is situated in the city of Cordoba, Spain. The study in Cordoba aims to explore how courtyards function within vernacular buildings in a Mediterranean climate. Factors such as sunlight exposure, temperature variations, and architectural design specific to this region may influence the role and effectiveness of courtyards in the built environment.

The reason for the selection of this particular example as one of the authors has been brought up in the southern region of Andalusia, making him familiar with traditional houses and cultural aspects. The identified

case example is a vernacular community residential building. This typology of building has evolved during the centuries and different families have inhabited the same throughout time. Long hours of solar radiation have left a great impact on the way people use their personal private space.

- **Latitude 26.9124° N – Jaipur, India**

At latitude 26.9124° N, the city of Jaipur, Indian state of Rajasthan, located in the northwest of the country. Jaipur experiences a hot-dry climate with distinct seasons. Summers in Jaipur are characterized by scorching hot and dry weather, with temperatures frequently exceeding 40°C (104°F) during the peak summer months while winters are relatively mild and dry with a mean temperature of around 15° (Fig. 6(b)). The city also receives most of its annual rainfall during the monsoon season, typically occurring from July to September (Tyagi *et al.*, 2012). Courtyards in this region may serve different functional requirements, such as providing shade, ventilation, and a cooler microclimate. Cultural and architectural practices specific to Jaipur may also influence the design and utilization of courtyards. This research paper has been written during a stay in the city of Jaipur, India, thus having access to the case study and also one of the authors belong to Jaipur. Courtyards in Jaipur not only work as to mitigate hot and harsh temperature but also the cultural aspects affect the architecture in a direct way from a gender point of view. In Jaipur vernacular houses, historically women spaces and men spaces were separated.

- **Latitude 6.1603° S - Stone Town, Zanzibar**

At latitude 6.1603° S, Stone Town, Zanzibar. It boasts a tropical climate typified by a distinct wet and dry season. The primary rainy periods are observed between March to May and November to December, contributing significantly to the island's annual precipitation and lush vegetation. The dry season prevails from June to October and January to February, marked by arid conditions and abundant sunshine. Stone Town maintains an average annual temperature of about 27°C (81°F), with temperatures often exceeding 30°C (86°F) during the hottest months (Luhr, 2016) (Fig. 6(c)). Stone Town, Zanzibar, situated at a southern latitude, offers a tropical context for the study. Here, the role of courtyards in managing heat, humidity, and fostering social interactions in vernacular buildings is likely to be different from the previously mentioned locations. Understanding how courtyards adapt to and compliment the architectural and environmental characteristics of this tropical region is a key aspect of the study. Stone Town has been chosen due to its latitude close to the equator, as to analyse a courtyard typology from a tropical zone. The convergence of cultures that took place in Zanzibar, with special emphasis on the Islamic and Indian influence, create a relationship between Stone Town and the two previous case studies. The different periods of Zanzibari history have made courtyard houses undergo different alterations that suppose an interesting cultural approach.

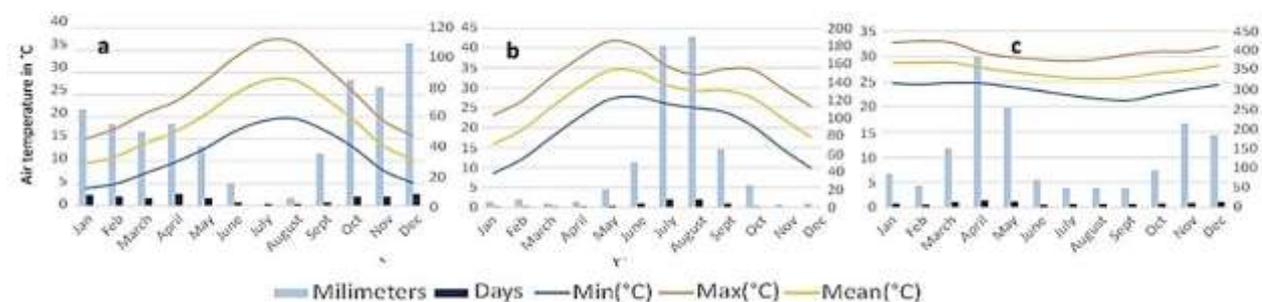


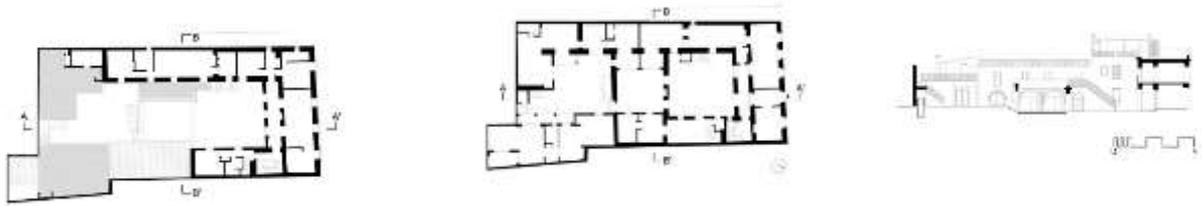
Figure 6. Climatic conditions at three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar; Source: Climate Data. <https://en.climate-data.org/>

By examining courtyards in these three diverse geographical locations, the research aims to provide a broader and more nuanced understanding of how vernacular buildings incorporate courtyards to meet functional requirements. This approach allows for a comparative analysis, considering the impact of climate and culture on the design and utilization of courtyards in different parts of the world. Ultimately, the findings from these varied latitudes contribute to a more comprehensive and adaptable knowledge base for the integration of courtyards in vernacular architecture.

4.1 Understanding Layout of Vernacular Houses

Three vernacular houses having courtyard planning at three different latitudes have been identified for analysing the relevance of courtyards w.r.t to climate and cultural of the place (Fig. 7). The study takes into consideration the specific climate and cultural of the given location where these houses are situated. Climate can influence architectural design for factors like temperature control, shading, ventilation etc. while culture may shape the way spaces are used across the day & night. Layout of identified vernacular houses has been recorded below.

Vernacular House at Cordoba, Spain [a]



Vernacular House at Jaipur, India [b]



Vernacular House at Stone town, Zanzibar[c]

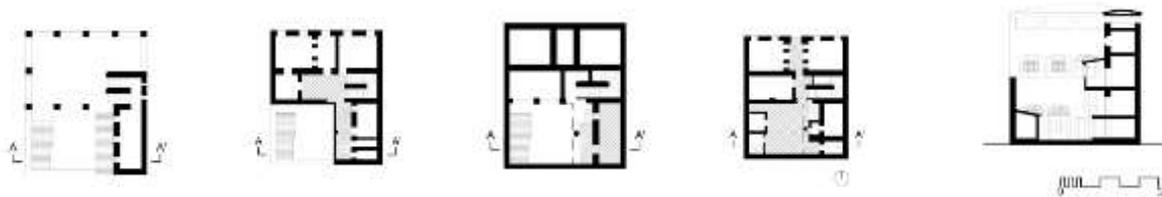


Figure 7. Case Study at three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar

Source: a. Redaelli, G. (2019); Bettolli, J. (2019), b. Measured drawings Hanuman Ji Ka Rasta
c. Steyn, G. (2001).

In the selected case studies, the vernacular building at Cordoba comprises of 3nos. courtyards in comparison to Jaipur and Zanzibar where the spaces are surrounded around one courtyard. In this section the comparative analysis of the courtyards for various spatial parameters have been performed. There are lot of factors which impacts the thermal performance of courtyards i.e. solar orientation of courtyard, aspect ratio, surface area to volume ratio etc which are been discussed in the next section.

4.2 Scale of Courtyards: P/A ratio, aspect ratio, shape factor, height, volume etc.

"The degree of openness to the sky" is how aspect ratio is described, which implies a qualitative indicator of how much of the courtyard is exposed to the sky. The aspect ratio of a courtyard numerically represents its shape. The proportion of courtyards at different latitudes has been compared through aspect ratio in Table 3 &

4. General profiles of courtyards have been represented through schematic sketches in Fig. 8. A higher aspect ratio number indicates that the courtyard is exposed to more of the sky. If a courtyard design has a greater aspect ratio, and wider side is in south-east direction, which indicates more natural light and views of the sky during most of the time in a day. A courtyard with a lower aspect ratio could be smaller or narrower.

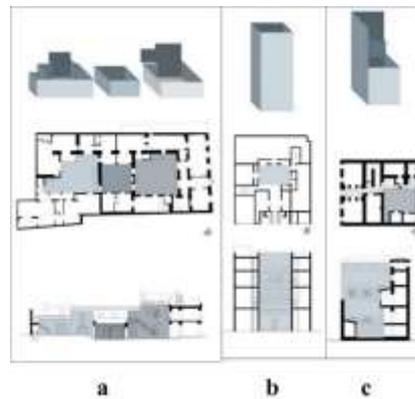


Figure 8. Scale and profile of courtyards at three identified latitudes. Ref, Fig. 5 for base drawings of case studies.

Table 3. Courtyard Details at Three Different Courtyards.

Case study	Courtyard	DaN	L_{cy}	W_{cy}	H_{cy}	L_{cy}/W_{cy}	H_{cy}/L_{cy}	H_{cy}/W_{cy}	Plan
Cordoba	Courtyard (1)	7° SW-NE	8,480	7,110	6,970	1,193	0,822	0,980	
	Courtyard (2)	7° SW-NE	6,110	5,710	3,470	1,070	0,568	0,608	
	Courtyard (3)	7° SW-NE	8,280	5,900	3,980	1,403	0,481	0,675	
Jaipur	Courtyard (1)	0	6,300	4,050	16,540	1,556	2,625	4,084	
Stone Town	Courtyard (1)	0	6,560	6,200	10,990	1,058	1,675	1,773	

Legend:

DaN = deviation from North

L_{cy} = average length of the courtyard

W_{cy} = average width of the courtyard

H_{cy} = average height of the courtyard

A courtyard with a more value of ratio among height to width/length (L_{cy}/W_{cy} and H_{cy}/W_{cy} , Ref: Table:3 and Fig. 9) indicates that adjoining walls of courtyard provides shade from the sun in the summer and more solar access in the winter. High shade levels during daytime might enhance summertime thermal comfort during the day. Understanding this practice has historically influenced the size of courtyards. People tried to ensure or prevent solar access and limited the same based on the needs of interior spaces. While courtyards in colder regions typically have low courtyard proportions to allow winter solar radiation with a low elevation angle to reach the inside envelope of the space, courtyards in hotter climates typically have deep depths to generate as much shadow as possible and prevent summer heat stress.

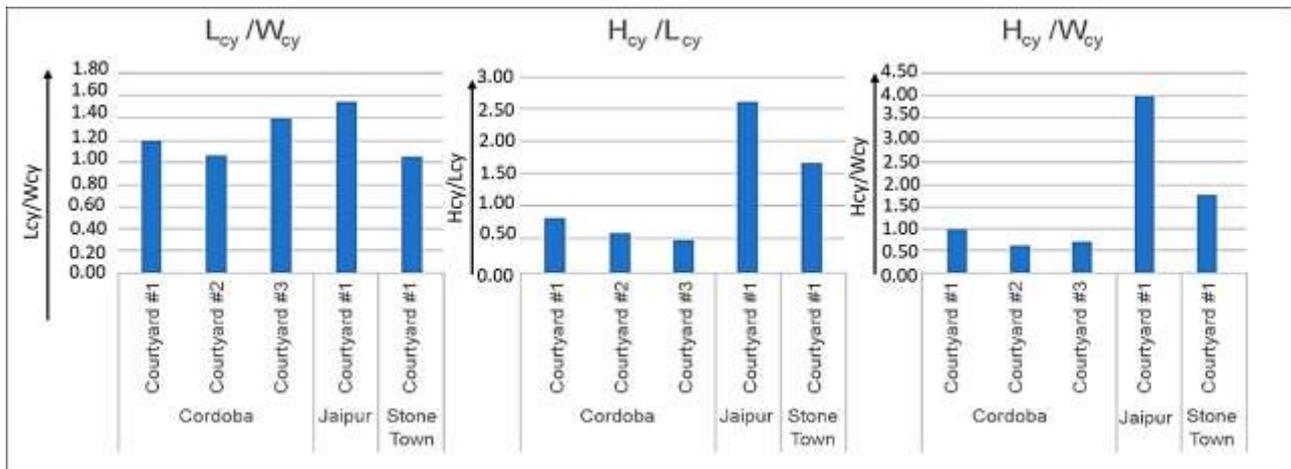


Figure 9. Scale and Proportion of Courtyards from Table 1

Source: Author

In vernacular architecture, the P/A ratio (perimeter to area) of a courtyard plays a crucial role in the planning and arrangement of the built environment. Courtyards with a lower P/A ratio can improve natural ventilation by providing proper screening against solar radiation (Renzi *et al.*, 2023). P/A ratio of a courtyard directly impact on how much light enters the area. An optimal P/A ratio can minimize the courtyard's exposure to solar radiation and thus allows only diffused natural light into the adjacent interior rooms. This results in generating comfortable indoors spaces without much depending upon active energy resources (Prakash, 2023). The P/A ratio of the courtyards of identified case studies has been computed [Table:4 & Figure 10] and has been seen that P/A ratio of all the courtyards is less than one. The highest P/A ratio is found at Stone town (latitude 6.1603° S) which means that the dimensions of the courtyard support more air circulation in the indoors. As stone town is a high humid area, so the scale & proportion of courtyard is aligned with the same. The courtyards of Cordoba, Spain (Latitude 37.8882° N) and Jaipur, India (Latitude 26.9124° N) are having lower values of P/A which ensures that solar radiation during peak summers do not penetrate in the indoors. The degree of security and confinement² in the courtyard is also influenced by the P/A ratio. A more enclosed area with a lower P/A ratio could give off a feeling of security and privacy. In vernacular architecture, courtyards frequently function as significant communal areas. The courtyard's size and ability to host different social and cultural events can be affected by the P/A ratio. For social events and festivities, a wider courtyard with a lower P/A ratio could be appropriate.

The Sky Exposure Index (SEI) is a metric used to determine how much of the open sky is seen from a given point inside a space (Wang *et al.*, 2022). In vernacular architecture, a well-designed courtyard frequently aims to maximise natural daylighting. The Sky Exposure Index is a useful tool for determining how much of the sky is seen from various points in the courtyard. Greater exposure to natural light is typically associated with a higher SEI, which enhances energy efficiency and produces a more aesthetically pleasing and comfortable atmosphere (Martinelli and Matzarakis, 2017). The visual relationship between the courtyard and its surroundings is determined by the SEI thus a higher SEI makes it possible to see more of the sky and the surrounding area, which enhances the visual integration and connectivity of the area. The minimum value of

² This was expressed by the people staying in courtyard houses during survey conducted in October 2023 at Jaipur, India

SEI has been observed in Jaipur, India as minimum exposure to solar radiation is required. The values of P/A ratio, SEI etc. for the three case examples have been computed in Table 4.

Table 4. Scale and Proportion of Courtyards.

	Cordoba			Jaipur	Stone Town
	Courtyard #1	Courtyard #2	Courtyard #3	Courtyard #1	Courtyard #1
Floor area (m²)	67.050	34.940	63.800	28.560	31.010
Perimeter (m)	34.640	23.670	33.660	21.880	26.120
P/A ratio (<i>Perimeter/Area</i>)	0.517	0.677	0.528	0.766	0.870
Wall Height at SE side (m)	7.640	3.470	3.030	16.540	7.376
Average Wall Height (m)	6.970	3.470	3.980	16.540	10.990
Aspect Ratio (<i>SE wall height</i>) / (<i>width NW-SE</i>)	0.922	0.567	0.357	2.604	1.123
Volume (m³)	467.339	121.242	253.924	472.525	478.660
Sky Exposure Index (<i>floor area/average wall height</i>)	9.620	10.069	16.030	0.625	4.271

Comparing all the courtyards, the wall height on SE Table 4 is maximum in Jaipur (Latitude 26.9124° N). As per climatic data of Jaipur, there is high solar radiation and high air temperature almost throughout the year. The south-east direction receives morning and part of afternoon solar radiation. The provision of tall walls on the south-east side of courtyards serves the purpose of screening the high-intensity solar radiation. This is crucial for maintaining comfortable indoor temperatures and reducing energy consumption for cooling purposes.

The calculation of aspect ratio (SE wall / NW wall - SE wall) is to analyse the solar exposure. This ratio helps architects and designers understand the extent of protection provided by the walls against solar radiation from the south-east direction. The value of aspect ratio is maximum in Jaipur, India thus ensuring maximum protection from SE direction. All these values i.e. P/A ratio, aspect ratio etc emphasizes the importance of architectural considerations in mitigating the impact of climatic factors such as solar radiation and high temperatures.

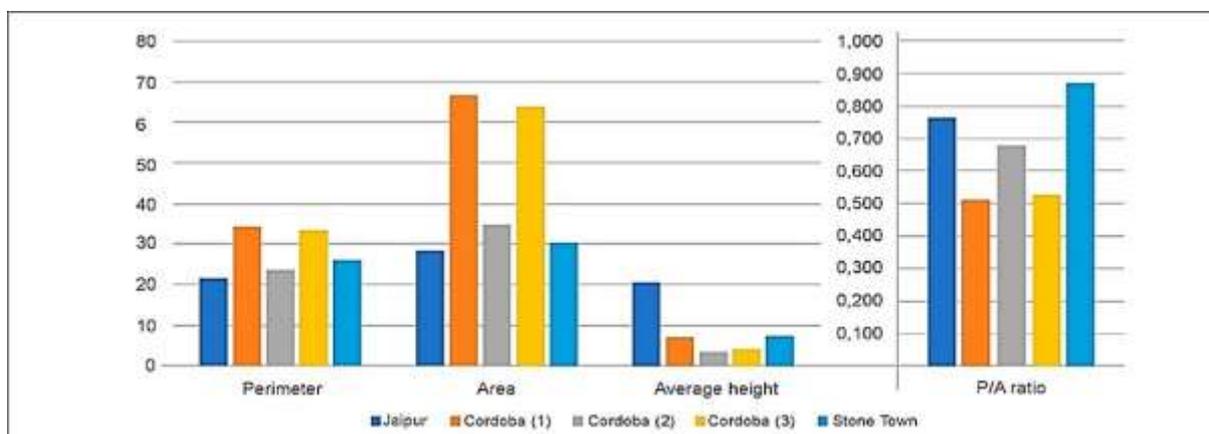


Figure 10. Comparison of parameters; Reference from Table 2.

Source: Author

Understanding the design specifications regarding the proportions of walls facing various directions is fundamental in architectural planning. In addition to the size, the orientation of a courtyard with respect to the solar chart is equally important. High-intensity solar radiation can be efficiently mitigated by designers by orienting the courtyard in accordance with the movement of the sun. Courtyards help provide a more comfortable and energy-efficient atmosphere within building spaces only when they are positioned properly to maximise/ minimize sunshine exposure as per requirement. The attentive orientation of the courtyards can minimise the need for excessive cooling methods, thus promote sustainability. The orientation of courtyard w.r.t solar chart has been discussed in the next section.

4.3 Analysing Courtyard W.R.T. Solar Chart of Related Latitude

A solar chart, sometimes referred to as a solar diagram or sun path diagram, shows the sun's path across the sky at various periods of the day and year. The solar chart in the context of courtyard design in vernacular architecture has a major impact on the entire layout and functionality of the courtyard. The sunlight exposure in the courtyard at various times of the day throughout the year for three latitudes has been analysed by the authors with the help of solar charts of particular latitudes. Designers can harness natural light to reduce the need for artificial lighting by carefully placing openings i.e. windows and doors. This results in a more sustainable and energy-efficient design. Solar charts are also useful for identifying spots in the courtyard that receive a lot of direct sunshine or the areas which are always in shade. With this understanding, designers can guard against excessive solar heat gain by incorporating shade components like overhangs, pergolas, or vegetation. The orientation of courtyards at three latitudes has been analysed. The orientation of courtyard at Jaipur, India and Stone town, Zanzibar is N-S axis and at Cordoba, Spain, it's at a tilt of approximately 5° from N-S axis [Fig: 11]. In Fig. 12 and Fig. 13, the solar altitude angles derived from the solar chart have been graphically represented. These angles provide insights into the position of the sun throughout the day. Notably, in both Cordoba and Jaipur, the solar altitude angle reaches its peak around noon, particularly during the summer months. However, it can be seen in Fig. 13 that direct solar radiation occurs only for a limited duration and courtyard can be screened from these intense solar radiations by choosing appropriate orientation and scale of courtyards. For the majority of the daylight hours, the buildings' profiles play a crucial role in screening and mitigating the effects of solar radiation. As illustrated in Fig. 13, the building profiles effectively provide shading and reduce the amount of direct sunlight entering the built environment. This strategic use of building design helps regulate indoor temperatures, minimize glare, and enhance overall comfort levels for occupants throughout the day. By leveraging the solar altitude angles and integrating appropriate building profiles, architects and urban planners can optimize the performance of buildings in mitigating the impact of solar radiation while ensuring sustainable and comfortable living spaces. On the other hand, the solar angle is higher during February & March and October & November in Stone town which is aligned with the warm & humid climate. This particular courtyard is also having the highest value P/A ratio (0.870) among the four courtyards [Ref. Table 2].

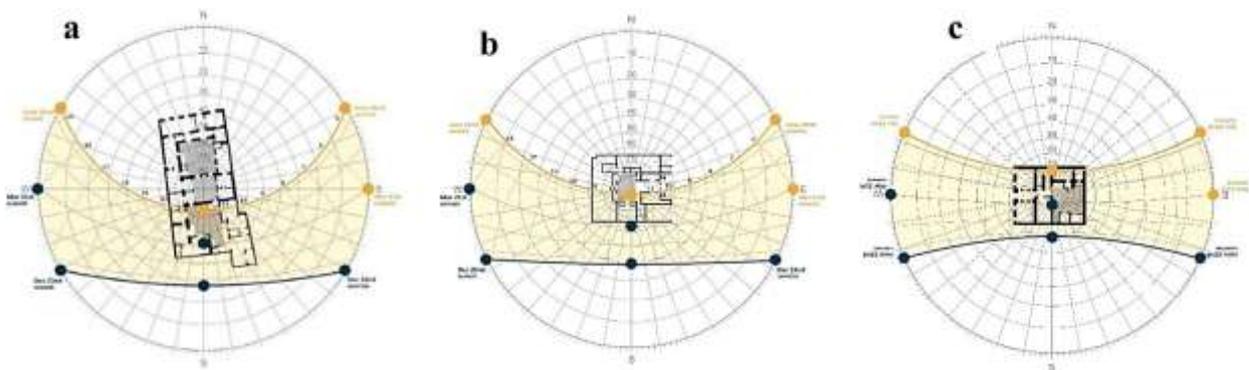


Figure 11. Solar path diagrams for three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar.

Source: Solar Chart from Koenigsberger, O. H. (1975). Manual of tropical housing & building.

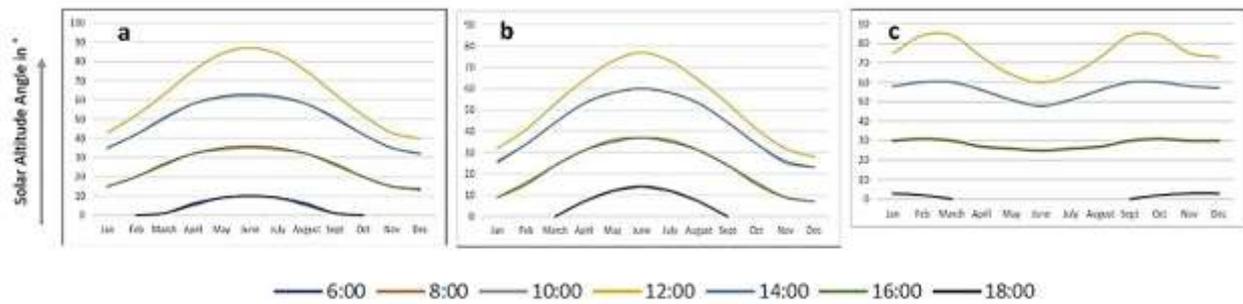


Figure 12. Solar Altitude angle for three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar.

Source: Generated from Fig. 9 by the Author

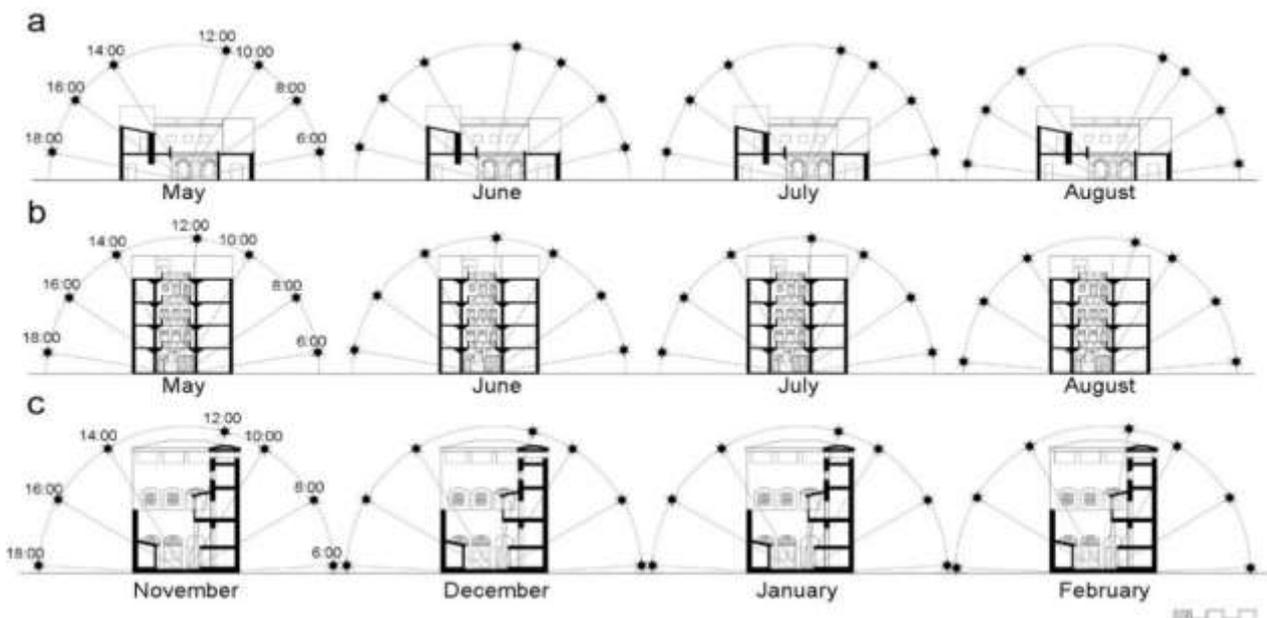


Figure 13. Solar altitude angle in relation to buildings for three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar.

Source: Derived from Fig. 6 by the Author

4.4 Selection of Material Along the Courtyard

In Andalusian architecture for the case of Cordoba, the massive arched white walls along the courtyards serve both as structural support and thermal regulators, absorbing heat slowly in the sun & releasing it gradually in the evening and overall time lag is increased. In addition to this, the material also reflects over 50% of the sun's visible radiation (Reynolds, 2002). Courtyard arcades provide effective shading to the building's rooms, resulting in cooler, darker interior. When considering thermal massiveness as the sole passive cooling strategy, the theoretical upper limit for achieving indoor comfort in outdoor temperatures is approximately 96°F (36°C). Success relies on factors like time lag (indoor temperatures peak hours after outdoor temperatures), adequate daytime ventilation for evaporation, and radiative cooling during the night. In hot and dry climates, evaporative cooling becomes an appealing alternative, extending the threshold for outdoor comfort to around 105°F (41°C). Similarly, thick materials are being applied at Jaipur and Stone town to increase the time lag (Table 5).

Table 5. Thermal conductivity of Materials.
Source: Fernandes et. al. (2014)

Material	Density Kg/m ³	Thermal Conductivity λ-Value (W/m °C)	Thermal Storage Capacity (Wh/kg °C)	Heat Transfer Time Lag for 250 mm Thickness (hour)	Embodied Energy (MJ eq./m ³)	Global Warming Potential (kg CO ₂ eq./m ³)
Rammed earth / adobe	1770-2000	1.00-1.20	0.23-0.30	10/9	943	38
Concrete bricks	1200	0.39-0.45	0.26	6	4245	357
Stone	2600-2800	2.3-3.5	0.22-0.24	-	1300	26
Concrete	2400	1.8	1.10	6.9	1450	264
Sandstone	2400	2.5-3.2	0.21-0.23	-	-	-

4.5 Cultural Context of the Courtyard

In Cordoban residential architecture, courtyards are a typical element, especially in the classic Andalusian residences called "casas-patio." These homes usually have a central courtyard that is encircled by rooms and functions as the dwelling's focal point (Leicher, 2015). Families congregate in the courtyard during the sweltering summer months to dine and socialise [Fig. 14 (a)]. In Cordoba's cultural life, courtyards are very important, notably during the yearly Festival de los Patios Cordobeses (Cordoba Patio Festival). Residents open their private courtyards to the public during this event, which has been designated as a UNESCO Intangible Cultural Heritage, highlighting their beauty with colourful displays of flowers, plants, and traditional decorations.

Jaipur is renowned for having a rich cultural legacy and history. In Jaipur's vernacular architecture, courtyards function as multipurpose areas for religious rites, social gatherings with family, and social interactions. They serve as both a social hub and a private space for residents to interact with one another, making them the centre of the house [Fig. 14 (b)]. This enclosure lets natural light and airflow into the room while providing a sense of privacy from the busy streets outside (Tipnis, 2012).

In Stone Town, courtyards are usually located inside "zana" or "dari," which are traditional Swahili homes (Harries, 1953). These homes have interior designs that face inward, with rooms grouped around a central courtyard. The courtyard offers tenants a secluded, shaded outdoor area where they may enjoy fresh air, daylighting, and a sense of peace amidst the busy streets [Fig. 14 (c)]. Decorative features like ornate stonework, carved wooden doors, and vibrant textiles are frequently used to beautify courtyards, which reflect various creative and cultural expressions.

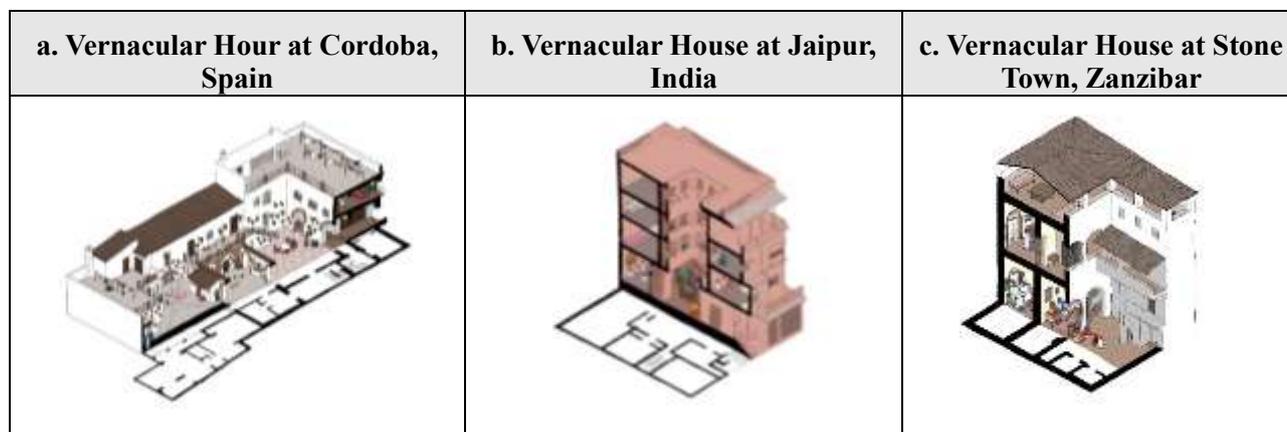


Figure 14. Cultural context for three locations; a: Cordoba, Spain, b: Jaipur, India, c: Stone Town, Zanzibar.

Source: Author

5.0 CONCLUSION

The buildings with the courtyard serve as both sun protectors and sun collectors (Taleghani, et. al. 2012). Here, sunlight plays a crucial role in addition to the sun's thermal influence. Consequently, consideration should be given to the suitable orientation of the structures and their courtyards as well as the appropriate placement of the void (court) inside a solid mass (building). Wind affects a courtyard building in two steps, it first moves through the court's cooler areas before it enters indoors to ventilate the building's interior. This is based upon the principle that first that the dimension of the courtyard is so adjusted that courtyard is always in shade and second that hot air being lighter in weight rises & leaves the court area comparatively cooler. The used air shall then be replaced by colder air. Thus, cool air from the courtyard is circulated to the rooms throughout the hot day, and the court can serve as a source of cool, fresh air (Harries, 1953).

In dry regions, humidity is necessary to create a comfortable atmosphere as water bears the higher thermal capacity and thus helps in absorbing the heat in the atmosphere. One key strategy for creating a cosier courtyard is to use natural features. The courtyard's humidity can be raised/adjusted by employing various natural factors. The two main natural components found in hot & dry courtyards are plants and water features. A courtyard building's microclimate is influenced by natural features including fountains, swimming pools, trees, plants and lawns (Spārītis, 2013). These elements have the ability to cool the air through evaporation in addition to absorbing, dispersing, or reflecting solar light (Taleghani, et. al. 2014). Adding native plants, green walls, and other eco-friendly elements to the built environment can improve air quality, boost biodiversity, and make it more sustainable overall. The sun and wind cause the evaporation, which raises the humidity in response (Taleghani, et. al. 2012; Taleghani, et. al. 2014).

Selecting the ideal courtyard orientation w.r.t sun chart is crucial since courtyards have a significant impact on the indoor climate. The first step is to determine the ideal courtyard's proportions and shape with respect to the given location as per section 4. The quantity of air that can be let inside for natural ventilation depends on the size of the courtyard. There are opportunities to incorporate greenery and eco-friendly design elements into courtyard spaces. Courtyards can therefore be utilised to modify conditions and temperature while also affecting the building's heating and cooling loads. A courtyard's openings facing various directions might provide natural sunlight for the structure. In this sense, climate and latitude are related to the quantity of sunshine received by various courtyard building faces. Because solar radiation impacts heating and cooling loads and natural illumination also affects a building's inside (visual) climate, it is crucial to take the climate of the building's location into account when designing the size of openings [Ref. Fig. 11, 12 & 13].

This has been observed that courtyards are becoming less popular in contemporary urban settings as vertical living is prioritised in high-rise structures and small residences due to space restrictions. The demand for courtyards as natural ventilation and lighting sources has decreased as a result of technological advancements like air conditioning and artificial lighting. Their significance has been further diminished by changes in lifestyle, such as reduced family sizes and indoor-focused living. Furthermore, courtyards need upkeep and in crowded places could be a privacy or security risk. Traditional courtyards have been replaced by more space-efficient options including balconies, rooftop gardens, and public parks.

Nowadays, with the rise of outdoor living spaces, well-designed courtyards are even more important. People can use courtyards as outdoor spaces for relaxation, socialising, and recreation. By slightly modifying this traditional component, courtyards can be included into contemporary designs of urban settings. These can be rethought as little atriums that provide natural light and ventilation without taking up any ground space in densely populated areas. Courtyards effectively blend indoor and outdoor areas by utilising large glass walls. Common courtyards in apartment buildings promote leisure and friendliness. Green courtyards with plants and trees provide natural insulation, which helps with energy efficiency. They can also be very important in sustainable design, encouraging passive ventilation and lowering the need for air conditioning. Furthermore, by using rainwater collection systems or naturally cooling water features, they can help with sustainable water management. Careful design can provide seamless transitions between indoor and outdoor living. Even today, courtyards can foster a sense of community and social engagement. Creating communal spaces for courtyard users or residents can encourage social interaction and a sense of community. This is crucial for urban planning, since creating vibrant, connected communities is one of the main objectives.

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