U.Porto Journal of Engineering, 9:1 (2023) 72-103
ISSN 2183-6493
DOI: 10.24840/2183-6493_009-001_001438

Received: 1 March, 2022
Revised: 14 May, 2022
Published: 23 January, 2023

Socio-Environmental Sustainability of Traditional Courtyard houses of Lucknow and Varanasi

Lalit Akash Verma[1], Farheen Bano[2]

[1]Research Scholar, Faculty of Architecture and Planning, Dr. APJ Abdul Kalam Technical University, Lucknow (verma.lalitakash@foaaktu.ac.in)

[2]Assistant Professor, Faculty of Architecture and Planning, Dr. APJ Abdul Kalam Technical University, Lucknow (bano.farheen@foaaktu.ac.in)

Abstract

The courtyard houses have an important place in the history of architecture. They play a vital role in the social and environmental sustainability of that place. This paper aims to identify the significance of courtyards in composite climate by analyzing the associated space, function, courtyard configuration, and socio-cultural connections. Accordingly, eight courtyard houses of Lucknow and Varanasi (Uttar Pradesh, India) were selected for analysis based on their heritage value (in terms of age) and placement in the courtyard. Drawings of these houses were prepared through a site survey. Illumination data in the courtyard and adjacent spaces was measured through a lux meter. Various parameters of the courtyard, such as placement, size (length, breadth, and height), and connection to adjacent spaces, were analyzed through the above-collected data. The analysis concluded that the courtyard houses with NS orientation with significant height have good thermal comfort and daylight in the adjacent spaces.

Author Keywords. Activities, Architectural element, Composite climate, Courtyard houses, Functional arrangement, Proportions, Socio-cultural.

Type: Research Article

1. Introduction

In the last decade, there was a massive transformation in the urban housing patterns due to the high population growth, change in social behavior, and high land prices. As a result of this transformation, a change in the vernacular language of the old settlements is evident. The development of housing typology is a continuous process; society and people add, subtract, and mold the design features with the climate, geography, introduction of new materials, technological intervention, and modern needs. The courtyard typology is the most common housing typology dating back to 3000 years, responding to socio-environmental needs (Yu 1999).

According to the architectural background of traditional courtyard houses of the Indian subcontinent, courtyards were based on climate responsiveness. Several regions of India have their vernacular language for designing a courtyard. "A courtyard is a circumscribed space open to the sky, often surrounded by a building or a complex structure" (Verma and Bano 2021). The courtyard absorbs the harsh solar radiation and provides an optimum sunshade to the building (Akbari and Teshnehdel 2018). The parameters of the courtyards, such as proportions, orientation, material, placements, surrounding spaces, and functions, play a critical role in providing comfort and delight to the user.

Nowadays, the continuous transformation in the traditional courtyard housing typology turns the courtyard into a small open to sky opening; henceforth, society loses the importance of

the courtyard. In addition, modern dwelling units are less climate-responsive and sustainable. The research aims to identify the significance of the courtyards of composite climate. The objectives are to analyze the functional arrangement of spaces around the courtyard, identify the benefits of spaces near courtyards, understand the configuration of courtyards of residential buildings in a composite climate, and study socio-cultural parameters related to the courtyard.

Lucknow and Varanasi are some of the world's oldest cities, having mythological and cultural connections. Both cities carry high population density and dense urban fabric and also share the same climatic zone (NBC, 2016). Hence, *eight courtyard houses have been selected for the case study; five in Lucknow and three in Varanasi.*

2. Methodology

The methodology adopted by the author in one of his studies (Verma and Bano, 2021) is used here, with a detailed study of socio-cultural aspects of the traditional courtyard typology added. The selection criteria for the case studies were based on the parameters mentioned below.

- Based on climate- Composite climate.
- Based on the age of the building- Houses with more than 50 years of age.
- Based on the type of courtyard placement, central, side, and corner courtyards were selected.

The study is done in two phases: Firstly, the analysis of the socio-cultural parameters was performed, followed by the analysis of courtyard houses' environmental parameters in a composite climate. The field study covers the measurement of the houses with the help of a digital distance meter, analysis of the site photographs, and interviews of the users. With the help of a certified Lux meter, Illumination levels were recorded for different times of the day at different locations in the courtyard and the surrounding spaces. The recorded data were analyzed through a comparative study.

2.1. Climate and geography classification

Lucknow and Varanasi lie in the composite climate zone of India. The maximum temperature of these cities rises to 45-47 degrees Celsius in summers (May - June). In winters (December - January), the minimum temperature drops to 4 degrees Celsius, and the average temperature is about 24 degrees Celsius. They receive 110 cm of rainfall in July-August (Kant 2016).

2.2. Traditional courtyard houses

As an element of architecture, the courtyard has a history that goes back to 8000 years in Iran (Khajehzadeh, Vale, and Yavari 2016). Abass, Ismail, and Solla (2016) state that it is not easy to determine the origin of the courtyard's construction practice; traces were also found in the Neolithic era. In the Indian region, the courtyard typology was named differently in different parts; for instance, in north India, it was called Haveli, Rajbari in West Bengal, Wada in Maharastra, Nalluketu in Kerala, and Chaturmukham in Tamil Nadu (Widiastuti 2018). Generally, courtyard construction was practiced in the Hot and arid region of the middle east (Abass, Ismail, and Solla 2016).

Recently, several studies have stated that the courtyard acts as a passive design element for achieving thermal comfort. Moreover, courtyards act as a transition space between private and public spaces in gulf countries to achieve privacy. In some cases, they act as a place for assembly, cultural activity, religious activity, cooking, sleeping, working, keeping animals, and

leisure. Courtyards have a strong mental and physiological sensation on their end-users (Lim and Tanko 2017).

The courtyards can be categorized based on their shapes, such as rectangular, square, circular, triangular, and polygonal (**Figure 1**). Rectangular courtyards are the most common shape of courtyards used in practice. In terms of summer, solar protection, and winter heat gain, the rectangular courtyard with a ratio (2:1) displays the highest value, and the circular courtyard form is more effective acoustically (Eldien 2015). Another basis of categorization is the placement of the courtyard in the house. Central courtyards are the most common; in some cases, the use of side and corner courtyards can also be seen.

Muhaisen and Gadi (2006) state it is desirable to minimize heating loads in winters and cooling loads in deeper courtyard shapes in summers. They also conclude that receiving solar radiation is more important in winters than avoiding it in summers.

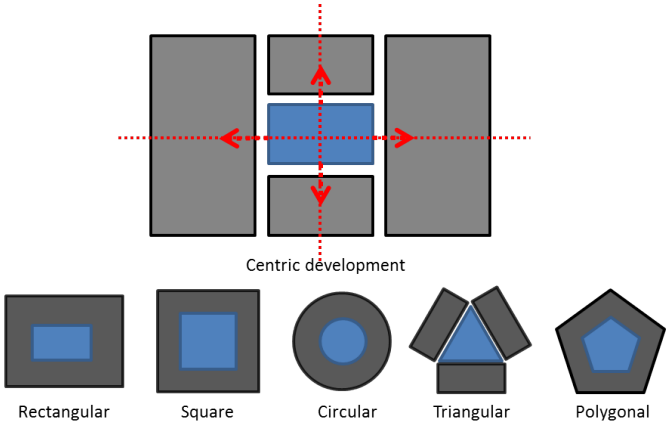


Figure 1: Types of courtyards and their centric development

2.3. Elements and Parameters of the Courtyard Houses in Composite Climate

Gupta et al. (2017) state that all the courtyard-type dwelling typologies are not necessarily thermally comfortable in composite climates. However, it has been mentioned in several studies that courtyard-type dwelling units are a good solution for thermal comfort within the dwellings in composite climate zones. Also, adding vegetation such as trees, bamboo, a lily pool, or a water reservoir can make a courtyard thermally comfortable in a composite climate (Gupta et al. 2017). Soflaei et al. (2017) concluded that square courtyards were better than rectangular courtyards, and adding height increases shading efficiency and thermal comfort in hot and dry climates. The N-S-oriented courtyard receives less radiation than E-W. Moreover, the orientation of NW-SE gets sun in the early hours, while the orientation of NE-SW is primarily in the afternoon (Taleghani et al. 2014).

The courtyard acts as a passive strategy to enhance daylight, thermal comfort, and ventilation in the interior spaces attached to it. Daylighting and ventilation through the courtyard generally depend on the form, area, proportions, orientation, shading elements, vegetation, built open ratio, aspect ratio, shape, perimeter ratio, and the water body (Markus 2016). Besides thermal comfort, ventilation, and daylighting, courtyards also have social and psychological effects. Appropriate daylight affects the psychology of the user and the visual comfort in the adjoining spaces (Markus 2016). Moreover, it segregates the social spaces, giving habitants a view of the sky and fresh air and bringing them closer to the outer environment.

3. Case Studies

Selected eight courtyard houses, *five in Lucknow and three in Varanasi* (Uttar Pradesh, India), were categorized based on their placement in the courtyard (**Figure 2**). Drawings of these houses were prepared through a site survey. Illumination data in the courtyard and adjacent spaces was measured through a lux meter. Various parameters of the courtyard, such as placement, size (length, breadth, and height), and connection to adjacent spaces, were analyzed through the above-collected data. Comparative charts and tables were developed for the statistical analysis.

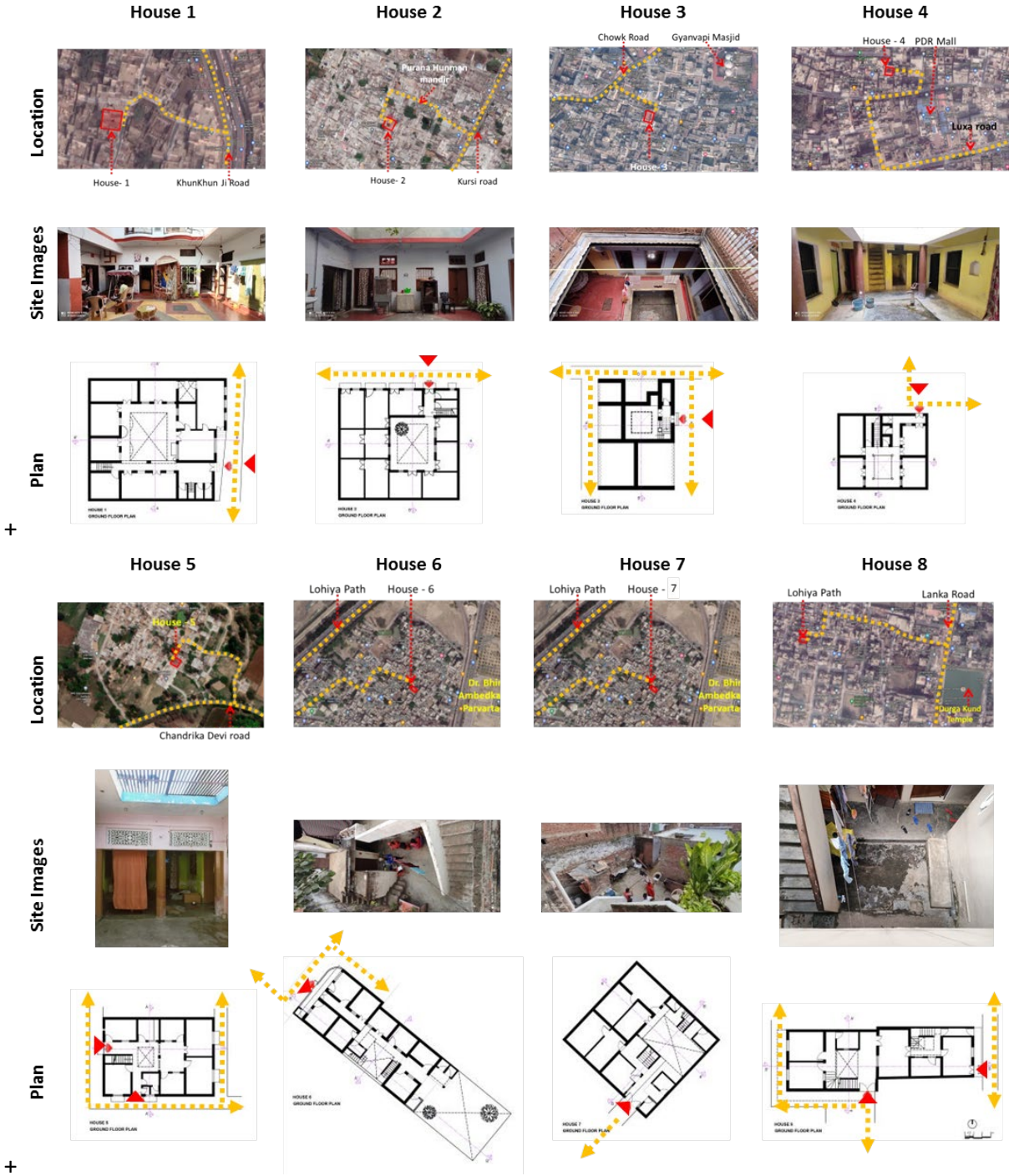


Figure 2: Selected courtyard houses of Lucknow and Varanasi, depicting the connecting streets and entrance of the houses (More details can find in the Annexure – 1)

3.1. House 1

House -1 was located in the Chowk area of Lucknow, 150 m from the Khunkhun Ji road (**Figure 2**). The house is a perfect example of local vernacular architecture, comprising a large central courtyard. The house is about 150 years old, constructed in Lakhori brick and lime mortar. The southern and western portions of the house's first floor were built as a new addition. This house had an eastward entry connected with a 2.1 m wide lane (**Figure 3**).

Figure 3: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 1

3.2. House 2

House - 2 was located in the Dandaiya area of Lucknow, 400 m from the Kursi road (**Figure 2**). This house was built in vernacular style, comprising a central courtyard with cement flooring and a Guava tree in the NW corner. The house was around 80 years old with minimal modifications and alterations. The entrance lobby holds separate toilets, baths, and staircases. The lobby opens in the courtyard; the room adjacent to it was used as the drawing-room (**Figure 4**).

3.3. House 3

House - 3 lies in the Basphatak area of Varanasi, which covers the significant temples such as Shir Kashi Viswanath temple (**Figure 2**). The building is G+3 (Ground Plus Three Building) with a central courtyard of rectangular shape. The effective opening of the courtyard is gradually increasing; on the ground floor, it is (2.3X 2.3) m, on the first floor (2.3X 3.1) m, and on the second floor, it is (3.8X 3.9) m. The house was a perfect example of local vernacular architecture having N-S oriented and an entry from the east (**Figure 5**).

Figure 4: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 2

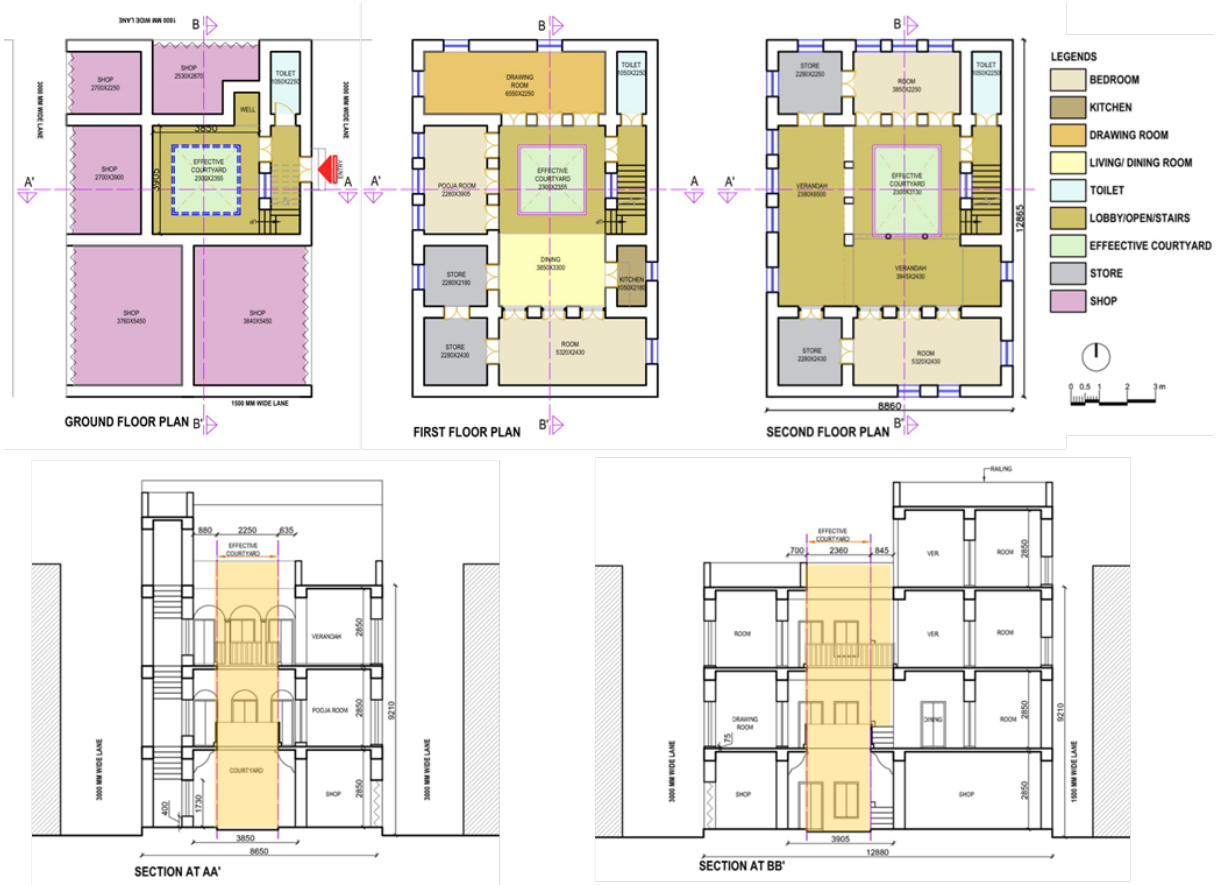


Figure 5: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 3

3.4. House 4

House - 4 was a 110-year-old building situated in the Luxa area (**Figure 2**).The house was blocked from the three sides with a rectangular central courtyard of size (2 X 2.7) m so that only the roof was exposed to the sun. The courtyard fulfilled the requirement of lighting and ventilation. The house was constructed in brick and lime mortar. The house has a north entrance leading to the entrance lobby in the courtyard, which carries a hand pump (**Figure 6**).

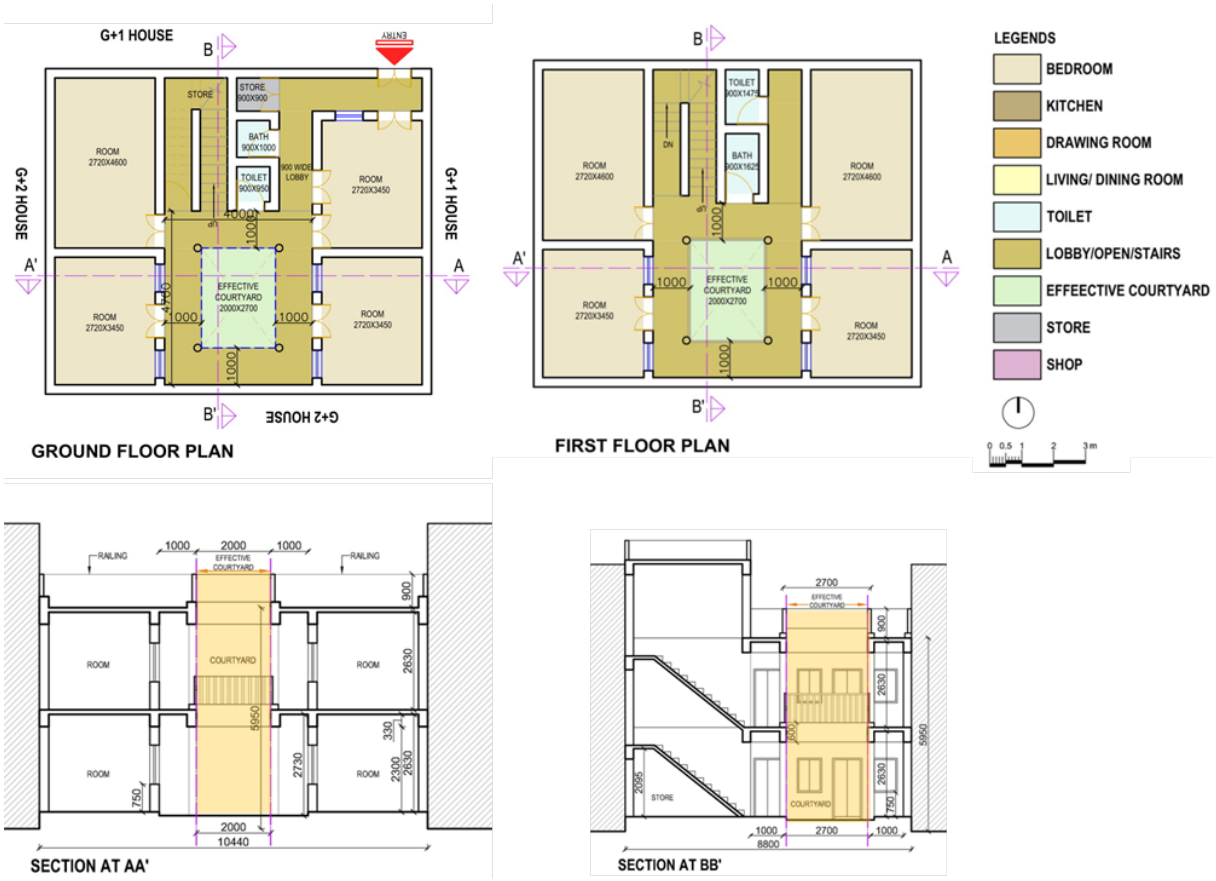


Figure 6: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 4

3.5. House 5

House - 5 was located in the Bakshi ka Talab area of Lucknow, 400 m from the Chandrika Devi Marg (Figure 2). The house was a part of the old village settlement. It was built in local vernacular architecture, comprising a small central courtyard of rectangular shape. The house is about 50 years old, made in brick and cement mortar. The structure was of single floor only with two entrances from south and west; the west entrance was used frequently. The drawing-room was located in the western entrance lobby. A verandah was in the central-eastern part of the house, acting as a living area for multifunctional activity (**Figure 7**).

Figure 7: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 5

3.6. House 6

House - 6 (75 years old) was located in the Jia Mau area of Lucknow, 500m from the Lohiya path (**Figure 2**). It was a part of an ancient rural settlement approached by narrow lanes such that the courtyard was the primary source of light and ventilation. It has ample open space on the rear side, having two mature trees. The side courtyard and the back courtyard were connected by a lobby, which acted as a wind channel. Rooms were arranged in a chain manner along the length. The room at the front was used as a drawing-room; the room behind was the living room (**Figure 8**).

3.7. House 7

House - 7 was also located in the Jia Mau area of Lucknow; it is about 60 years old G+1 (Ground plus First floor) structure (**Figure 2**). Several modifications were incorporated with time like small temporary structures were added in the courtyard. The house has a South-West (SW) entrance, along which the drawing-room was planned (**Figure 9**).

Figure 8: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 6

Figure 9: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 7

3.8. House 8

House - 8 was located in the Durgakund area of Varanasi (**Figure 2**). It was constructed in two phases; the eastern half of the house was initially built, and later, the western half was added. It was a G+1, 60 years old structure. The east portion carries a minor open to sky area, while the western portion was planned with an appropriate courtyard. The house has two entrances, and the southern door opens in the entrance lobby, which is also used as a verandah. It connects the living room to the courtyard (Figure 10).

Figure 10: The figure above depicts the ground and first-floor plan space arrangement and effective proportions of the courtyard of House 8

4. Analysis of Socio-Environmental Characteristics of Selected Courtyard Houses

The courtyard is the most significant passive architectural element of the traditional building and is designed according to the socio-cultural needs of the users. Thus, it can have many variants depending on the geographical locations, climate, and society, but it can have similar characteristics. The courtyards are based on the idea of sustainable designs that unifies social, environmental, and economic sustainability. The selected courtyard houses were analyzed based on their significance in socio-cultural and environmental aspects.

4.1. Analysis of Socio-cultural parameters

As central open to sky space, Courtyards are used for multiple activities in various phases of their life. It has been analyzed based on urban form, entrance and circulation, architectural character, symmetry and formality, community and privacy, and activity and rituals.

4.1.1. Urban Form

The selected traditional houses of both the cities belonged to the old dense urban settlement of the city, built like row houses with common sharing walls. Mostly, they were blocked from three sides, reducing the exposed area to the sun and reducing the heat intake. The streets act as the public zone shaded by the old urban fabric; people sit on the Chabutras (a raised platform or an extended plinth along the sides of the main entrance of the house) and participate in street activities. The courtyards were the primary source of light and ventilation in these houses. The houses were generally G (Ground floor) and G+1 in height except House 3, which was G+3. The southern and western end was higher than the rest of the portion to block the late afternoon sun, as shown in House 1, 2, 3, 5, and 8 (**Figure 11**)

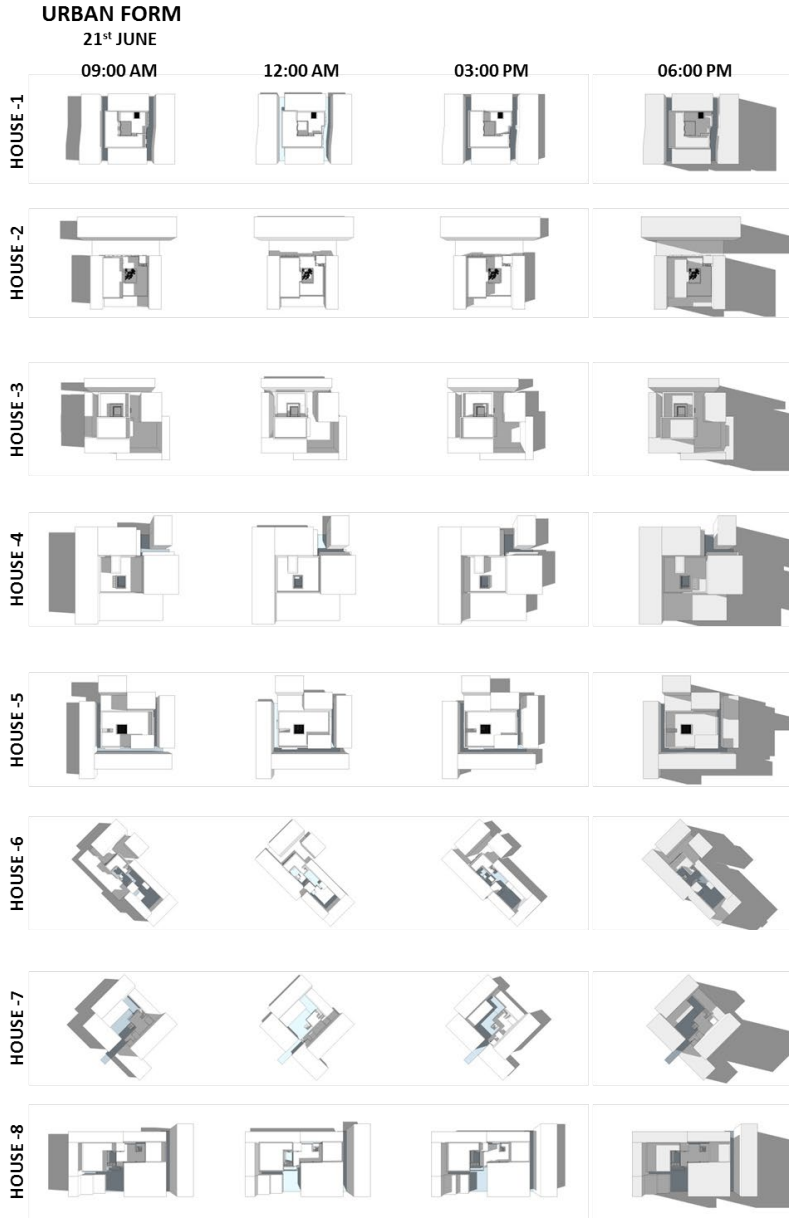


Figure 11: The illustration above shows the urban form of the selected courtyard houses and sun shadow at intervals of 3 hrs on 21st June.

4.1.2. Enter sequence and circulation

The courtyard houses of India were planned on the principle of Vastu, an ancient science of building and space planning. Vastu recommends that the house entrance should be from the North or East. The main entrance door should have Chaukhat (a door frame having four wooden pieces) with double shutters (**Figure 13**- C, D, G, and T). Usually, the lintel height of the main entrance door should be kept a bit low from the average Indian height so that one enters the house by bending his head in front of God. The houses of North India are usually planned with a single courtyard in the center that opens to the sky. The main entrance outside Chabutra (**Figure 14**- C) and the entrance lobby carry a separate bath, toilet, and a staircase. A loft above the entrance lobby can be seen in some cases, which reduces the ceiling height. A sense of surprise was generated when a person entered from a narrow street into the courtyard from the narrow entrance lobby. Houses 1, 2, 3, 4, and 5 show the same entry sequence but in different directions (Figure 12). House 8 has two entrance doors, the eastern door occasionally used for auspicious activities (like marriage, pooja, festivals, etc.) and the southern door for regular use and parking (Figure 12).

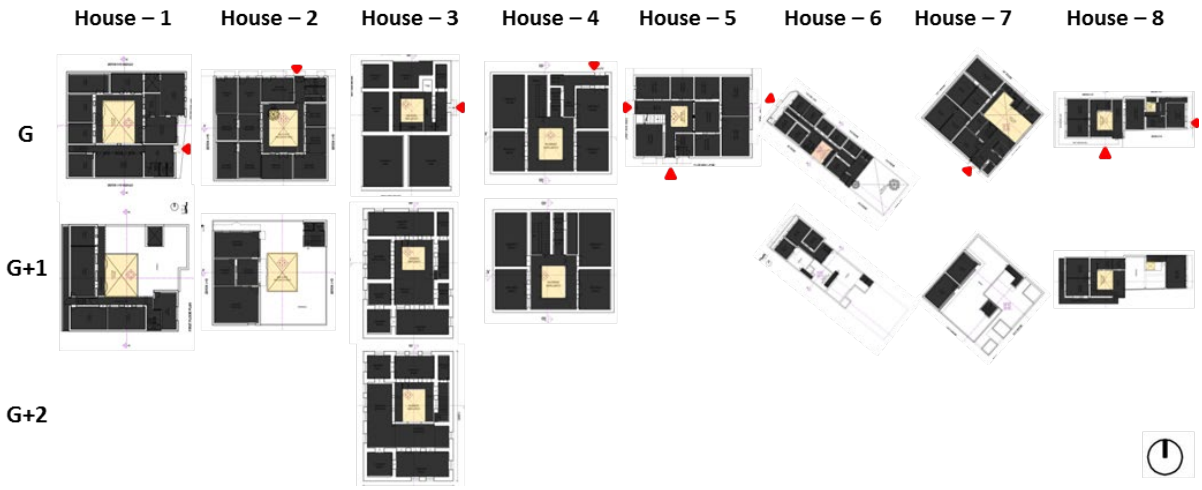


Figure 12: The figure shows the entrance and build- unbuild of the selected courtyard houses

4.1.3. Architectural character

The courtyard houses of Lucknow and Varanasi are smaller than the Middle Eastern and Latin American countries, such that vegetation, water bodies, and ponds are absent. These courtyards were characterized by a solid surface decorated by the geometrical patterns with a lintel-post structure of Verandahs (if present) with no arcades. Sometimes extended projections acting as Verandahs were added as spillover space for general activities. In Houses 1, 2 & 3, the entrance lobby serves as the core for vertical circulation opens in the courtyard; in Houses 4, 5, 6, 7, & 8, the stairs open in the courtyard with the adjacent toilet. The projection acts as the central circulation passage connecting the spaces on the first floor. On the first and second floors of House 3, an open veranda on the southern side was used as the living and dining space by increasing the courtyard opening.

Molding and cornice can be seen in Houses 1, 2, 3, and 8 (**Figure 13**- A, F, I, K, N, and S). Perforated parapet walls and grilled railings were used in Houses 1, 3, 4, and 7 (**Figure 13**- A, F, L, N, and P). Cement jaali (a perforated panel made in cement or lime concrete, with a floral design) in Houses 1, 2, 5, 6, and 7 (**Figure 13**- G, R, and T). Wall niches were used in Houses 1, 3, 4, and 7 (**Figure 13**- M, and O).

Figure 13: The figure shows the architectural elements of the selected courtyard houses

4.1.4.Symmetry and Formality

Reynolds, York, and Wiley (2002) state that "at formal extreme, all four sides of the courtyard are identical, at informal extreme, no two sides of the courtyard are alike". The courtyard houses of Lucknow and Varanasi were on the verge of change. The Courtyard of House 1 initially has three identical sides, but the courtyard loses its formality and symmetry due to alteration and addition. A similar pattern was traced in Houses 2, 3, and 4; two walls still share typical characteristics, such as opening, placement of opening, and axial placement of spaces adjacent to the courtyard. House 5 shows the symmetry of placement of architectural elements such as openings and jaalis for ventilation. Houses 6, 7, and 8 have informal and asymmetrical courtyards (**Figure 14**).

Figure 14: The figure shows the symmetry and formality used in the selected courtyard houses

4.1.5. Community and privacy

The courtyard house typologies are categorized into public, semi-public, semi-private, and private zones (**Figure 15**). Shaded streets and chabutras (raised platform at the entrance) were the public zones (**Figure 13**- C), courtyards were the private zones, and entrance foyers were the semi-private zones. While maintaining privacy, the visual connection between the courtyard and the street was broken. The visitors were taken to the drawing-room from the external door which directly opens in the street, making it a semi-private space. The entry of the worker, sweeper, or cleaner was limited to the entrance lobby. Another door added between the entrance lobby and the courtyard acts as a curtain to maintain privacy. Consequently, spaces adjacent to courtyards enjoy the advantage of privacy from the outside. There are many guiding principles in different religions that promote women's privacy, like courtyard houses of Arabic countries have two separate courtyards for men and women. Houses 1, 3, 4, 5, 6, and 7 belong to the Hindu community, House 2 to the Muslim community, and House 8 to the Jain community, but all share common characteristics. On the note of privacy, all the communities follow a similar typology, having a single rectangular courtyard. The entrance lobby segregates the public and private spaces. Both the houses have separate toilets and baths in the entrance lobby. Drawing rooms were placed in the front with a direct opening into the street so that the visitors or guests could be taken directly to the guest area. The visitors can use the toilet and bath without disturbing the privacy of the family members. The double shutter wooden windows with vertical iron bar grill for safety and security purposes, having sill height of 0.75 m (**Figure 13**- B, H, O), were installed in both houses on the walls for light and ventilation.

Figure 15: The illustration depicts the different privacy levels in the selected courtyard houses.

4.1.6. Activities and Rituals

In the Indian scenario, courtyard houses of composite climate, which act as a semi-private zone, are used for multipurpose activities varying with time, season, and the user's age group. It is the central focus zone for social interaction. It also generates a sense of confidentiality for the user to maintain acoustic and visual privacy from outside. The use of light-colored lime wash is a common trait; it reduces the degree of enclosure of courtyards (**Figure 25**). The Verandahs were the transition spaces or shaded extensions of the courtyards, generally placed at the southern end of the courtyard. Some furniture was added in these zones for pleasure and delight, as it protects the occupants from direct sun, wind, and rain exposure.

The activities described here and presented in the (**Figure 16**, 17, 18, 19, and 20) were collected during visits to the houses, by observation and interviewing the residents. The activities and rituals in the courtyard change with the weather, festivals, functions, holidays, and daily activities. During high summers, the daytime activities are significantly less, and people prefer to stay inside due to high ambient air temperature. People start assembling in the evening for casual interaction and prefer to use the courtyard for sleeping at night. In winters, people come outside to take the heat in the daytime and stay inside on colder nights. People like sitting on the verandah during the monsoon to enjoy the rain shower. Daily routine activities such as early morning yoga, meditation, puja, newspaper reading, breakfast, and sometimes bathing were commonly seen (**Figure 16**, 17, 18, 19, and 20). During summer noon, drying utensils, clothes, masalas, and food items can be seen (**Figure 17** and 20).

Men assemble after office hours for interaction in the evening, and kids after school to play games (**Figure 17**, 18, and 19). Holidays are the whole day of interaction time for all family members. The activities in the courtyard enhance on special occasions such as festivals like Holi, Diwali, Id, and likewise. Rituals of marriage, religious activities, birthdays, and sometimes the rituals associated with the death of a person were also performed in the courtyard. The above-discussed activities and practices are prevalent in both Lucknow and Varanasi.

The terraces are also an essential element of these typologies because they visually and physically connect the user with the surrounding environment and the next-door neighbor. The activities vary with time and season. During festivals such as Makarsankranti, Diwali, Id, etc., the terrace was used for celebration and social interaction.

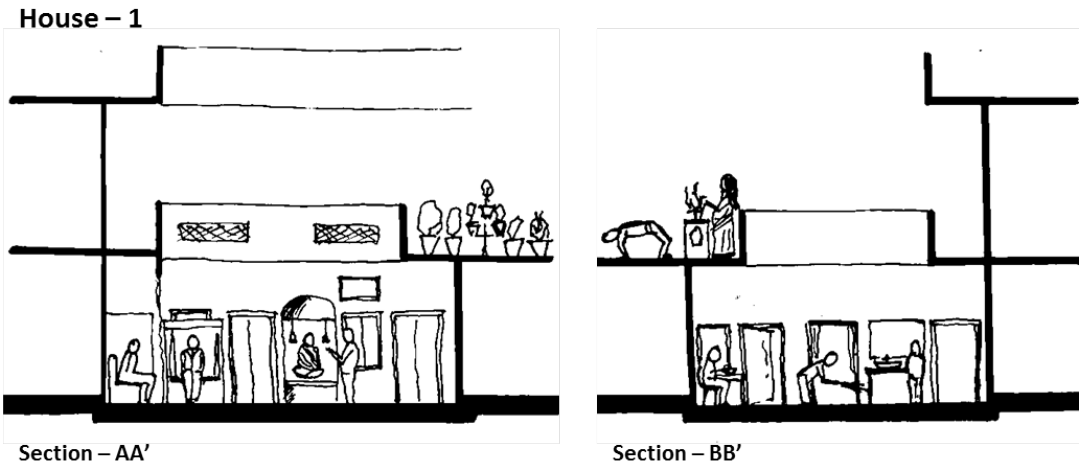


Figure 16: The figure shows the activities and rituals of House 1

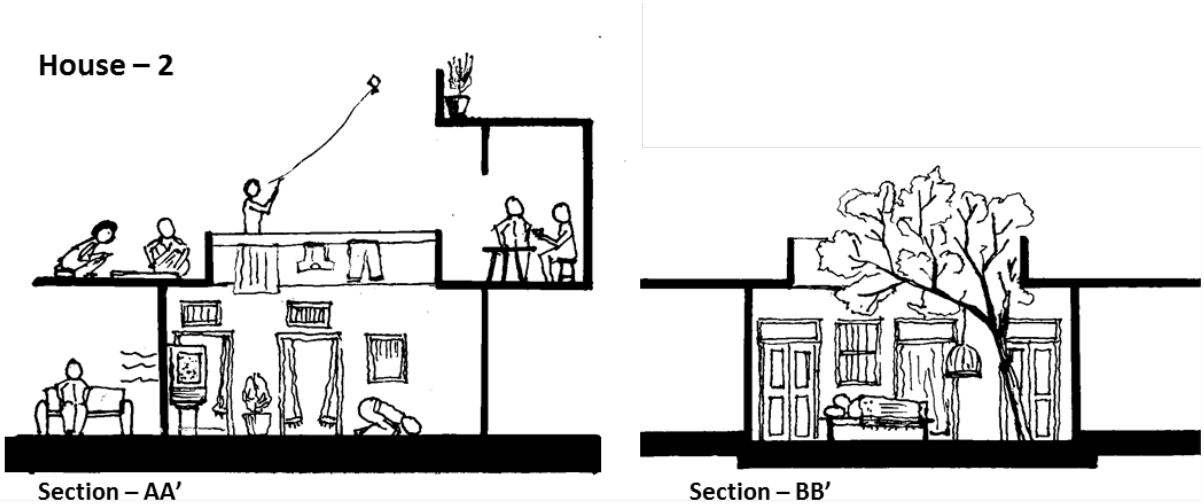


Figure 17: The figure shows the activities and rituals of House 2

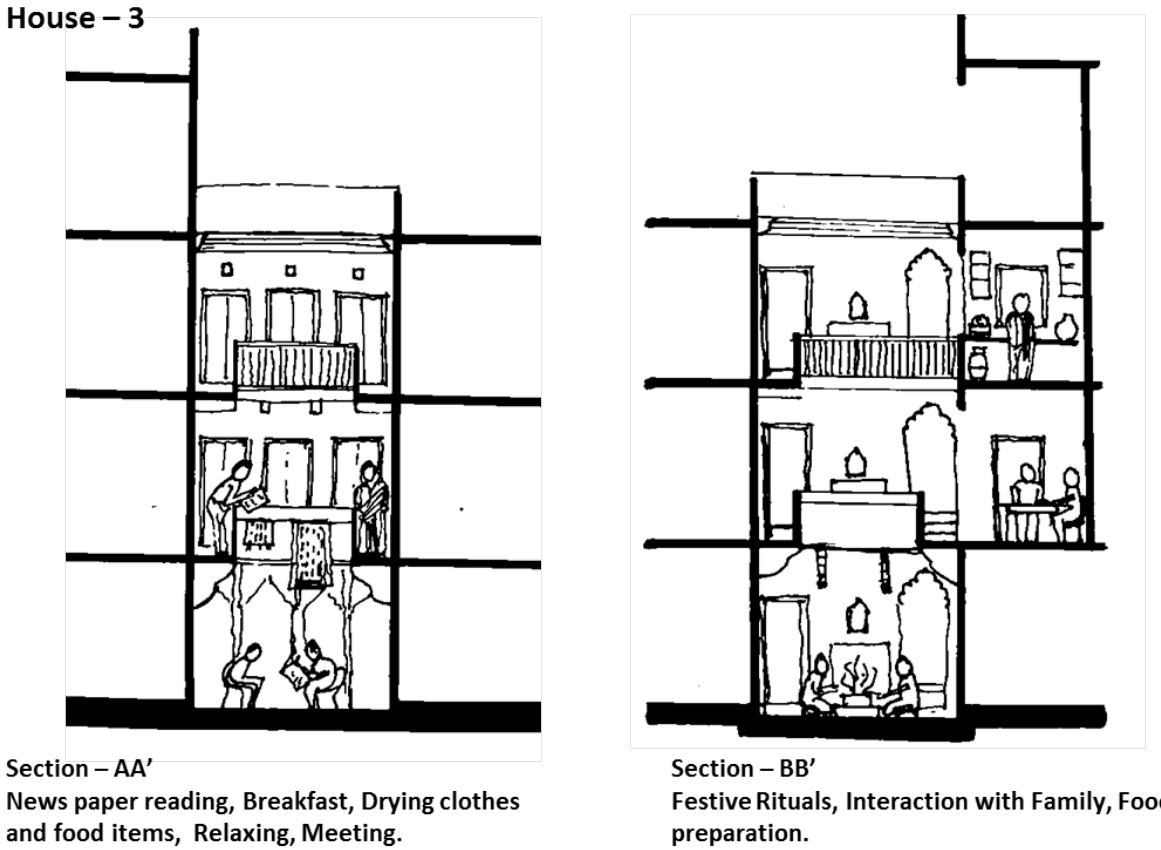


Figure 18: The figure shows the activities and rituals of House 3

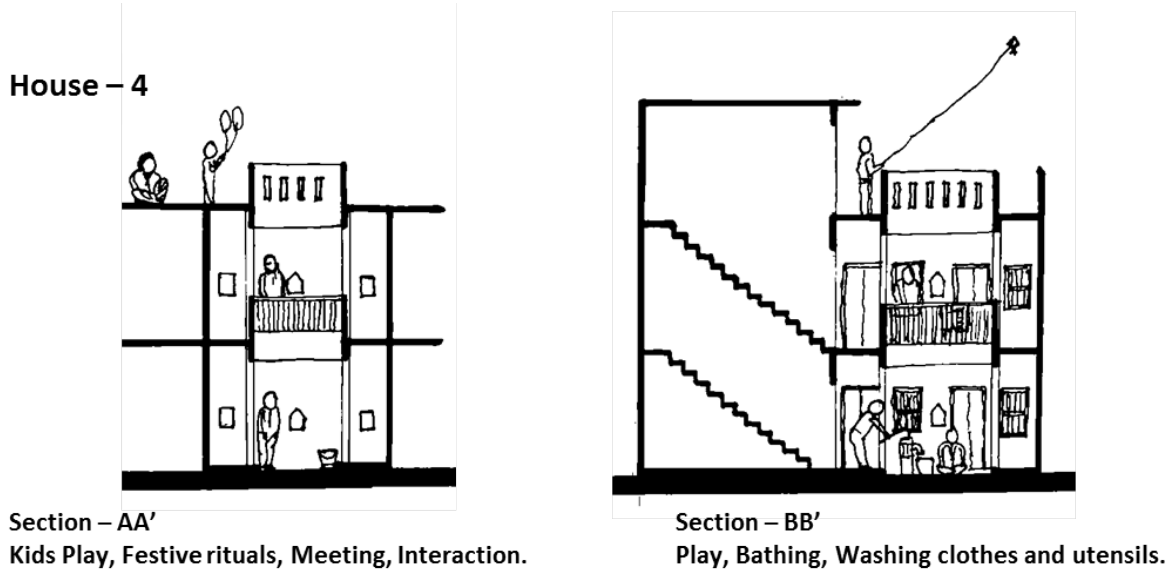


Figure 19: The figure shows the activities and rituals of House 4

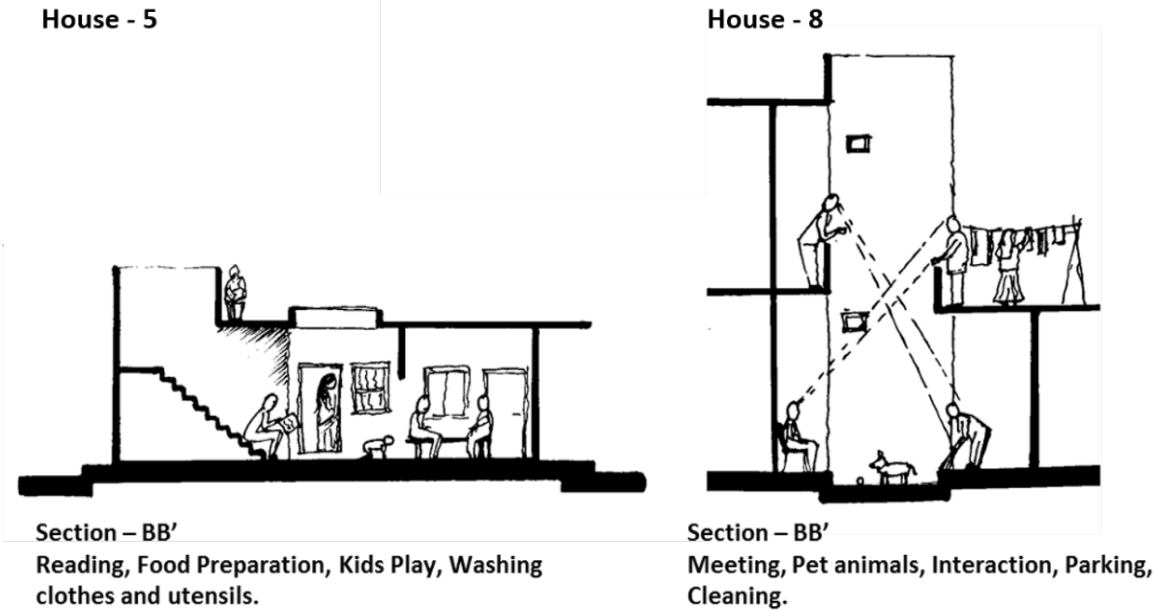


Figure 20: The figure shows the activities and rituals of House 5 (left) and House 8 (right)

4.2. Analysis of environmental parameters

The houses in these settlements were compact and connected with narrow lanes. The sharing walls blocked almost three sides of the house with the neighboring houses, and the roofs were exposed to the sun. The courtyards were the only source of light and ventilation in the house. The courtyards were analyzed for optimum environmental properties concerning thermal mass, orientation, vegetation-waterbody, proportions, material structure, color, and daylighting.

4.2.1. Thermal mass

The outer walls of the ground floor for Houses 2, 4, 5, 6, 7, and 8 have 250-300 mm thick brick walls, House 1 has 350 mm thick brick walls, and House 3 has 450 mm thick brick walls. Thin walls were used for the inner partition. Initially, the houses had roofs constructed in lime concrete and Surkhi (Powdered brick), usually thicker and heavier than the modern-day

Reinforced Cement Concrete (RCC) slabs. The new addition was done in brick, cement mortar, and RCC work in all the houses. All houses have wooden doors and windows except House 5. The sill level in all the houses ranges between 750 - 900 mm, and the lintel level varies between 1700 - 2100 mm (**Figure 21**). The ventilators opening in the courtyard were seen only in Houses 2 and 6. The Window to Wall Ratio (WWR) of the southern wall is greater than the northern wall in most cases, and the WWR of the eastern and western walls were almost similar. The combined WWR of each house with a central courtyard is identical to the houses with side and corner courtyards.

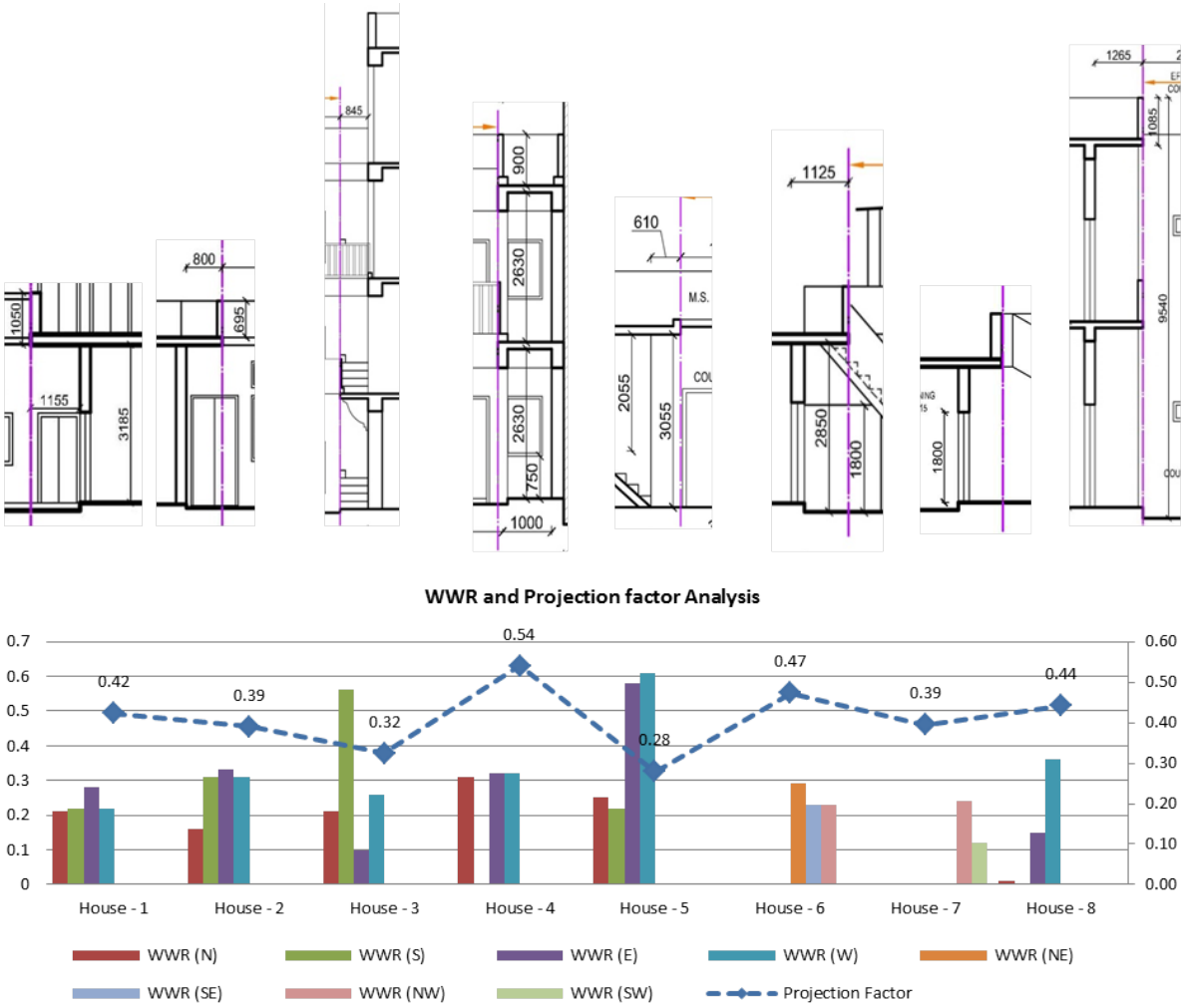


Figure 21: The figure depicts the details of the window and shading configurations of the selected courtyard houses

4.2.2. Orientation

The orientation of the building defines the building performance in terms of thermal comfort, visual comfort, and delight. Building facades with different orientations receive different amounts of radiation and daylight (Vaisi and Kharvari, 2019). Mostly the courtyards were aligned in the direction parallel to the adjoining street. Organically developed cities have an irregular plot size with varying orientations. Thus, the courtyard follows the orientation of the plot and space organization. The N-S oriented courtyards receive direct sun on the short east and west walls in the morning and evening and the southern wall in the noon. Henceforth only one wall gets direct radiation at a time rest were shaded with little exposure to the east and west sun. The courtyards with E-W orientation receives partially shaded longer wall in the morning and evening time, and direct sun in the afternoon of high summers such that it gets

no sun in the winters (Reynolds, York, and Wiley 2002). Five out of eight houses have E-W, one has N-S, 1 has SW-NE, and the other has NW-SE orientation. 6 out of 8 houses have a courtyard with a longer side in N-S orientation. The orientation of the internal courtyard is almost parallel to the street, and the longer side was oriented in the N-S direction (Figure 22).

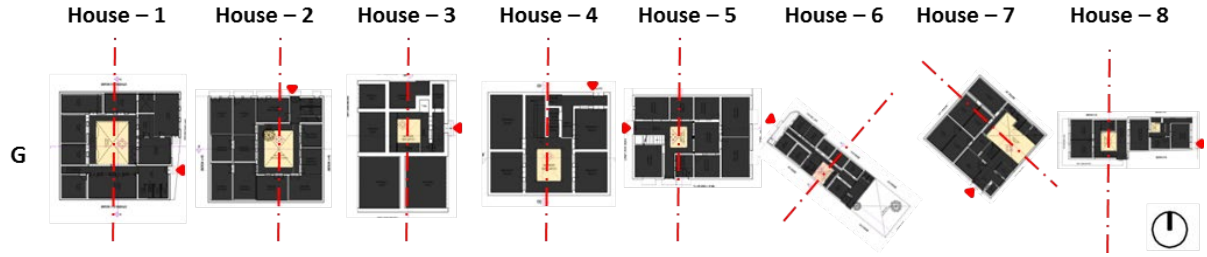


Figure 22: The illustration shows the orientation of the courtyards

4.2.3. Vegetation and water body

"Plants appeal to all senses" (Reynolds, York, and Wiley 2002). Plants act as the elderly ancestor in the house, providing shade and delight to the user. Several aromas were generated, attracting insects, bees, and butterflies, which changed the space's experience. House 2 holds a Guava tree in the NW corner of the courtyard. Initially, Houses 1, 3, and 4 also had light vegetation in their courtyard. House 3 carries a well in the courtyard, while house 4 carries a hand pump. Vegetation and water body are commonly not used in the courtyards of the composite climate.

4.2.4. Proportions

Six out of eight courtyard houses have an effective length-to-width ratio between 0.74 and 0.82 (**Table 1**) (**Figure 24**). The percentage of the verandah area lies between 50% to 70% of the courtyard area (**Table 1**). House 3 holds the highest average height of the walls, which is 10.65 m. the average overhang height (Parapet wall) is 0.93 m and the average overhang width (projection) is 0.88 m (**Figure 24**). The high aspect ratio increases the sky exposure of courtyards and increases the natural light intake (Reynolds, York, and Wiley 2002). Houses 1, 2, 6, and 7 have an aspect ratio above 1 (**Figure 23**). They have higher sun exposure and more winter shadow on the north wall (Reynolds, York, and Wiley 2002). Whereas houses 3, 4, and 8 have high solar sun exposure, 3.30, 1.38, and 1.65, respectively. These houses have a deeper courtyard and receive less winter sun. The projection factor lies between 0.28 and 0.54 (**Figure 24**); the average projection factor of the houses was 0.40. The average WWR of the N-wall is 0.19, and the average WWR of the S-Wall is 0.22.

Case study	House - 1	House - 2	House - 3	House - 4	House - 5	House - 6	House - 7	House - 8
Ratio of Eff. Length and Width	0.77	0.78	0.98	0.74	0.82	1.09	0.58	0.74
Percentage of Varanda area	51.63	49.12	64.00	71.28	59.87	21.17	10.86	58.60

Table 1: The table below shows the ratio of the effective length–width and the percentage of the courtyard's verandah

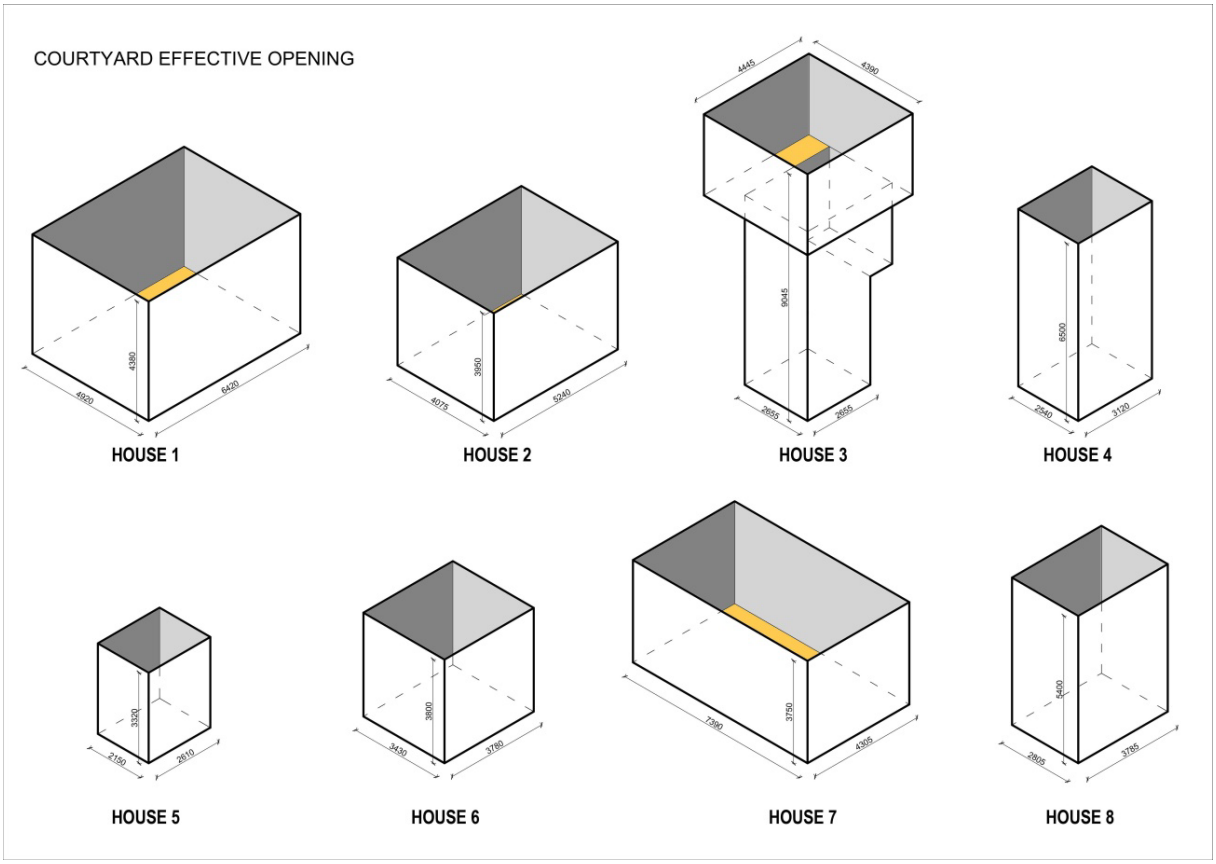


Figure 23: The figure shows the effective openings of the courtyards.

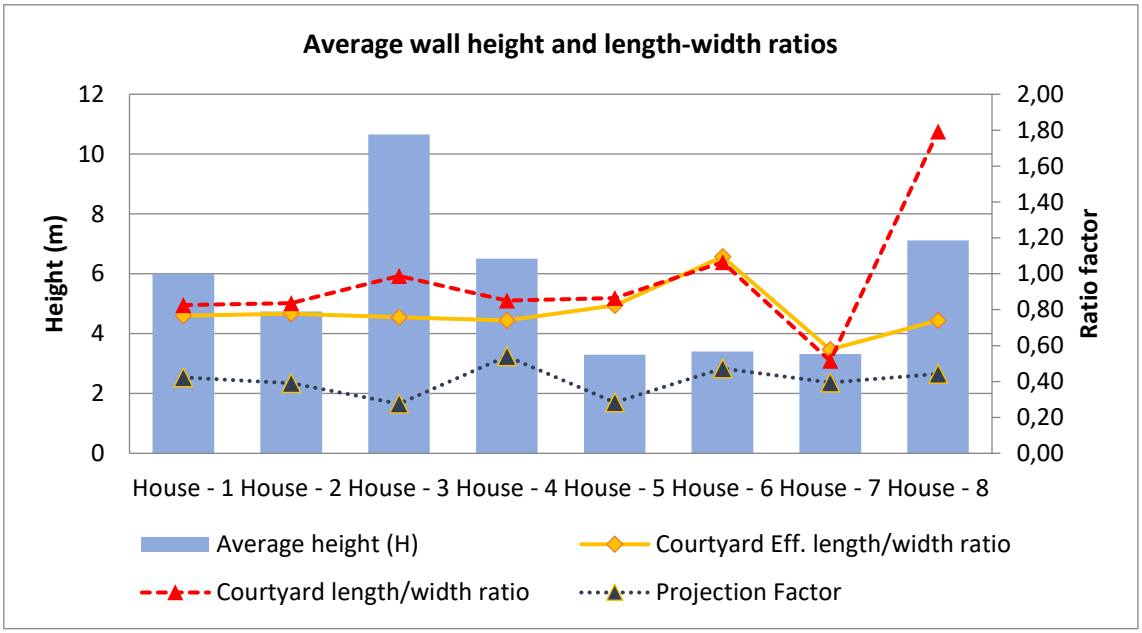


Figure 24: The figure shows the average wall height, courtyard length-width ratio, effective length-width ratio, and projection factor

4.2.5. Material and structure

Thin burnt clay brick, traditionally called Lakhori, is the chief material for construction in the region used in the significant historical building of the Nawabi and the British era. Houses 1 and 3 were built in the Lakhori bricks and lime mortar; Houses 2, 4, 5, 6, 7, and 8 were constructed in brick with cement mortar; in some cases, the lime mortar was used. In Houses

1, 2, 6, 7, and 8, a new addition on the upper floors was executed in RCC and brickwork using cement mortar. While House 3 has sandstone cladding over the brickwork, projections were made in stone slabs supported by beautiful stone brackets. Stone pillars were used to support the verandah and stone slabs for lintels. The house has the old traditional double shutter entrance doors with chaukhat (door frame). The double shutter wooden windows with iron bars (painted black using bitumen) for security, whereas in house 1, wooden panels of the windows were replaced with glass. Houses 1, 2, 4, 5, 6, and 8 have cement flooring in the courtyard (**Figure 26**), and House 3 has sandstone flooring. Houses 1 and 2 have geometric pattern designs on the courtyard floor (**Figure 26**). The steps at the entrance and chabutara (raised platform at the entrance) were made of sandstone in significant cases. White limewash was commonly used for the surface finish in the courtyards.

4.2.6. Colour

The traditional use of limewash was widespread in the region; it was the people's first choice in the rural areas. Houses 2, 3, 4, 6, and 7 used lime wash in the courtyard (**Figure 25**), while Houses 1, 5, and 8 used distemper paints for the surface finish. Shades of whites were the standard color in all houses, except House 4 (light yellow) and 5 (light pink). Cement jaalis were used for the ventilators in most houses (**Figure 13**). For example, wooden doors and windows, painted in black bitumen for termite and moisture protection, were generally used in houses 3, 4, and 6.

Figure 25: The figure shows the houses painted in tones of white color A - House 1, B - House 2, C - House 3, D - House 6, and E - House 7.

Figure 26: The figure shows the geometrical patterns and red and yellow colors used in cement flooring A - House 1, B - House 2, C - House 3, and D - House 4

4.2.7. Daylighting

Natural daylight plays a significant role in transforming the quality of the space, such as the visual comfort, psychology of the user, and delight. In the field study, illumination levels were recorded in the courtyards at different points for different times of the day. The results show that a house with a central courtyard, such as Houses 1, 2, 3, 4, and 5, performs better with respect to daylight. The houses with a side courtyard (Houses 6, 8) and a corner courtyard (House - 7) receive high illumination, causing visual discomfort due to glare.

5. Conclusion

As discussed above, courtyard typology is a very common housing typology in India. In this paper, various social and environmental parameters of the courtyard houses of composite climate were analyzed and concluded that:

- The E-W-oriented houses with N-S-oriented courtyards are prominent in this climatic zone.
- Generally, all the houses have a main entrance from the east or north, with a wooden chaukat door; the entrance lobby has a detached toilet –bath, stairs, and the drawing-room has a direct entry from the street.
- Most of the houses follow the principles of Vastu.
- Cement flooring with geometrical patterns in yellow and red is prominent.
- The houses have high southern and western walls to counter the sun and maintain thermal comfort.
- The absence of vegetation and a water body was observed.
- The light color matt finish of limewash reflects sunlight, avoiding heat transfer from walls and roofs.
- The urban form with continuous sharing walls and narrow streets reduces the surface area exposed to the direct sun, and the thick courtyard walls act as a thermal mass that restricts heat during the day and dissipates it during the night.
- The effective length to width ratio range of 0.74 to 0.82, with 50-70% of verandah area, is recommended for designing courtyards.
- The diurnal and seasonal changes in the light, temperature and wind pattern generate variation in the user's experience.
- The courtyard provides a sense of privacy, security, and safety to the occupant and thermal, visual, and acoustical comfort.

The courtyards are not only microclimate modifiers; they modify the user's perception, experience, and activity. The results show that the traditional houses of Lucknow and Varanasi are responsive to the climate and socio-cultural context and generate physical and psychological balance for the user. The research provides a background for future research on the courtyards of composite climate, and environmental performance of such houses can be studied.

ANNEXURE

House – 1 Details

Key plan

House Details

Case study	House - 1
Location	Chowk, Lucknow
Climate	Composite
Orientation	E-W
Age	150
Building type	Residential
Plot Area	216.6
Total Built up area	347.3
Building Volume	1093.83
No. of Floors	G+1
Floor to Floor height	3.38
Occupancy (hr)	24
Wall	Lahkori Brick Work
Wall finish	Paint over Putty
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	Yes
Courtyard shape	Rectangular
Courtyard Placement	Central Open
Courtyard Length (L)	6.36
Courtyard Width (W)	7.7
Average height (H)	6

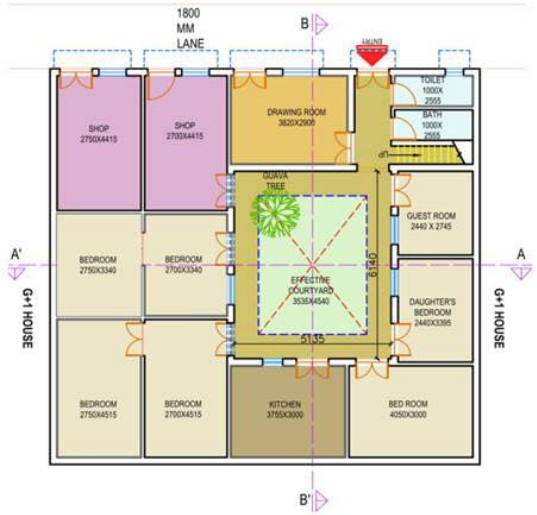
View from the first floor

View of northern wall

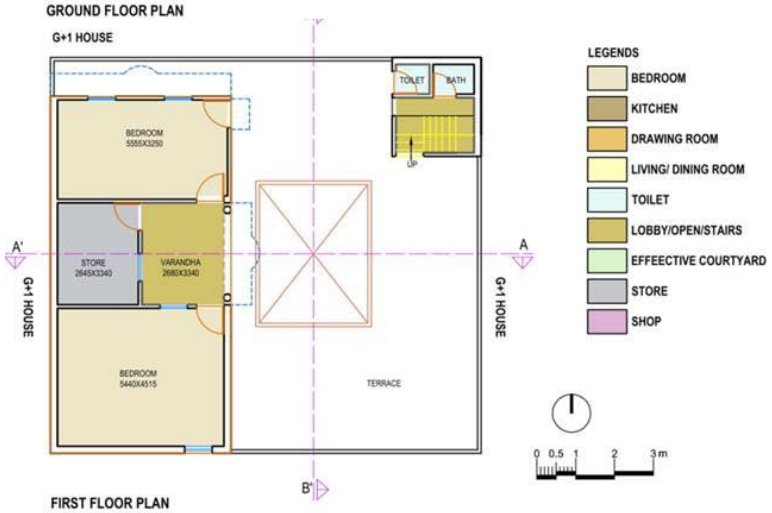
View of southern wall

Figure 27: House 1 details

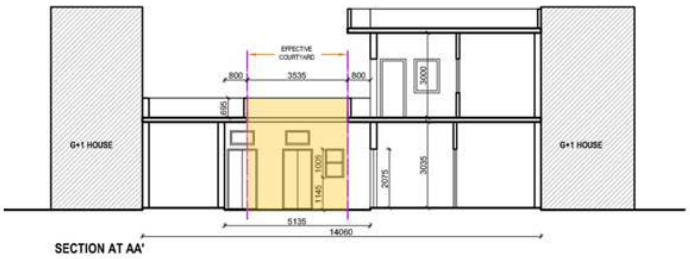
House – 2 Details



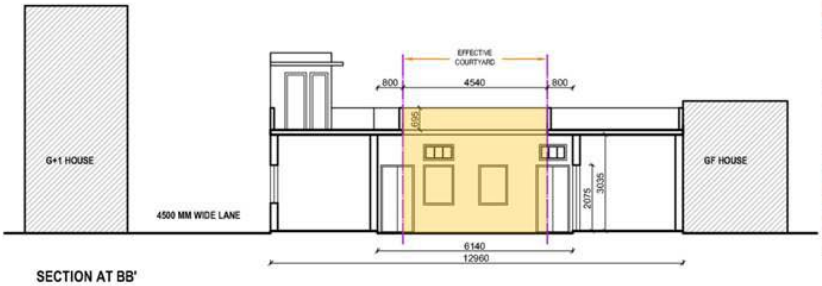
GROUND FLOOR PLAN



FIRST FLOOR PLAN



SECTION AT AA'



SECTION AT BB'

Key plan

House Details

Case study	House - 2
Location	Dandaiya, Lucknow
Climate	Composite
Orientation	E-W
Age	80
Building type	Residential
Plot Area	182.2
Total Built up area	252.11
Building Volume	709.9
No. of Floors	G+1
Floor to Floor height	3.1
Occupancy (hr)	24
Wall	Brick Work
Wall finish	Lime wash over Plaster
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Central Open
Courtyard Length (L)	6.14
Courtyard Width (W)	5.13
Average height (H)	4.74

View from the entrance lobby

Bird eye view of first floor

View of eastern wall

Figure 28: House 2 details

Key plan

House Details

Case study	House - 3
Location	Basphatak, Varanasi
Climate	Composite
Orientation	N-S
Age	200
Building type	Residential
Plot Area	113.9
Total Built up area	381.7
Building Volume	1117.9
No. of Floors	G+3
Floor to Floor height	2.97
Occupancy (hr)	24
Wall	Stone cladding over Lahkori Brick Work
Wall finish	Lime wash over Plaster
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Central Open
Courtyard Length (L)	3.9
Courtyard Width (W)	3.85
Average height (H)	10.65

View from the verandah of second floor

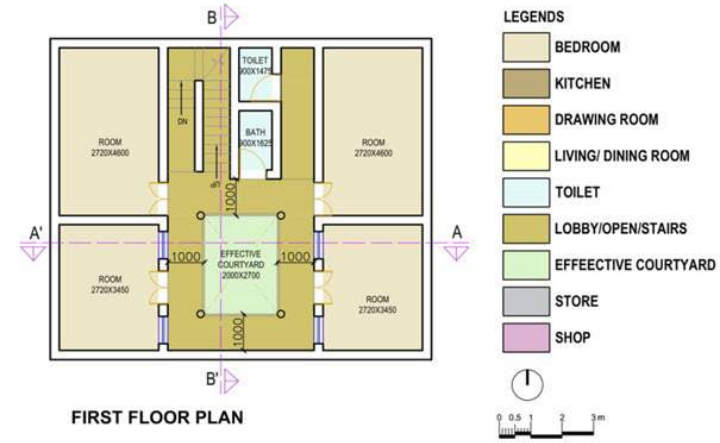
View from the ground floor

Bird eye view from the second floor

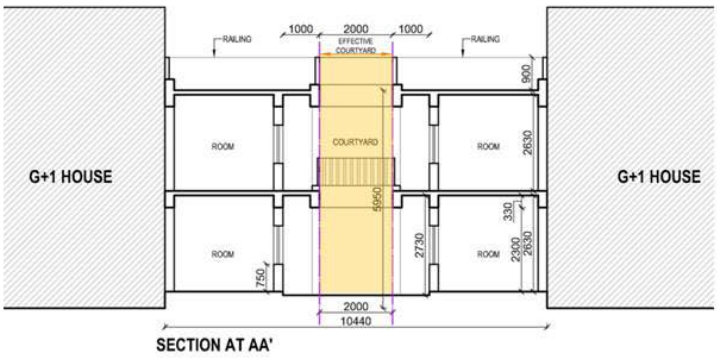
Figure 29: House 3 details

House – 4 Details

GROUND FLOOR PLAN



FIRST FLOOR PLAN



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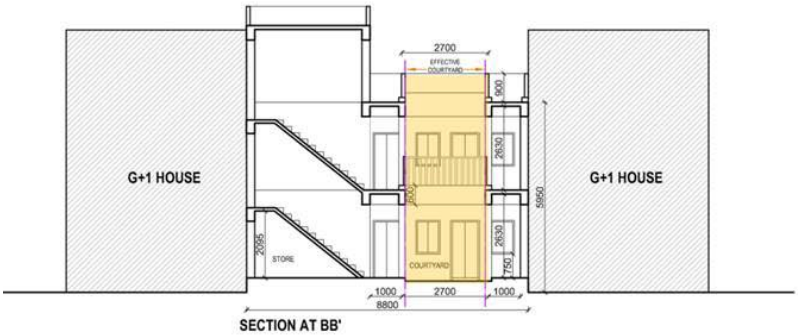


SECTION AT BB'

Key plan

House Details

Case study	House - 4
Location	Luxa, Varanasi
Climate	Composite
Orientation	E-W
Age	110
Building type	Residential
Plot Area	91.87
Total Built up area	178.34
Building Volume	475.58
No. of Floors	G+1
Floor to Floor height	2.75
Occupancy (hr)	24
Wall	Traditional Brick Work
Wall finish	Lime wash over Plaster
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Central Open
Courtyard Length (L)	4.7
Courtyard Width (W)	4
Average height (H)	6.5

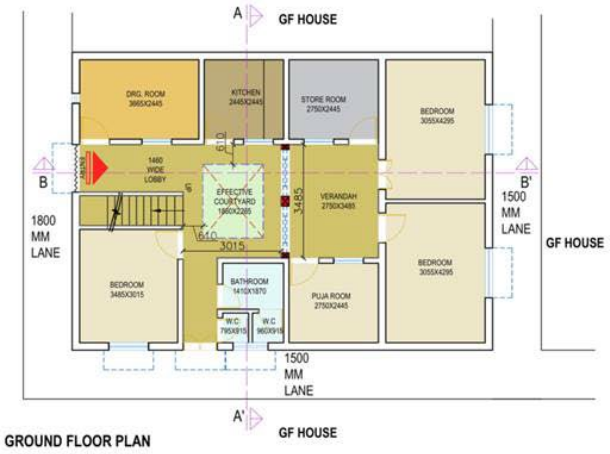
Upside View from the first floor

View of northern wall

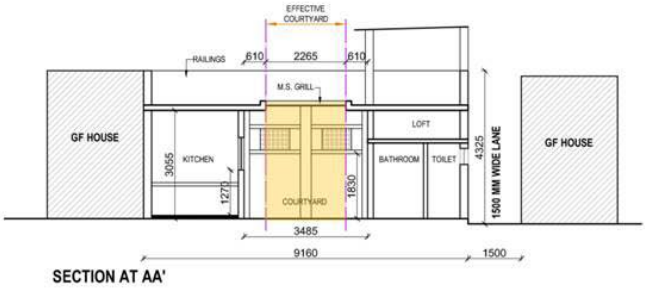
Bird eye view of first floor

Figure 30: House 4 details

House – 5 Details



GROUND FLOOR PLAN



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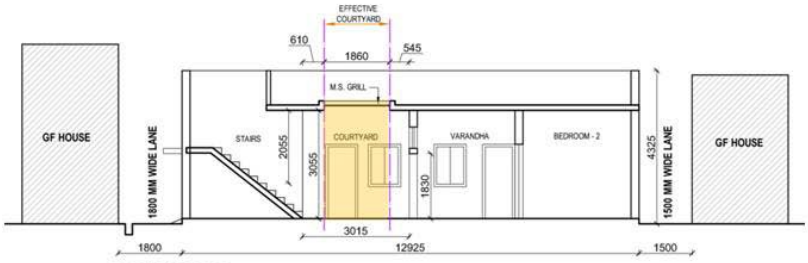


SECTION AT BB'

Chandrika Devi road

Key plan

House Details

Case study	House - 5
Location	BKT, Lucknow
Climate	Composite
Orientation	E-W
Age	50
Building type	Residential
Plot Area	118.3
Total Built up area	118.3
Building Volume	365.12
No. of Floors	G
Floor to Floor height	3.2
Occupancy (hr)	24
Wall	Brick Work
Wall finish	-
Ceiling	Cement concrete
Flooring	Cement Flooring
Window	MS frame with single shutter and single panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Central Open with MS grill
Courtyard Length (L)	3.01
Courtyard Width (W)	3.48
Average height (H)	3.3

View of staircase

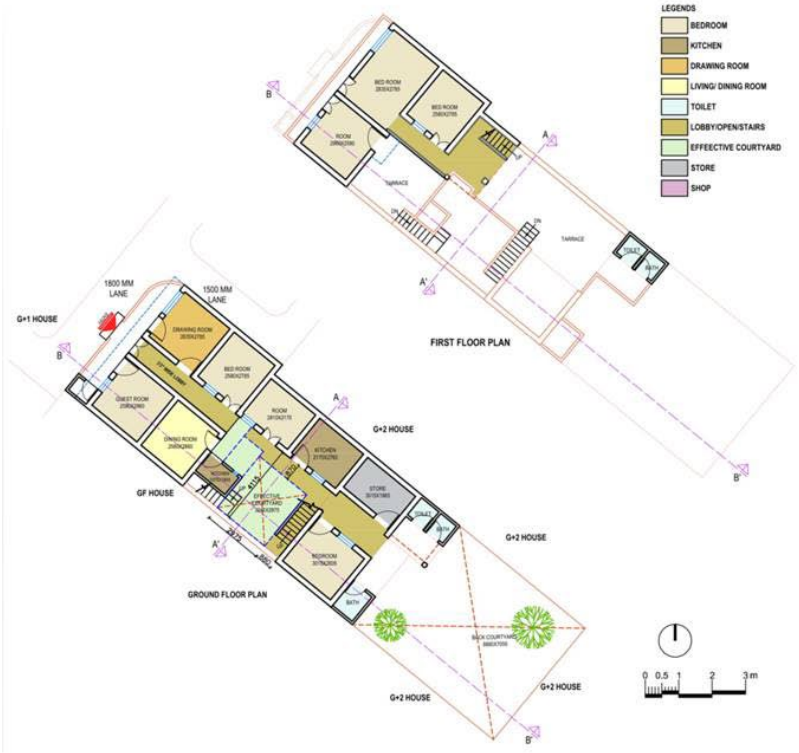
Upside View of opening

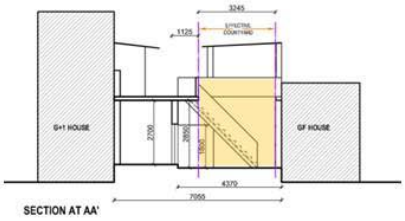
View of entrance lobby

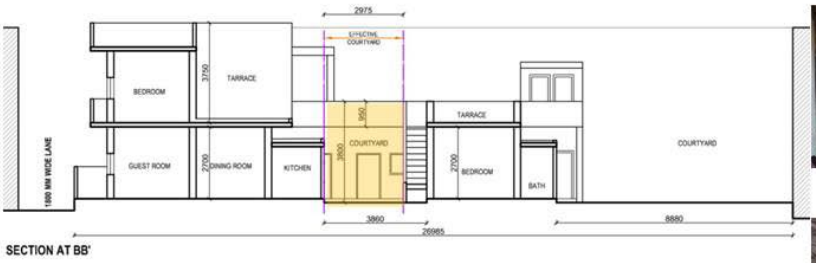
View of western wall

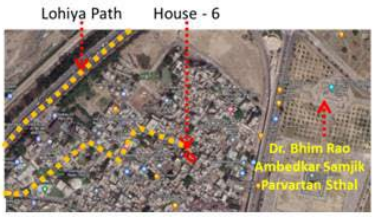
Figure 31: House 5 details

House – 6 Details









Key plan

House Details

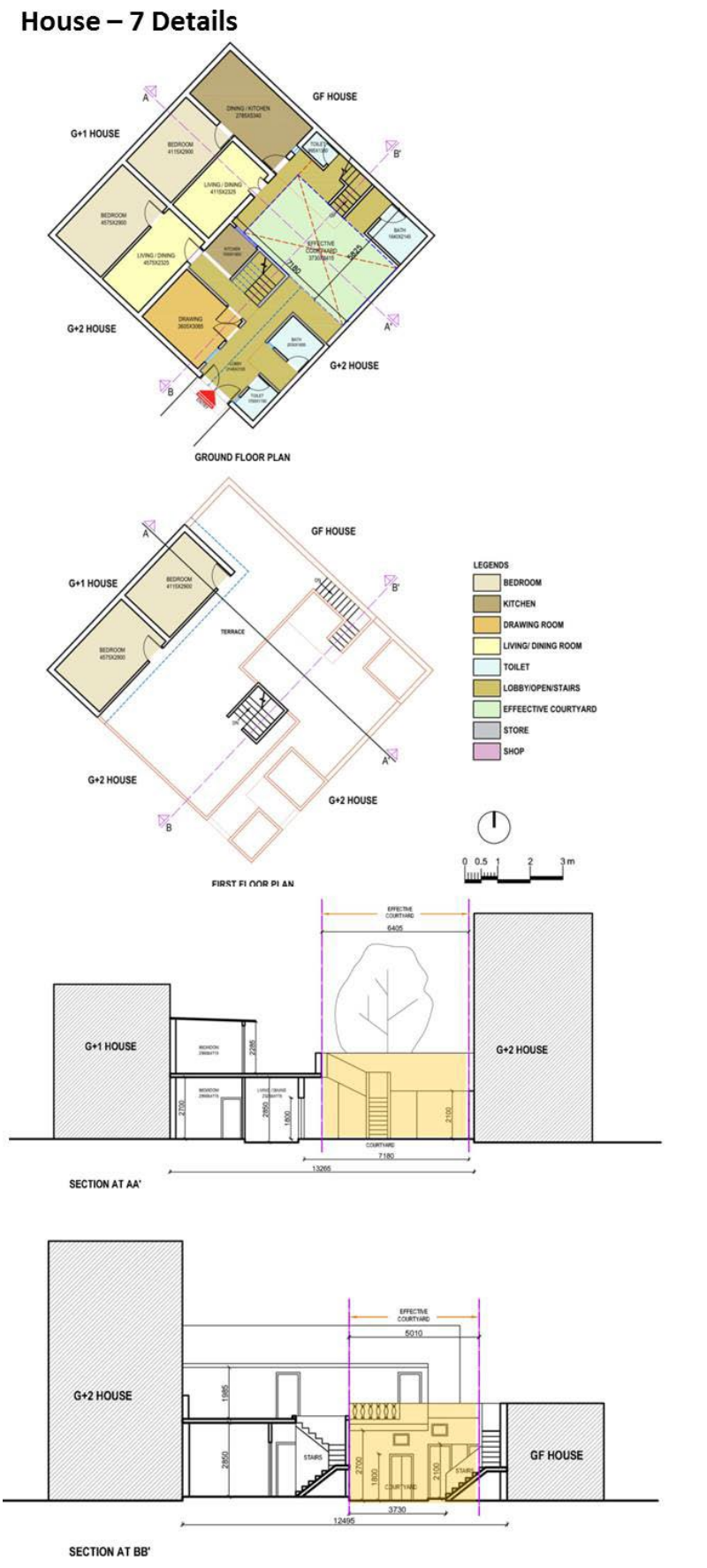
Case study	House - 6
Location	Jia Mau, Lucknow
Climate	Composite
Orientation	NW-SE
Age	75
Building type	Residential
Plot Area	194.4
Total Built up area	173.79
Building Volume	448.84
No. of Floors	G+1
Floor to Floor height	2.85
Occupancy (hr)	24
Wall	Brick Work
Wall finish	Lime wash over Plaster
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	No
Courtyard parameters	
Courtyard shape	Rectangular
Courtyard Placement	Side Open
Courtyard Length (L)	4.18
Courtyard Width (W)	4.11
Average height (H)	3.4

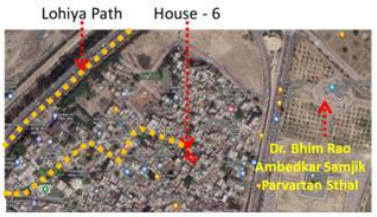
View from the southern corner of the courtyard

View from the entrance lobby

View from the eastern corner of the courtyard

Figure 32: House 6 details





Key plan

House Details

Case study	House - 7
Location	Jia Mau, Lucknow
Climate	Composite
Orientation	SW-NE
Age	60
Building type	Residential
Plot Area	165.7
Total Built up area	196.6
Building Volume	437.48
No. of Floors	G+1
Floor to Floor height	2.95
Occupancy (hr)	24
Wall	Brick Work
Wall finish	Lime wash over Plaster
Ceiling	Lime concrete
Flooring	Cement Flooring
Window	Wooden frame with double shutter and double panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Corner Open
Courtyard Length (L)	5
Courtyard Width (W)	7.18
Average height (H)	3.31

View from the eastern corner of the courtyard

Bird eye view of first floor

View from the staircase

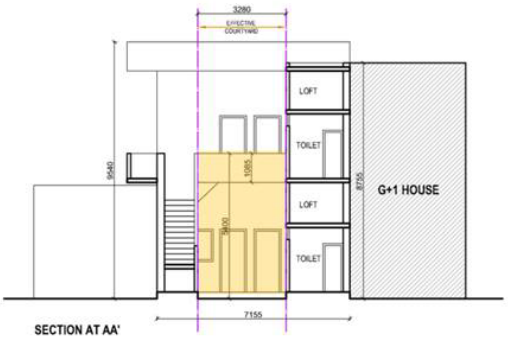
Figure 33: House 7 details

House – 8 Details

Key plan

House Details

Case study	House - 8
Location	Durgakund, Varanasi
Climate	Composite
Orientation	E-W
Age	60
Building type	Residential
Plot Area	148.5
Total Built up area	230.1
Building Volume	908.85
No. of Floors	G+1
Floor to Floor height	3.9
Occupancy (hr)	24
Wall	Brick Work
Wall finish	Paint over Putty
Ceiling	Cement concrete
Flooring	Cement Flooring
Window	MS frame with single shutter and single panel
Glazing	No
Courtyard shape	Rectangular
Courtyard Placement	Side Open
Courtyard Length (L)	5.87
Courtyard Width (W)	3.28
Average height (H)	7.12



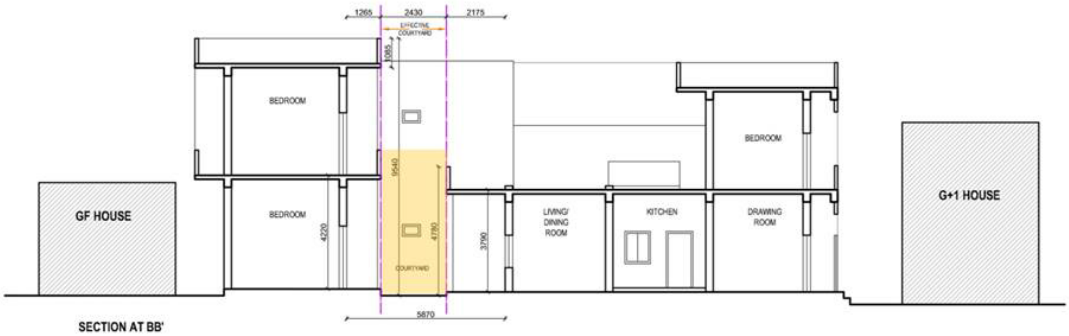


Figure 34: House 8 details

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