KEY WORDS:
Traditional House Form, Climate Response, Kathiyawadi Haveli, Shading, Ventilation

Analyzing traditional house form for climate response: A case of Kathiyawadi Haveli

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ABSTRACT

Climate plays an important role in design of traditional houses. They are required to achieve human thermal comfort without the use of active systems. These houses have distinct forms and features that responds to local climate. In India, with wide cultural variations, the climatic response takes varied forms in different regions to suit local culture and traditions. Most of the studies while analyzing a traditional house for climate responsiveness lack scientific approach and generally are descriptive without any framework of analysis. With a wide variety of house forms, it is worth analyzing strategies which are used to respond to specific climate. The purpose of this paper is to document and analyze various strategies and house forms designed to achieve ventilation in warm and humid climates. First, based on the review of literature a framework is proposed to analyze climatic response of a traditional house form in warm and humid climate by identifying strategies and resulting features. Second, using this framework, a traditional house in the same climate is analyzed. The results are also triangulated using other methods such as climatic data records and user interviews.

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Introduction

Traditional house form has been influenced by various factors such as culture, climate, economics, local material, and technology (Rapoport, 2007, Paul, 2007). Out of these factors, climate plays an important role as houses are designed to achieve human thermal comfort without use of active systems. These houses have distinct house form and features reflecting response to local climate. For example, cold climate regions have compact house forms to store the heat (Koenigsberger, Mayhew, & Szokolay, 1975) whereas houses in warm and humid climates of Sri Lanka, India and Thailand have high pitched sloping roofs to keep away the rains (Koenigsberger, Mayhew, Szokolay, & Ingersoll, 1975). Within the same climatic zone, the response takes various forms in different regions to suit local culture and traditions. For instance, houses in Malaya use a thin plan (Hassan & Ramli, 2010) whereas houses of Kerala have a courtyard within though both fall under warm and humid climatic zones (Dilli, Naseer, & Varghese, 2010) to achieve ventilation.

There are plethora of studies establishing a link between climate and traditional house form (Rapoport, 2007). Most of the studies while analyzing a traditional house for climate responsiveness lack scientific approach and generally are descriptive without any framework of analysis. With a wide variety of house forms, it is worth analyzing various strategies used to respond to specific climate. In India, according to the climate zones marked out by ECBC (Energy conservation building code, 2017), most of the country falls in the warm & humid climate zone which includes all the coastal regions of India. However, traditional house form in these regions varies greatly. Ventilating buildings to achieve thermal comfort is a predominant strategy used across regions. The purpose of this paper is to document and analyze the house form and various strategies used to achieve ventilation in warm and humid climate. First, based on the review of literature a framework is proposed to analyze climatic responsiveness of traditional house form in the same climate by identifying various strategies and resulting features. Second, using this framework, a traditional house in a warm and humid climate is analyzed. The results are also triangulated using other methods such as recording climatic data and interviewing users.

Methodology

First, based on the literature study a framework to analyze climate responsiveness of traditional house form was derived. Then empirical study of a traditional house in Kathiyawad, Gujarat was carried out and analyzed for climate responsiveness using the framework derived in step one. The findings of the study were triangulated with field observations using data logger and user's interviews. House form for the purpose of this study includes various features and elements used in the dwelling unit such as plan form, courtyard, envelope, doors, and windows, etc.

About the Haveli

The selected *haveli* for study is in Bhavnagar which falls in Kathiyawad region of Gujarat, India. It has a courtyard type planning with the rooms organized around the courtyard (**Figure 1,2,3)**. As most part of *haveli* is not in use, a part of *haveli* that is inhabited is highlighted in color in figure 1. This area is taken for the detailed study to know about the perceived thermal comfort by the occupants.

According to Indian Meteorological Data, temperature of Bhavnagar ranges from 25-35°C, whereas, humidity rises to 85% from 55% during monsoon. Precipitation is only 600mm annually. Overall, the diurnal variations are very less, and humidity is beyond comfort level. Wind direction is south-west and north with a velocity of 2.6 m/s which increases from March till June (IMD).

The construction material used for *haveli* is fossil stone for walls and timber for upper floors and roof. It has a sloping roof with Mangalore tiles. The walls are 450mm thick with lime plaster. There are variety of window types according to the function of the room and they have mostly opaque wooden shutters. The interior of haveli has intricate carvings on wooden brackets and wooden *jali* above lintel. Haveli has two entrances one is *khadki* for vehicular access and other is for pedestrians from *otlo* to enter directly from street. *Khadki* is narrow passage to enter into the haveli through the larger door and otlo is an elevated plinth segregating the street and *haveli*, often used as seating. *Khadki* is entered from a large doorway on street, called *delo*. The structure is double storied with upper floor projecting out. The kitchen, living, dinning and one bedroom is on ground floor and there are other bedrooms on first floor.

Procedures for Data Collection

The data was collected in three different stages:

1. To study the climatic features of warm and humid climate and response of traditional houses to achieve thermal comfort, a literature study was carried out. This was done with a focus on studying various strategies and building elements used in different parts of India. It helped in analyzing house form of the *haveli* for climate response.

2. Using this framework, various strategies used to achieve thermal comfort in the case of Kathiyawadi Haveli, were identified. Visual observations were carried out first to document various elements of the house. A field survey in the month of September 2022 was carried out to measure the wind speed and wind direction at various points (**Figure 6**). A data logger was installed to collect data for temperature and humidity at the locations shown in figure 6 for a period of two months which is from September to October 2022.

3. An interview was conducted with occupants using an open ended questionnaire to know their perception of comfort during various seasons and strategies they use to mitigate the discomfort.

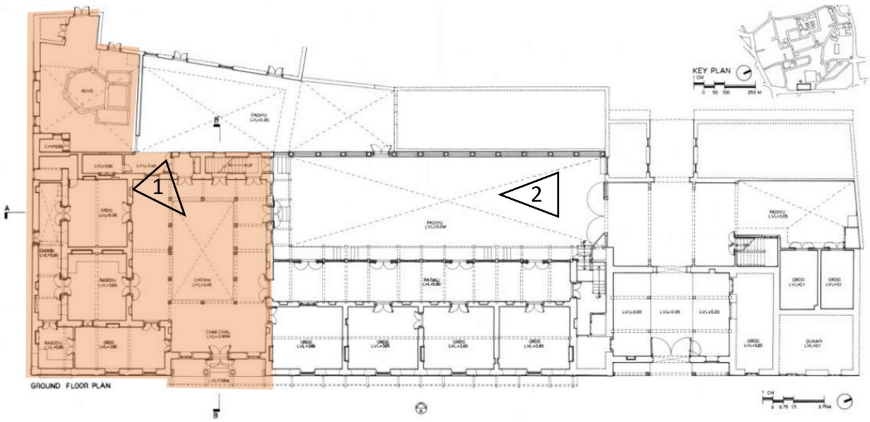


Figure 1: *Plan of Haveli, (Source: IPSA Library, Rajkot with permission to use as base map for reference) Area of Study is highlighted.*

Figure 2: *Courtyard complex seen from point 1 in fig.1 (Image source: Author)*

Figure 3: *Haveli seen from point 2 in fig.1 (Image source: Author)*

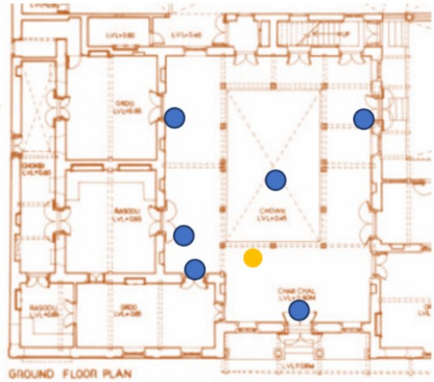
Wind anemometers (**Figure 4**) were used to record wind velocity at apertures with: 1. Open apertures. 2. Closed apertures to understand the efficiency of wind flow throughout the plan. A Data Logger (**Figure 5**) was installed in *baithak* at 1.7m height to record temperature and humidity at body level. Following plan (**Figure 6**) shows location of data collection points using instruments.

Tools used for field data collection

Elements of the house which are used to cut off the radiation and enhance ventilation were identified using the framework based on the literature. These findings were validated through simulation. A CFD (Computational Fluid Dynamics) analysis was carried out by building the model in Autodesk Flow Design student version to understand the wind flow throughout the habitable spaces. These findings were triangulated with interview data.

Figure 4: *Wind Anemometer*

Figure 5: *Data Logger*



- Measurement position of wind speed is shown as a blue dot.
- Measurement position of data logger is shown as a yellow dot.

Figure 6: *Plan showing locations of instruments installed at haveli*

Characteristics of warm and humid climate

The most significant character of warm and humid climate is a continuous presence of moisture in the environment creating a sticky condition along with the hotness. Temperature ranges between 20-35C with minimal diurnal variations. Sky condition is normally cloudy with presence of water vapor in the air which further acts as a filter to direct solar radiation, and this is the reason, diffused radiation is mostly observed (Koyningsberger, Mayhew, Szokolay & Ingersoll, 1975).

Overall, humidity is high around the year and the air temperature is near to skin temperature which is why the heat loss from body to air via convection and conduction is minimal. Additionally, due to high humidity, a small amount of evaporation would cause formation of a saturated air envelope which further prevents evaporation, ultimately blocking the heat removal. Due to these factors, air movement is the primary and dominating strategy to achieve thermal comfort in this climate. It would remove the air envelope, which is recommended at body level and in building designs. Finally, radiant heat gains from direct solar insolation must be avoided (Koyningsberger, Mayhew, Szokolay & Ingersoll, 1975).

Framework to Analyze a Traditional House in Warm and Humid Climate

From literature study, it is found that thermal comfort is achieved by using two predominant strategies. First to provide shading and second enhance ventilation (Dekay & Brown, 1985; Koenigsberger, Mayhew, Szokolay & Ingersoll, 1975). Shading is provided by a buffer zone in the form of a veranda between exterior and interior spaces to avoid direct heating and by using long projecting eaves that shade the exteriors apart from protecting from rain. These shaded spaces precool the wind. Ventilation is enhanced by making buildings permeable which is achieved through courtyard planning, locating openings appropriately to achieve cross and stack ventilation. So, to analyze climate responsiveness of traditional houses in warm and humid climate, one should focus on these two important strategies and identify elements of the house that are used to achieve these goals of reducing direct heat gain and enhanced ventilation.

In India, house forms vary across cultures, but the principles of climate responsiveness are similar. It is worth recording the variety of elements contributing to it in different cultures using scientific methods. Following section presents elements used in Indian traditional houses from warm and humid climate as reported in the literature.

Cross Ventilation:

According to the literature study, in Kerala, openings are provided throughout the house whereas in Konkan region, openings are at low level, and smaller to induce speed. In North-East region it can be seen that the openings are smaller with a window to wall ratio of 22% only. But here the overall envelope is kept porous to help ventilation (Dilli, Naseer, & Varghese, 2010; Chavan & Chandar, 2016; Singh, Mahapatra, & Atreya, 2011).

Stack Ventilation:

In Kerala, Konkan and in North-East houses, courtyard plays an important role in stack ventilation. The fresh, cooler air enters from windows replacing the hot air and this hot air travels towards the courtyard as it gets heated up and thus, exits the house. In Konkan region, in addition to courtyard the stairwell window at high level also helps in stack ventilation. (Chavan & Chandar, 2016; Singh, Mahapatra, & Atreya, 2011; Dilli, Naseer & Verghese 2010) Elements like courtyard and *jali* help in ample cross ventilation in a warm and humid climate. Steeply sloping roof and curved eaves facilitates efficient rainwater run-off (Pandya 2022). Another paper explains that a relatively better indoor thermal environment is observed by introducing a *chowk* as it acts as air funnel discharging indoor air into the sky and a suction zone inducing air from its sky opening during daytime hours. Furthermore, the North-Eastern houses, small air inlets are provided at lower level to induce draft and hot air exits through gaps in the sloping roof. Not just that, many houses have chimneys which allow hot air to move out (Singh, Mahapatra & Atreya 2011).

Permeable Building:

Air flows throughout the plan and section of the house effectively in Konkan and North-Eastern house. In North-Eastern house, the plinth is high and there are small voids in wall at floor level at certain distances which helps in efficient ventilation. Overall, the walls are comparatively porous due to multiple openings (Chavan & Chandar, 2016, Singh, Mahapatra, & Atreya, 2011).

Buffer Zone:

Buffer zone strategy is not much talked about for warm and humid climate. Although, in a Konkan house, the veranda obstructs direct solar insolation in the interior (Chavan & Chander, 2016).

Climate Responsive Strategies Used in Kathiyawadi Haveli:

1. **Cross Ventilation:** A continuous cross ventilation is achieved through following different ways as listed below.

    a) **Windows:** The windows and doors are mostly opaque using timber obstructing direct exposure to sun. There are mainly three kinds of windows as observed in this *haveli*.

    - Type 1: Windows at 700mm sill: such windows are present in the public area like *baithak* and *ravesh* (**Figure 7**).
    - Type 2: Double level windows: Could be opened both together or simultaneously according to the requirement of wind and privacy (**Figure 7**).
    - Type3: Window above lintel level: such windows are seen in kitchen and bedroom where privacy is needed. Additionally, according to the CFD results, a negative pressure is formed and hence, wind exits from these windows (**Figure 8**).

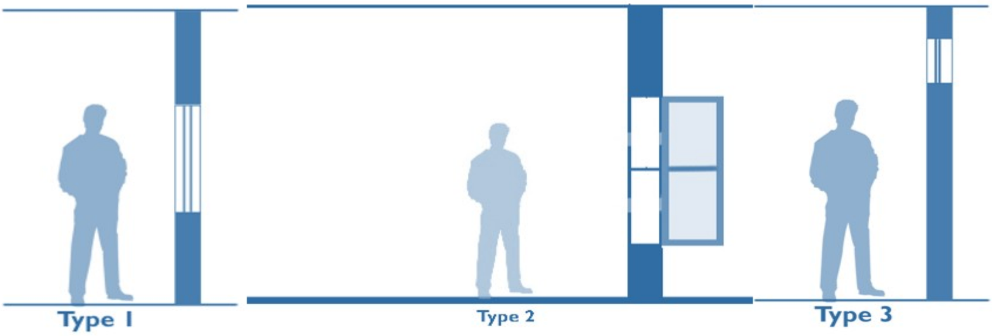


Figure 7: *Types of windows observed under area of study*

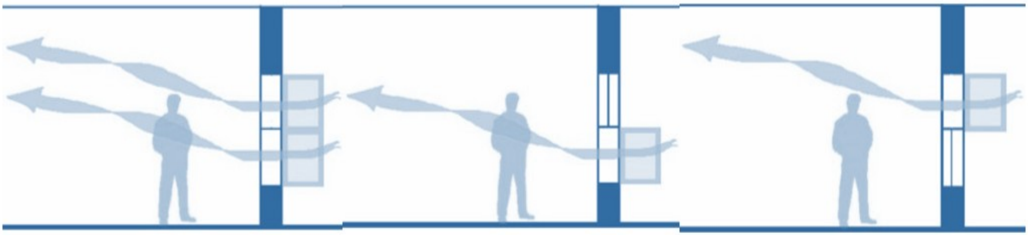


Figure 8: *Window mechanism for Type 2 window*

b) ***Jali*****:** A band of wooden *jali* is placed above lintel level facing north-west, throughout the length of the rooms (**Figure 9**). The working principle of airflow enhancement in perforated walls is based on Bernoulli's principle, which states that when air flows through a perforated wall, the air molecules are forced to accelerate as they pass through the small openings in the wall. This increase in velocity creates a region of lower pressure immediately downstream of the wall, which draws in additional air from the surrounding environment. A study shows that with increase in percentage of perforation, variation between internal and external temperature keeps on reducing (A & R, 2022).

c) **Courtyard planning to enhance ventilation:** Courtyard is exposed to direct solar insolation, especially during afternoon. Therefore, it gets heated up and absorbs hot air from the surrounding, thus, working as a stack of *haveli*. This was observed in the CFD as well.

Figure 9: *Use of Jali (Image source: Author)*

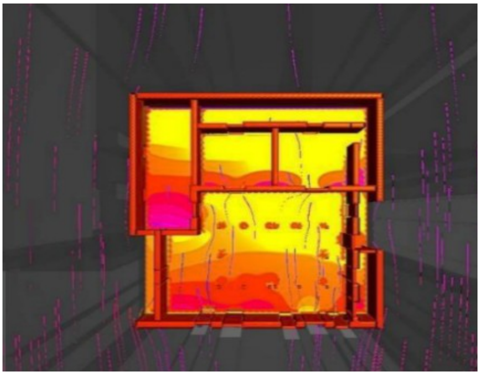


Figure 10: *CFD results for North winds*

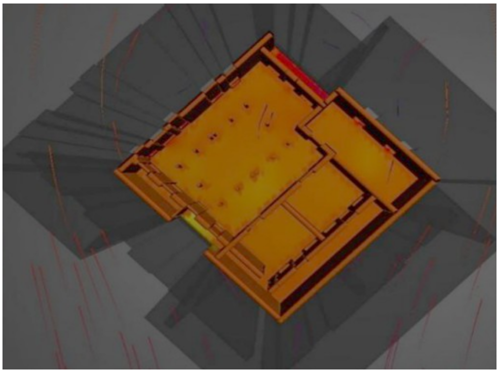
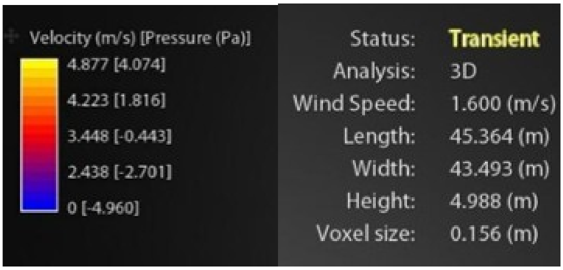


Figure 11: *CFD results for South-West winds*



Velocity (m/s) [Pressure (Pa)]
4.877 [4.074]
4.223 [1.816]
3.448 [-0.443]
2.438 [-2.701]
0 [-4.960]

Status: Transient
Analysis: 3D
Wind Speed: 1.600 (m/s)
Length: 45.364 (m)
Width: 43.493 (m)
Height: 4.988 (m)
Voxel size: 0.156 (m)

Figure 12: *Parameters for CFD simulations*

CFD Analysis to validate use of courtyard, windows and Jali to enhance cross ventilation: According to the data provided by the IMD, the city receives wind from south-west and north dominantly. The south-west winds are blocked partially because minimal openings are provided on that surface (**Figure 11**). However, north winds get full access and south is again fully blocked. Therefore, according to the laws of fluid dynamics, because of the surrounding walls in south, a negative pressure is built which makes the air flow more efficiently (**Figure 10**). Overall, as shown in **figure 7**, winds from north enter through the windows, the stale, hot air is absorbed out through courtyard. And the rest of fresh, cooler and denser air moves forward into the bedroom and kitchen, where, hot air exits through high level windows on south. The simulation parameters are presented in a table format (**Figure 12**).

d) ***Jhoola*****:** The swing is called *jhoola* in native language and is generally placed in public areas like *ravesh* (at B) and *baithak* (at A). Although the *jhoola* holds a cultural value, it is actually really helpful in achieving thermal comfort in a warm and humid climate. The gentle motion of the *jhoola* induces air flow without much more physical effort, which leads to reduced sweating and cooler feeling. At this *haveli*, two *jhoolas* were installed, one in *baithak* at A and another in *ravesh* at B as demarcated in the figures below (**Figure 13, 14, 15**).

2. **Stack Ventilation:** The *chowk* gets heated up throughout the day and wind from north replaces hot air with fresh cold air. Additionally, the windows in the bedroom and kitchen are above lintel level (**Figure 16**) which works as a stack outlet. These windows are angular from inside which according to fluid dynamics, efficiently removes the air out (**Figure 7**).

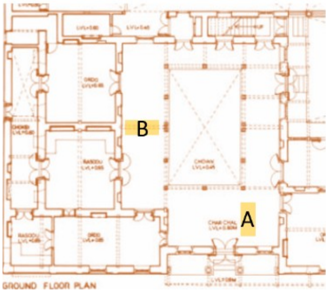


Figure 13: *Location of Jhoola in haveli plan*

Figure 14: *Jhoola at location A (Image source: Author)*

Figure 15: *Jhoola at location B (Image source: Author)*

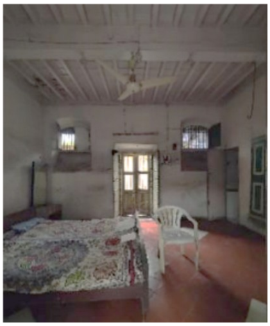


Figure 16: *Windows in bedroom (Image source: Author)*

3. **Buffer Zone:**

   a) ***Otlo***: *Otlo* with projecting balcony above works as a thermal buffer for the internal spaces. As it is semi-covered, the morning east sun is given access when the temperatures are lower throughout the year. Additionally, summer sun is partially blocked because of the same (**Figure 17)**. Therefore, total wall area exposed to sun is reduced which ultimately reduces heat gain in interior spaces.

   b) ***Ravesh***: *Ravesh* is the internal corridor surrounding the *chowk* which connects to the bedroom, kitchen, dining, *baithak* and backyard (**Figure 18**). It works as a buffer for other rooms. It cuts down the direct solar insolation (**Figure 19**) through *chowk* to the interior living spaces, hence it works as a buffer area for bed room, kitchen and *baithak*.

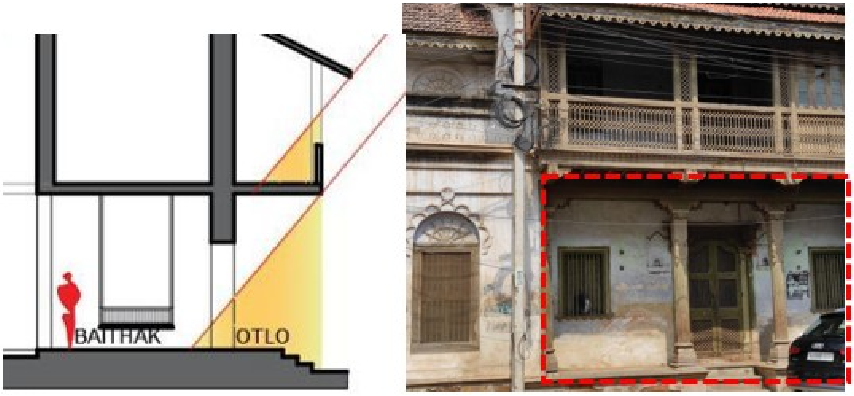


Figure 17: *Solar angle 52 deg. In May on the left and shaded otlo at 10 am (Image source: Author)*

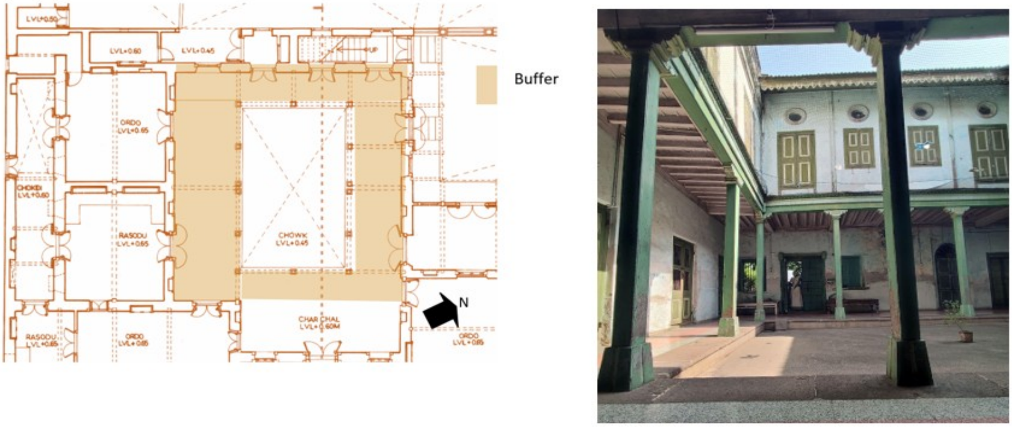


Figure 18: *Buffer area ravesh surrounding courtyard (Image source: Author)*

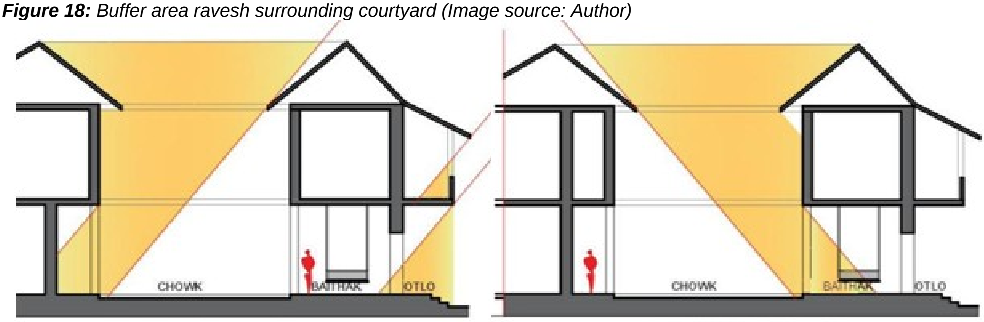


Figure 19: *May 9 AM Solar Azimuth angle 52-degree on left and May 4 PM Solar Azimuth angle 52 degree on right*

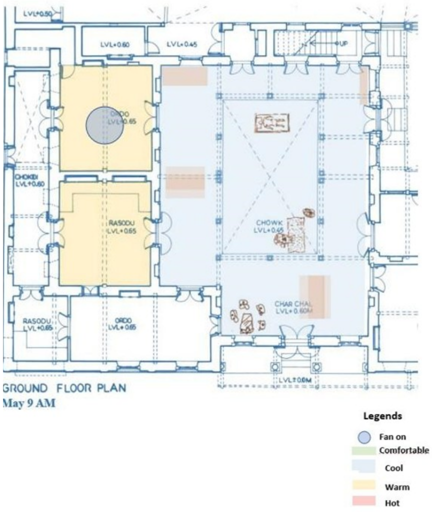


Figure 20: *Activity map of May recorded at 9 am*

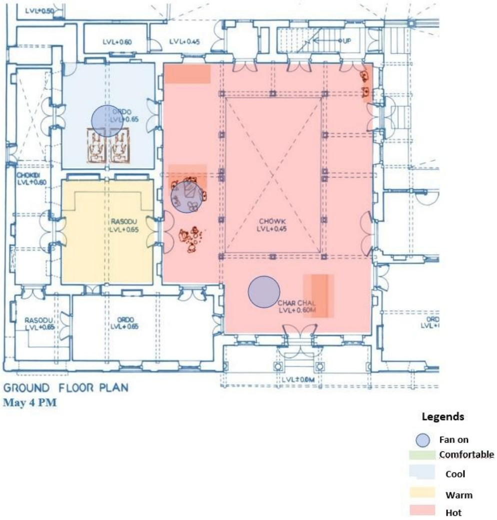


Figure 21: *Activity map of May recorded at 4 pm*

4. **Migration:** Interviews revealed that apart from the house form, occupants also adapt some strategies to keep them comfortable. Migration is one such strategies adapted here. *Ravesh* and *chowk* have movable furniture so according to the need of the hour, a person can shift from one place to another. According to the survey carried out, it was found that during winters when heating is required, occupants sit in *baithak* during evening when it gets solar access. Again, during summer, *baithak* remains vacant as it gets direct solar access and increased temperature creates uncomfortable conditions. The following thermal map shows how occupants migrate throughout the day in summer according to their comfort conditions (**Figure 20 & 21**).

Conclusion

The literature review revealed that ventilation and shading are two predominant strategies required for a warm and humid climate to achieve thermal comfort. In the *haveli* discussed above, efficient wind flow occurs from north which moves throughout the plan. In south, windows above lintel level are contributing to stack ventilation as observed in the simulation and due to this, wind flow is very efficient. Additionally, to cut down direct radiation through *chowk, ravesh* works as a buffer and same is the case with *otlo* which obstructs summer east sun entering the room. Migration is preferable for extreme climate conditions, but here also migration occurs throughout the plan. Residents move from one place to other depending upon the season, type of activity and thermal needs. Similarly, night time ventilation is recommended for climate zones with high diurnal variations which is irrelevant in this city but the provision of *jali* throughout north-west elongated rooms, heat transfer continue happening throughout day and night. Thick stone walls add to the thermal mass, which is again not recommended for this climate but due to material availability and construction technology limitations in those times, stone walls would have been more feasible.

Overall, there has not been a need for air cooling or heating units yet, residents regulate the thermal comfort by changing spaces, adding, or reducing clothing layers, opening apertures and switching on ceiling fans during critical hours of the season. This study has discussed various elements of Kathiyawadi house form and strategies used by the occupants to achieve thermal comfort without active means of ventilation. Modern planning has a lot to learn from these precedents to design energy efficient buildings.

Acknowledgments

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