RESEARCH ARTICLE OPEN ACCESS

Passive Design guidelines for Hot and Dry climate: Study of Traditional House forms of Jaisalmer, India

Anjali Verma[1], Riddhi Parmar[2]
[1]*Center for Environmental Planning and Technology, Kasturbhai Lalbhai Campus, Navarangpura, Ahmedabad380009, India*
[2]*Institute of Architecture, Hemchandracharya North Gujarat University, University Road, Patan384265, India*
Corresponding Author: Anjali Verma

ABSTRACT: This study is about finding guidelines for Designing the building and its spaces within it to benefit from natural light, ventilation and controlling the temperatures with the help of building design parameters, for Hot and Dry Climate. The elements of design for analysis would be Space, Void, Form and Light for spatial quality of building, which will be based on some Parameters of Calculation, (qualitative as well as quantitative).For the same case study of 4 house forms, each developed between the timeline of past 800 years, located in Jaisalmer city have been done. Each house is documented and analyzed which eventually leads towards forming Thumb Rule for further application.

Key words: Passive Design, Spatial Performance, Transition Spaces, Building Compactness, Courtyard-Building Volume Ratio, Percentage of Openings, Thermal Transmission Efficiency, Standard Ratio for Opening, Types of Opening.

Date of Submission: 05-06-2019 Date Of Acceptance: 20-06-2019

I. INTRODUCTION

Every settlement among the world has its unique identity and different characteristics. India has its own valuable and incredible culture, lifestyle and identity. There are different region, people, their habitations, culture, etc. All settlements comprises the dwellings related to their environmental contexts and available resources, they are customarily owner- or community-built, utilizing traditional technologies. And those settlements becomes Indigenous to a particular location.

These settlements have years of knowledge and experience of built forms responding to a particular set of climatic conditions and naturally makes them Climate Responsive and Energy efficient. There are many Passive solar techniques visible in these traditional house forms which help generations to deal with such harsh living conditions with simple measures.

Solar Passive Architecture involves blending conventional architectural principles with natural elements such as wind movement and shaded areas, less exposure to sun and the inherent properties of building materials to ensure that the interiors remain cool during day and warm during nights, thus creating a comfortable environment throughout 24 hours of the day. Various solar passive techniques have been studied with the example of this indigenous settlement, so that the undesirable impact in hot and dry climate could be mitigated. It is concluded that with the application of these techniques the building could be made comfortable with comparatively less use of energy.

1.1. Need and Concern for Passive Design

The consumption of energy in the buildings is increasing as the development is taking at a very fast rate. No evidence is now required to prove that the present climate changes are directly linked to the human activities and also the concerns regarding exploitation of the fossil fuel have reached a level where the negative effect are having impact on the life of a common man. (Sharma 2016)

Passive design helps in reducing the energy required for the construction and maintenance of building. It can be achieved by using indigenous architectural techniques, the simplest form for addressing human needs. It puts an emphasis on sustainability, using materials ensuring the home which stays cooler from inside without the need of power intensive air-conditioning. It includes the basic architectural principles of energy efficiency. Many principals of Passive design get reference from indigenous architecture of particular place with respect to the climatic zone of that area.

1.2. Objective of the study

This study aims at finding out solution to use inherent knowledge of previous generations, in modern context without compromising on the spatial quality of Built forms of Hot and Dry Arid climate.

The intension is to find out thumb rule for design. Rules of thumb exist in most discipline areas particularly those that involve the application of knowledge related to complex phenomena such as quality of light, compactness, shaded area in courtyard and orientation, also where absolute precision may not be required. They provide a practical and approximate way of doing or measuring something'. (Press 2019)

II. UNDERSTANDING HOT AND DRY ARID CLIMATE

India can be divided into six climatic zones, namely, hot and dry, warm and humid, moderate, cold and cloudy, cold and sunny and composite. The hot and dry zone lies in the western and the central part of India. Jaisalmer lies in the North western Rajasthan region. It is situated at 26.55^{o} N latitude and 75.55^{o} E longitude and is 1.7m above mean sea level. The State of Rajasthan has mostly hot-dry climate zone & partly composite climate. Monthly mean temperature remains 30 degree Celsius and relative humidity 55 %.Hot winds blow during the day in summer and sand storms are also experienced. The night is usually cool and pleasant. A generally clear sky, with high solar radiation causing an uncomfortable glare, is typical of this zone. Hence, the air is much cooler at night than during the day. In such a climate, it is imperative to control solar radiation and movement of hot winds.

Figure 1, Climatic Zones of India (Limited 2019)

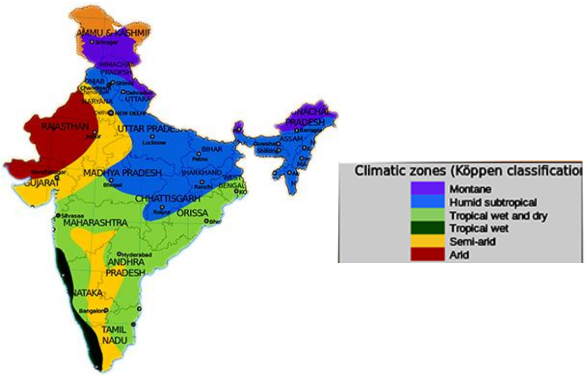


Figure 1, Average Rainfall in India(Limited 2019)

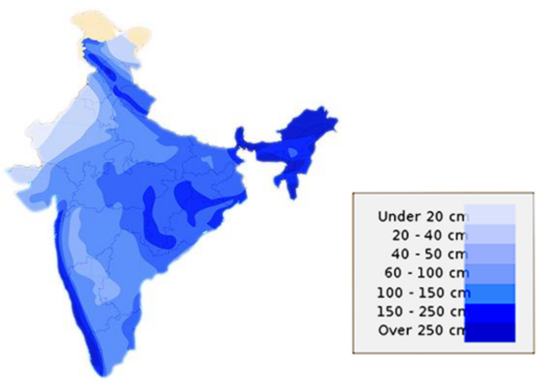
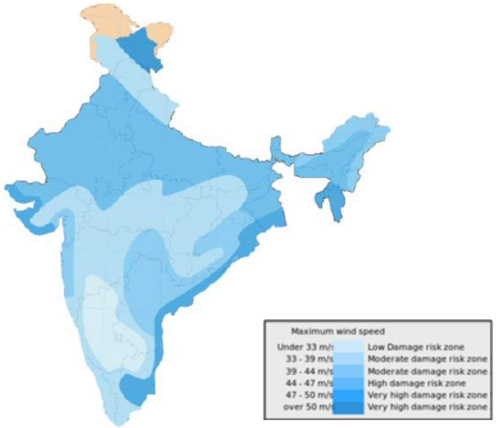


Figure 2, Wind Speed in India



The design criteria should therefore aim at resisting heat gain by providing shading, reducing exposed area, controlling and scheduling ventilation and increasing thermal capacity.

1.3. Built forms of Jaisalmer

The City of Jaisalmer is known for its Fort, the fort boundary encloses core city area and all the dwellings inside the fort wall are almost as old as the fort itself and situated on the heist contour of the city. The architecture of the city displays a strong sense of anonymity. The spaces acquire non – specific character. They change in their use as the morning changes into noon and noon changes into evening. The major streets are oriented East-West and minor streets at right angles to the former. Jaisalmer is a compact network of short streets. They are also used differently in summer and winter.

Figure 3 Street Pattern in the core city of Jaisalmer (Google 2019)

Interior open spaces like courtyard, terraces and balconies have special significance under such situations. The ground floor has no openings on the street except the entrance door approached by some steps; the houses are on a plinth. With compact organization, the house and streets become very close to each other, so the most natural thing was to close the house to the exterior and open it to the interior, thus the courtyard became essential. This idea is reinforced by climatic needs. The courtyard acts as a heat sinking summer day time and is used for sleeping at night. Every house has balconies and Jharokas which shade the lower floors and is also a source of light and ventilation. The facades of the building are carved (textured) which helps in shading by texture. Fairly high building sand the streets rarely more than 4 mts. Wide and the latter are almost always in cool shade. (Arora n.d.)

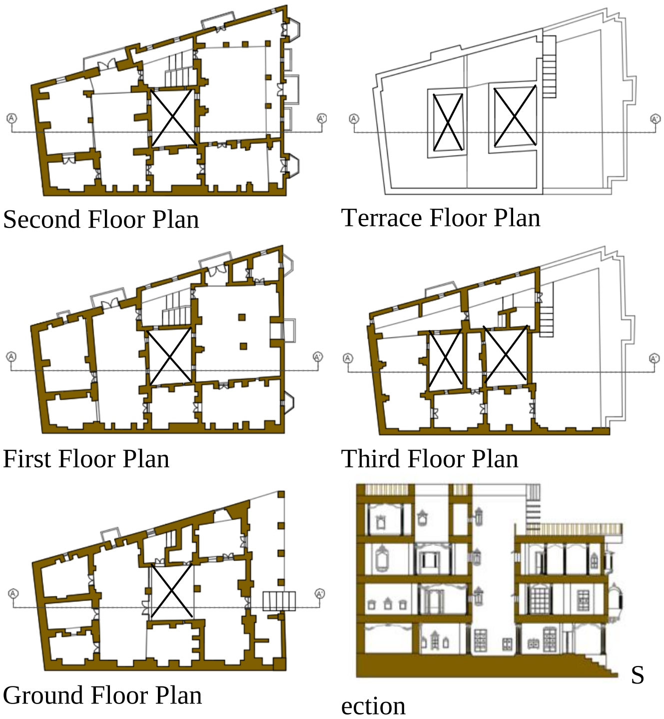
III. SITE SELECTION – DWELLINGS FOR ANALYSIS

For the study, 4 houses of various timeline and different sizes varying from 81 Sq m to 900 Sq m have been selected out of which House 1 and House 3 comes under the old city precinct, and House 2 and House 4are just outside of the fort wall, based on several parameters discussed in this paper, starting from oldest to newest.

3.1 Bari ki Haveli- House 1

Bari ki haveli is situated inside the fort prescient of Jaisalmer. This house belongs to one of the minister's family of earlier kings. The total area of 900 sq. m is divided into four equal floors; each measuring 225 sq.m. This building has all the indigenous characters of architectural style of Jaisalmer region.

Figure 4 Drawings of Bari ki Haveli - House 1

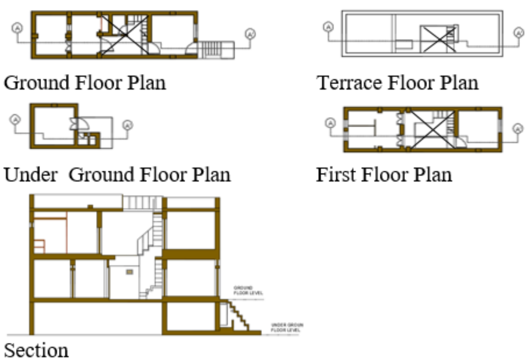


The lower floors are for armory and accommodations for soldiers, upper floors are for guests and private spaces for females in the family. This dwelling is presently being used as a Museum.

3.2 House of Mahindra Vyas - House 2

This house is located near the Fort boundary. It has four floors, including one basement floor and has a total area of 233 sq. m. This house has typical plan form of the architectural style followed in this region. The ground floor gets only two openings which are Entrance and separate exit to the house. And upper floor has different types of openings such as Jharokas, Jalis, windows and doors. The courtyard in this house is smaller compared to other houses selected.

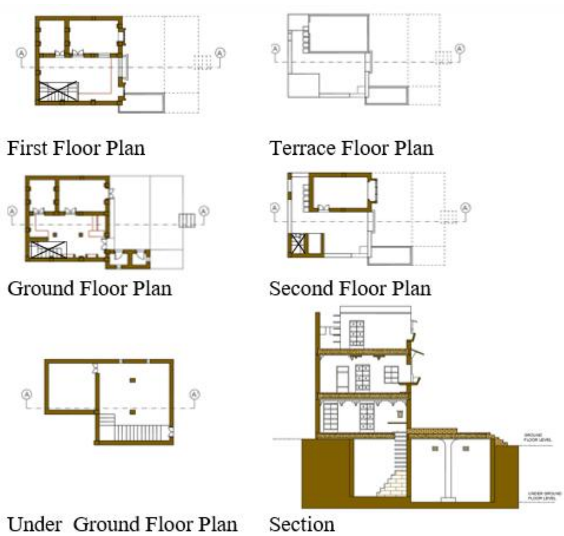
Figure 5 Drawings of House 2



3.3 House of Manoj Vyas– House 3

This house is located inside the fort boundary, has area of 110 sq. m. it was an old building but renovated recently. So the plan form follows indigenous character but in Elevation and facade it has contemporary character.

Figure 6 Drawings of House of Manoj Vyas

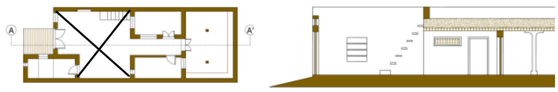


Experientially this house had most comfortable interiors, because it had controlled openings and less floor height which made spaces less prone to heating, presently family of seven lives in this house. Basement is used for storage purpose ground floor and first floor is used for habitation.

3.4 House of Narendra Singh Rathore-House 4

This house is 60 year old, a little away from Fort boundary, has floor area of 81 sq. m. It is made of Sandstone and has some of the characters of this region in its architectural style. This is a good example of smaller dwellings of same character, presently used as residential building for the family of four.

Figure 7 Drawings of House 4

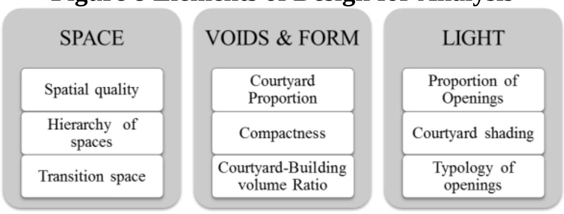


Ground Floor Plan Section

4 Parameters of Calculation - Methodology

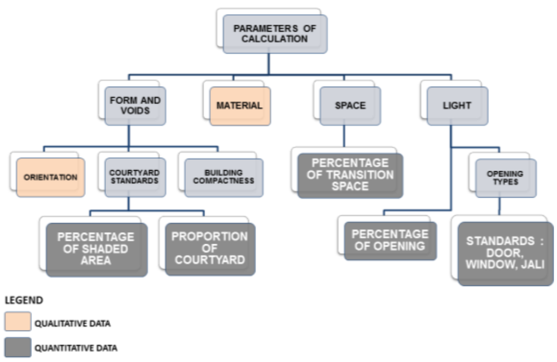
There are some parameters which directly or indirectly affects the architectural built form and spaces within. Those elements of design are Space, Light, Voids and Form, as well as Material of construction plays an important role in defining particular architectural style. The further categorization of these elements based on their qualitative or quantitative outputs, as follows

Figure 8 Elements of Design for Analysis



Based on this categorization each element of design is divided into building design parameters, which further atomized into smaller quantifiable parameters.

Figure 9 Flowchart of Methodology



In all the tables grey scale is representing performance of parameter. The darker the better it is for Hot and Dry Climate. In the end the performance of all parameters has been compiled, and a matrix is made in which each performance is graded from 1 to 10 scales, to analyses the overall performance of all 4 houses.

4.1 Form and Void

Form and Voids are what makes material a building. Voids are important parameters in design of building in hot and dry climate, because voids makes transition areas, which helps converting internal dwelling atmosphere as comfortable as possible. Form controls the amount of radiation on the surfaces. Voids reduce radiation area inside the building because it breaks the whole mass into various units. Voids may be created by courtyards, openings and semi open passages. They become the guiding tool for reducing adverse climatic effect in harsh climatic condition. Together Form and Void brings the study to following parameters for moving towards the final guidelines:

- Percentage of shaded area
- Proportion of courtyard
- Thermal Transmission Efficiency (Building Compactness)
- Orientation

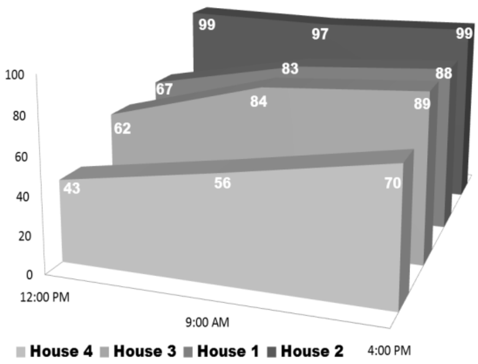
4.1.1 Percentage of shaded area in courtyards

Table 1 Percentage of Shaded Area in Courtyard

UNIT NAME	TIME	TOTAL ENEVELOPE AREA (Sq m)	TOTAL SHADED AREA (Sq m)	SHADED AREA IN PLAN AND FOLDED ELEVATION OF COURTYARD	PERCENTAGE OF AVERAGE SHADED AREA
HOUSE 1	09:00 AM	339.7	282.8 83%		79%
	12:00 PM		226.5 67%		
	04:00 PM		297.3 88%		
HOUSE 2	09:00 AM	66.3	64 97%		98%
	12:00 PM		65.5 99%		
	04:00 PM		65.5 99%		
HOUSE 3	09:00 AM	100	84.4 84%		79%
	12:00 PM		62.1 62%		
	04:00 PM		89.4 89%		
HOUSE 4	09:00 AM	97	54 56%		56%
	12:00 PM		41.3 43%		
	04:00 PM		68.2 70%		

According to calculation of average shaded area House 2 gets maximum of 96% shaded area, which is a lot compared to House 4 which gets least of 56% shaded area. This further helps in determining the better proportions of courtyards for the guidelines.

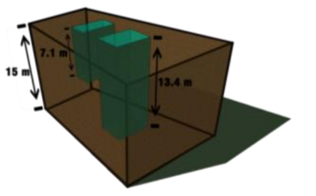
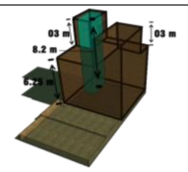
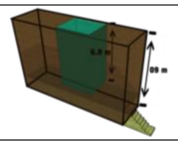
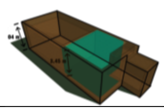
Figure 10Amount of Shaded area in all houses (in sq. m)



4.1.2 Proportion of courtyard

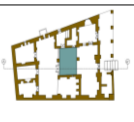
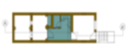
The investigation demonstrated that courtyard shading is affected by its various geometrical properties, which have different degrees of impact. But, as a rule, to get a higher shading level, courtyards should be designed to take the deep and narrow forms. Regarding the relative impact of courtyard design parameters on shading, courtyard shading is mostly affected by the ratio of courtyard's width to height, while courtyard orientation is the least effective factor. (Al-Hafith 2017)

Table 2 Building Courtyard Volume

UNIT NAME	BUILDING VOLUME	COURTYARD VOLUME	BUILDING & COURTYARD VOLUME
HOUSE 1	3375	283	
HOUSE 2	336.4	26	
HOUSE 3	407.7	73	
HOUSE 4	315	80.7	

According to the courtyard shading performance in all 4 houses the best performance is of House 2 and second best performance is House 1, which ultimately gives the range of W/H Ratio 1:0.2 - 1:0.6. That means more height gives better performance in these dwellings.

Table 3 Ratio of Width to Length & Width to Height of Courtyard

UNIT NAME	WIDTH (m)	LENGTH (m)	HEIGHT (m)	COURTYARD AREA	ASPECT RATIO	
					WIDTH - LENGTH RATIO	WIDTH - HEIGHT RATIO
HOUSE 1	4.5	3.4	13.4		1 :: 0.8	1 :: 3
	4.5	2.7	7.1		1 :: 0.6	1 :: 1.6
HOUSE 2	1.3	2.5	8.2		1 :: 2	1 :: 6.3
HOUSE 3	3	3.5	6.9		1 :: 1.2	1 :: 2.3
HOUSE 4	4.9	5.35	3.45		1 :: 1.1	1 :: 0.7

For the Width to Length Ratio we get 1:2 as best proportion and 1:0.6 is the second best. The other two houses have comparatively square shapes having ratio from 1:1.2 – 1:1.1.

4.1.3 Thermal Transmission Efficiency (Building Compactness)

The building thermal envelope consists of two components of different geometrical functions; the external horizontal surfaces as roofs and lowest floors (A_{hs}) and the external vertical surfaces as walls (A_{vs}), as follows:

$A = A_{vs} + A_h (1)$

When dividing the two sides of Equation (1) by the building volume (V), it will result that the rates of building Exposure equals the sum of the two rates of vertical and horizontal Exposure, as shown in Equation(2) which indicates that (A/V) value of a given geometry, can be factorized to infinite solution sets of the two variables (A_{vs}/V) and (A_{hs}/V), and consequently interpreted to an infinite number of morphologies that associate inversely to each other, and have a constant sum.

$A/V = A_{hs}/V + A_{vs}/V$(2)

Assuming that standard rates of vertical exposure $(A_{vs}/V)_{std}$ ranges from 0.15 m up to 0.25 m and the standard rates of horizontal exposure $(A_{hs}/V)_{std} \leq 0.33$ m. (Almumar 2016)

The solution started by computing rates of vertical, horizontal, and building Exposure, A_{vs}/V, A_{hs}/V, and A/V for the four houses, computing $(A/V)_{std}$ / A/V, and calculate Thermal Transmission Efficiency values for the Four Houses by comparing their(A/V) with the computed Standard rate as follows;$(A/V)_{std} = 0.25 + 0.33 = 0.58$ m-1. (Almumar 2016)

Table 4 gives the analysis of combination of different results we get after calculation of Rate of Horizontal and Vertical Exposure of each house. It concludes that building status can be divided into three types over compact, Compact and Over Exposed.

Table 4Six probable cases of geometry in respect to Standard ranges of Exposure

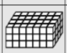
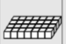
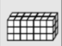
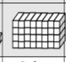
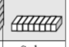
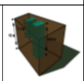
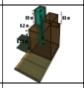
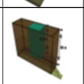
Case	1	2	3	4	5	6
Examples / Criteria						
Rate of vertical Exposure (A_{vs}/V)	< Std. Range	< Std. Range	Within Std. Range	Within Std. Range	> Std. Range	> Std. Range
Rate of horizontal Exposure (A_{hs}/V)	Within Std. Range	> Std. Range	Within Std. Range	> Std. Range	Within Std. Range	> Std. Range
Status	Over-compact		Compact	Over-exposed		

Table 5 Thermal Transmission Efficiency of Courtyard

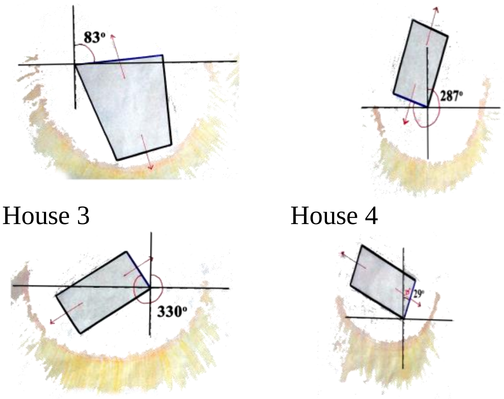
UNIT NAME	AREA OF THE HORIZONTAL SURFACES (Sq m)	AREA OF THE VERTICAL SURFACES (Sq m)	VOLUME OF THE BUILDING m^3		RATE OF HORIZONTAL A_{hs}/V	RATE OF VERTICAL EXPOSURE A_{vs}/V	SURFACE VOLUME RATIO $A/V = A_{hs}/V + A_{vs}/V$	THERMAL TRANSMISSION EFFICIENCY $(A/V)_{std}/A/V$	$>A_{vs}/V$ OR $>A_{hs}/V$ OVER EXPOSED; $= A_{vs}/V$ & $= A_{hs}/V$ COMPACT
House 1	423.2	940.0	3092.0		0.14	0.30	0.44	1.32	ALMOST COMPACT
House 2	88.4	241.0	336.4		0.26	0.72	0.98	0.59	OVER EXPOSED
House 3	80.0	291.6	334.7		0.24	0.87	1.11	0.52	OVER EXPOSED
House 4	134.0	169.4	234.3		0.57	0.72	1.29	0.45	OVER EXPOSED

House 1 gets maximum Thermal Transmission Efficiency (Building Compactness); House 2 gets lesser Compactness; House 3 and 4 are comparatively Exposed Buildings.

4.1.4 Orientation

Building Orientation for all four buildings has been analyzed based on their angles from Cardinal directions. House 1 and 2 are N-S oriented and has shorter facade on south. It is observed that the lesser exposure to south the better the performance. House 3 and 4 are oriented more towards NE-SW and NW-SE respectively. And their performance is compromised compared to the other two houses.

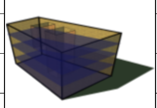
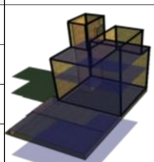
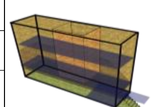
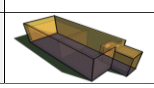
Figure 11 Orientation of all houses



4.2 Space

4.2.1 Transition space

Table 6 Percentage of Transition Space

UNIT NAME	FLOOR NAME	FLOOR AREA (Sq m)		TRANSITION SPACE AREA (Sq m)	PERCENTAGE OUT OF TOTAL AREA
House 1	Ground Floor	225		98.5	44%
	First Floor	225		73.8	33%
	Second Floor	225		114.7	51%
	Third Floor	225		80.9	36%
	TOTAL	900		367.9	41%
House 2	Under Ground Floor	57.9		0	0%
	Ground Floor	86.7		51.3	59%
	First Floor	44.2		10.8	24%
	Second Floor	44.2		19.6	44%
	TOTAL	233		81.7	35%
House 3	Under Ground Floor	15.9		4.6	29%
	Ground Floor	48.8		15.9	33%
	First Floor	45.3		14.5	32%
	TOTAL	110		35	32%
House 4	TOTAL	82		28	34%

It is important to create complete journey of space with purpose. Some elements or spaces in the house makes the space more effective and experiential; functionally and climatically. While designing the plan, separations of spaces are made with walls directly and openings and semi opens are added later, but better experiential journey can be created with transition, barrier, filtrations, layers and levels. It can be created through Jalis (Stone screens), Chajjas (sunshade devices above openings), passages, columns, openings, partitions, steps, etc.

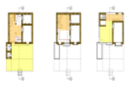
These types of elements and spaces becomes the activity generator, creates more opportunity for random conversation, visualization, circulation, influence activities, indirect light and good ventilation as well. These spaces are called transition spaces. These spaces become more dominant on human interactions and for passive cooling aspects of buildings, psychologically and physically.

In this study courtyards, passages, front otta (outdoor sitting in front elevation), foyer, balconies, Jharokas (Carved stone bay window on upper floor) and Staircase are considered as transition spaces. For the calculation of percent of transition spaces the total areas of above mentioned spaces has been calculated for each floor and total area of the floor is considered for respective floors.

4.2.2 Ratio of Direct light and Diffused light

The transition space in all buildings has been categorized into direct light and defuses light. The direct light areas are courtyards, semi open spaces, and spaces with big windows, and defuse light areas are spaces with indirect light which comes from passages, Jalis, internal windows and doors, etc.

Table 7Ratio and Percentage of Transition Space

UNIT NAME	FLOOR NAME	DIRECT LIGHT AREA (sq m)	PERCENTAGE OF DIRECT LIGHT AREA	DEFUSED LIGHT AREA (sq m)	PERCENTAGE OF DEFUSED LIGHT AREA	DIRECT LIGHT - DEFUSED LIGHT AREA	RATIO
House 1	Ground Floor	..	..	98.5	43.80%		1 :: 2.26
	First Floor	33.3	14.80%	43.6	19.40%		
	Second Floor	53.7	23.90%	61	27.10%		
	Third Floor	26.8	12.00%	54.1	24.00%		
	TOTAL	113.80	50.70%	257.20	114.30%		
House 2	Ground Floor	37.5	43.20%	13.7	15.80%		1 :: 0.60
	First Floor	...	..	10.8	24.40%		
	Second Floor	13.3	30.10%	6.2	14.00%		
	TOTAL	50.8	73.30%	30.7	54.20%		
House 3	Under Ground Floor	4.6	29.00%	...	...		1 :: 0.61
	Ground Floor	11.5	23.60%	4.3	8.80%		
	First Floor	9	19.90%	11.5	25.40%		
	TOTAL	25.10	72.50%	15.80	34.20%		
House 4	TOTAL	23.4	28.53%	4.5	5.50%		1 :: 0.19

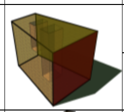
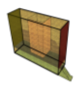
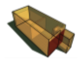
4.3 Light

'Light' plays an important role in the building in assessment of functional use of its spaces. The quality of light determines the use of space at a particular time of the day in residential buildings. As the Transition spaces in these houses are studied the outcome shows that House 2 and House 3 had good percentages of openings and good ratio of direct light and defused light. Based on the opening styles of these two houses types of openings are concluded.

4.3.1 Openings Ratio and Openings Types

The percentage of opening has been analyzed on the basis of experiential, quality of spaces. Based on good amount of direct light and defuse light house 2 and house 3 were having the best quality of light, so the conclusion is ratio of opening is best in house 2 and house 3. And types of openings are concluded based on all the typologies available in all four houses.

Table 8 Percentage of Openings

UNIT NAME	FACADE TYPE	LARGE OPEN-INGS AREA (sq. m)	SMALL OPEN-INGS AREA (sq. m)	OUTER FACADE AREA (sq. m)	TOTAL OPENINGS AREA IN OUTER PERIFERY	TOTAL OUTER FACADE AREA (sq. m)	BUILDING FACADES	PERCEN-TAGE OF LARGE OPEN-INGS	PERCEN-TAGE OF SMALL OPEN-INGS	PERCEN-TAGE OF TOTAL OPEN-INGS
House 1	FRONT FACADE	6.97	8.6	201	31.33	495		3%	4%	6%
	SIDE FACADE	8.95	6.79	294				3%	2%	
House 2	FRONT FACADE	5.32	2.77	46.6	8.08	46.6		11%	6%	17%
House 3	FRONT FACADE	2.97	4.57	21.6	8.04	46.8		14%	21%	17%
	BACK FACADE	—	0.5	25.2				—	2%	
House 4	FRONT FACADE	—	3.61	19.8	3.61	19.8		—	18%	18%

The opening standards have been drawn from the average of all the sizes available for different types of openings from Outer facade as well as internal walls. The typology covers doors, windows and Jalis of various sizes. The outcome suggests that in hot and dry climate smaller openings and perforated jali openings are desirable to reduce impact of harsh winds.

Table 9Range of different Opening types

OPENINGS TYPE	OPENING NAME	RANGE	
		WIDTH (m)	HEIGHT (m)
OUTER, OPEN, LARGE : BAD	DOOR	0.9 - 1.4	2 - 2.2
	WINDOW	1.1 - 1.5	1.1 - 1.7
OUTER, OPEN, SMALL : GOOD	DOOR	0.8 - 0.9	1.5 - 1.8
	WINDOW	0.2 - 0.8	0.3 - 0.6
INTERNAL, OPEN : EXCELLENT	DOOR	0.8 - 0.9	1.5 - 1.8
	WINDOW	0.4 - 0.9	0.7 - 1.1
INTERNAL, JALI : GOOD	WINDOW	0.5	0.5
	WALL JALI	0.6	0.2
OUTER, JALI : EXCELLENT	DOOR	1.1	1.8
	WINDOW	0.3 - 1.1	1.3 - 1.7
	WALL JALI	0.8 - 1.1	0.3 - 2

4.4 Material

All the buildings are made out of locally available yellow sand stone (common for hot and dry desert climatic regions) The walls of the building are thicker and perforated(with Jalis and Jharokas) on the outer facade and thinner and more perforated on the inside and the structures are load bearing. Slabs are made of mud, timber and stone having thickness between 0.3 to 0.65 m. The doors and windows are made out timber and Jalis are carved out of stone. Stone having high thermal resistance keeps the interiors cool, thus helping the passive cooling of structures.

IV. CONCLUSION

Table 10Conclusion of all Parameters

PARAMETERS	HOUSE 01	HOUSE 02	HOUSE 03	HOUSE 04
PERCENTAGE OF SHADED EVNELOPE	79%	98%	79%	56%
WIDTH - LENGTH RATIO	1 :: 0.8 1 :: 0.6	1 :: 2	1 :: 1.2	1 :: 1.1
WIDTH - HEIGHT RATIO	1 :: 3 1 :: 1.6	1 :: 6.3	1 :: 2.3	1 :: 0.7
COMPACTNESS	1.32	0.59	0.52	0.45
TRANSITION SPACE - FLOOR SPACE RATIO	41%	35%	32%	34%
DIRECT LIGHT - DEFUSE LIGHT RATIO	1 :: 2.26	1 :: 0.60	1 :: 0.61	1 :: 0.19
OPENINGS - FACADE RATIO	6%	17%	17%	18%

All the parameters have been concluded based on the calculation in Table 7. The performance of each parameter has been shown with the gradation of color. The Darker it is the better performance it has.

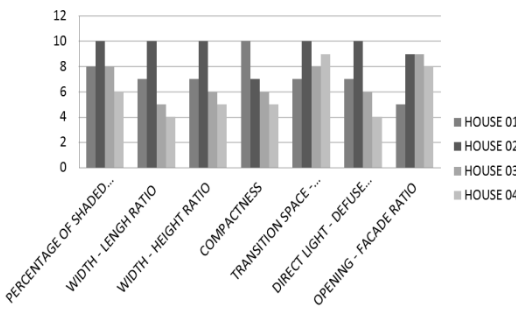
Later to this each parameter have been given grade from 1- 10 in performance Matrix which is shown in Table 8.

4.5 The performance matrix

PARAMETERS	HOUSE 01	HOUSE 02	HOUSE 03	HOUSE 04
PERCENTAGE OF SHADED ENVELOPE	8	10	8	6
WIDTH - LENGTH RATIO	7	10	5	4
WIDTH - HEIGHT RATIO	7	10	6	5
COMPACTNESS	10	7	6	5
TRANSITION SPACE - FLOOR SPACE RATIO	7	10	8	9
DIRECT LIGHT - DEFUSE LIGHT RATIO	7	10	6	4
OPENINGS - FACADE RATIO	5	9	9	8
TOTAL PERFORMANCE GRADING (out of 70)	51	66	48	41

According to the Matrix, House 2 gets the best performance of all considering the courtyard proportions and transition space percentage was best in it. These parameters help most in passive cooling of building. House 1 is most compact building but in terms of light and transition spaces its performance is not up to the mark. House 3 and 4 lacks in most of the parameters. So gets lesser ranking in the overall performance matrix.

Figure 12 Performance of all units of analysis



V. GUIDELINES

Space

- Percentage of transition space should be 30% - 40% of its whole space unit area.
- Direct light area / defuse light area ratio should be as near as possible. (desirable 1:0.6 to 1:1.5)

Form and Void

- Building height should be low (2.5 – 2.8 m)
- Building orientation should be North – South.

- Rate of Horizontal exposure should be less or equal to 0.33 m-1 (for improve thermal performance)
- Rate of Vertical exposure should be between 0.15 to 0.25 m-1
- Surface – Volume ratio (A/V = Ahs/V + Avs/V) should be less than 0.58 m-1 for reduced thermal transmission.
- Courtyard should be heighted as much as possible. (stack effect)
- W/L ratio of courtyard should be such that difference between widths to length is as much as possible (between 1: 0.4 to 1:0.6 or 1:1.8 to 1:2.5) for reducing direct sunlight.
- W/H ratio of courtyard should be as lower as possible. (for better and more shaded area)
- Average shaded area of the courtyard throughout the day should be as much as possible.

Light

- Percentage of the openings area should be 10% - 15% of the total facade area.
- Large opening – small opening proportion for the front facade should be 1 : 0.6 to 1 : 1.3
- Large opening – small opening proportion for the side facade should be 1 : 0.7 to 1 : 1.2
- Percentage of large openings in front side should be 10% - 16% and for side facade should be 3% - 6%.
- Percentage of small openings in front side should be 9% - 12% and for side facade should be 2% - 7%.

Material

- Buildings should be made out of locally available materials.
- Whichever materials used in horizontal and vertical building elements, its thickness should be more for reducing the heat gain in the house.

Other Considerations

- Slab thickness should be more for thermal resistance.(0.25 to 0.4)
- Textures and Level differences in elevations are good for the shading of surfaces.
- Transition spaces with Jalis, water body, vegetation, and pergolas help in passive cooling.
- Underground spaces should be provided to get the comfort during the hot summer days.
- Wall thickness of the outer facade should be thicker (0.3 to 0.45) to avoid radiation, unnecessary heat gain and getting the better thermal performance.

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