Passive design strategies: Contribution for residences in Pune to achieve thermal comfort and user satisfaction.

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Abstract - Since the beginning of time, it has been observed that climate-responsive design strategies have been governing architectural designs, all around the world. The sole purpose of taking shelter in enclosed spaces has been to achieve comfortable living conditions, despite the changing weather conditions outside. The world of architecture is undergoing a revolution, where thermal comfort and thermal satisfaction of the end user have become crucial factors which determine the success and credibility of any design, in the long run. Unfortunately, at present, achieving thermal comfort has become synonymous to environmental degradation, where the latter seems inevitable. There is an urgent need to find a balance between these two governing factors, to arrive at a responsible and sustainable design for the future years. The focus of this research is to study passive design strategies that successfully aid thermal comfort, user comfort and optimal energy consumptions. A comparative case study of two residences in Pune city has been done, to analyze the passive design strategies used. The first case is Sahastrabuddhe Wada, located in the old-city area of Pune and is built in 1897. The other case is Khadke House, built in 2010 and is a modern interpretation of 'traditional Wada' design. A survey of all the residents has also been taken to understand user perceptions of comfort. The strategies used in both the designs are compared to a base case, prepared using Mahoney's Tables for passive design. The resultant matrix compares all parameters, while also highlighting, the strategy that works better. The research takes an interesting turn when it analyses the behavior of passive strategies used for a 'moderate' climate, in the present day 'warm and humid' conditions. As climate change is inevitably upon us, this research will set a base for future researchers who want to study the effects of climate change on passive design strategies and propose modifications in existing designs to enhance thermal comfort.

Index Terms – Climate responsive architecture, Passive design strategies, Thermal comfort, User comfort, Wada-design technique

1 INTRODUCTION

The field of architecture and construction is undergoing a revolution, where the thermal comfort and end user satisfaction has become an extremely important factor for describing the success and credibility of any design. It has also become necessary to cause minimum disturbances to the environment while achieving this. A balance of both these considerations may constitute for a decent design in sustainable architecture. There are various ways in which designers around the world are trying to achieve the above, depending on the context that they are practicing in. Context has been influential in this field of practice because it is predominant in age old buildings and changes with locality. The focus of this research is to study the contribution of passive design techniques, in fulfilling thermal comfort and end user satisfaction in sustainable building design. Pune is currently witnessing rapid urbanization [1]. Hence, to be able to design successfully, it is time to go back to the roots of indigenous or local building design strategies.

2. THERMAL COMFORT – ACCORDING TO INDIAN STANDARDS

The term 'thermal comfort' refers to the intangible comfort of a person, in terms of feeling hot, warm, or cold at a resting position. A combination of environmental factors, combined with personal comfort factors and work-related factors, influence a person's thermal comfort. But, as this feeling differs from person to person, the optimum scenario that a designer can opt for is a thermal environment that satisfies majority of occupants using that space [2]. Air temperature, air velocity, radiant temperature, humidity, clothing and metabolic activities, all affect thermal comfort and the ambient micro-climate and hence, it is different for each person, even if they are working in a relatively similar context.

2.1 Pune – Climatic Zone as Per ECBC 2017

Tropical Wet (Humid): The tropical wet (humid) climate group in India is divided into two subparts; the tropical monsoon climate or the tropical wet climate, and tropical wet and dry climate. The Western Ghats, the Malabar Coast, Southern Assam, Lakshadweep and Andaman and the Nicobar Islands have this type of tropical monsoon climate. It experiences moderate to high temperatures with seasonal but heavy rainfall. The months from June to November experience the most rainfall and the rain received during this period is stored and used for drinking, washing and agriculture throughout the year. Tropical wet and dry climate or the savannah climate is most common in the country. It prevails mainly in the inland peninsular region of the country except for some portion of the Western Ghats. Hot and humid summers, heavy monsoons and cold winters are prevalent in such regions [3]. However, when we compare this climatic data with the data for Delhi, it is observed that both cities have a very similar climate. Thus, it is safe to assume that Pune too is moving towards a moderate climate like Delhi.

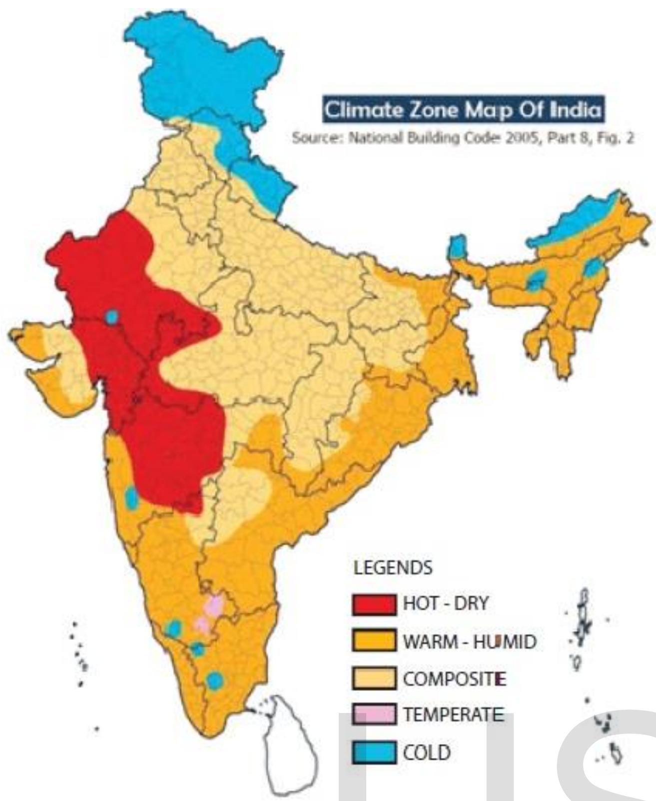


Fig. 2.1.1 Climatic zones of India
Source - [14]

2.2 Passive Design – It's Relationship with Thermal Comfort

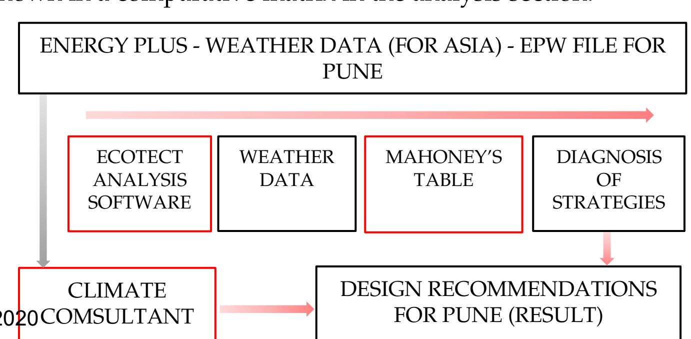
The predominant climate and local environment affect the human body directly. Our daily life cycle comprises states of activity, fatigue, and recovery. The human body produces heat, through metabolism, in order to maintain an optimum body temperature between 37 to 39 degrees. The task of the designer is to create the best possible indoor climate for the occupants considering the kind of activity that is taking place in that space. Studies have shown that the occupants of a building generally judge the design by tangible as well as intangible aspects. An overall understanding of well-being or discomfort contributes to the total verdict on any indoor environment. It is a challenge for the designer to strive towards the optimum of total comfort which may be defined as the sensation of complete physical and mental wellbeing. Considerable information has now been published on the physical but not much on the emotional aspects of our environment.

2.3 Literature Review

Active strategies used to achieve thermal comfort exert unnecessary strain on the available natural resources. This subsequently increases the energy demands. This problem has attracted much attention due to a dire need of conserving the rapidly depleting resources. Most studies related to thermal comfort and post occupancy user satisfaction has been conducted outside India [4]. A few studies have concentrated on user perception, but in relation with green building rating and the perceived satisfaction [5]. A comparative study of artificially ventilated space and a naturally ventilated space has been carried out in Ahmedabad and was based on a survey of users of the building [6]. But there is a gap in literature when it comes to evaluation of a built space with respect to the passive design strategies used and their effects on the thermal comfort levels and user perceptions. This research will try and fill those gaps by doing a survey of two residences in Pune, that were constructed a decade apart and by further analyzing their thermal performance in accordance with the techniques used. This paper will also address the shift of climatic zones for Pune from moderate to composite and how the passive design strategies adapted to built spaces transitioned, respectively. The study will further overlay if the strategies designed for a moderate climatic zone would still boost thermal comfort while the climatic parameters have moved towards composite.

3 Research Methodology

A comparative study of two residences in Pune city that have used passive design strategies and are constructed in two different time zones, to determine successful design strategies for the climate of Pune and to understand user preference for thermal comfort. The first structure is a 120-year-old structure; Sahastrabuddhe Wada, while the other is a residence; Khadke House, which has been constructed within the last 20 years. The residences are of a small scale and hence the resultant strategies might only be useful for designing residential units in Pune and would probably not work entirely for other large-scale projects. Both these structures have been analyzed for their thermal performance and energy consumption patterns with respect to the passive design strategies using parameters like wall sections, materials, orientation, size of openings, design of openings, temperature, humidity, heights of courtyards, shading devices and so on. All these parameters need to be incorporated at the design stage and cannot be added on after a built form has been constructed. Although the parameters remain the same, their use and definition varies with the respective climatic zone in which the designer is designing the structure, for arriving at a climate responsive design solution. Mahoney's Tables and Climate Consultant were the two tools used to work out the ideal climate responsive strategies, which were then compared to the observations made on site. This is shown in a comparative matrix in the analysis section.



The following parameters were chosen to assess the passive design strategies as they were major influencers for thermal comfort:

Orientation: The orientation of any structure with respect to the prevailing wind conditions will determine the pressure sustained by that building. Maximum pressure is generated when the façade is at a right angle to the wind direction, whereas a 45 degrees incidence will reduce this pressure by 50%.

Ventilation: Ventilation can be natural or mechanical. Natural ventilation can either be cross ventilation or stack ventilation. In both cases the goal is to provide seamless air movement inside an occupied space. The common technique is to allow fresh, cool air to enter which replaces the stagnant, warmer air which is present inside.

Size of Openings: The size of the opening will determine the wind velocity entering the structure as well as the radiant heat. Smaller openings will increase the velocity of air, leaving less scope for radiant heat to enter. This works efficiently in hot and dry climate where humidity levels are generally low. Whereas, in warm and humid climates larger openings are preferred which facilitate a large volume of air to be replaced.

Thickness of Walls: The thickness of walls and even sometimes the roof becomes an important factor which determines the time taken for conductive heat transfer from outside to inside or vice versa. In hot and dry climates, it is important to delay this process of heat transfer during daytime to maintain cooler indoor temperatures. On the other hand, the heat stored by the walls and roof material is released at night-time, to ensure warmer interiors and subsequent comfort of the user. Hence, to meet this requirement thicker wall and roof sections are recommended.

Roof and Wall Surface Area: Maximum heat gain occurs when the radiation from the sun is at 90 degrees with the wall or roof surface. To minimize this, one technique is to reduce the surface area of the roof on the southern side.

4 Case Studies

Two case studies were chosen built in two different centuries. Case study 1 is a representative of a case where Pune was considered under the moderate climatic zone.

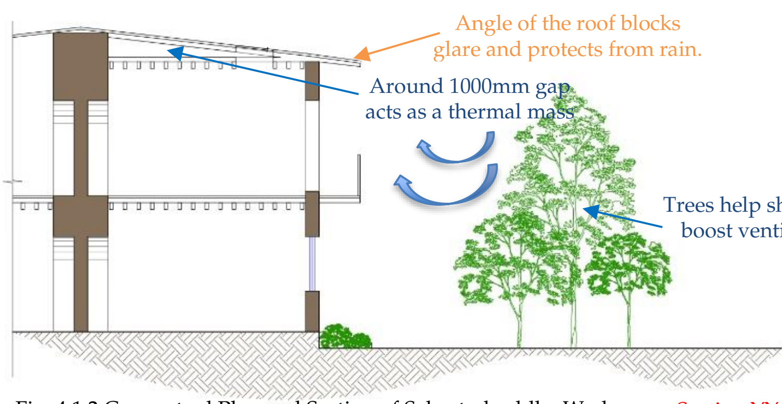
Case 2 is a representative of a case where Pune migrated to a composite climatic zone. The research paper further explorers the passive design strategies used in these two cases and compares them against two simulation tools and the Mahoney's table to draw parallels between the climatic zones and the strategies implemented.

4.1 Case Study 1 – Sahastrabuddhe Wada (Pune, 1890)

Sahastrabuddhe Wada had been constructed in year 1890, in Shanivar Peth (the Old City area of present-day Pune). The Wada is a G+1 structure and is used as a residence space for the Sahastrabuddhe family. In the year 1890 Pune was classified under the moderate climatic zone, up until 2005. [7] The orientation of the central courtyard is to the west of the present-day residential unit. Before the construction of the Wada, 3 existing water wells were sealed and therefore the plinth has been raised by 0.45m.

The primary materials used for construction were Flat earth bricks, wooden members used in columns, beams, flooring, cantilevered balconies, brackets, etc., lime plaster for the external façade and exposed brickwork from the inside, which was later plastered with cow-dung, lime mortar for brick walls and floors plastered using cow-dung.

Fig. 4.1.1 Street Facing (Northern) Façade of the Wada
Source – Author



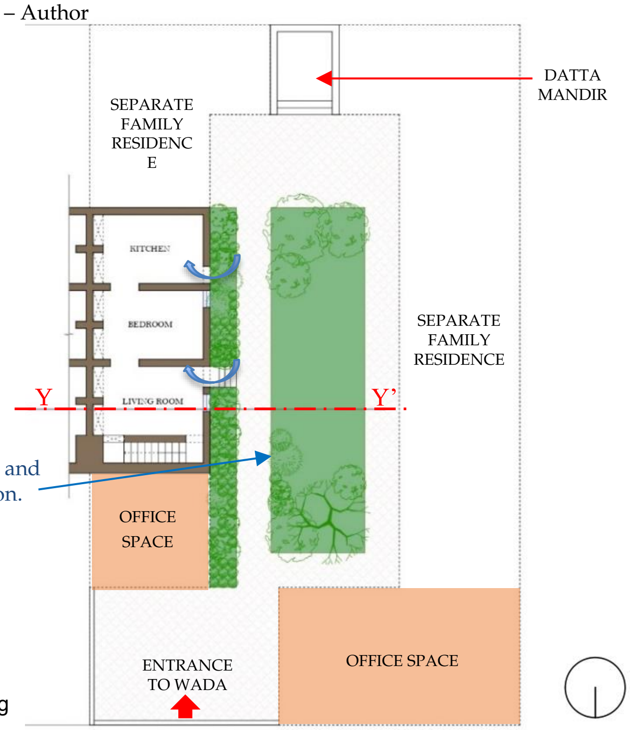


Fig. 4.1.2 Conceptual Plan and Section of Sahastrabuddhe Wada
Source – Author

Fig. 4.1.3 Central Courtyard – West Facing
Source – Author

4.2 Case Study 2 – Khadke House (Pune, 2010)

Khadke house, designed by Girish Doshi for Pune's composite climate, with its hot-dry summers, appears to be any elegant contemporary house. But, being built for a joint family (Khadke family) which previously resided in a traditional Wada , the structure takes inspiration from Wada architecture and design principles while providing the usual modernist characteristics - white walls (inside and out), a simple cuboidal form, and the very contemporary accent of polished wooden elements in windows and related elements. This is one of the few residences which carries forward our traditional wisdom (passive design strategies and built form).

Fig. 4.2.1 Skylight and the double volume volume creating stack ventilation effect
Source – Navkar Architects [13]

Fig. 4.2.2 Opening sizes and orientation to boost thermal comfort
Source – Navkar Architects [13]

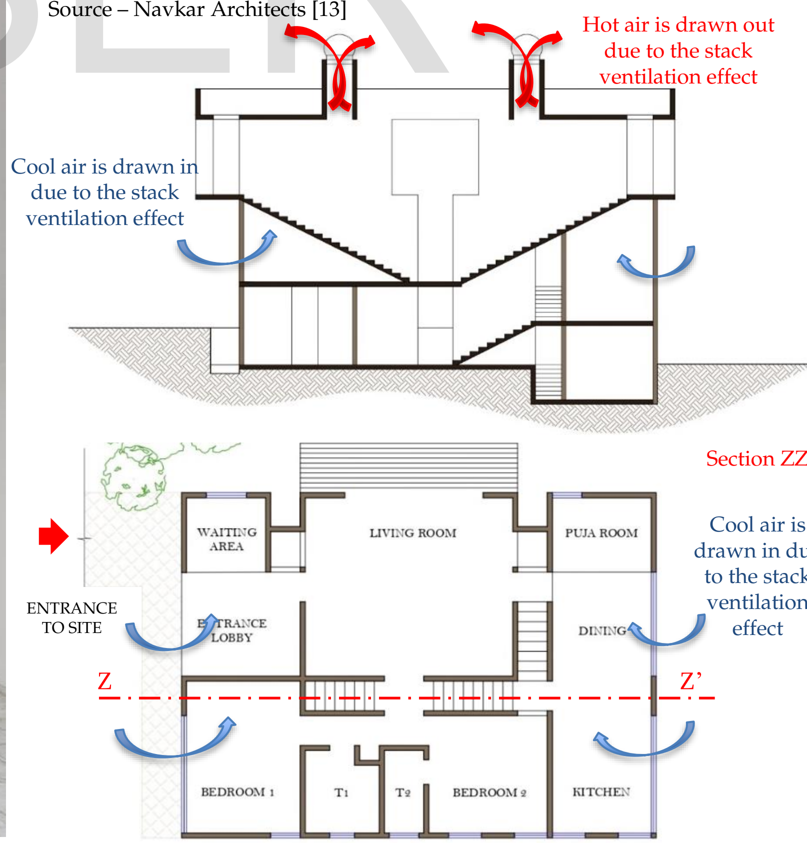


Fig. 4.2.3 Conceptual Plan and Section of Khadke House
Source – Author

5. Analysis

The tools used to analyse and compare climatic data are two software based tools namely- Ecotect weather tool and Climate consultant and one matrix based tool - Mahoney's table developed by architect Carl Mahoney, along with John Martin Evans, and Otto Königsberger.
Ecotect weather tool is used as a base to derive climatic data based on a .epw file (containing weather information compiled from the IMD for the past 20 years on an average). Climate consultant is a tool developed by UCLA to help arrive on passive design strategies to be used.

5.1 Mahoney's Tables

The Mahoney tables are a set of reference tables used as a guide to climate-appropriate design. They were first published in 1971 by the United Nations Department of Economic and Social Affairs. They do not constitute for a complete and continuous process of design but indicate stages when climatic factors must be brought in and considered in conjunction with other factors. A series of tables have been devised by C. Mahoney and is used to record essential climatic data, facilitate a diagnosis of the climate, and develop a series of climatic indicators and translate these into performance specifications or sketch design recommendations.
There are six tables; four are used for entering climatic data, to help compare the requirements for thermal comfort; and two for deciding on appropriate passive-design strategies for a built space.

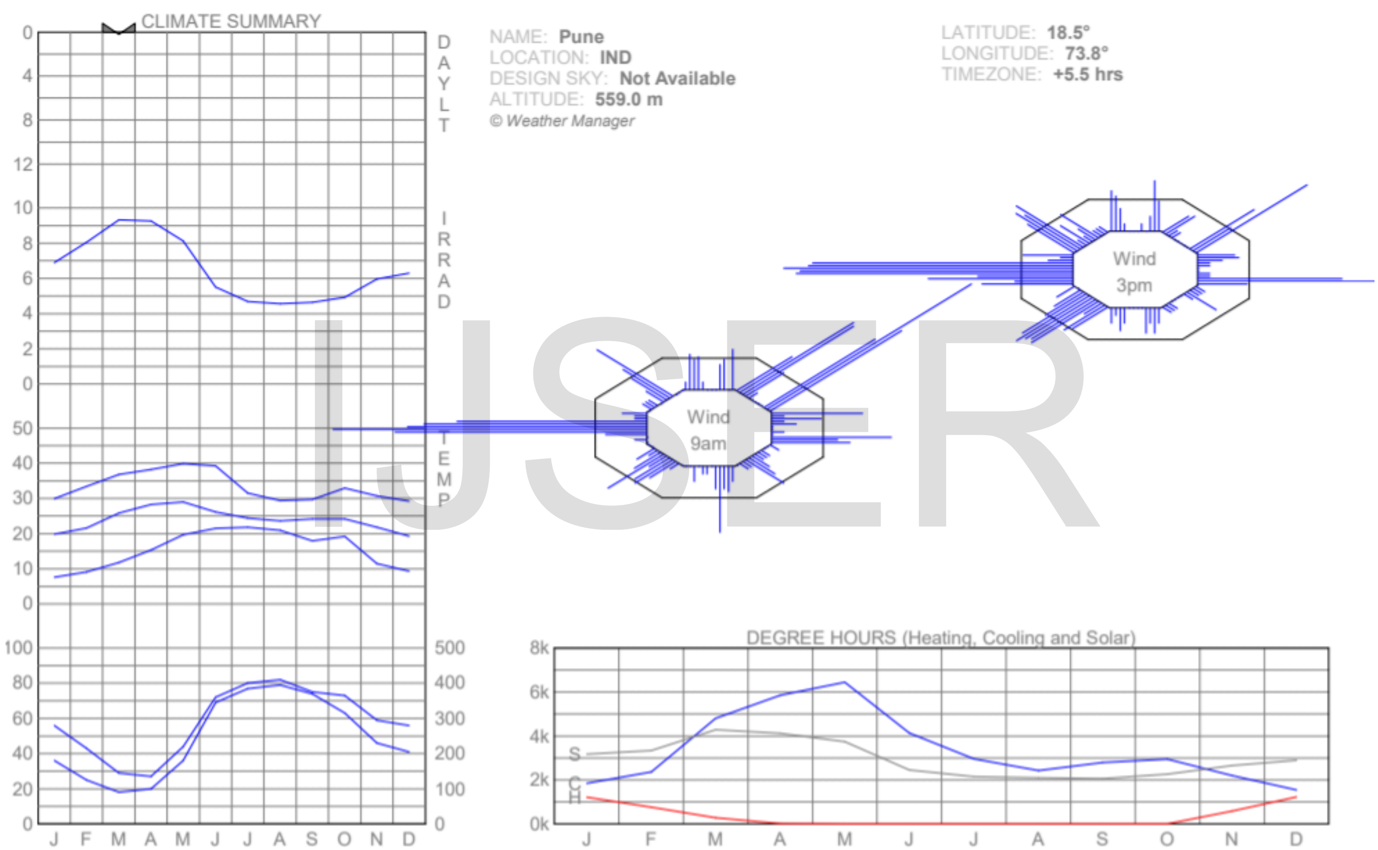


Fig. 5.1.1 – General Climate Data of Pune city.
Source – Weather Tool, Autodesk Ecotect Analysis Software

AIR TEMPERATURE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	High	AMT
Monthly Mean Max	29.9	33.4	36.8	38.2	39.9	39.2	31.5	29.4	29.7	32.9	30.7	29.2	39.9	23.75
Monthly Mean Min	7.6	9.1	11.8	15.3	19.7	21.5	21.8	20.9	17.9	19.2	11.5	9.3	7.6	32.3
Monthly Mean Range	22.3	24.3	25	22.9	20.2	17.7	9.7	8.5	11.8	13.7	19.2	19.9	Low	AMR
RELATIVE HUMIDITY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
Monthly Mean Max a.m.	56	43	29	27	44	72	80	82	75	73	59	56		
Monthly Mean Min p.m.	36	25	18	20	36	69	77	79	74	63	46	41		
Average	46	34	23.5	23.5	40	70.5	78.5	80.5	74.5	68	52.5	48.5		
Humidity Group	2	2	1	1	2	4	4	4	4	3	3	2		
RAIN AND WIND														
Rainfall, mm	0.77	1.25	3.94	3.87	7.09	124.02	138.69	88.01	107.1	99.57	42.04	24.41		
Wind Prevailing	N	N	NW	NW	W	W	W	W	W	E	E	E		
Wind, Secondary	NE	NW	NW	NW	NW	NW	NW	NW	W	NE	SE	SE		
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		

Image 5.1.2 – Available Data for Temperature, Relative Humidity and Rainfall [10], [7], [11], [12].
Source – Author

Rainfall Average	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2009	0.27	0	7.68	1	20.73	81.03	321.38	33.88	77.86	84.4	87.1	2
2010	5	0.05	0.35	2.04	2	119.18	106.16	90.46	73.91	68.59	115.62	0.71
2011	0	4.03	1.26	0.58	12.95	146.12	86.34	83.49	53.2	68.19	0.18	0
2012	0.01	0	0	17.83	1.89	60.63	80	80.78	92	112.53	6.64	0.11
2013	0	0.3	0.08	0.44	2.69	112.86	146.58	53.87	78.02	31.03	7.98	3.55
2014	2.01	2.34	13.33	0.4	5.34	22.2	134.94	116.63	41.95	31.86	23.45	5.85
2015	1.09	5.3	11.53	12.08	18.11	132.58	44.88	34.08	95.14	46.23	30.26	0.86
2016	0.02	1.71	7.64	2.41	5.85	114.73	129.4	102.67	95.8	20.23	0.43	0.52
2017	0.02	0	1.03	0.01	4.58	141.8	63.73	69.63	141.2	97.69	2.27	4.4
2018	0	0	0.48	1.23	3.88	155.85	119.23	56.16	69.83	22.1	98	0
2019	0	0	0	4.6	0	277.2	293	246.5	359.5	512.4	90.5	8.5
	8.42	13.73	43.38	42.62	78.02	1364.2	1525.6	968.15	1178	1095.3	462.43	26.5
	0.76545	1.2482	3.9436	3.8745	7.0927	124.02	138.69	88.014	107.1	99.568	42.039	2.409091
Avg	0.77	1.25	3.94	3.87	7.09	124.02	138.69	88.01	107.1	99.57	42.04	24.41
2009	0.27	0	7.68	1	20.73	81.03	321.38	33.88	77.86	84.4	87.1	2
2019	0	0	0	4.6	0	277.2	293	246.5	359.5	512.4	90.5	8.5

Image 5.1.3 – Calculations for Average Rainfall data from 2009-2019 [9], [10].
Source – Author

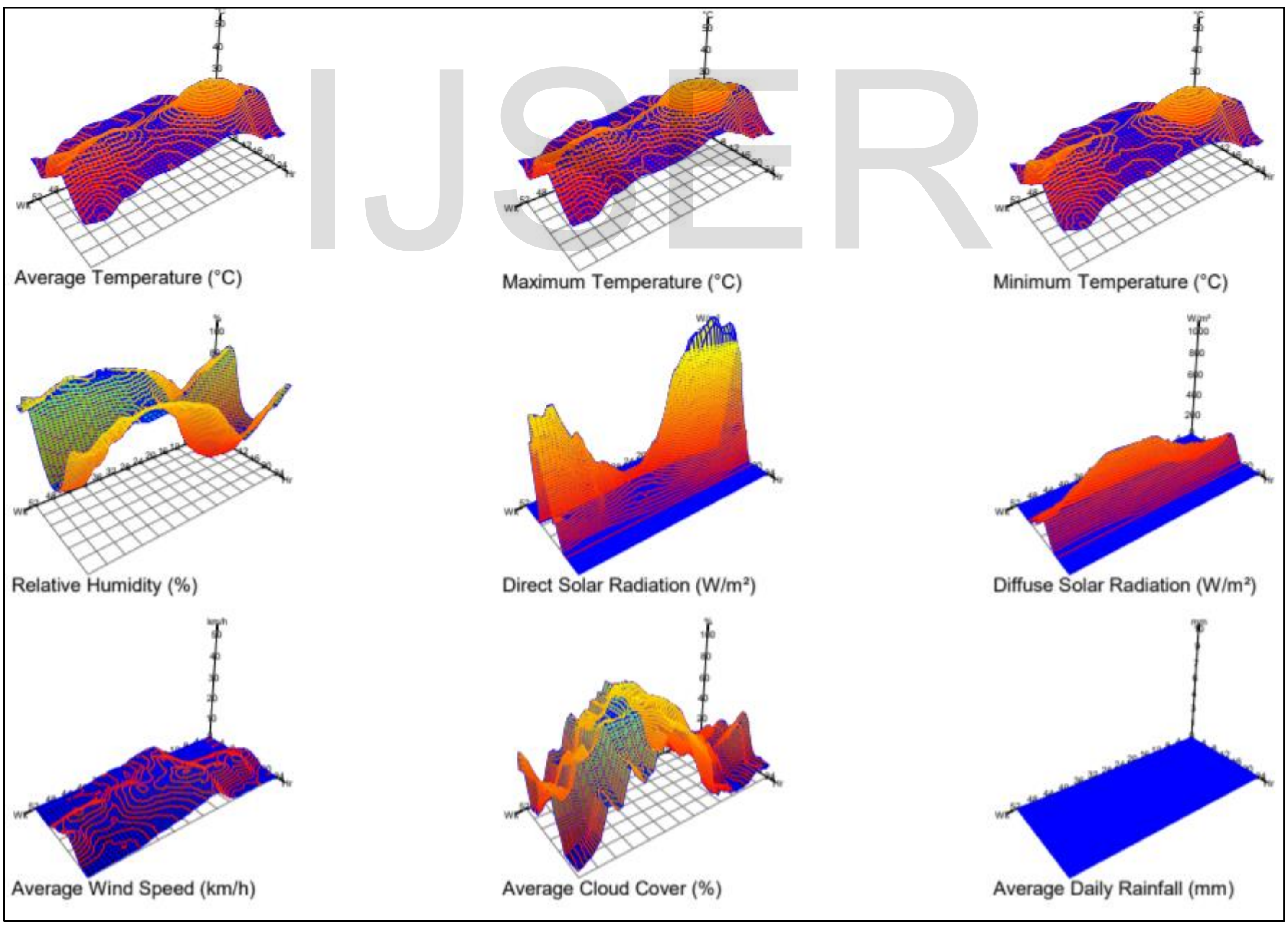


Image 5.1.4 – Weekly Averages
Source – Weather Tool, Autodesk Ecotect Analysis Software

5	TABLE 2														
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AMT
	Monthly Mean Max		29.9	33.4	36.8	38.2	39.9	39.2	31.5	29.4	29.7	32.9	30.7	29.2	23.75
	Day Comfort Upper		31	31	34	34	31	27	27	27	27	29	29	31	
	Day Comfort Lower		25	25	26	26	25	22	22	22	22	23	23	25	
	Monthly Mean Min		7.6	9.1	11.8	15.3	19.7	21.5	21.8	20.9	17.9	19.2	11.5	9.3	
	Night Comfort Upper		24	24	25	25	24	21	21	21	21	23	23	24	
	Night Comfort Lower		17	17	17	17	17	17	17	17	17	17	17	17	
	Thermal Stress Day		O	H	H	H	H	H	H	H	H	H	H	O	
	Thermal Stress Night		C	C	C	C	O	H	H	O	O	O	C	C	
	Indicators														
			JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Totals
	Humid	H1													4
		H2													0
		H3													0
	Arid	A1													8
		A2													2
		A3													0

Image 5.1.5 – Diagnosis of Strategies using Indicators - Mahoney's table [9] – the green boxes represent a 'tick or yes' mark.
Source – Author

1	Orientation North and South along axis east-west		10	Very small openings 10-20%	
2	Compact Courtyard Planning		11	Medium openings 20-40%	
3	Open space for breeze penetrartion		12	Light walls - short time lag	
4	As 3, Protection from hot and cold		13	Heavy internal and external walls	
5	Compact layout of estates				
			14	Light insulated roofs	
6	Permanent provision for air movement - single banked rooms		15	Heavy roofs - over 8hr time lag	
7	Temporary provision for air movement - double banked rooms				
8	No air movement required		16	Space for outdoor sleeping required	
9	Large openings 40-80%		17	Protection from heavy rain necessary	

Fig. 5.2.1 Design Recommendations for the available climate data of Pune – as given by Mahoney's Table [9]
Source – Author

5.2 Climate Consultant

Climate consultant is a computer program developed by the was also used by architects, builders, contractor, homeowners, and students understand their local climate. Climate Consultant translates this raw climate data into dozens of meaningful graphic displays. [8]

1. COMFORT: (using ASHRAE Handbook through 2005 Model)

20.0	Comfort Low - Min. Comfort Effective Temp @ 50% RH (ET* C)
23.3	Comfort High - Max. Comfort Effective Temp @ 50% RH (ET* C)
17.8	Max. Wet Bulb Temperature (°C)
2.2	Min. Dew Point Temperature (°C)
2.8	Summer Comfort Zone shifted by this Temperature (ET* C)
1.0	Winter Clothing Indoors (1.0 Clo=long pants,sweater)
0.5	Summer Clothing Indoors (.5 Clo=shorts,light top)
1.1	Activity Level Daytime (1.1 Met=sitting,reading)

2. SUN SHADING ZONE: (Defaults to Comfort Low)

22.8	Min. Dry Bulb Temperature when Need for Shading Begins (°C)
315.5	Min. Global Horiz. Radiation when Need for Shading Begins (Wh/sq.m)

3. HIGH THERMAL MASS ZONE:

8.3	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:

16.7	Max. Outdoor Temperature Difference above Comfort High (°C)
1.7	Min. Nighttime Temperature Difference below Comfort High (°C)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)

20.0	Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°C)
11.0	Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°C)

6. TWO-STAGE EVAPORATIVE COOLING ZONE:

50.0	% Efficiency of Indirect Stage

Fig. 5.2.1 Passive design strategies recommended by the climate consultant tool for the climate file of Pune as given by ECBC 2017

7. NATURAL VENTILATION COOLING ZONE:

2.0	Terrain Category to modify Wind Speed (2=suburban)
0.2	Min. Indoor Velocity to Effect Indoor Comfort (m/s)
1.5	Max. Comfortable Velocity (per ASHRAE Std. 55) (m/s)
3.6	Max. Perceived Temperature Reduction (°C)
90.0	Max. Relative Humidity (%)
22.8	Max. Wet Bulb Temperature (°C)

8. FAN-FORCED VENTILATION COOLING ZONE:

0.8	Max. Mechanical Ventilation Velocity (m/s)
3.0	Max. Perceived Temperature Reduction (°C)
	(Min Vel, Max RH, Max WB match Natural Ventilation)

9. INTERNAL HEAT GAIN ZONE (lights, people, equipment):

12.8	Balance Point Temperature below which Heating is Needed (°C)

10. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
3.0	Thermal Time Lag for Low Mass Buildings (hours)

11. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:

157.7	Min. South Window Radiation for 5.56°C Temperature Rise (Wh/sq.m)
12.0	Thermal Time Lag for High Mass Buildings (hours)

12. WIND PROTECTION OF OUTDOOR SPACES:

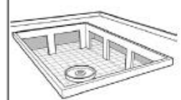
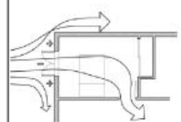
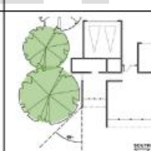
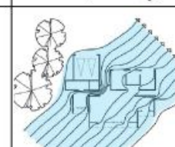
8.5	Velocity above which Wind Protection is Desirable (m/s)
11.1	Dry Bulb Temperature Above or Below Comfort Zone (°C)

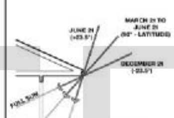
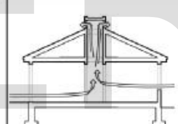
13. HUMIDIFICATION ZONE: (defined by and below Comfort Zone)

14. DEHUMIDIFICATION ZONE: (defined by and above Comfort Zone)

6. Comparative Analysis

The following matrix compares the passive design strategies observed in both cases, in comparison with the design strategies recommended by the weather calculations done using Mahoney's Tables as well as the design recommendations given by the Climate consultant tool.

Sr No	Strategies Observed on Site		Strategies Recommended by Mahoney's Table	Strategies Recommended by Climate Consultant
	Khadke House	Sahastrabuddhe Wada		
1	 Square Plan East-West Orientation	 North-South Orientation	Orientation North and South (along axis east-west)	 Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
2	Compact Courtyard Planning	Linear Compact Planning	Compact Courtyard Planning	 Traditional passive homes in hot windy dry climates used enclosed well shaded courtyards, with a small fountain to provide wind-protected microclimates
3	Yes	Yes	Open space for breeze penetrartion	 Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
4	Not Applicable	Compact Planning with respect to Adjoining Wadas	Compact layout of estates	N/A
5	All rooms are single banked	All rooms are single banked	Permanent provision for air movement - single banked rooms	N/A
6	No	No	Temporary provision for air movement - double banked rooms	N/A
7	Southern façade opens up into a deck area that provides as a vegetated buffer against direct heat gain	West facing courtyard is densely vegetated with native species of trees and shrubs.	N/A	 Use plant materials (bushes, trees, ivy-covered walls) especially on the west to minimize heat gain (if summer rains support native plant growth)
8	Large Openings	Openings are single-sided facing the west (windward-direction), with extended balconies on the first floor	Large openings 40-80%	 To facilitate cross ventilation, locate door and window openings on opposite sides of building with larger openings facing up-wind if possible
9	Not Applicable	Not Applicable	Very small openings 10-20%	N/A
10	Medium openings on east-west facade and on toilet walls	Medium sized openings in-between two occupancy spaces, provide for cross-ventilation and free flow of air	Medium openings 20-40%	N/A
11	Not Applicable	Not Applicable	Light walls - short time lag	N/A

12	Wall thickess is of standard 150mm. Fly ash bricks prolong the heat gain, white washed walls reflect radiant heat.	Wall thickness of around 450mm is achieved by usimg flat bricks and mud plaster	Heavy internal and external walls	N/A
13	Not Applicable	Yes	Light insulated roofs	N/A
14	150mm concrete slab with white paint finish relects most of the heat back into the atmophere	About 1000mm inhabitable space is achieved between the first floor ceiling and the roof, acting as a buffer for heat gain	Heavy roofs - over 8hr time lag	N/A
15	Flat roof provides for space on the terrace for sleeping and other activities	Common courtyard outside the house, used for many activities.	Space for outdoor sleeping required	 Flat roofs work well in hot dry climates (especially if light colored).
16	White coloured roofs and walls.	Mild steel used as roofing sheet above the timber rafters.	N/A	 A radiant barrier (shiny foil) will help reduce radiated heat gain through the roof in hot climates.
17	Flat roof with parapet wall - rain water runoff into gutters	Sloping roof and chajjas have been provided with long overhangs	Protection from heavy rain necessary	 Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning
18	Turbo ventilators placed above the central double height space act as an outlet for heated air	Cross ventilation is prevalent, all openings are located on the west-facing wall and are covered with chajjas	N/A	 To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and outlet (open stairwells, two story spaces, roof). Use open plan interiors to promote natural cross ventilation, or use louvered doors.

7. Conclusion

It is observed that in both the case studies, the design parameters observed on site are a nice blend of the parameters recommended by Mahoney's tables and the recommendations given by Climate Consultant. Quite naturally, both designs have adopted the climate responsive strategies using different techniques, influenced by factors such as age of construction, available materials, monetary restrictions, client preferences, etc. However, final goal of both designs was to achieve thermally comfortable interiors, with minimum use of active strategies (mechanical means of ventilation and thermal comfort). The expected outcome of research was to derive parameters (passive design strategies) for designing a 'thermally comfortable' residence in Pune city, while reducing the demand for energy and resources. The aim was to create a passive strategy matrix which is suitable for the current scenario and climatic parameters in Pune city. Designers who are looking to design in this climate setting can use these strategies reliably. It is thus safe to say, that using indigenous methods and passive strategies, relieves the stress from artificial heating and cooling equipment, thus conserving energy. These methods are more permanent in nature, require minimum maintenance, could be incorporated at the design stage, thus adding to the aesthetic and thermal comfort of the users once implemented.

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