Bio-climatic design for disaster resilient vernacular housing of Saurashtra, Gujarat

Passive design guidelines for the rural housing of Saurashtra region through assessment of vernacular houses built by the AKPBSI.

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Thesis submitted in fulfillment of the requirements of the degree of

Masters in Environmental Architecture

To

Yashwantrao Chavan Maharashtra Open University (Y.C.M.O.U.), Nasik

July 2016

CERTIFICATE

This is to certify that the Report titled

Bio-climatic design for disaster resilient vernacular housing

of Saurashtra, Gujarat

is the bona-fide work of

Sana Sultan Dharani

submitted to the faculty of

Rizvi College of Architecture

for

Dissertation 1 & 2 in Semester 4 of

Masters in Environmental Architecture

at Y.C.M.O.U

during the Academic Year 2015-2016

Ar. Saurabh Barde	**Prof. Akhtar Chauhan**
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DECLARATION

I hereby declare that the report titled **"Bio-climatic design for disaster resilient vernacular housing of Saurashtra, Gujarat"**, submitted by me to the faculty of Rizvi College of Architecture in fulfillment of the requirements for semester 4 of the degree of **Masters in Environmental Architecture** of Yashwantrao Chavan Maharashtra Open University (Y.C.M.O.U.), Nasik, under the guidance of Ar. Saurabh Barde.

I further declare that this written submission represents my ideas and findings in my own words and where others ideas, findings and words have been included, I have appropriately cited the original sources. I affirm that I have adhered to the research ethics of honesty and integrity to the best of my knowledge and have not falsely represented any idea, data, fact or source.

I understand that any violation of academic ethics may cause disciplinary action by the Institutes and can evoke action from the sources which have not been cited properly.

Place: Mumbai

Date: 29th July 2016

Signature

Sana Sultan Dharani

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I am thankful to ALLAH the Generator, Operator, and the Destroyer of this world.

My parents, my sister Shomaela, brother in-law Azim Virani, my grandmother, aunt Nazima, best friend Saad Siddiqui without whose help, love and support, this would have been difficult.

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Abstract

Rural planning is need of the hour based on the principles of sustainable development which includes the use of local labor, low-cost local materials, technology and energy efficiency. Rural housing exemplifies some of the bioclimatic principles of adaptive thermal comfort; vernacular and contextual solutions; response to microclimate: sun path, wind and rain; working with primarily passive elements; and development of a responsive form. It is essential to acknowledge and reinforce these design elements of vernacular architecture into new rural housing designs and test their response to the topography, climate and evolving culture of the region.

Quantifying building performance is essential to meet environmental targets for the built environment like the ones set by international policy organizations, such as the Kyoto Protocol. Building monitoring and computer simulation are valuable tools that are easily available today for use in the area of building energy simulation and adaptation to climate change. Measuring the performance of such vernacular dwelling will help to understand the comfort and well being of occupants in the given set of social and economic conditions. The adaptation to a warming world as an impact of climate change is essential along with reducing the energy demands for cooling through a NEW COOL VERNACULAR BUILDING APPROACH.

In this study the new vernacular houses built by the Aga Khan Planning and building Services India, (AKPBSI) in Saurashtra region of Gujarat, India have been used as a medium of research. The houses have been selected from two villages, namely Jivapar in Jamnagar district and Chitrawad in Junagadh district and are analyzed with respect to the context, house form and building materials. The study endeavors to examine the new disaster-resilient vernacular houses built by the AKPBSI in the rural areas of Saurashtra , which are conceptually understood as shelters that fulfill people's needs according to their socio-economic & cultural criteria as well responding positively to the climatic factors.

The research has been assessed by means of on-site monitoring, field survey and building performance simulation. Field survey questionnaire provides lessons that act as catalyst and model for future house form, building materials and elements. Monitoring the thermal performance of a typical vernacular house provides information on the thermal comfort in houses built by the AKPBSI. The outcome of the survey is three main findings, firstly it sets the preference of the house form and building materials by the end users, secondly, the verification of the window areas that are sufficient for daylight and comfort ventilation in the various rooms of the house and thirdly, the site monitoring provides the temperatures for comparison with thermal performance simulation model. The energy simulations results of the eighteen cases with

combination of wall & roof materials and orientations provides the comparison of thermal comfort within the house in Saurashtra during the entire year.

Passive design strategies are proposed by the author keeping in view the economic, site and social context that is the available local material and the traditional solutions to establish an indoor comfort environment that is acceptable as per standards. The findings of the study fills the part of the gap in the AKPBSI's building design standard by setting a thermal comfort performance standard for the houses in Saurashtra, and gives the possibility to enhance thermal comfort in the future houses compared to the existing houses. It also concludes with number of research avenues that can be carried out for comprehensive answer to the issue of thermal comfort and building design strategies for low cost houses in Saurashtra.

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List of acronyms abbreviations

ach	air changes per hour
ACS	Adaptive Comfort Standard
AKDN	Aga Khan Development Network
AKPBSI	Aga Khan Planning and Building Services, India
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BPS	Building Performance Simulation
clo	clothing value
CSEB	Compressed Stabilised Earth Blocks
DB	Design Builder
E10	Energy 10
ECBC	Energy Conservation Building Code
EPW	Energy Plus Weather file format
GBS	Green Building Studio
GI	Galvanized Iron
GUI	Graphic User Interface
H.S.A.	Horizontal Shadow angle
HIP	Habitat Improvement Program
HVAC	Heating, Ventilation and Air Conditioning
IES VE	Integrated Environmental Solutions
IMAC	India Model for Adaptive thermal Comfort
ISHRAE	Indian Society of Heating, Refrigerating and Air-Conditioning Engineers
m/s	meters per second
MAX	Maximum
met	metablic rate value
MIN	Minimum
PCC	Plain Cement Concrete
PMV	Predicted Mean Vote
RCC	Reinforced Cement Concrete
RH	Relative Humidity
RHDP	Rural Habitat Development Program
sq.ft.	Square feet
U value	Transmittance Value
UCLA	University of California, Los Angeles
V.S.A.	Vertical Shadow Angle
W/sq.m.	Watts per meter spuare
WWR	Window to Wall Ratio

CHAPTER 1

INTRODUCTION

1. Introduction

Chapter 1 introduces the topic of the dissertation by justifying the need for bio-climatic design, stating the significance of selecting disaster-resilient vernacular housing in Saurashtra as a medium for the study by describing the area of the study, case study selection criteria, the aim and objectives of the study, scope and limitations, hypotheses of the research study.

1.1. Need for the study

The architectural characteristics of different regions of India and climatic zones have started losing their regional identity with the advent of globalization. This has resulted in the use of modern design principles and materials in the built environment, that have less relevance to their context, climate, and the user and thus lead to environmental degradation. In the global scenario, rapid urbanization results in the merging of rural areas into the peri-urban areas of nearby towns and cities. The major impact of this process on the rural areas is the migration, change of occupation and life style, and introduction of new materials and techniques in construction. But, the architecture of these rural areas is always sustainable in nature, due to its strong and deep rooted vernacular tradition.

Vernacular architecture is the most wide spread practice with over 90% of the world's architecture being vernacular. The term vernacular architecture is synonymous with primitive, rural, ethnic, informal, folk, traditional, indigenous, ethno-architecture, informal, anonymous architecture or architecture without architects. The recent interest in this practice is mainly due to the global environmental crisis of 1990's when the architecture fraternity realized that the building industry (construction and operation) is consuming a major part of the energy causing the green house gas emissions and global warming. A green design approach that enlists vernacular techniques and materials became an important part of the solution of the environmental crisis and thus research and documentation of vernacular architecture is carried out in different parts of the world (Arboleda, 2006).

To categorize a dwelling as vernacular the following characteristics are essential (Rapoport, 1969):

- Design process of models and adjustments
- Individual variability
- Owner driven process
- Simple and direct solution to a design problem
- Working with site and microclimate
- Respond to surrounding - houses, people and environment
- Manmade and natural materials

- Variations within a given order
- Additive quality - evolves overtime through collaborations with many people over many generations
- Traditional laws honored by all and collective control
- Clear link between form and life pattern
- Climate as one of the form-generating forces

Vernacular solutions are of a large variety related to the conditions surrounding the people along with the cultural aspects of the community and their definition of comfort. These are not individual but group solutions that represent a culture and its response to its region, its climate, materials and topography. These form the bulk of the built environment and are a direct response to culture, climate, people's needs, values and constraints (Rapoport, 1969).

The thesis is founded on the basis that thermal performance study is one of the critical aspects of vernacular houses. The intention is that an assessment of the climatic parameters together with the socio-cultural aspects of design will lead to a comprehensive approach to the design of future housing in Saurashtra. The new vernacular house forms built by the Aga Khan Planning and Building services India (AKPBSI) will be used as a vehicle for the research, directing the outcomes to the design of passive houses.

The framework to derive the solution set for the Saurashtra region in general and AKPBSI housing in particular will be based on the principles of Bio-climatic housing which is defined as a relationship between climate, living organisms and the form and fabric of the building. Material, building systems (energy, water and waste) and user's way of living, all of this are an important part of the relationship. Research suggests that primarily through the use of the buildings' microclimate, form and fabric bioclimatic buildings will use five to six times less energy than conventional buildings over their lifetime. (Hyde, 2008)
Numerous studies and researches have been conducted so far in the domain of vernacular architecture, mainly focusing on the thermal performance assessment of the structures. This post graduation dissertation work looks at understanding how AKPBSI can incorporate bioclimatic design for disaster- resilient houses built by them in the Saurashtra region of India as shown in Figure 1 and assessing its appropriateness in the present context, with specific reference to users' comfort, preferences and constraints.

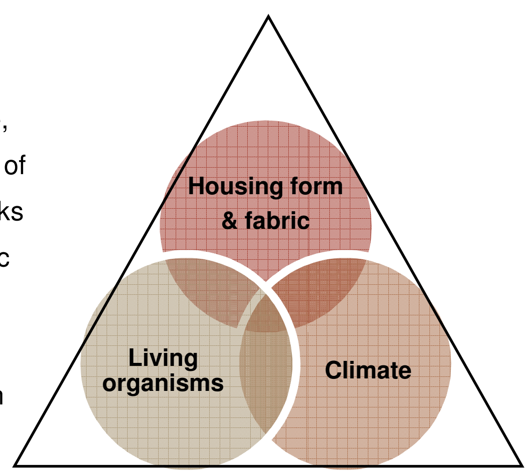


Figure 1 Balance between design dimensions for Sustainability (Hyde, 2008)

1.2. Area of study

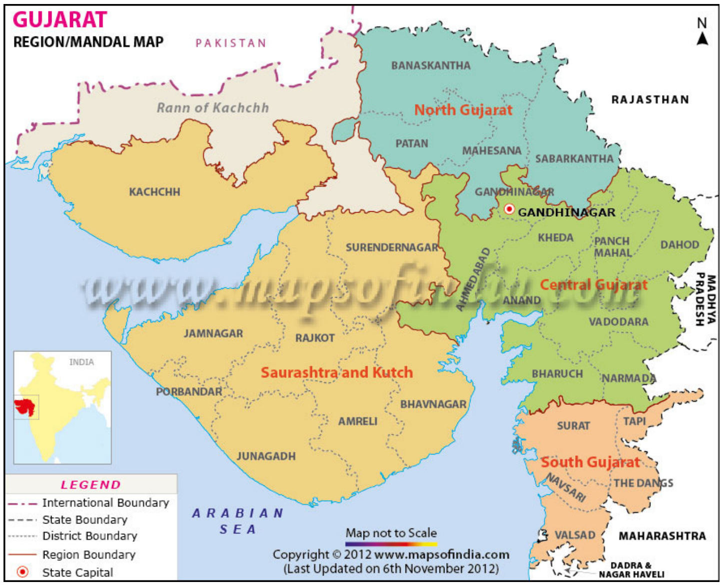


Figure 2 Map of Gujarat showing different regions (Maps of India, 2013)

India is largely rural in population, as per 2011 census of India about 68.84% resides in rural areas, although the urban population is increasing rapidly with industrialization. Rural areas will be particularly affected as it impacts on water resources, agriculture, overall biodiversity and ecosystems like forests and coastal zones, as well as human health. Climate change will affect the livelihoods of 700 million people in rural India of people, resulting in a need for adaptation in key development sectors. **For maximum effectiveness, adaptation need to be integrated into development planning and decisions by making use of climate information, applying a cost-benefit rationale, broadening climate risk management, improving coordination and communication among involved stakeholders, making use of good practices and innovations** (Porsché, Kalisch, & Füglein, 2011).

In June 2008, Prime Minister Manmohan Singh released the first National Action Plan on Climate Change (NAPCC) for India and all Indian states are to have State Action Plans on Climate Change (SAPCC) to execute the following NAPCC.

- The National Solar Mission promotes the development and use of solar energy for power generation and other uses.
- The National Mission for Enhanced Energy Efficiency aims at implementing a host of programmes that will improve energy efficiency in the energy-consuming industries and sectors.
- **The National Mission on Sustainable Habitat promotes energy efficiency as a core component of planning.** (Porsché, Kalisch, & Füglein, 2011)

The State of Gujarat has the longest coast-line and also is an earthquake prone state and as such is more vulnerable compared to other states to the impacts of climate change. Gujarat is regionally divided into 5 mandals (regions) Kutch, Saurashtra, North, Central and South Gujarat of which Saurashtra and Kutch are the larger and comparatively have higher rural population. The Saurashtra region has 7 districts namely Jamanagar, Junagadh, Amreli, Porbandar, Bhavnagar, Rajkot and Surendranagar while Kutch is one district which is partly a seasonal salt marsh.

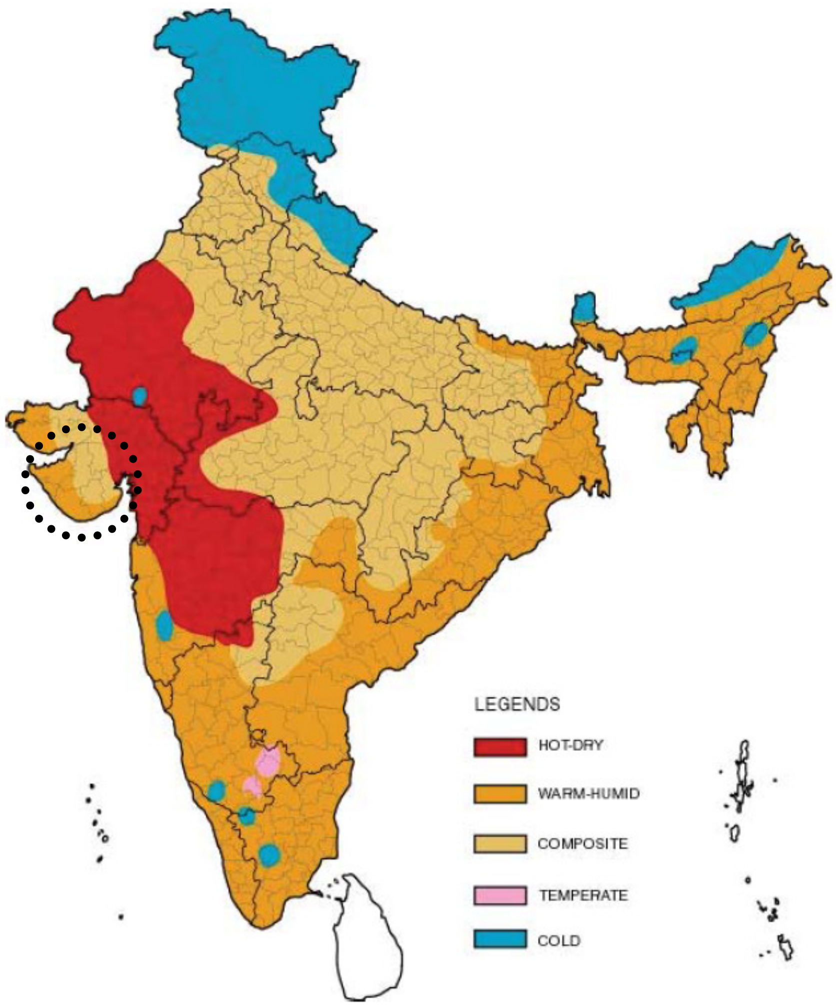


Figure 3 Climatic Zones of India (ECBC, 2009)

The Saurashtra region has 2 distinct climate types as per the ECBC - Warm and humid climate along the coast and composite towards the inland as seen in Figure 3. As per the Koppen Classification of the climatic zones of India the Saurashtra region falls under the Semi-Arid as shown in Figure 4.

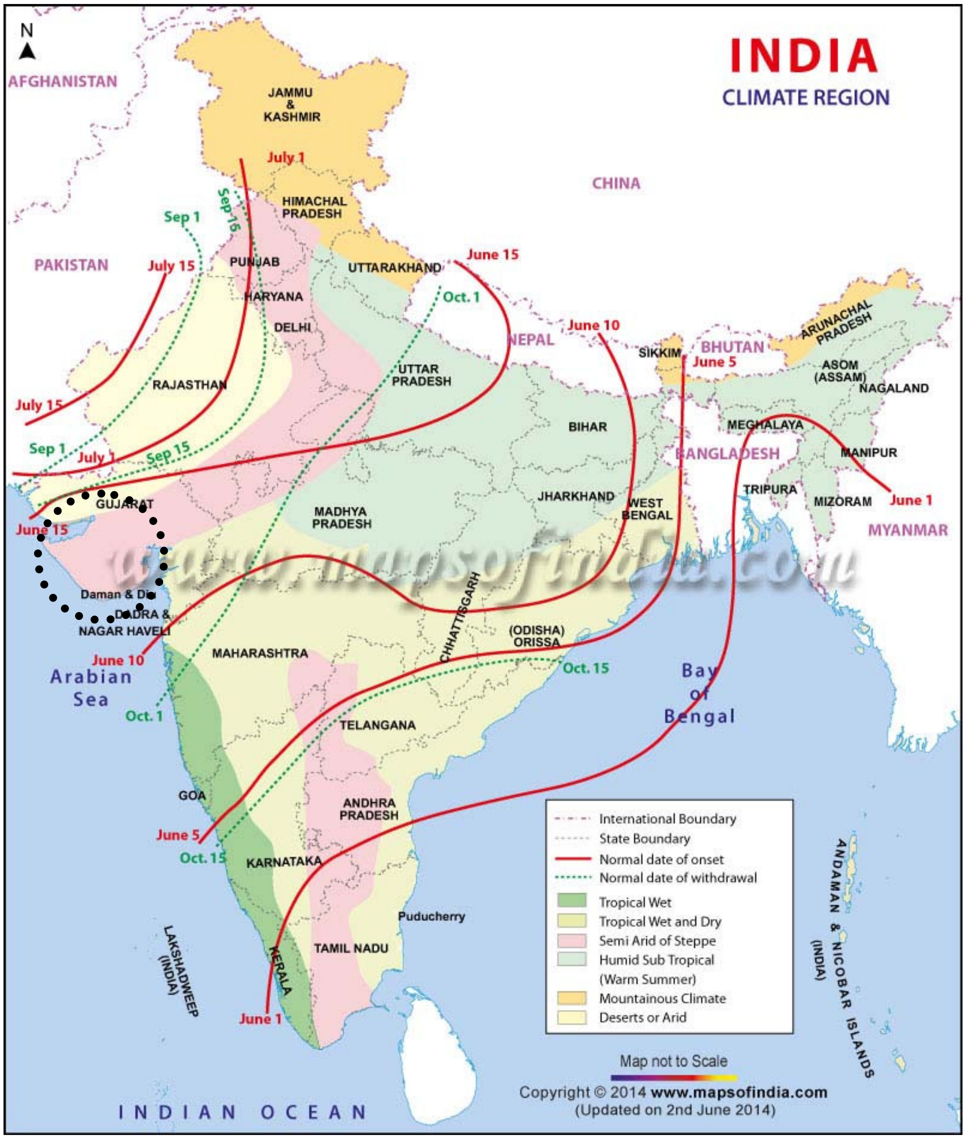


Figure 4 Climatic Zones of India as per Koppen Classification (Map of Climatic Regions of India, 2014)

Jivapar and Chitrawad are located in the coastal districts of Gujarat. Jivapar falls under Zone IV (high damage risk zone) and is vulnerable to natural as well as man-made calamities like earthquake, cyclone, floods, tsunami, drought and chemical and industrial hazards. The map in Figure 5 depicts the range of relative climate vulnerability across the districts of India. While the location of Jivapar is depicting highest climate change vulnerability that of Chitrawad is depicting medium in zone III. The major calamity that occurred in Jivapar & Chitrawad was the Earthquake in 2001. This led to a large scale destruction in the built environment. AKPBSI has been active for decades in providing its services in areas like these and bringing about a change in the quality of life through interventions in the built environment.

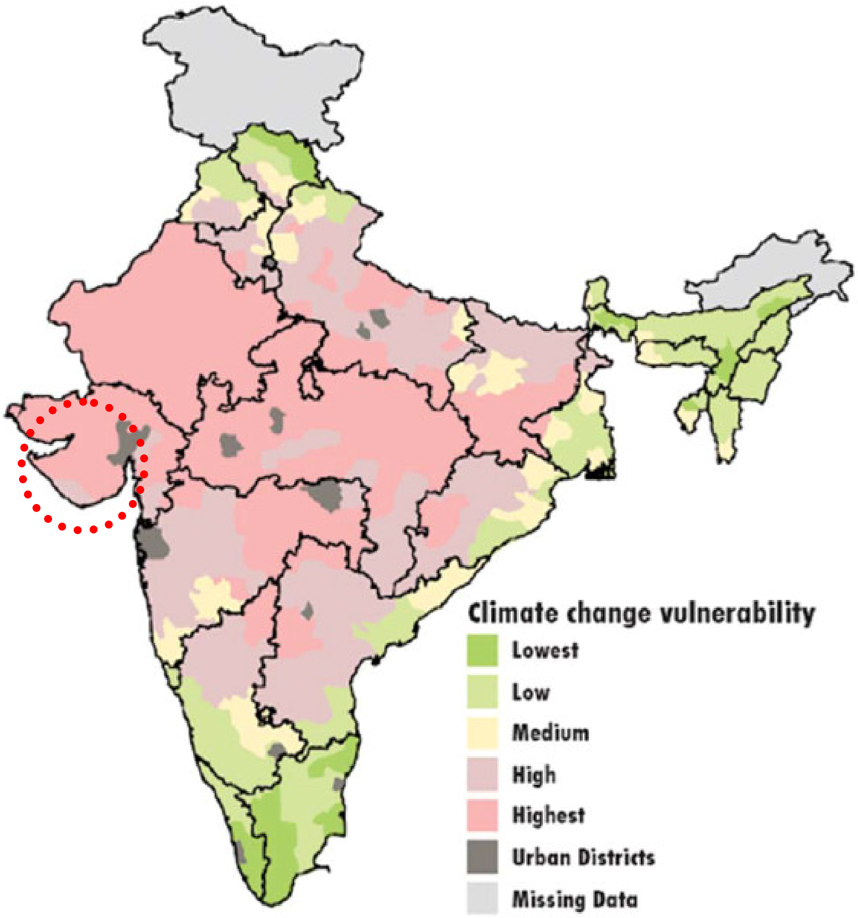


Figure 5 District level vulnerability to climate change (TERI, 2003)

Discomfort is still manageable as it occurs only for few hours daily and occurs rarely but safety of the structures on occasional events like floods, earthquakes, tornadoes, hurricanes and dust storms must be assured through design (Koenigsberger, 1975). Thus the disaster resilient vernacular houses of AKPBSI are appropriate cases for study and evaluation of thermal performance and to prepare solution set for bioclimatic design.

The Aga Khan Planning and Building Services India (AKPBSI) is a part of the Aga Khan Development Network (AKDN), a group of private, international, non-denominational agencies that works to improve the built environment, particularly housing design and construction, village planning, natural hazard mitigation, environmental sanitation, water supplies and other living conditions. AKPBSI achieves these goals through the provision of material and technical assistance and construction management services for rural and urban areas.

Rural Habitat Development Programme (RHDP) is an initiative under the Habitat Improvement Programme (HIP), where the focus is on rural families of the community having a weak socio-economic profile with poor habitat conditions. The goal of RHDP is to address important issues:

1. **To reach out to the families and ensure safe, secure and healthy habitat.**
2. To provide appropriate facilities and incentives for livelihoods combined with improved rural housing which can help retain these human resources in the rural economy.

Disaster Resilient Habitat design considerations by AKPBSI

1. **Earth quake Resistant** design and construction techniques.
2. Design of habitats to avoid and minimize damage due to **floods and cyclone**.
3. Access to **safe water** and provision of **sanitation** to meet health requirements.
4. Affordable and culturally acceptable, executed with an owner driven process.
5. Use of local materials, labor and including rain water harvesting as water management strategy at the planning stage.

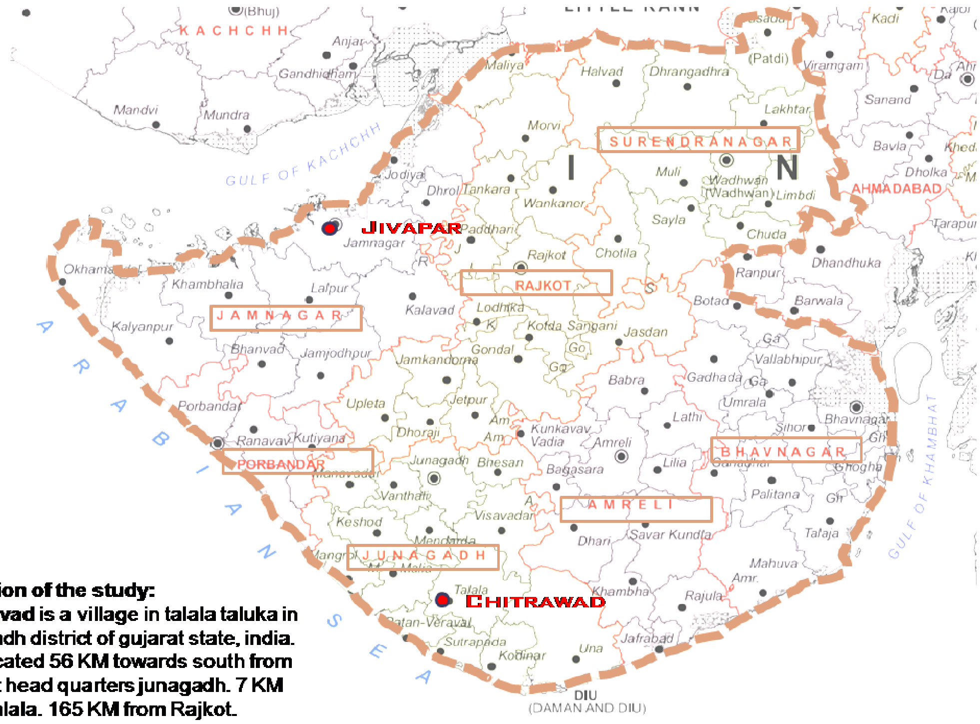
The AKPBSI carried the following activities under RHDP:

- Masons training to promote safe construction practices.
- Planning, designing and construction of rural group housing catering to the need of the families migrating to Jivapar from nearby villages.
- Rural reconstruction of seismic-resistant houses by trained masons and technical supervision of AKPBSI.
- Structural repairs and retrofitting of houses were carried out in Jivapar and surrounding villages through trained masons, appointed by beneficiaries and monitored by AKPBSI. This decreased the vulnerability of these houses and rendered them as multi-hazard resistant.
- Rural communities, especially lower Income Group families were made aware of the importance of improved habitat conditions.
- Low-income rural families living in highly vulnerable habitat conditions who were unable to afford the cost of construction or repair/retrofitting of their houses with were provided financial assistance and support in accessing habitat finance. (AKPBSI, 2016)

The objectives of successful housing is to be socially and culturally valid, economically affordable to majority, healthy for occupants with minimum maintenance (Rapoport, 1969). All of this is fulfilled by the AKPBSI activities of RHDP, thus a study of thermal performance and incorporating bioclimatic design principles under this program will add to the objectives of the organization which is habitat improvement, safe water and sanitation provision.

1.3. Case Study selection

Location of the villages



Location of the study:
Chitravad is a village in talala taluka in junagadh district of gujarat state, india. It is located 56 KM towards south from district head quarters junagadh. 7 KM from talala. 165 KM from Rajkot.

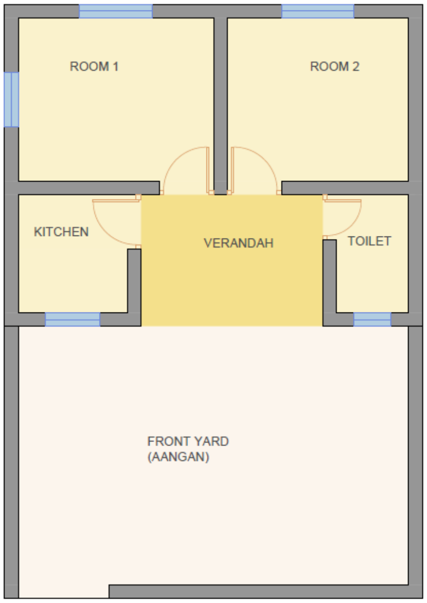
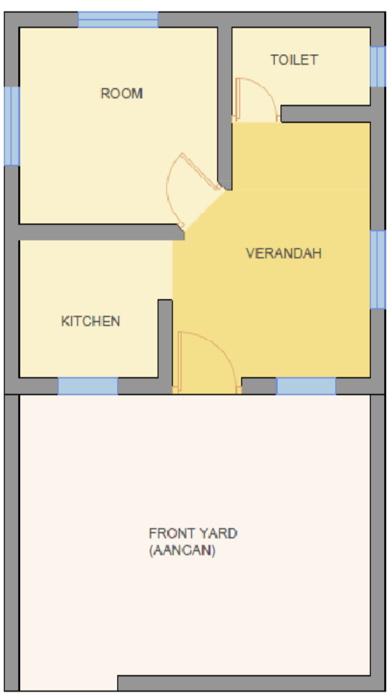
Jivapar is a village in Jamnagar Taluka in Jamnagar District of Gujarat State, India. It is located 16 KM on the west from District headquarters Jamnagar.

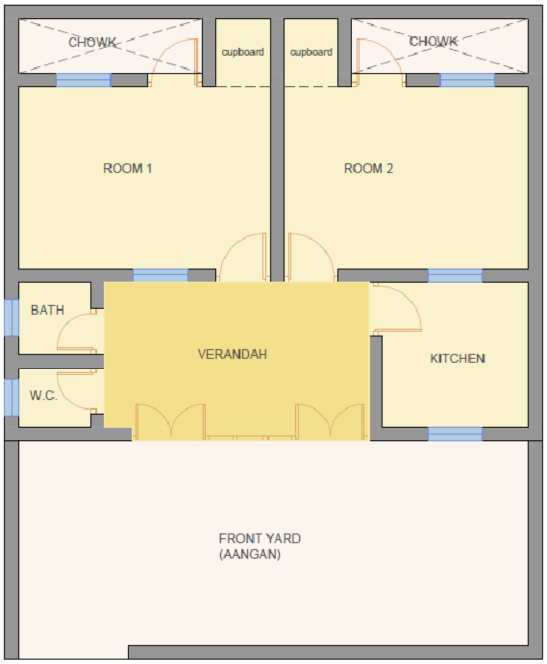
	Jamnagar	Junagadh
Latitude	22.45° N	21.52° N
Longitude	70.08° E	70.46° E

Figure 6 Location of villages with AKPBSI housing

Table 1 The new variants of houses constructed by AKPBSI (Source: Author from information given by AKPBSI)

Type	1	2	3	4	5	6
Units with similar Roof type	11	4	3	1	1	120
Location	Chitrawad	Jivapar	Jivapar	Jivapar	Jivapar	Chitrawad
House type	Detached	Detached	Row house	Detached	Detached	Detached
Wall type	9" Limestone	9" BRICK	9" BRICK	9" BRICK	9" BRICK	9" Limestone
Roof form & material	Sloping mangalore tiled roof	Sloping sheet roof	Sloping zinc coated GI roof	Vaulted Roof with roman tiles	RCC Flat roof with thermocol insulation	RCC Flat roof

Type 1. Form & fabric: Single storey detached house with sloping Mangalore tile roof and limestone wall. Spatial Planning: Verandah+ 2 rooms + toilet and Kitchen	Location: Chitrawad BUA: 400 sq.ft. Number of similar units: 11
	 
Type 2. Form & fabric: Single storey detached with sloping sheet roof and brick wall. Spatial Planning: Verandah+ 1 room + toilet and Kitchen	Location: Jivapar BUA: 370 sq.ft. Number of similar units: 4
	 

<table>
<tr><td>Type 3. Form & fabric: Single storey row house with sloping zinc coated GI sheet roof and brick wall.
Spatial Planning: Verandah+ 2 rooms +Bath+ WC, Kitchen</td><td>Location: Jivapar
BUA: 593 sq.ft.
Number of similar units: 3</td></tr>
<tr><td>
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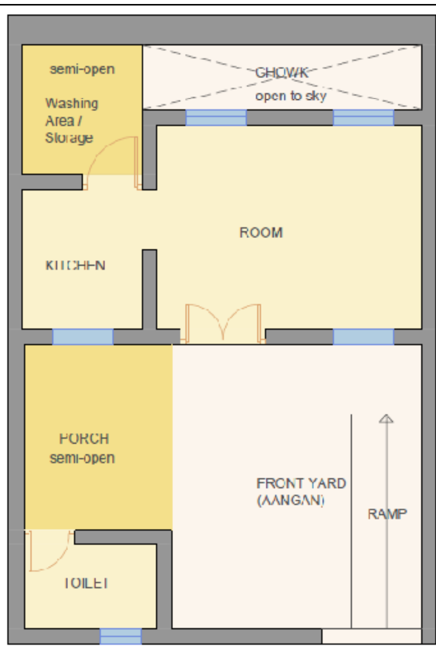
<tr><td>Type 4. Form & fabric: Single storey detached house with vaulted Mangalore tile roof and brick wall.
Spatial Planning: 1 rooms + toilet and Kitchen</td><td>Location: Jivapar
BUA: 302 sq.ft.
Number of similar units: 1</td></tr>
<tr><td>
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<tr>
<td>Type 5. Form & fabric: Single storey detached with 4.5" RCC roof with thermocol insulation and brick wall
Spatial Planning: Verandah+ 2 rooms +Bath, WC, Kitchen</td>
<td>Location: Jivapar
BUA: 433 sq.ft.
Number of similar units: 1</td>
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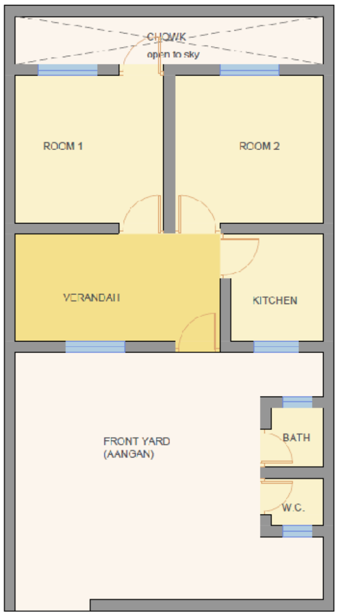

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<tr>
<td>Type 6. Form & fabric: Single storey detached with RCC roof and limestone wall
Spatial Planning: Verandah+ 2 rooms + WC, 2 bathrooms + Kitchen</td>
<td>Location: Chitrawad
BUA: 750 sq.ft.
Number of similar units:120 by 2019</td>
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The most common and preferable variant of house form and fabric is the detached single storey Flat RCC roof with stone walls located at Chitrawad which is selected as base case.</td>
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1.4. Aim, objectives and hypotheses

Aim

To formulate Bio-climatic design guidelines for the rural housing for Saurashtra region.

Objectives

1. To identify the bio-climatic design principles for the selected region.
2. To evaluate site conditions and occupant lifestyle for the formulation of optimized design guidelines for the disaster resilient rural housing built by the AKPBSI for Saurashtra region.
3. To evaluate the thermal performance of the envelope of selected case study with respect to an established thermal comfort standard.
4. To conduct a thermal performance comparison of design cases with existing case study.

Hypotheses

- The thermal performance of disaster resilient dwellings in Saurashtra region can be improved through bio-climatic design principles.
- Occupant behavior & lifestyle reduces demand for energy and therefore a passive low energy and low cost design solution for rural dwelling can be achieved.

1.5. Scope and limitations

1. The geographic study area is confined to Saurashtra region's villages having earthquake, flood and cyclone resistant low-cost rural housing built by the AKPBSI.
2. The site measurement for validation of simulation model is limited to one Summer week.
3. The weather file of Jamnagar shall be used for both the areas of study – Jivapar (Jamnagar district) and Chitrawad (Junagadh District) since weather file is not available for Junagadh.

CHAPTER 2

REVIEW OF LITERATURE

2. Review of Literature

Chapter 2 defines and describes important concepts and models relevant to the research like thermal comfort. Literature review of research papers on thermal performance evaluation and thermal comfort analysis of vernacular houses in India using different tools and techniques.

2.1. Adaptive thermal comfort

Occupants of a building perceive design at a physical level and at an emotional level. Total comfort is related to all human senses and encompasses the physical, emotional, mental relationship of each individual with his surrounding, but it's the human thermal comfort which is the important concern for a designer in a tropical climate and his task to achieve the best indoor climate (Koenigsberger, 1975). ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) defines thermal comfort as “the condition of mind that expresses satisfaction with the thermal environment”. This definition is the most internationally recognized definition of thermal comfort. The purpose of ASHRAE Standard 55—thermal environmental conditions for human occupancy, is ‘‘to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space’’ (ASHRAE, 1992).

Thermal comfort or discomfort is influenced by environmental factors like air temperature, humidity, radiation and air movement and also by individual factors like clothing, acclimatization, age, gender, body shape, skin color, subcutaneous fat, state of health, food and drink as they affect metabolic rate (Koenigsberger, 1975). The environmental factors vary from region to region and hence have a wide range of possible combinations that affect the human body simultaneously although their independent of each other. A thermal comfort index or standard is a combination of environmental factors into a single parameter that helps designers to estimate the thermal stress due to wide range of climatic conditions (SP:41, 1988). Internal thermal comfort conditions decides how much energy would be consumed while operating a building and this plays an important role in sustainable design of buildings (Jayasudha et al. October 2014).

Thermal comfort is subject to the context in which it is being evaluated. Occupants living and working in unconditioned or free-running buildings where there is user-control on windows, clothing, have a better thermal adaptation and acceptance of wider range of temperatures and humidity. ASHRAE Standard 55 is based on the assumption that thermal sensation is exclusively influenced by four environmental factors (temperature, thermal radiation, humidity and air speed), and two personal factors (activity and clothing) while ignoring the psychological dimension of adaptation that influences the expectation of an individual about the indoor climate in a particular context. Thus an Adaptive Comfort Standard (ACS) was developed as an alternative to the heat-balance thermal comfort model of ASHRAE standard 55 for naturally ventilated buildings (Dear & Brager, 2002).

The features of the ACS are as follows

1. This comfort standard is only applicable if the mean monthly outdoor temperature ranges between 10°C to 33°C. The comfort zone widths across the naturally ventilated buildings is of 5°C for 90% acceptability and 7°C for 80% acceptability both centered around the optimum comfort temperature.
2. The scope of applicability of this standard is limited to the following
   - Naturally conditioned spaces which may have mechanical ventilation with unconditioned air but where the occupants primarily open and close windows to regulate the thermal conditions of the space.
   - Spaces without mechanical cooling systems like refrigerated air conditioning, radiant cooling or desiccant cooling.
   - Occupants must be involved in a sedentary activity (1-1.13 met) an d must be allowed to freely adapt their clothing to the thermal conditions - indoor and/or outdoor.
3. The environmental inputs to conventional heat-balance thermal comfort models (e.g. PMV) are all taken from the indoor environment factors immediately surrounding the building occupants. But adaptive comfort models uses an outdoor thermal environmental variable as their input. One of the advantages of the ACS over the PMV-based model is its simplicity. One needs to estimate what mean clo and met levels might be before using the PMV model, but the relationship between clothing and climate is already accounted for in the ACS.
4. The ACS is to be used as a design standard or tool to determine whether the predicted or recorded indoor thermal conditions are acceptable or not such as design modifications can be incorporated (Dear & Brager, 2002).

Thus ADAPTIVE thermal comfort depends in part on outdoor conditions and occupants will have a wider comfort range than in buildings with centralized HVAC systems. Optimum comfort temperature, T_{comf} , is given in terms of T_{out} , the mean outdoor dry bulb temperature as

$T_{comf} = 0.31T_{out} + 17.8$ (ASHRAE, 1992)

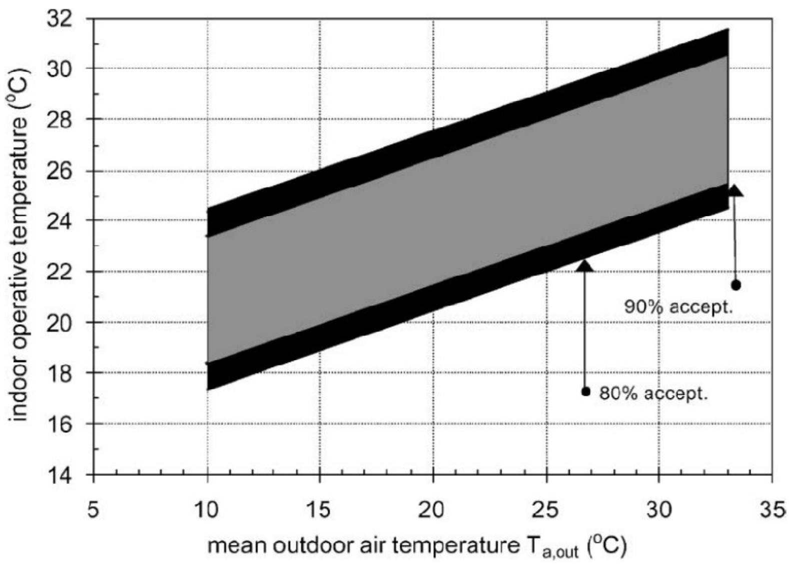


Figure 7 Adaptive comfort standard (ACS) for ASHRAE Standard 55, applicable for naturally ventilated buildings (Dear & Brager, 2002)

Since the houses under consideration are naturally ventilated spaces with no mechanical cooling systems this thermal comfort standard is to be used as a tool to formulate guidelines of bioclimatic housing for Saurashtra region.

2.2. Thermal performance study of vernacular houses in India

Thermal performance of a building refers mainly how well a building is insulated from the external weather conditions in order to achieve a comfortable indoor temperature. This can be achieved by keeping the internal temperature higher or lower than the external temperature as per the requirement of comfort temperature. A number of studies have been conducted in different parts of India on the diverse vernacular architecture documenting the sustainable design principles like orientation, building components that use local materials, climate responsive design & detailing, spatial planning through qualitative and quantitative analysis.

Rangwala (2014) documented the traditional homes of Siddhpur that is located in the Kutch region of gujarat, and concluded that these are thermally more comfortable than the modern homes and certain passive design strategies of these vernacular houses like envelope design, architectural features, spatial organization, house form can be applied while designing more thermally comfortable modern homes in the area. The parameter used to evaluate comfort was temperature and adaptive thermal comfort of ASHRAE standard 55 using tools like observation, occupant survey, thermo-hygrometer, infrared non-contact thermometer, building simulation software Integrated environmental solutions (IES). The study includes the potential strategies for contemporary buildings to achieve thermal comfort and thereby reduce energy consumption by evaluating the following

- local climate and comfort conditions
- thermal perception of users
- role of built mass
- heat gain behavior of envelope
- architectural features

Jayasudha P. et al. (2014) conducted a case study in a traditional settlement of Thanjavur region, on a 3rd century vernacular house with single courtyard, in Tamilnadu through documentation and simulation. The climate of the region is warm and humid with summer temperatures of 27-42°C, winter temperatures of 19-30.5°C and relative humidity of 45-65% through the year which requires reduction in solar heat gain and comfort ventilation through proper orientation, openings, house form, shading, spatial organization, thermal mass etc. The settlement shows roads with east-west orientation to allow free passage of breeze from the predominant wind direction and the openings of the houses are North-south oriented in order to reduce solar heat gain.
The key features of the house are as follows

- Appropriate orientation along with narrow mutually shaded alley between houses reduces heat gain and space between houses for breeze promotes heat loss.
- The courtyard of the house enables it to become a micro-cosmos with its own version of sun, wind and rain.
- Simple grid, free flowing spaces, flexible areas with no unnecessary partitions, alignment of doors with courtyard for air circulation and stack effect reflects the traditional knowledge integrating cultural, social, economic and environmental understanding of the users.
- The composite construction of the 65 cm outer wall with laterite stone and mud bricks with mud mortar, internal mud wall with agricultural waste like sugarcane molasses, paper and nutmeg.
- 30-35° pitched roof of wooden rafter and battens and small shaded openings
- Components made from local materials with low embodied energy and thus reflect the sustainability.

The key findings of the study are

- A thermal performance study through ECOTECT analysis for the hottest day and coldest day revealed that there is around 10°C of diurnal temperature variation in outdoor ambient air on both days.

- The difference in indoor and outdoor ambient temperature is 0.2°C minimum and maximum 5.9°C on hottest day and 0.1°C minimum and maximum 4.7°C on coldest day indicating performance of thermally insulating building components.
- The stack effect due to the courtyard enhances the air circulation inside the dwelling when the wind speed gets reduces and with the minimum help of mechanical ventilation (fans) the comfort conditions are achieved even when summer temperatures and peak winter temperatures (11am to 2pm) are above the comfort zone prescribed by ASHRAE.

The overall house form with courtyard, buffer spaces (passage around the courtyard), building materials, spatial design with flexible and multi-use spaces, projecting eaves for shading are evolved in response to climate, culture, lifestyle and available materials & technology of the region emphasizing that quality of spaces with efficient use is more sustainable than the quantitative aspects like size and variety of spaces. The thermal conditions of the individual spaces of the dwelling lie within comfort zone due to its planning, architectural details, materials and techniques which can be modified to suit modern context for the design of resource efficient buildings.

The study of a vernacular settlement of Meenakshipuram village of Madurai using building performance analysis and climate analysis was done to explore traditional construction techniques employed in building the rammed earth houses along with keeping in view humidity, light, air movement and activity pattern of occupants. Madurai district has a warm and humid climate with summer temperatures reaching maximum 40°C and minimum 26.3°C and winter temperatures between 29.6°C and 18°C. The 90 year old hut under study was built from local materials like timber, bamboo, clay, straw, cow-dung and grass with walls around 450 mm, thatched roof with wooden posts and purlins, bamboo mullions have high thermal mass and insulating properties. The parameters like orientation, plan-form, building exposure to the sun, surface volume ratio, openings, shading, building envelope materials and ventilation are studied using ECOTECT analysis and on site measurements. The key findings are as follows

- The indoor temperature during summer remains constant between 31.7 to 32.9°C which is much below the maximum of 40°C outdoor temperature and the indoor temperature average for April is 32.3 whereas the ASHRAE standard 55, adaptive comfort specifies a maximum of 32.2 for April.
- The annual comfort hours is more compared to a similar house with brick wall and concrete roof thus verifying the efficiency of traditional mud houses in providing thermal comfort with the use of affordable local materials and techniques (Madhumati et al. 2014).

The most important factors from architectural design point of view that affect thermal performance include site, location, orientation, form and massing, spatial organization, Open-Built distribution, material and construction techniques. These factors were studied using the medium of vernacular houses in Lucknow with on-site simultaneous measurements using data logger for similar periods throughout the year and simulation models on ECOTECT. Lucknow has a composite climate with hot and dry summers, warm and humid monsoon season and cold and dry winters. The thermal performances of different houses were assessed with comparison of their cooling and heating loads, monthly discomfort hours and temperature distribution.

The significant findings of the study includes

- Introverted courtyard planning with minimum external fenestration prevents heat gain and similarly the verandahs act as buffer spaces and reduce heat gain in case of large openings on external side along with high ceiling with ventilators.
- High thermal mass along with night purge, high thermal lag in all cases had contributed to constant temperatures all day throughout the year.
- Thermal mass improved the performance of the envelope to 70% while orientation with respect to the sun improved the performance only between 5-10% but mutual shading improved the same up to 30%.
- Roof shading improved performance of lower floor up to 45% while effective shading of walls and openings had reduced cooling and heating loads up to 30% (Gulati & Pandya, 2014).

The thermal performance study of a mud house in Jharkhand using Autodesk ECOTECT Analysis tool and validation of simulation model with onsite measurements for the hottest day, coldest day and windiest day, was done with parameters like roof and wall insulation, direct and indirect heat gain, ventilation and orientation. The findings of the study are

- Inter-zonal heat gain and loss can be reduced in the hut with roof insulation and further to provide better thermal comfort wall insulation can be used.
- The ideal orientation would be north-west south-east with lower surface area to volume ratio to reduce heat gain
- For better thermal performance provision for night ventilation, use of thick mud walls, thatch roof with Mangalore tiles or vaulted roof with mud blocks for roofing are essential (Gupta & Chakraborty, June 2013).

The solar passive techniques of a multiple courtyard vernacular residence of Thanjavur region of Tamilnadu was studied through thermal performance analysis using ECOTECT simulation software for the months of May and January as critical summer and winter months respectively. The results of the simulation reveals that indoor temperature ranges steadily between 32°C to

35°C for the month of May while outdoor temperatures range between 26.7°C to 41.3°C, thus the fluctuation of indoor temperature is only 3.2°C on an average for all rooms while fluctuation in the external environment is 14.6°C. For the month of January the indoor temperature ranges between 24.5°C to 30.4°C while outdoor temperatures range between 20.6°C to 32.7°C, thus the fluctuation of indoor temperature is only 3.24°C on an average for all rooms while fluctuation in the external environment is 12.1°C. The findings of lower indoor temperatures vs. outdoor temperatures reveals the effectiveness of solar passive techniques which are as follows

- Openings aligned along the axis for cross ventilation
- North-South orientation of houses and eat wets orientation streets
- Compact moderate density Row house pattern of settlement facilitating mutual shading
- 60cm thick and high density composite walls made of flat mud bricks, laterite stone, mud & lime mortar for thermal insulation
- Minimum and smaller size of openings to reduce heat gain
- 30-35° angle of sloping roof made up of 3 layers of country tiles and supported by wooden or bamboo rafters and battens reflect the heat back
- A 5m ridge height acts as insulation and facilitates air flow
- Courtyards allow stack ventilation and filtered daylight
- 0.7 m eaves projection of internal side of courtyards and external sides for shading to reduce heat gain
- Colonnaded passage around courtyard and entrance are acts as a buffer space and dissipates the heat gain due to incident solar radiation back to the environment (Dhanasekaran & Jayasudha, 2014)

In an another study the optimum wall configuration for the warm and humid North-east Indian vernacular houses that will provide enough time lag and reduce discomfort hours was obtained through simulation of thermal performance using TRNSYS 16. The building envelope with its walls, roof, openings and shading devices play an important role in heat transfer between the indoor and outdoor environment along with WWR, orientation and type of window are all critical design elements to achieve energy efficient buildings with high thermal performance. A base case model of the vernacular house with flat roof, single glazing and standard brick wall is compared with 44 simulation cases with the following alterations to the base case

1. increased thickness of wall
2. three different insulation materials of wall - extruded polystyrene, cell glass (high density), polyurethane.
3. insulation at different locations in the wall
4. roof insulation
5. double glazing and overhang

6. increased WWR
7. different orientation of the house

The inputs parameters includes thermo-physical properties of materials like the density, thermal capacity and conductivity, infiltration rate of 3 air changes per hour (ach) and the main output of the simulation is zone temperature. Time lag and decrement factors are calculated and compared as an indicator of heat storage capability of the materials for different cases. Simulation data for whole year 8760 hours with January and July as representative winter and summer month respectively is obtained and following findings were concluded

- Lower thermal transmittance (U value) provides maximum resistance to heat flow improving thermal comfort of occupants by reducing temperature variations;
- Lower U value reduced the maximum indoor temperature thus wall with lowest U value must be selected
- 0° and 45° orientation decreased maximum indoor temperatures compared to 90° and 135°
- The insulation on the outside and middle position gives similar results of lower maximum temperature but much better performance than the insulation placed on the inner surface.
- Higher WWR results on more heat gain and loss and increase in discomfort conditions. Thus WWR between 20-40% with shading devices for single and double glazed windows is required.
- Double glazed windows have a lower solar heat gain coefficient by 10% and lower U value of 2.7 w/m2 K compared to 4.8 w/m2 K of single glazed window.
- The 24 hour temperature throughout the year swing is lesser with polyurethane compared to extruded polystyrene and cell glass.
- Appropriate depth of overhang results in decrease in maximum summer temperature by blocking the sun and increase in minimum winter temperature by allowing the sun to enter the house (Dhar et al. December 2014)

2.3. Building performance simulation (BPS)- Tools and techniques

The uses of BPS tools:

1. Simulation is used as a design instrument in considering various design strategies such as the building form, orientation, materials, shading strategies, day lighting, ventilation, heating and cooling systems during the design process.
2. It can also be used to test the impact of design alternatives or solution sets either on the internal comfort or on energy use and total costs to rank the solution sets according to their level of impact.
3. It can be used to ‘fine-tune’ the design, for example, the optimized size of the horizontal overhangs and roof insulation can be obtained, by conducting ‘parametric runs’ – that is,

by varying the width of the overhangs or the thickness of the insulation systematically for each run until the best results are achieved.

4. Assessment of the overall performance of the building to meet certain requirements or codes in order to obtain building approval, diagnosis of the issues related to thermal comfort and energy use in an existing building, prediction of the energy use from elements of the building such as heating, cooling, ventilation, lighting, equipment and domestic hot water are other capabilities of simulation tool.
5. The amount of heat gains and losses through walls, roof, floor, windows, lights, equipment, ventilation, infiltration and people is also obtained through simulation (Hyde, 2008).

Since each design stage has its own purpose and constraints, opting for different simulation programs is a choice but it is more practical if the selected program is suitable for all stages of the design process. Also accuracy of the program being an important issue, testing the accuracy by simulating the building and monitoring data for the building as a reference point for the simulation results is an essential step. The measured data can be hourly indoor temperature and humidity or monthly energy use or even energy use breakdowns such as electricity use for lighting and equipment. The simulation program can then be trusted if the simulation results match the measured data closely (Hyde, 2008).

A study identified the two main factors for selecting a BPS tool in design practice as Usability and Information Management of interface and the Integration of Intelligent design Knowledge-Base. In order to identify the basic criteria for BPS tools that can support architects and designers making sustainable design more efficient, and cost effective. A comparative study was done between ten BPS tools namely ECOTECT, HEED, Energy 10, Design Builder, eQUEST, DOE-2, Green Building Studio, IES VE, Energy Plus and Energy Plus-Sketch Up Plugin (OpenStudio) through survey and literature review. The findings ranked IES VE (85%), HEED (82%) and eQuest (77%) in the first category as respondents strongly agreed these tools to be '*Architect Friendly*' but were constrained when it came to unconventional building components or systems. In the second category, came ECOTECT (61%), DB (58%), GBS (58%) and E10 (57%) that are popular and are known for having friendly GUI and varied graphical output features. Over 64% (159 individuals) of the respondents reported they use ECOTECT making it the most commonly used tool (Shady, Liliana, & De Herde, July 27-30, 2009).

2.4. Passive design strategies

Passive design is a way to positively make use of environmental parameters and resources such as daylight, wind, sun in order to provide indoor comfort to buildings while maximizing energy efficiency of buildings and minimizing its dependency on mechanical climate control systems. Naturally ventilated buildings not only are energy efficient but also healthier and more pleasant for the users and as such passive design techniques can reduce or avoid the reliance on air conditioning to achieve comfort. (Chenvidyakarn, 2008). The objective of bioclimatic design is to provide high quality passive design through new technologies in the building envelope and in its form and fabric (Hyde, 2008).

A study on the thermal comfort performance of a low cost residential building in Delhi as a composite climate representation and Mumbai as a warm and humid climate representation was done by incorporating passive design strategies such as appropriate building orientation and shading devices coupled with low energy strategies that increased the number of comfortable hours by about 60% in both Delhi and Mumbai climates, thus decreasing the requirement of cooling/heating (IIEC, EDS, & IMC, December 2011). Key findings are as follows:

1. Passive design strategies such as application of thermal insulation to the building envelope, day lighting, optimized orientation and appropriately sized shading devices for the windows substantially reduce the operational energy and increase the comfort levels.
2. One of the most effective strategies to reduce solar gains is a north-south orientation where in most of the fenestration faces north or south.
3. For both the climate zones shading reduces solar gains and gives better thermal performance. While a 45 cm deep horizontal shade reduce the operational energy by over 10%, any more depth to the shades and vertical shading gives marginal benefits as compared to 45 cm horizontal shade.
4. Natural ventilation is very effective for maintaining indoor comfort conditions when outside temperature is less than the inside temperature especially for Mumbai because of mild ambient conditions coupled with high humidity. Openings should be designed and orientated to take advantage of the prevailing sea breeze. For New Delhi, night time ventilation is efficient for pre-cooling the thermal mass as there is a considerable diurnal range for dry-bulb temperature.
5. Along with natural ventilation, additional mechanical ventilation through fans can be provided when outside temperature is less than the inside temperature for additional pre-cooling and providing comfortable indoor environment.
6. Higher thermal mass is effective for both New Delhi and Mumbai as it prevents indoor environment from reaching extreme conditions but is more important for Delhi.

The prime concern for warm and humid climate is to maximize air movement. Deep window shades are not a concern as radiation is largely diffused compared to hot and dry climate zone. Indoor temperature that varies with outdoor temperature can help save energy on cooling by reducing cooling load. Sensible air movement of 1.5 m/s can make 35°C acceptable and natural ventilation is effective between 25-35°C. (Krishnan, 2001)

CHAPTER 3

METHODOLOGY

3. Methodology

Chapter 3 details out the structure of the study and steps for conducting the research. It describes tools and techniques used for data collection, simulation and analysis during site study and simulation study.

3.1. Structure of the study

The method to formulate Bio-climatic design guidelines for the rural housing for Saurashtra region is based on the components of bioclimatic housing that is finding out climate types and requirements, using adaptive thermal comfort standard, understanding vernacular and contextual solutions, using tools and assessment methods to study microclimate and work with the elements, such as passive and active systems to develop a responsive form. Housing is primarily a social challenge but often its relationship with climate and living organisms is lost, particularly in developing countries. Achieving sustainability means the form and fabric of the building should be matched to human and climate factors in order to optimize climate response. The focus should be on providing a home that increases the quality of life of its occupants through comfort, health and well-being (Hyde, 2008). Thus, the understanding of occupant lifestyle, choices and behavior must be integrated to the process of developing the guideline.

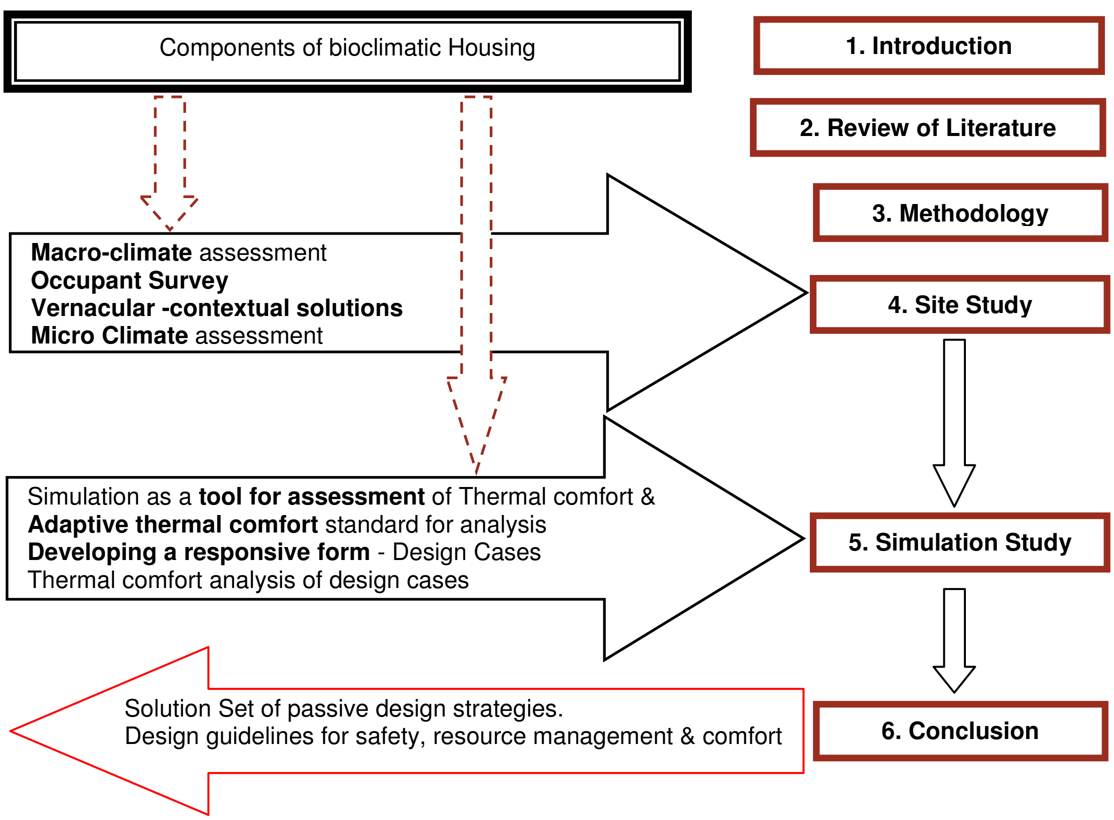


Figure 8 Methodology of the study (Source: Author)

3.2. Tools for data collection

Table 2 Parameters of study and Tools & assessment methods (Source: Author)

	Parameters of study	Tools & assessment methods
1	Macro climate	Mahoney table
		Psychrometric Chart
2	Vernacular and contextual solutions	Observation and literature review
3	Occupant lifestyle and behavior	Interview Schedule
4	Micro climate	Luxmeter - daylight
		Weather tool, sun path diagram, solar access analysis using ECOTECT
5	Thermal comfort analysis	Thermal analysis on ECOTECT
		Validation with site measurements using data loggers
6	Adaptive thermal comfort model	IMAC - India model of adaptive comfort based on ASHRAE standard 55 ACS
7	Design case analysis	Thermal analysis on ECOTECT
8	Passive design strategies	Solution set

3.2.1. Mahoney table

Source: It is a system involving series of tables developed by C Mahoney to take into account climatic factors and give performance specifications or sketch design recommendations based on them (see appendix 1).

Usability:

1. Table 1 is used to fill in the most essential climatic data namely

- Temperature- monthly mean maximum, minimum and mean range.
- Relative humidity - monthly mean maximum, minimum and average
- Rainfall and wind data - monthly rainfall in mm, prevailing and secondary wind directions.

2. Table 2 gives the diagnosis of the climate and a series of indicators that are to be used in Table 3 The annual mean temperature and humidity group obtained from Table 1 data will help in arriving at upper and lower day and night comfort temperatures. Comparison of the mean maximum (day) temperature and mean minimum (night) temperature with the range establishes the nature of thermal stress namely Hot, Comfortable or Cold. This monthly thermal stress gives remedial actions based on 6 indicators 3 humid indicators - H1, H2, H3 and 3 arid indicators - A1, A2, A3.

3. Table 3 translates these indicators into sketch design recommendations grouped under eight headings: Layout, Spacing, Air movement, Openings, Wall, Roofs, Outdoor sleeping and rain protection (Koenigsberger, 1975).

3.2.2. Psychrometric Chart

Source: Psychrometric Chart is a design tool in Climate Consultant 5.5 developed by Robin Liggett and Murray Mine of the UCLA Energy Design Tools Group with the technical support of Carlos Gomez and Don Leeper.

Usability: Psychrometric Chart shows dry bulb temperature across the bottom and moisture content of the air up the side. This vertical scale is also called absolute humidity and can be shown as the humidity ratio in pounds of water per pound of dry air (or grams of water per kilogram of dry air), or as the vapor pressure. The curved line on the far left is the saturation line (100% Relative Humidity line) which represents the fact that at lower temperatures air can hold less moisture than at higher temperatures. Every hour in the EPW climate data file is shown as a dot on this chart. The color of each dot can represent whether or not the hour is Comfortable (green) or Uncomfortable (red), according to the inputs defining Comfort on the Criteria screen. Four other Plot options are available on the left hand Legend panel, each plotting hourly data in a range of colors. These other Plot options are Dry Bulb Temperature, Global Horizontal Radiation, Sky Cover, and Wind Speed. The units for each variable are indicated in the upper left. The values for each variable are divided into five different ranges which are plotted in colors from blue to red, or if the plot represents Comfort there are just two colors: dark green is comfortable, red is not comfortable. The percentages of hours that fall in each category are also shown.

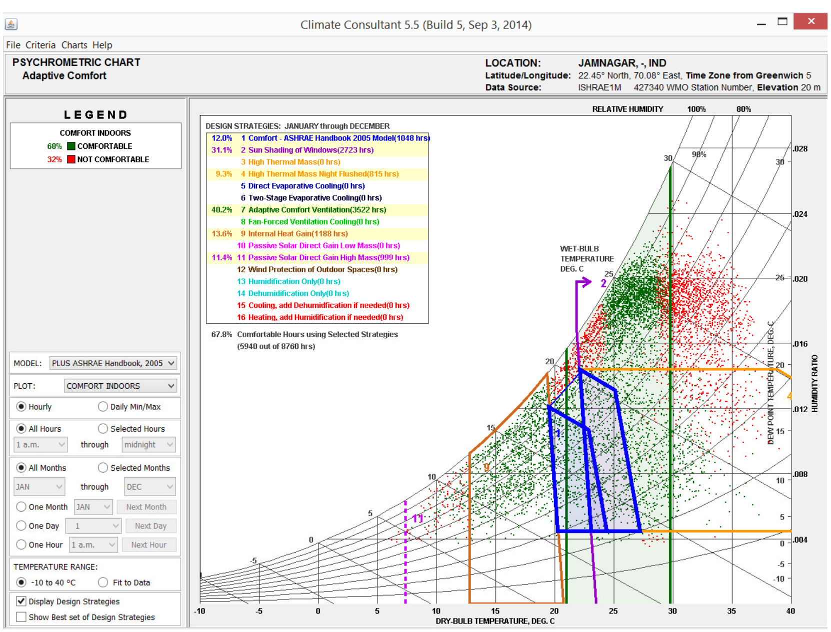


Figure 9 Screenshot of Psychrometric Chart from Climate Consultant 5.5

3.2.3. Interview Schedule

Source: Interview Schedule developed by the author has 6 categories of questions (Appendix 2)

1. House usability
2. Construction
3. Daylight
4. Thermal comfort
5. Discomfort and adaptability
6. Satisfaction

Usability: The universe consists of only 33 houses in the 2 Villages namely Jivapar and Chitrawad in Saurashtra having new vernacular houses built by the AKPBSI built for disaster resilience. AKPBSI targets to build 120 houses by 2019 and as such evaluation of occupants lifestyle and preferences is essential for recommending an optimized solution set.

The purpose of the questionnaire is following:

1. To understand usability of spaces with respect to time and seasons.
2. To find out average occupancy.
3. To find out user preferences of form and fabric with reasons.
4. To find out range of mechanical cooling or heating systems used during periods of discomfort.
5. To find the users' satisfaction with overall daylight and comfort in the house.
6. To understand the seasonal discomfort, adaptability and acclimatization of the users.

3.2.4. Instruments

Selection of equipment: Indoor data monitored at site can be used to 'calibrate' the simulation model to validate that the model closely represents the actual building. The indoor environment (temperature, humidity and light level) can be monitored according to various time intervals from every five minutes to every hour but the most common practice is to monitor either at 30-minute intervals or hourly since the weather data recorded by city level weather stations at airports is also compiled hourly. Indoor monitoring done with simple portable data loggers are usually small and non-intrusive, making it possible to obtain the occupants' permission to monitor the indoor performance.

Usability: The best location for data loggers to monitor indoor air temperature and humidity (as well as light level) is in the middle of the room at the height of an average person or slightly above it but this can be intrusive for the occupants (and it may invite the curiosity of the occupants to touch it, which will affect the accuracy of the data recorded). The next option is to attach it to an adjacent wall as long as the equipment will not receive direct solar radiation
or heat from any other heat source, such as the heat from a cooking appliance, computer, etc. It is important that any device to monitor temperature should be shielded from direct solar radiation.

Accuracy: With the increase in accuracy the cost of data loggers significantly increases. The choice of equipment depends on the expected energy-cost savings and if the purpose is only to assess indoor thermal comfort, affordable portable data loggers are sufficient (Hyde, 2008).

Luxmeter

Technical Specification from manufacturer: 0-2,00,000 lux with accuracy ± 5%

For calibration certificate prepared using national standards by government recognized laboratory see appendix 3.

Figure 10 HTC Lux Meter: LX101A/LX102A (left) and Easy Log -RH- Temp data logger (right) (Source: Author)

Portable temperature and humidity data logger

Technical Specification from manufacturer

Range for temperature -40°C to 70°C

Accuracy: -40°C to 40°C is ± 1°C, 40°C to 70°C is ± 2°C, Resolution: ± 0.1°C

Range for humidity: 0-100% RH

Accuracy: 0-35% and 80-100% is ± 5%RH , 35-80% is ± 3%RH, Resolution: ± 0.1% RH

For calibration certificate prepared using national standards by government recognized laboratory see appendix 3.

3.2.5. IMAC - India Model for Adaptive (thermal) Comfort 2014

Adaptive Comfort Model in ASHRAE Standard 55-2010 applies to naturally ventilated spaces where people can open and close windows. IMAC 2014 was developed using surveys done in five cities during monsoon, summer and winter in naturally ventilated, air conditioned and mixed mode buildings initiated in January 2012. This India specific model allows for broader comfort band suited to the Indian context providing design and operation guidelines for air conditioned as well as naturally ventilated buildings. (Manu, Shukla, & Rawal, 2014). The monthly comfort limits-upper and lower and annual comfort band for naturally ventilated buildings for 90% acceptability is obtained from the tool developed by the Center for Advanced Research in Building Science, CEPT (Center for Environmental Planning and Technology) is shown in appendix 5.

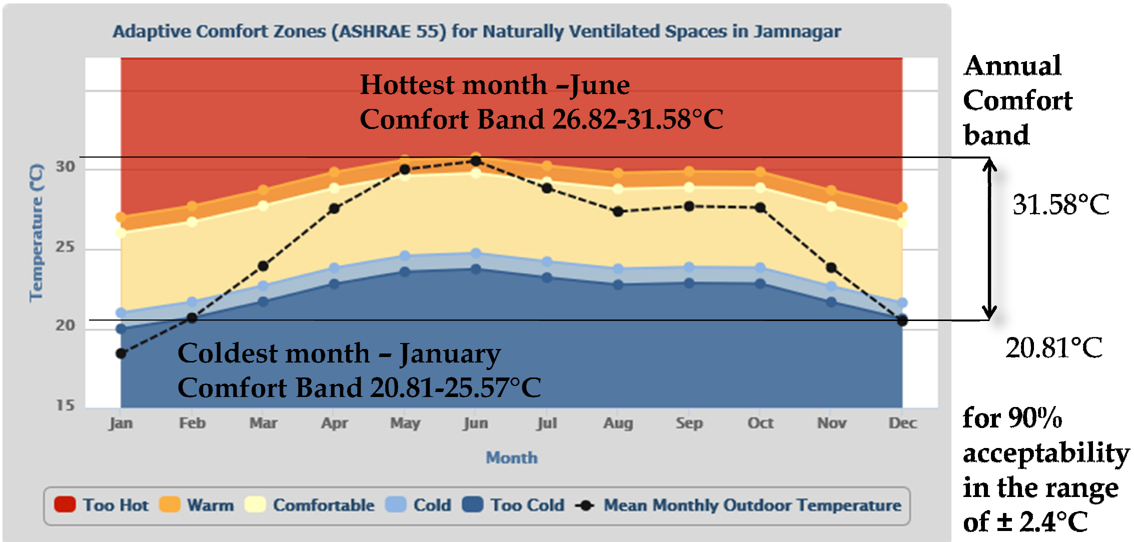


Figure 11 India model for adaptive thermal comfort developed on the basis of ASHRAE standard 55 (Manu, Shukla, & Rawal, 2014)

3.2.6. Autodesk ECOTECT Analysis 2011

The ECOTECT program (developed by Cardiff University in the UK) is one of the few tools that can used at all stages of the design process and consists of a 3D modelling interface along with an intensive solar, thermal, lighting, acoustics and cost-analysis functions. The program uses the heat balance method to perform hourly energy calculations and complex geometry and any types of building materials, insulation and glazing can be modeled within the program. ECOTECT can be used to accurately design or test the design of shading devices and allows for comfort predictions of occupants at different room temperatures in a naturally ventilated building. The building geometry needs to be drawn and materials can be picked from the program database and assigned to the building envelope and location of the building has to be specified as a minimum to run simulation giving results in various forms like spatial distribution of both mean radiant temperatures within a model and predicted comfort levels, indoor hourly temperature for any day of the year, heating and cooling loads, load distribution, and discomfort times in a non-air-conditioned mode. This program requires minimal input when used in a preliminary design stage, while more detailed data is required for detailed and accurate simulation. The input data need to be accurately given in order to obtain accurate output from any simulation tool (Hyde, 2008).

The following tools of ECOTECT analysis 2011 are going to be used by the author

1. Weather Tool
2. Sun path Diagram
3. Solar Access analysis
4. Thermal Analysis

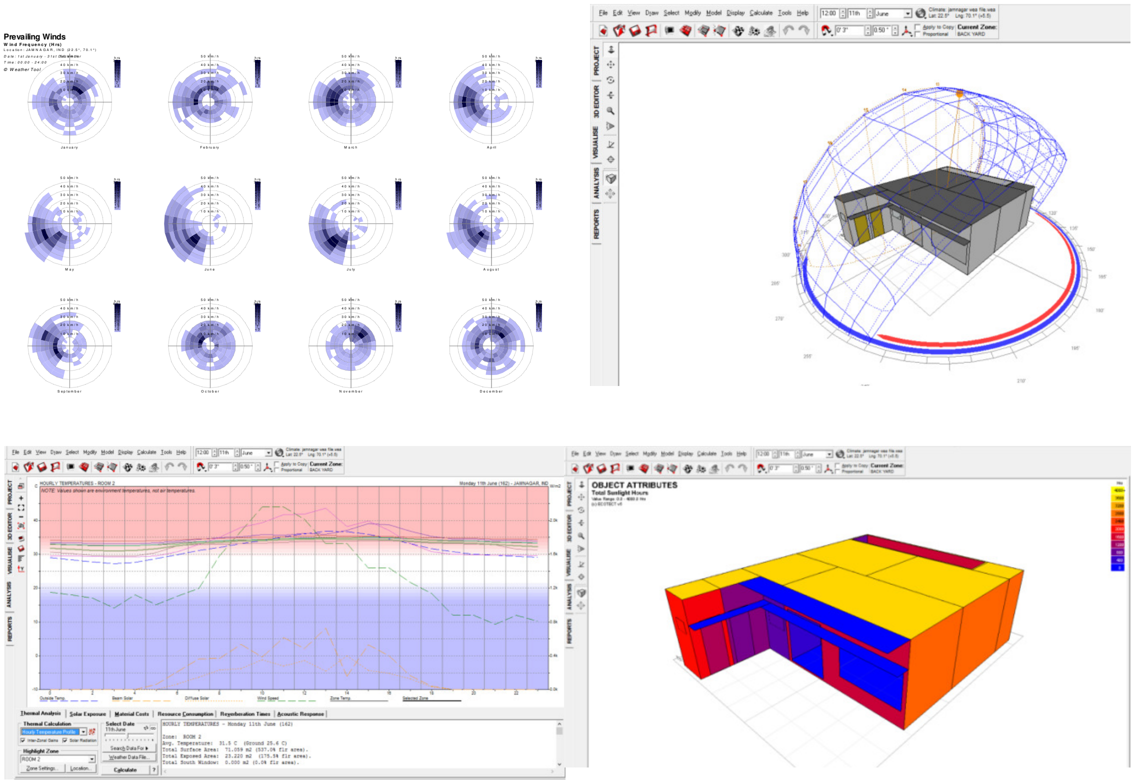


Figure 12 ECOTECT analysis Tools - Weather Tool, Sun path Diagram, Solar Access analysis, Thermal Analysis (clockwise)

Table 3 Types of tools, input and output (Source: Author)

No.	Tools	Type of Tool	Input	Output
1	Mahoney table	Table	Weather data	List
2	Climate consultant	Psychrometric Chart	Weather file - epw format	Graph
3	Interview Schedule	Survey	Questionnaire	Graphs
4	Luxmeter and data loggers	Instrument		Reading in lux; Hourly air temperature and relative humidity
5	ECOTECT analysis	Software	Weather file; Model	Graph, Table, Diagram, Images.
6	IMAC - India model of adaptive comfort	Graph	Weather data	Comfort band on Graph

CHAPTER 4

SITE STUDY

4. Site Study

Chapter 5 provides the data collected of macro-climate of the site, occupant lifestyle, vernacular and contextual solutions, microclimate of the case study, using graphical tools, instruments, interview schedules and observation..

4.1. Macroclimate assessment

4.1.1. Mahoney Table for Jamnagar

Table 4 Mahoney Table for Jamnagar (Source: Author)

TABLE 1 - PART 1	**AIR TEMPERATURE: °C**													
	J	F	M	A	M	J	J	A	S	O	N	D	High	**AMT**
MONTHLY MEAN MAX	28.5	31.1	32.6	35.3	37.9	36	36.2	32.5	32.9	34.5	32.9	31.3	38	**22.5**
MONTHLY MEAN MIN	7	9	10.5	20	21.2	26	25.2	23.3	22	20.9	14.6	10.6	7	31
MONTHLY MEAN RANGE	21.5	22.1	22.1	15.3	16.7	10	11	9.2	10.9	13.6	18.3	20.7	Low	AMR

TABLE 1 - PART 2	**RELATIVE HUMIDITY: %**												
	J	F	M	A	M	J	J	A	S	O	N	D	AVG
MONTHLY MEAN MAX	57	55	57	59	57	64	72	83	72	66	50	58	63
MONTHLY MEAN MIN	41	32	37	49	54	60	67	77	66	55	33	38	51
MONTHLY AVERAGE	49	44	47	54	56	62	70	80	69	61	42	48	57
HUMIDITY GROUP	**2**	**2**	**2**	**3**	**3**	**3**	**4**	**4**	**3**	**3**	**2**	**2**	

RAIN AND WIND													TOTAL
	J	F	M	A	M	J	J	A	S	O	N	D	
RAINFALL	0.2	0.7	0.4	0	3.1	116	328	273	136	6.2	9	0.4	873
WIND PREVAILING	NE	W	W	W	SW	SW	SW	SW	SW	NW	NE	NE	
WIND SECONDARY	W	N	NW	NW	W	W	W	W	NW	W	E	W	

TABLE 2 - PART 1 **DIAGNOSIS**

	J	F	M	A	M	J	J	A	S	O	N	D
MONTHLY MEAN MAX	28.5	31.1	32.6	35.3	37.9	36	36.2	32.5	32.9	34.5	32.9	31.3
DAY COMFORT - UPPER	31	31	31	29	29	29	27	27	29	29	31	31
DAY COMFORT - LOWER	25	25	25	23	23	23	22	22	23	23	25	25
MONTHLY MEAN MIN	7	9	10.5	20	21.2	26	25.2	23.3	22	20.9	14.6	10.6
NIGHT COMFORT - UPPER	24	24	24	23	23	23	21	21	23	23	24	24
NIGHT COMFORT - LOWER	17	17	17	17	17	17	17	17	17	17	17	17
THERMAL STRESS - DAY			H	H	H	H	H	H	H	H	H	
THERMAL STRESS - NIGHT	C	C	C			H	H	H			C	C

TABLE 2 - PART 2 INDICATORS

HUMID	J	F	M	A	M	J	J	A	S	O	N	D	**Total**
H1 (Air Movement essential)													**2**
H2 (Air Movement Desirable)													**0**
H3 (Rain Protection)													**2**
A1 (Thermal Storage)													**9**
A2 (Out Door Sleeping)													**4**
A3 (Cold Season problems)													**0**

TABLE 3			SKETCH DESIGN RECOMMENDATIONS				
INDICATOR TOTALS FROM TABLE 2- PART 2							Recommendations
H1			A1				
H1	H2	H3	A1	A2	A3		
2	0	2	9	4	0		
							LAYOUT
			0-10		5-12		**1. Building Oriented on east-west axis to reduce exposure to sun**
			11 or 12		0-4		2. Compact Courtyard Planning
							SPACING
11 or 12							3. Open Spacing for Breeze penetration
2-10							**4. As 3, but protect from cold/hot wind**
0, 1							5. Compact planning
							AIR MOVEMENT
3-12			0-5				6. Rooms single banked. Permanent provision for air movement
1 or 2	2-12		6-12				**7. double banked rooms with temporary provision for air movement**
0	0 or 1						8. No air movement required
							OPENINGS
			0 or 1		0		9. Large openings, 40-80% of n and S walls
			11 or 12		0 or 1		10. Very Small openings 10-20%
							11. Medium openings 20-40%
							WALLS
			0-2				12. Light Walls; short time lag
			3-12				**13. Heavy external and internal walls**
							ROOFS
			0-5				14. Light Insulated roofs
			6-12				**15. heavy roofs; over 8 Hours time lag**
							OUTDOOR SLEEPING
				2-12			**16. Space for outdoor sleeping**
							RAIN PROTECTION
		3-12					17. Protection from heavy rain needed

Sketch Design Recommendations to be part of solution set

1. Building oriented on east-west axis to reduce exposure to sun
2. Open spacing for breeze penetration, but protect from cold/hot wind
3. Double banked rooms with temporary provision for air movement
4. Medium openings 20-40% WWR
5. Heavy external and internal walls
6. Heavy roofs; over 8 hours time lag
7. Space for outdoor sleeping

4.1.2. Psychrometric Chart for Jamnagar

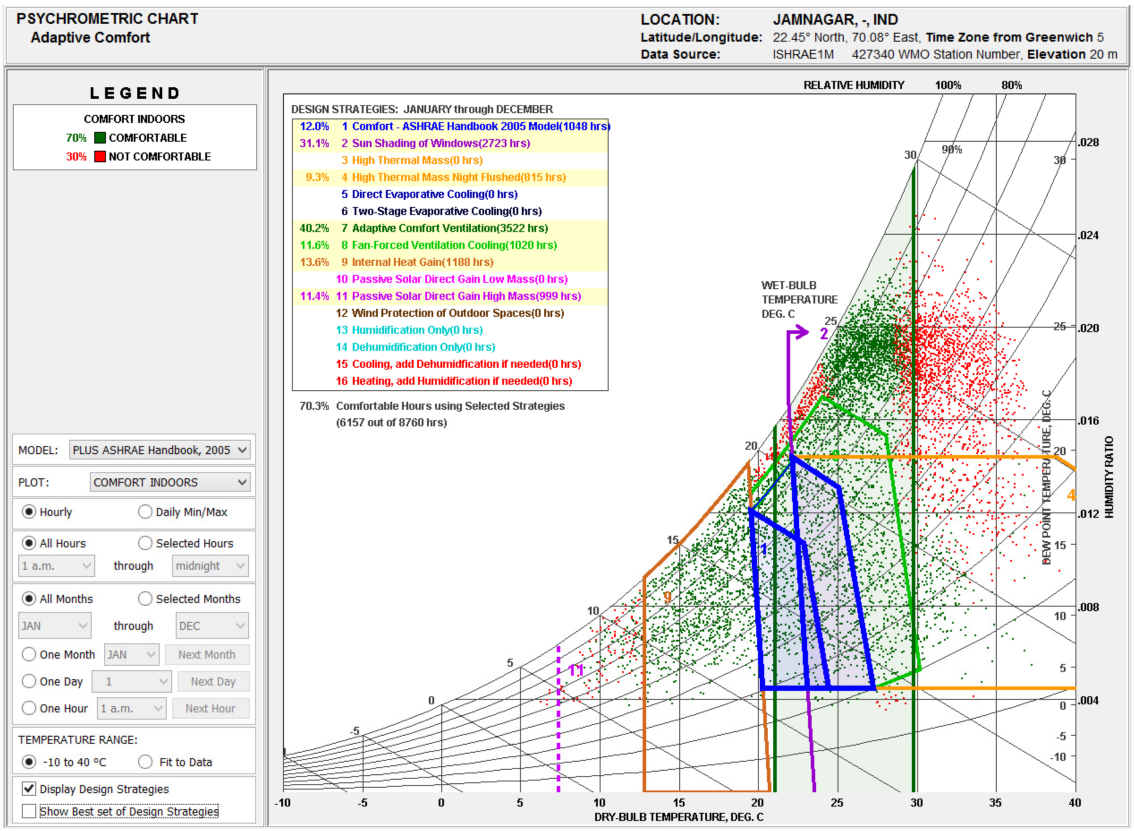


Figure 13 Psychrometric chart for Jamnagar showing passive design strategies and comfort hours (Source: Climate Consultant 5.5)

Passive design strategies can achieve comfort conditions for 70% of year (6157 hours out of 8760 hours)

Design Strategies for Thermal Comfort

- **31.1% -Sun Shading of Windows**
- **40.2% -Adaptive Comfort Ventilation**
- **11.6% - Fan Forced Ventilation**

- **13.6% -Internal heat gain**
- **9.3% -High Thermal Mass + Night Flush Cooling**
- **11.4% -Passive Solar Heat Gain**

4.2. Occupant survey

Interview Schedule graphical analysis and conclusion

- Most usable space is the semi-open space – Verandah for almost all activities but sleeping, studying i.e. more quiet activities are done in the room. (Figure 14)

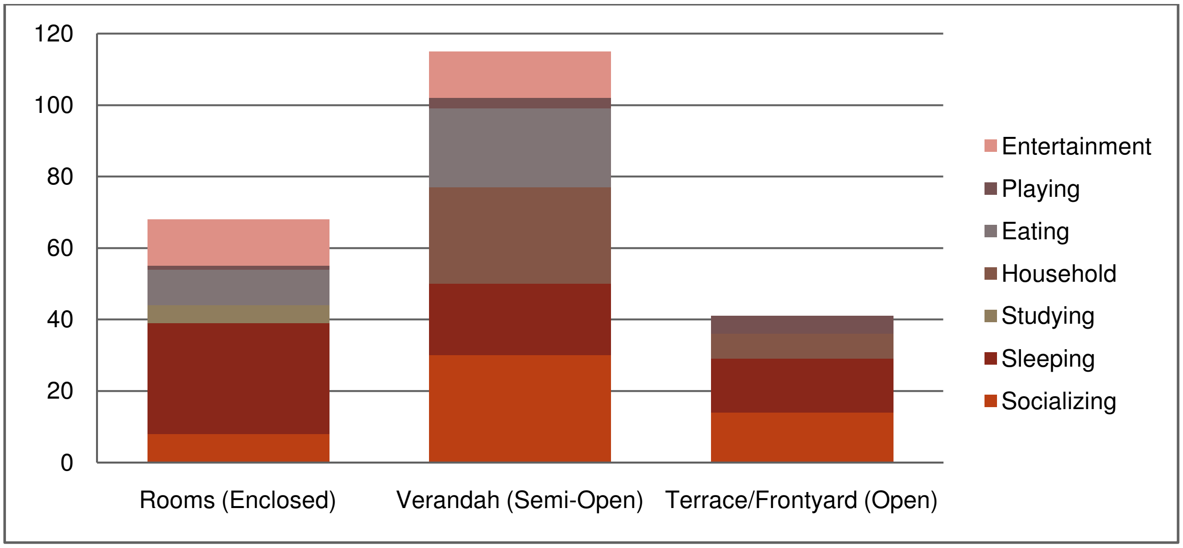
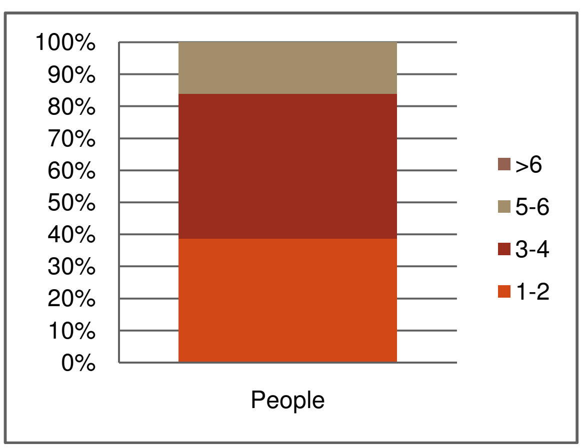


Figure 14 Activity and Space use (Source: Author)

- Average occupancy is about 3-4 people and mostly people occupy the houses almost throughout the day. (Figure 15)



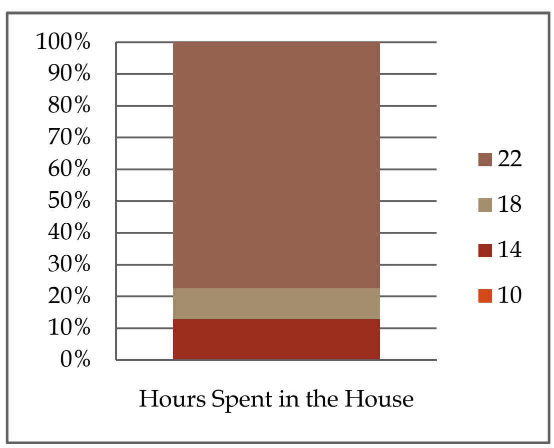


Figure 15 Average occupants and occupancy hours (Source: Author)

- Most usable space in the morning and afternoon is Verandah, and rooms are used mostly in the evening and night. (Figure 16)

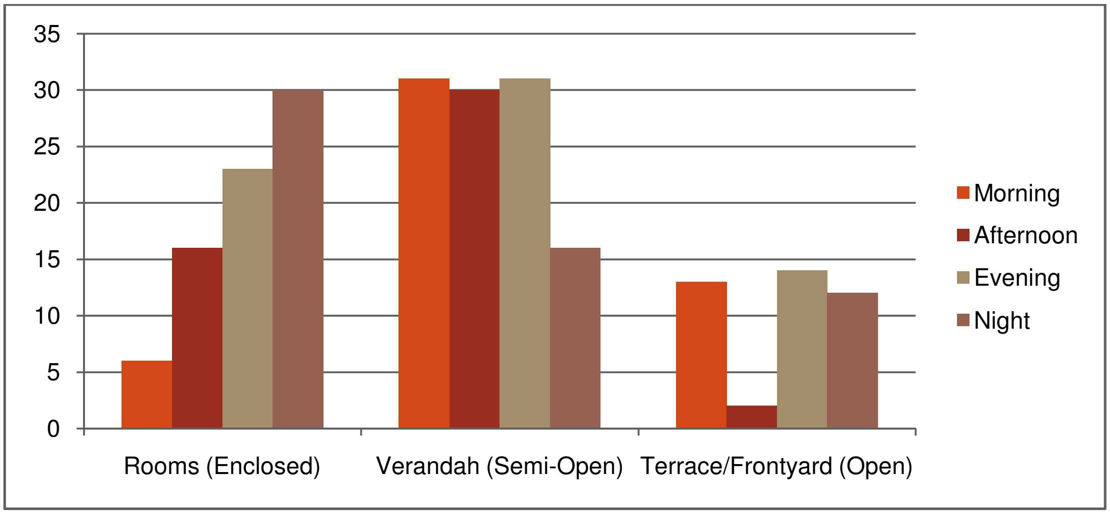


Figure 16 Space use at different times of the day (Source: Author)

- Most preferred Roof type is flat RCC slab, Flooring is tiles, window is precast cement and in walls 67% like cement plaster with paint and 33% like tile dado on walls. (Figure 17)

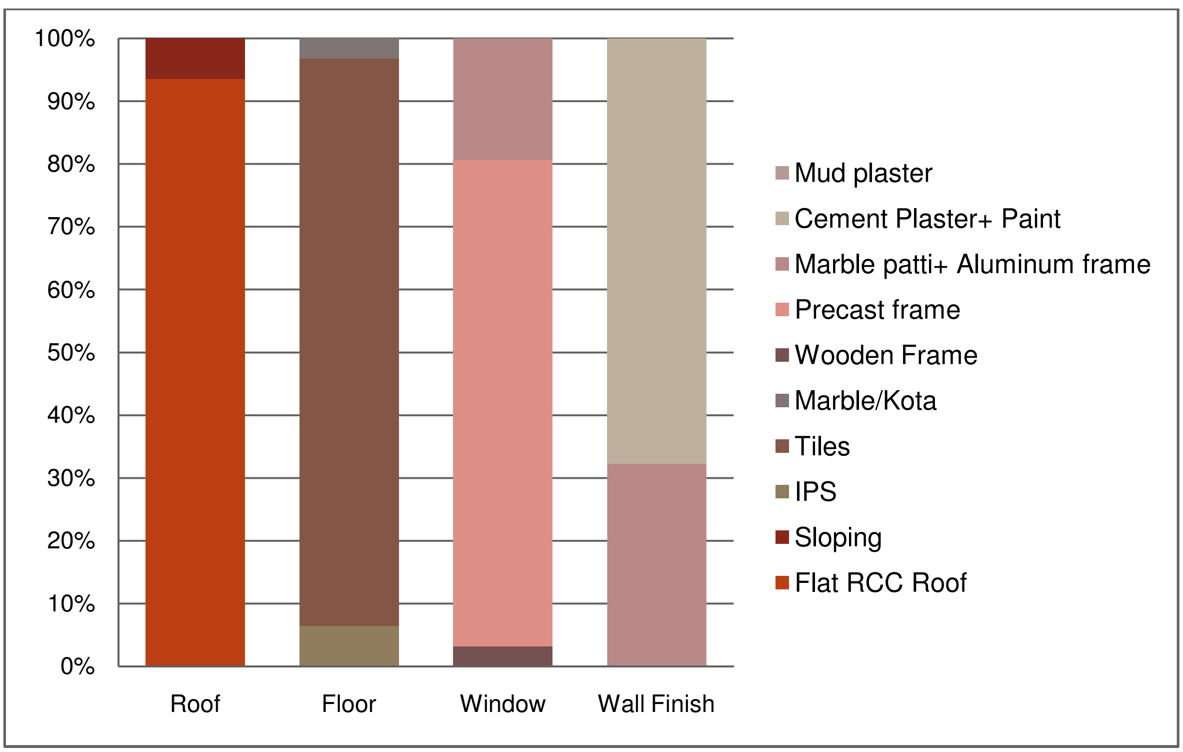


Figure 17 House Form and fabric preference

- Most comfortable time indoors is Morning and outdoors is night and evening. Most uncomfortable time indoor is afternoon. Most comfortable season is winter and most uncomfortable season is summer. (Figure 18)

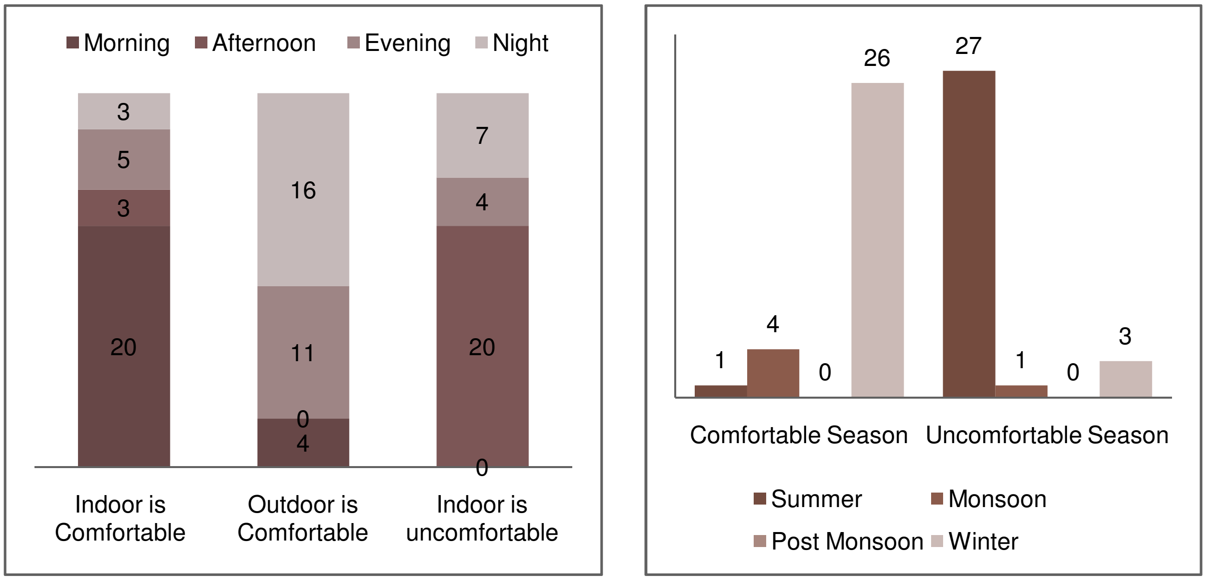


Figure 18 Thermal Comfort and Discomfort (Source: Author)

- Most uncomfortable element is the temperature. All the respondents open the windows and switch on the fan to alleviate the discomfort due to heat. Almost 45% always keep windows open. (Figure 19)

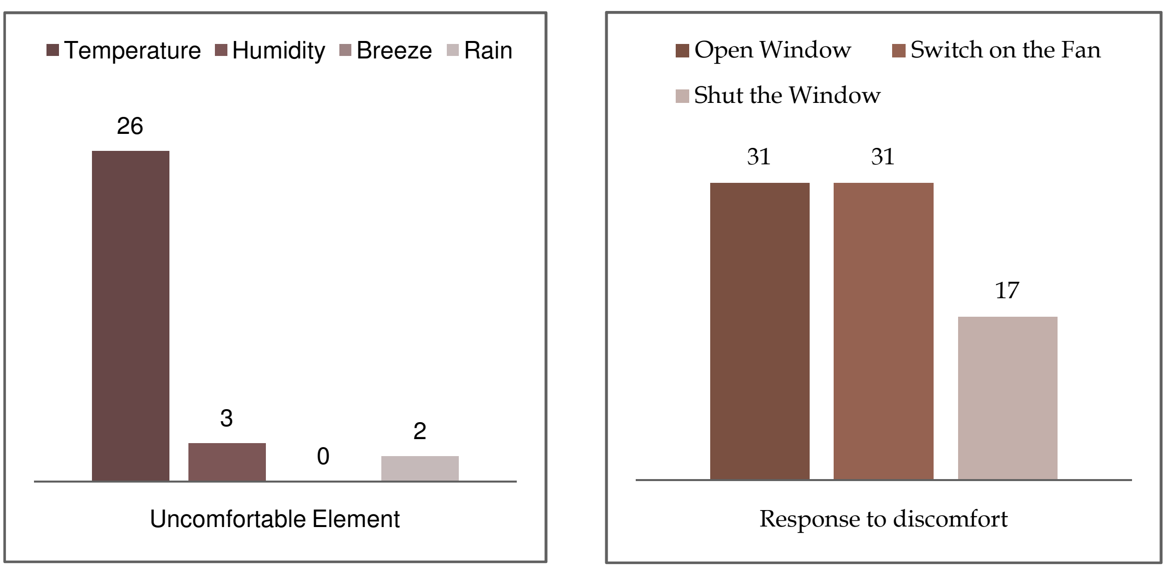


Figure 19 Discomfort and adaptability (Source: Author)

- Mostly no changes have been made to the original house. Mostly just fans are used for comfort throughout the day and year except in winter. (Figure 20)

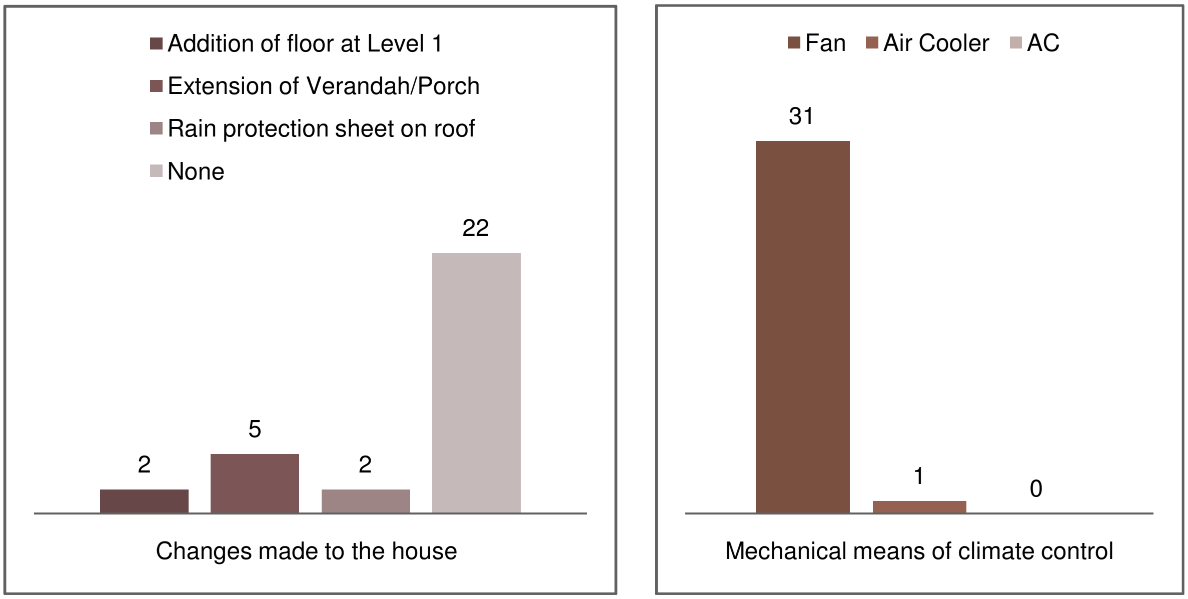


Figure 20 Changes and response to adapt to climate (Source: Author)

- 6% House have Rooms and 3% house have kitchens with single window due to site restriction which leads to inadequate daylight and require the use of artificial light in the day time. 61% are very satisfied, 36% are satisfied, 3% are not satisfied. (Figure 21)

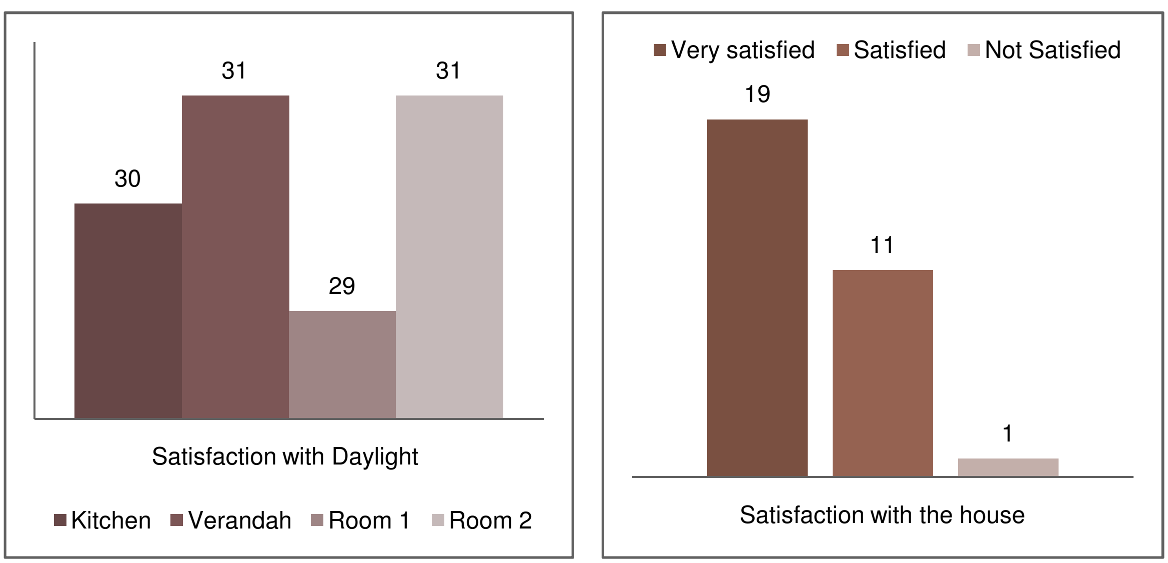


Figure 21 Daylight and overall satisfaction (Source: Author)

4.3. Vernacular and contextual solutions

a) House form - Sloping roof, simple grid with verandah, one or two rooms, kitchen, front yard with bath and WC. Flexible use of spaces like verandah and front yard for household chores, socializing, storage, outdoor sleeping etc.

Figure 22 Variations in spatial planning with veranda, front yard and rooms (Left). Verandah, sloping roof -form, front yard (Right top to bottom) (Source: Author)

b) Fabric - Random rubble limestone wall about one feet thick with mud plaster, flooring - lime and mud - cool in summer and warm in winter. Casement type Window with 4 shutters and ventilators, thick walls (thermal mass) and sloping roof with mangalore tiles and wooden members, house fan for cooling.

Figure 23 Flooring and interior wall finish, structure and external wall finish, wooden window shutter with opening options from 25 to 100%, roof structure and materials (Clockwise) (Source: Author)

4.4. Micro climate

4.4.1. Description of the base case dwelling

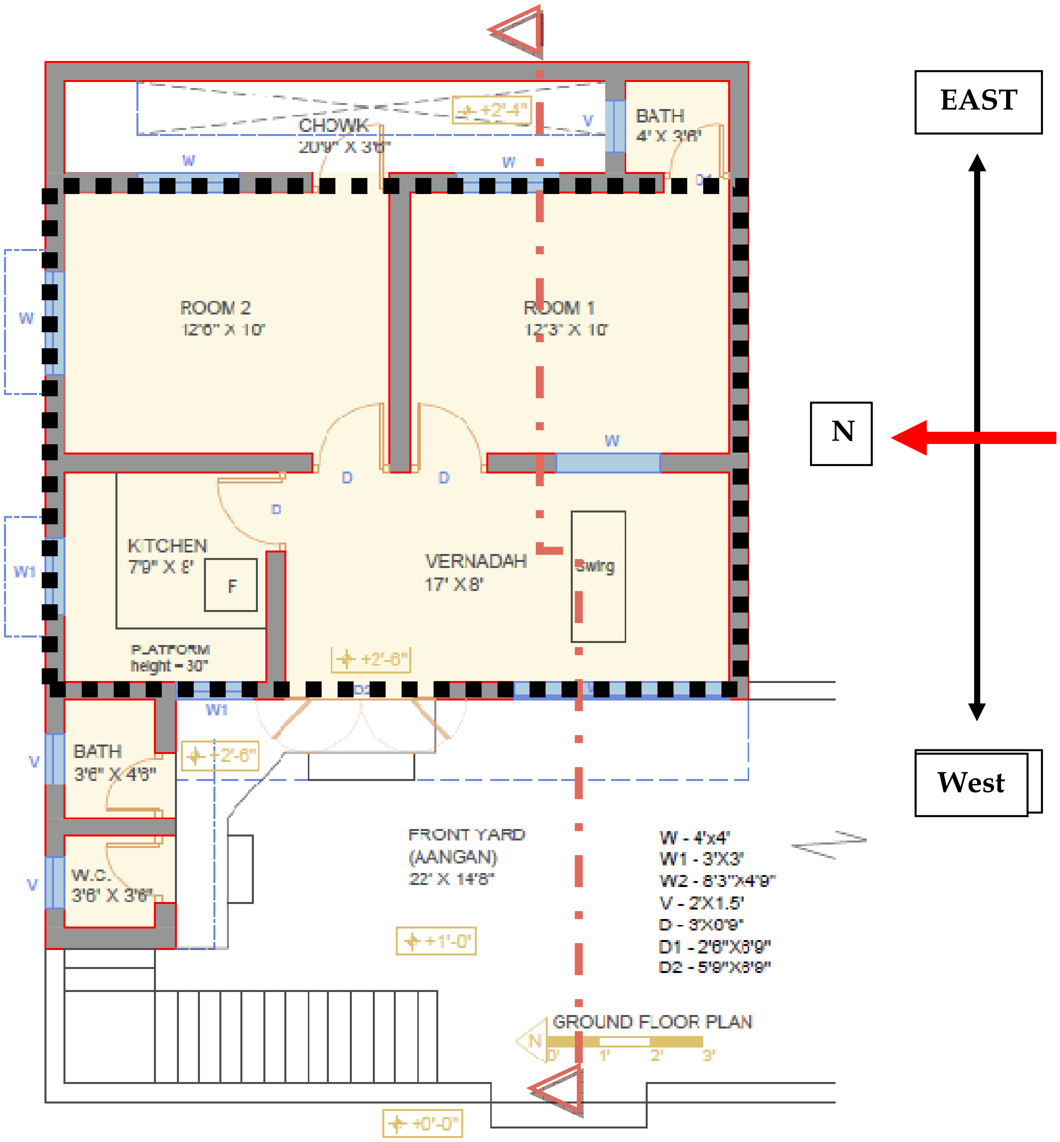


Figure 24 Plan of the base case house in Chitrawad (Source: Author)

Form: Single storey detached house with rectangular plan form; Orientation East-West - Openings on north, east and west facades; Spatial organization - Verandah – 2 Rooms – Kitchen – 2 bathrooms – 1 WC.

Fabric: Local limestone called Bela for 9" wall with RCC bands reinforced with 8-12 mm M.S.; 4.5” RCC roof with IPS finish; Floor- Earth filing, compaction, rubble soling and PCC with screed and ceramic tiles; Precast RCC door and window frames; Cement plaster externally; Internal wall finish - plaster and ceramic wall tiles.

4.4.2. Sun analysis

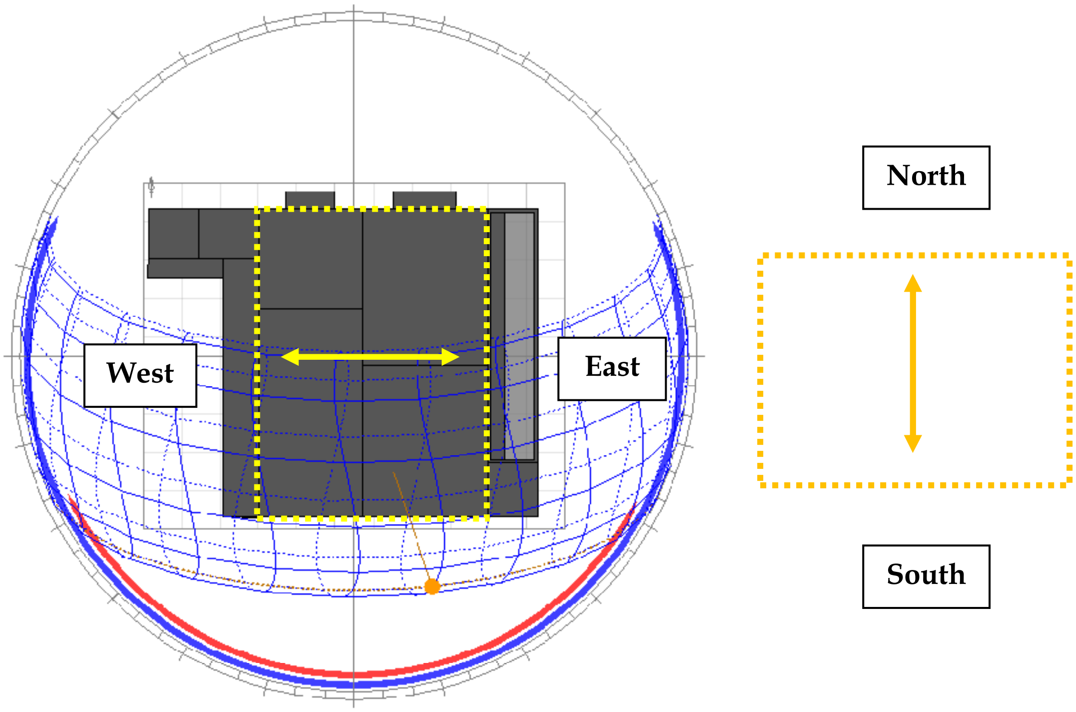


Figure 25 Sunpath Diagram with case study orientation and Ideal orientation (Source: Author)

- Orientation of the base case dwelling is East- West (i.e. longer facades facing east-west)
- Ideal Orientation as per Sun-Path to reduce solar heat gain is North South.
- Solar Access analysis - The average hourly solar radiation from 8 am to 5 pm throughout the year in W/sq.m. given in the above figures shows that roof receives the highest solar radiation >600 w/sq.m. per hour.

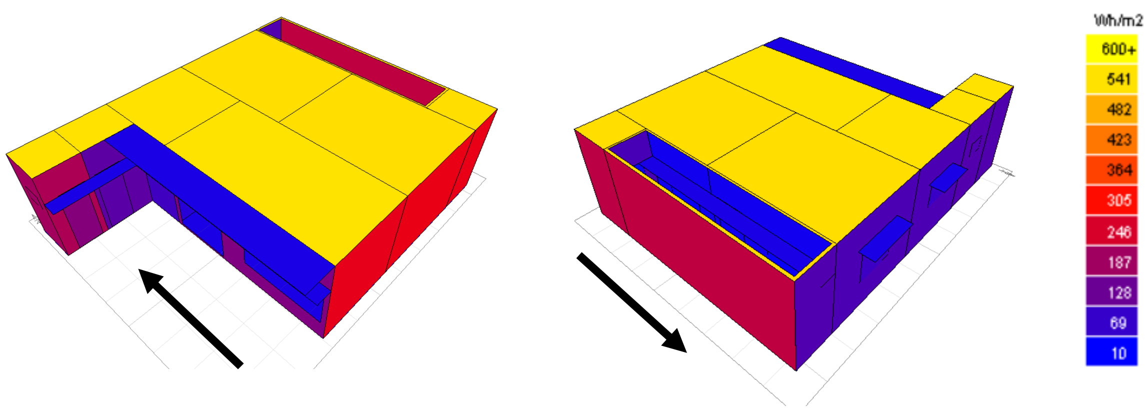
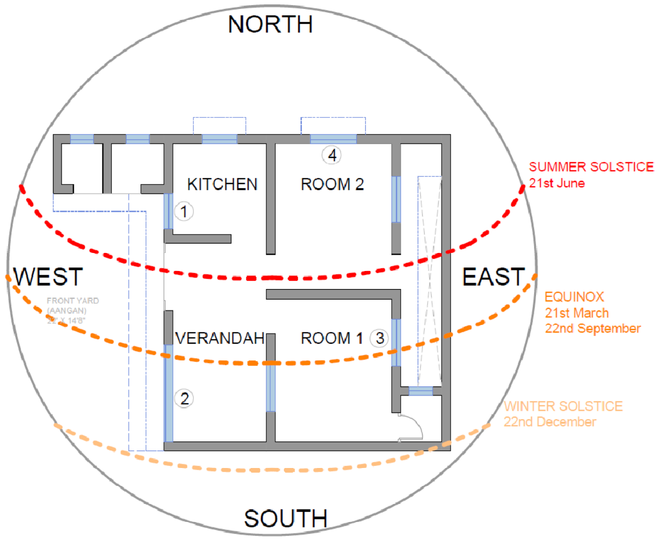


Figure 26 Average hourly incident solar radiation in W/sq.m. on the dwelling between 8 am to 5 pm annually (Source: Author)



Effectiveness of the Shading device

- All windows have 1'6" sunshades.
- The north windows are well protected from the summer sun.
- The east opening open up in the chowk and thus are well protected from direct solar radiation.
- The west openings are unprotected with the sunshade of 1'6" and result in direct solar heat gain during summer which is undesirable.

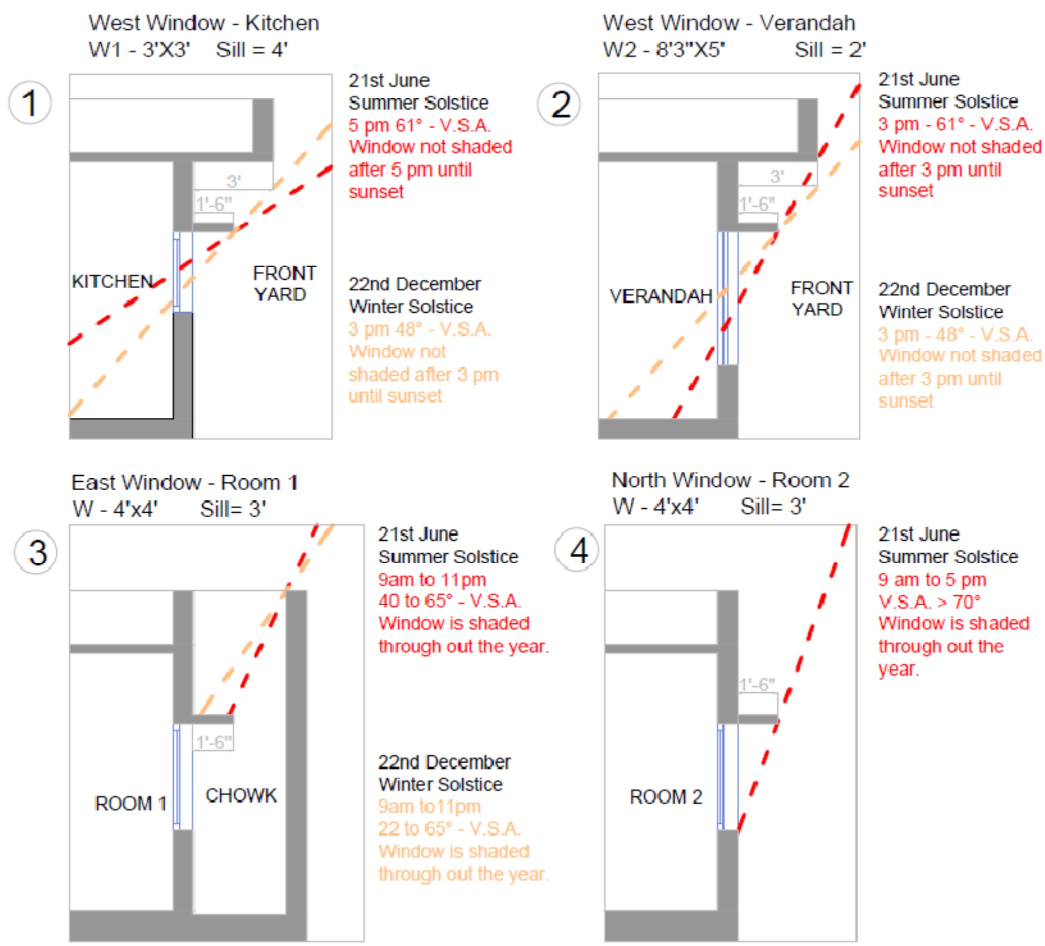
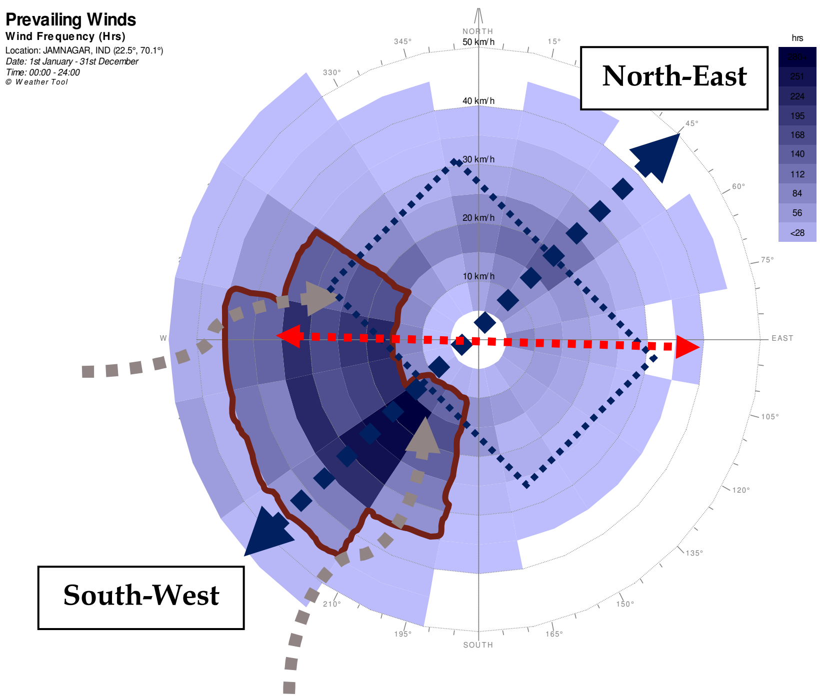


Figure 27 Sun angles on windows at different orientations (Source: Author)

4.4.3. Wind analysis



- **Predominant wind direction is Southwest and secondary is west.**
- Ideal wind orientation - Northeast-Southwest and East-West (i.e. longer facades facing it)
- For hot and humid regions in case of conflict between sun and wind orientation ventilation should be the primary factor. (Givoni, 1994)
- Ideal orientation for the base case is thus Northeast -Southwest and East-West
- With respect to Mahoney table sketch design recommendations WWR should be between 20-40% while the case study has a WWR of 22%.

Table 5 Window Wall Ratio (WWR) Calculation

Space	WINDOW area in sq.ft.	WALL area in sq.ft.	WWR in %
Room 1	32	232.75	**14**
Room 2	32	213.75	**15**
Kitchen	18	149.625	**12**
Verandah	78	161.5	**48**
	160	**757.625**	**22**
	Total	**Total**	**Average**

- Cross ventilation and stack ventilation as seen below due to the location and number of openings reduces discomfort.

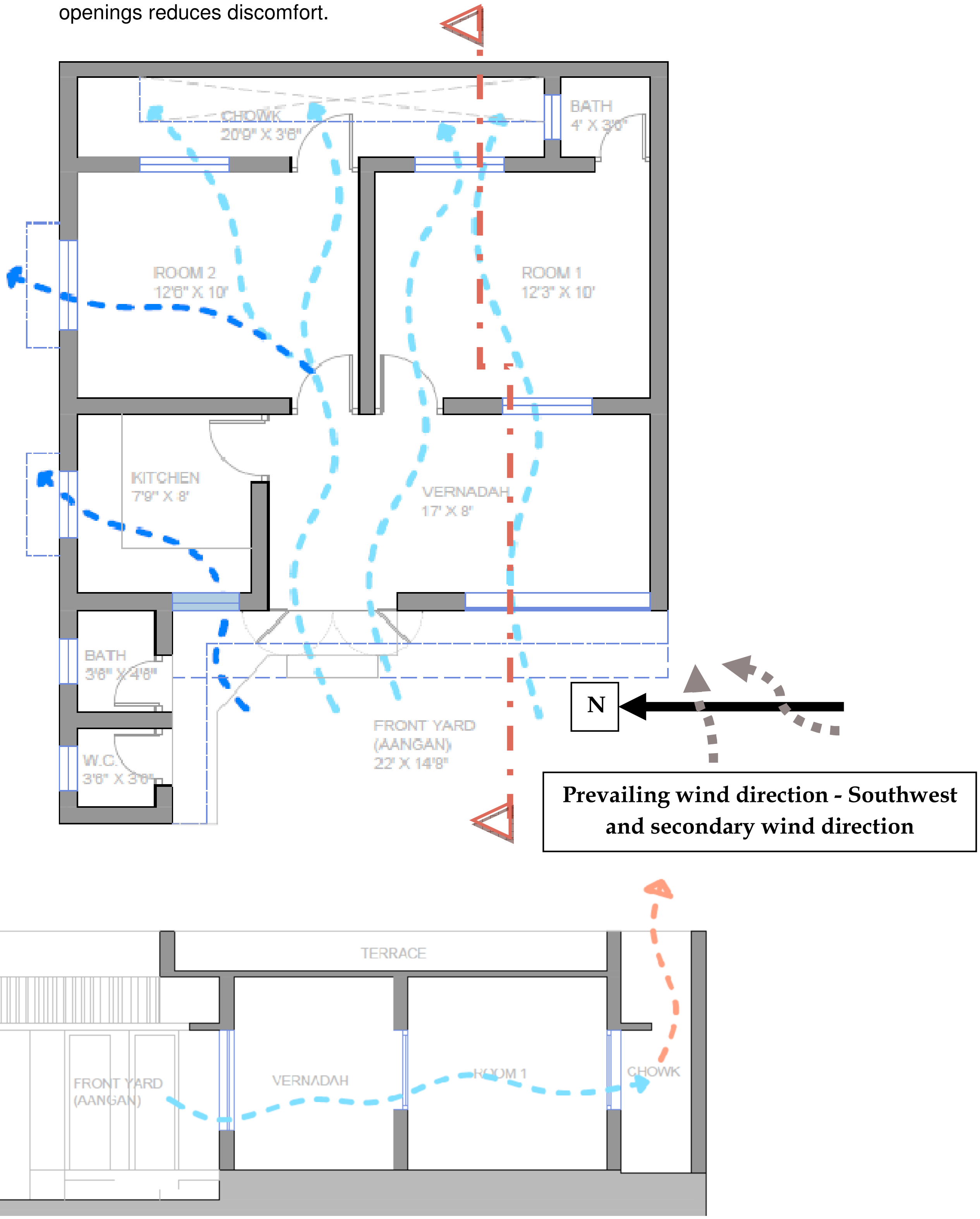


Figure 28 Plan (above) and section (below) showing the wind flow within the case study dwelling

- As per the table 6 required wind speed indoors can be obtained during periods of average high temperature and humidity with fenestration area equal to 50% of floor area which is the verandah that has a fenestration area of about 57% of floor area (Table 5)
- With opening equal to 35% of floor area in Table 6, the average wind speed indoors will be equal to 33% of outdoor velocity that is 1m/s as per graph in figure 29.
- Thus the location, size and area of openings are appropriate for comfort ventilation, required indoor air velocity.

Table 6 Probable Indoor air speed (Source: Author)

Space	Floor Area in sq.ft.	Opening area in sq.ft.	Openings as percentage of Floor Area	Available indoor wind speed as a percentage of outdoor wind speed from graph in figure 29	Available indoor wind speed in m/s with average outdoor speed 3m/s (see appendix 5)
Room 1	122.5	32	**26**	**27**	**0.81**
Room 2	120	32	**27**	**28**	**0.84**
Kitchen	62	18	**29**	**30**	**0.9**
Verandah	136	78	**57**	**40**	**1.2**
	Total = 440.5	Total = 160	Average =34.75%		Average = 0.94 m/s

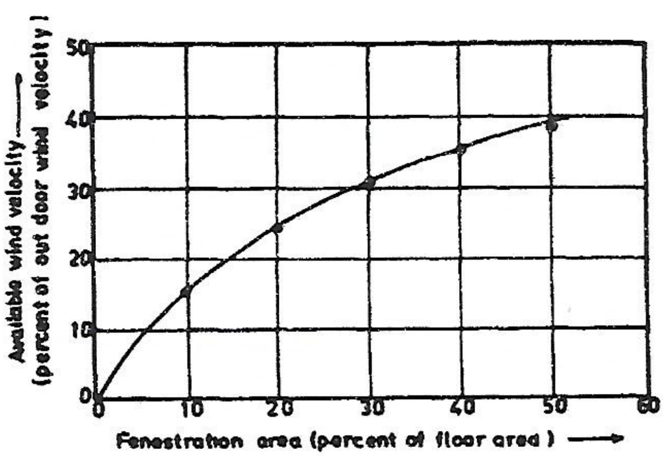


Figure 29 Effect of Area of Openings on Average Indoor Wind Speed (SP:41, 1988)

The area of openings around 20 to 30% of floor area the average indoor wind velocity is around 30% and further increasing area of openings does not substantially increase the indoor wind velocity as seen in figure 29 (SP:41, 1988). Thus the area of openings, its location and numbers are adequate for comfort ventilation.

4.4.4. Daylight

Daylight readings taken on a grid of 2'6"x2'6" in all rooms (see appendix 6)

Table 7 Average indoor daylight readings for case study and comparison with standards (Source: Author)

Room name	Lux levels on 9th May 2016 at 12 pm	Daylight factor	Recommended values of illumination as per SP 41 Pg 115 Processes	Recommended values of illumination as per SP 41 Pg 115 Lux levels
Verandah	1760	1.2	Sewing / Darning	700
Room 1	258	0.2	Reading (casual)	150
Room 2	600	0.4	Homework and sustained reading	300
Kitchen	444	0.3	Kitchen	200
Chowk	7480	5		
Outdoor	145000			

- As per the occupancy survey graphs and analysis in the Figure the verandah is used for almost all activities from casual sitting, socializing, dining, household chores - sewing, pre preparation of cooking.
- Rooms are used for quiet activities like studying, reading, sleeping, dining, etc.
- The average daylight in lux is more that the minimum NBC standards although daylight factors are as low as 0.2. On clear summer days outdoor lux levels can be as high at 1,45,000 at noon. Thus the daylight factor indoors can be as low as 0.5 and yet be acceptable in terms of actual daylight in lux.
- Thus the WWR of case study is appropriate for the required daylight.

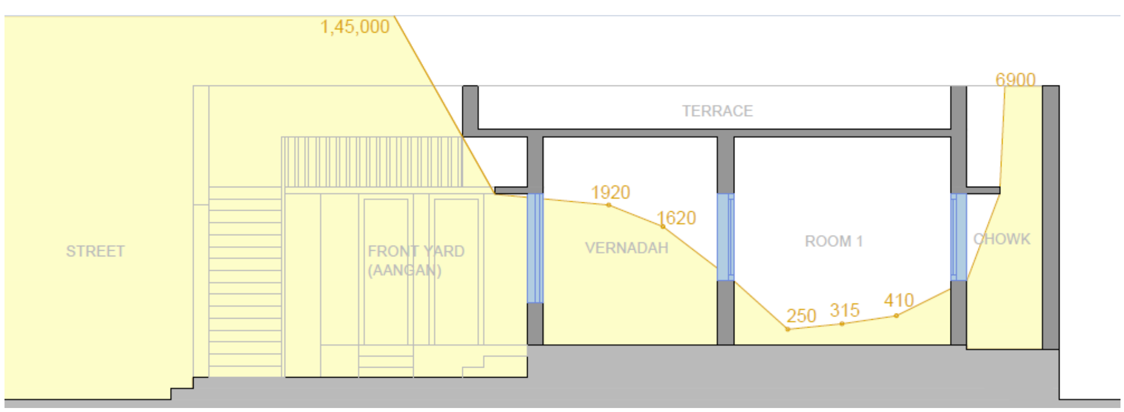


Figure 30 Daylight levels shown in Section (Source: Author)

Figure 31 Case Study Images -Verandah, Front yard, Kitchen, Chowk, Room 1, Room2. (Clockwise) (Source: Author)

Conclusion: The micro climate assessment through sun, wind and daylight analysis justifies the WWR and horizontal shade as appropriate for shading, ventilation and indoor daylight for the base case.

CHAPTER 5

SIMULATION STUDY

5. Simulation study

Chapter 5 presents the thermal performance of base case and its validation through comparison with site readings. The identification and selection of variables on basis of field study and details of each variable and other inputs of simulation. Simulation of all cases and comparison with respect to thermal comfort hours.

5.1.Validation of simulation model

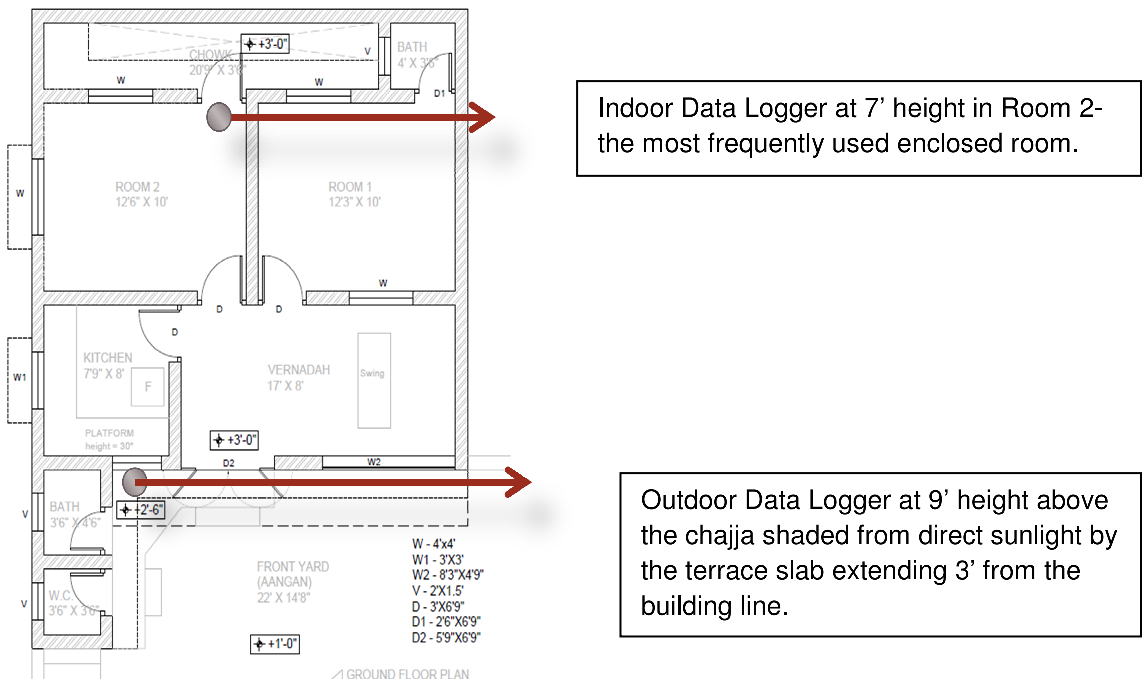


Figure 32 Location of data loggers (Source Author)

Figure 33 Outdoor data logger location (Left); Indoor data logger location (Right) (Source Author)

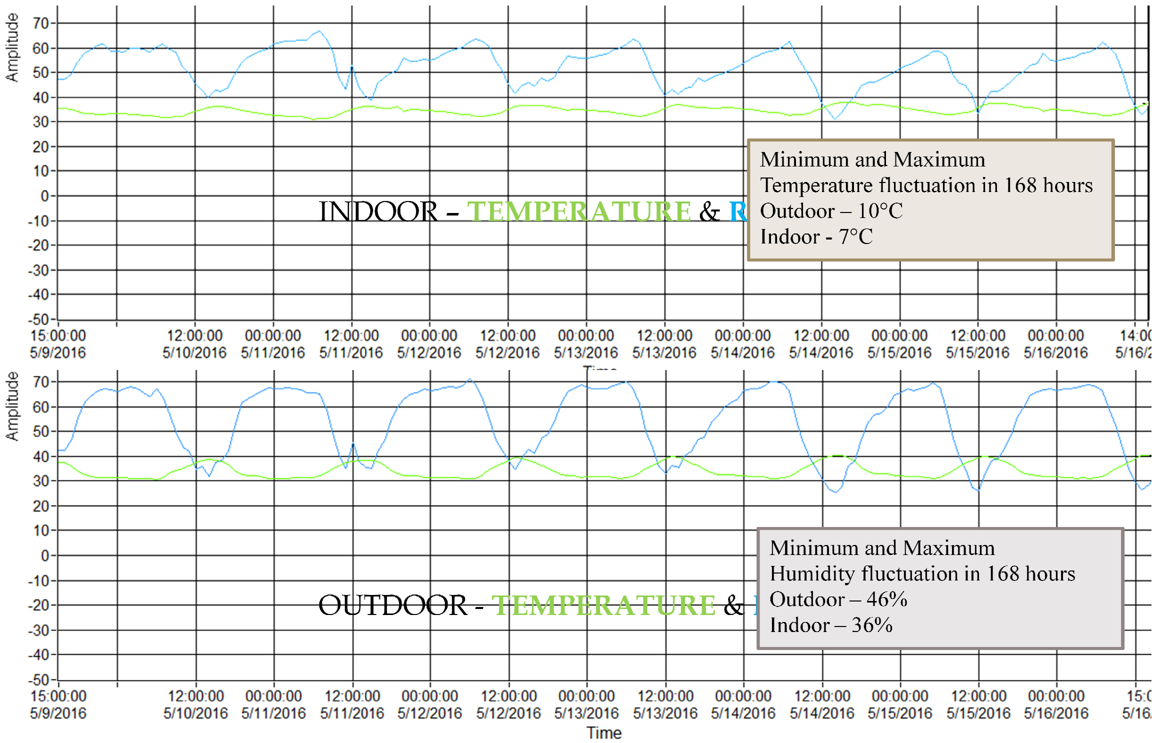


Figure 34 168 hours RH and Temperature Readings from 9th May 2016 3 pm to 16th May 2016 3 pm (Source: Author)

The inputs for simulation model prepared using ECOTECT analysis as a tool for thermal analysis.

Table 8 Simulation input data (Source: Author)

No.	Input	Value	Source
1	Weather data	.epw weather file from ISHRAE	
2	Material properties - Wall, Roof.	Appendix 8	
3	Clothing	0.6 - Trousers and T-shirt	Site study
4	Humidity	57	Mahoney Table
5	Indoor Air Speed	1m/s	Table 6
6	Lighting level	400	Table 7
7	Occupancy	2	Interview Schedule
8	Activity	Sedentary - 80 W	Interview Schedule
9	Schedule		Interview Schedule
10	Infiltration rate	3 ach	(SP:41, 1988)
11	Sensible heat gain	6 w/sq.m.	(Brown & DeKay, 2001)
12	Comfort Band	20.8 to 31.6° C	Figure 11
13	Type of ventilation system	Natural Ventilation	Interview Schedule
14	Hours of operation	24 hours	Interview Schedule

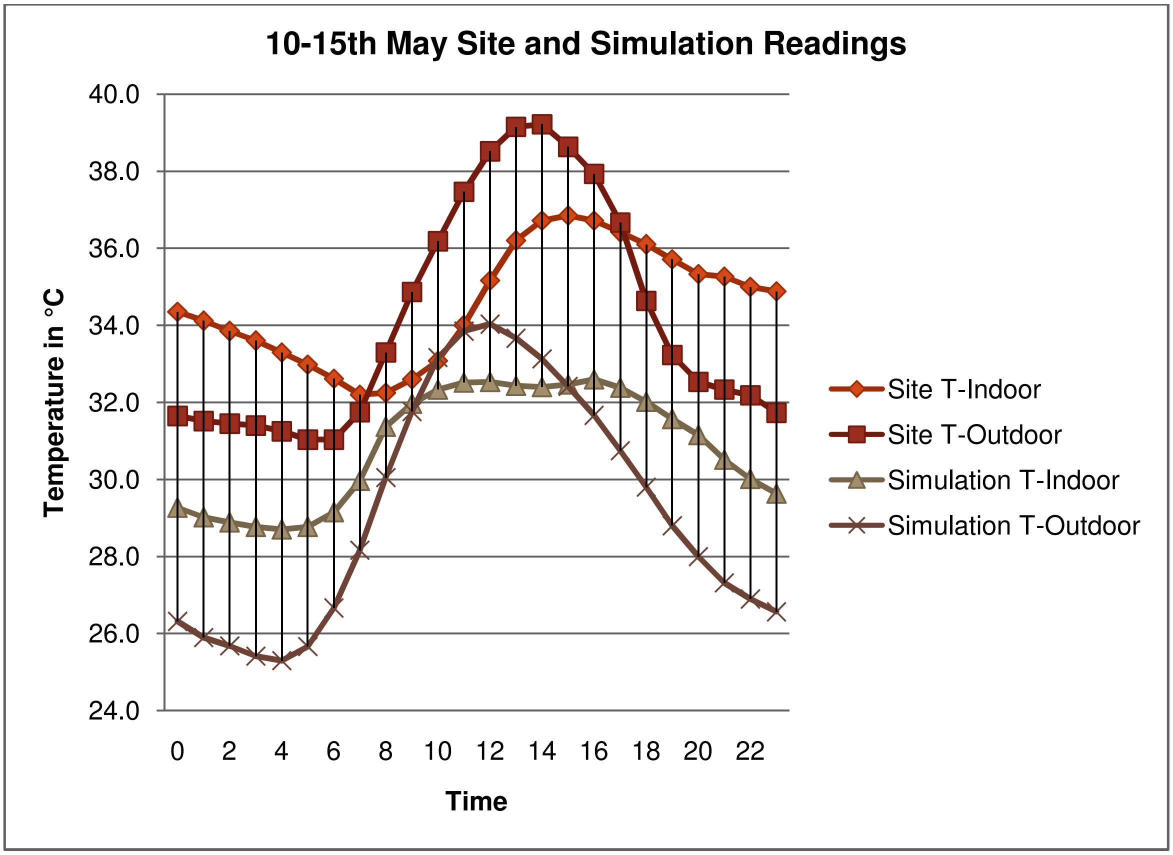
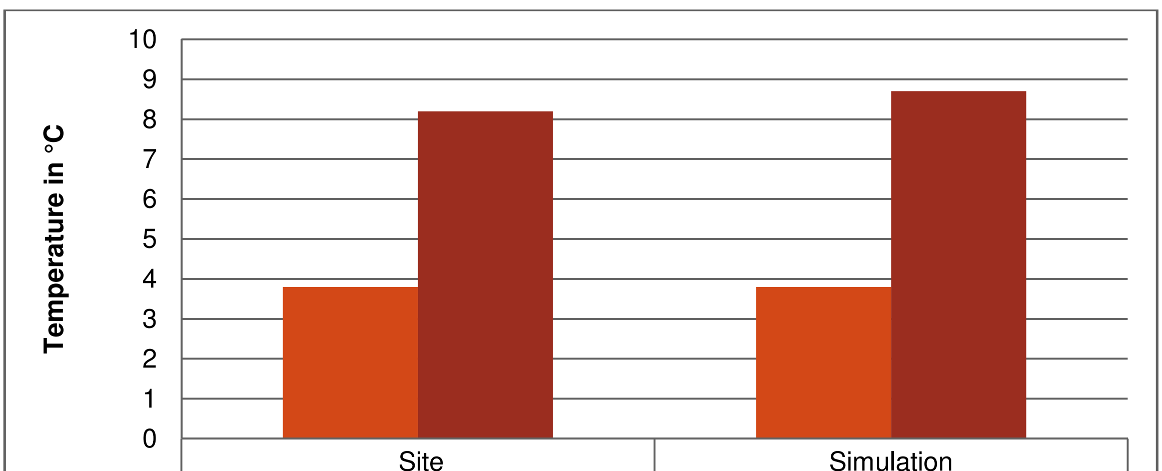


Figure 35 Average Indoor and outdoor hourly data graph comparing site and simulation reading for 10th to 15th May (Source: Author) See appendices 8 and 10



	Site	Simulation
Indoor	3.8	3.8
Outdoor	8.2	8.7

Figure 36 Indoor vs. Outdoor Temperature fluctuation comparison between site and simulation data for 10th to 15th May (Source: Author) See appendices 8 and 10

5.2. Comparative analysis of base case and design cases

Selecting variables and constants for design cases based on site study analysis.

Table 9 Selection criteria of variables and constants for design cases (Source: Author)

	Variables	Dependent upon	For Simulation purpose
	House Plans	Site/Owner/ earthquake resilience	Constant – Verandah+2 Rooms
	Window and door frame and Shutter	Availability/Durability/ Affordability	Constant – Precast RCC frame aluminum casement window. wooden block board door shutter
	Flooring	Availability/Durability/ Affordability	Constant - Tiles – 2x2 feet ceramic
	Massing	Owner requirements	Constant - Ground floor structure
	WWR & shading device	Daylight, Ventilation, solar access requirements as per the climate.	Constant - case study WWR is appropriate.
	Orientation		
1	East West	Site consideration	Variable
2	North South	Solar consideration	Variable
3	Northeast-Southwest	Wind consideration	Variable
	Wall types	AKPBSI construction standards	
1	Limestone / Bela stone units		Variable
2	CSEB	Availability/Durability/ Affordability/ Aesthetics Climate Type Indian Standards Code	Variable
3	Brick wall		Variable
4	Brick Cavity Wall		Variable
	Roof types		
1	RCC+IPS		Variable
2	RCC+Thermocol		Variable
3	Double Roof		Variable
4	Filler Slab		Variable

Description of variables and annual comfort hours for 16 cases.

Table 10 Description of variables for Simulation (Source: Author)

	Material	Thickness	U value (W/m2 K)
Wall	**I.S. Code Standard** (Nayak & Prajapati, 2006)		**2.91**
Base Case **W1 - Variable - Stone**	1" external plaster+9" Bela stone (local limestone)+ 0.5" plaster+ 1" mortar and tile internally	11.5"	2.40
W2 - Variable - CSEB	1" external plaster+ 9.5" Compressed Stabilized Earth blocks (CSEB)+ 0.5" internal plaster	11"	1.64
W3 - Variable - Brick	1" external plaster+ 9" Brick + 0.5" internal plaster	10.5"	1.95
W4 - Variable - Cavity wall	1" external plaster+ 4" Brick + 2" air gap+ 4" Brick+0.5" internal plaster	11.5"	1.51
Roof	**I.S. Code Standard** (Nayak & Prajapati, 2006)		**2.33**
Base Case **R1 –Variable - RCC**	4.5" RCC+ 1" Screed (IPS)	5.5"	3.2
R2 - Variable - RCC+ Thermocol	4.5" RCC+ 1.5" Thermocol + 1" Screed	7"	0.71
R3 -Variable - RCC+false Ceiling	4.5" RCC + 2" Air gap+ 0.5" false ceiling	7"	1.77
R4 -Variable - Filler slab	5" Filler Slab (RCC and tiles) + 3"BBC and 1" screed	9"	2.26

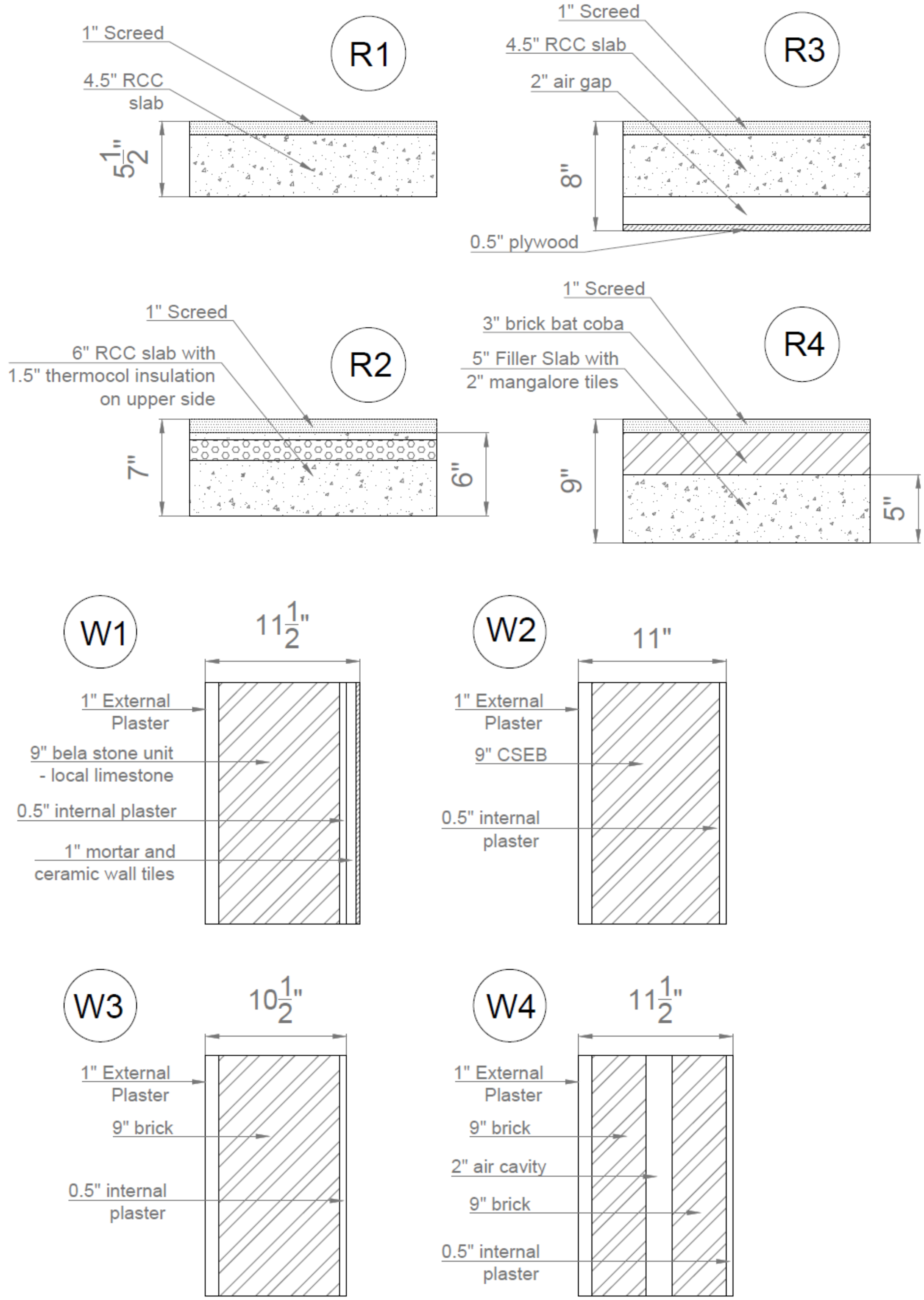


Figure 37 Description of Variables - Walls and roof sections (Source: Author)

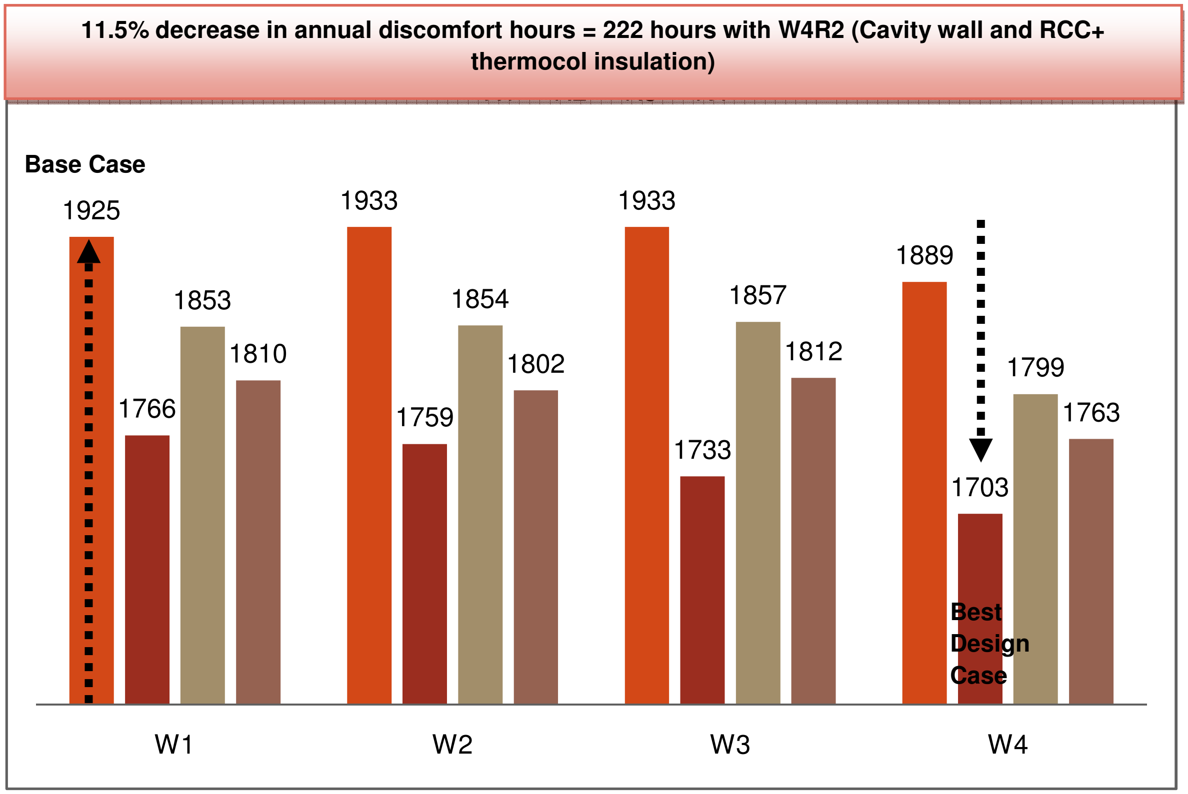


Figure 38 Comparative analysis of annual discomfort hours for all cases (Source: Author) see appendix 11

Wall	Analysis of Graph in Figure 37
Base Case W1 - Variable - Stone	• There is only 2.6% reduction in discomfort on an average with variation in wall type from cavity wall performing better than Brick, CSEB and limestone wall. • Roof material has a more significant impact on reducing discomfort than wall materials. • There is 9% average reduction in discomfort hours with variation in roof type from thermocol insulated RCC roof performing better than filler slab which is performing better than False ceiling under RCC roof compared to the base case RCC slab. • Best wall type = W4 - Variable - Cavity wall • Best roof type = R3 - Variable - RCC+ Thermocol.
W2 - Variable - CSEB	
W3 - Variable - Brick	
W4 - Variable - Cavity wall	
Roof	
Base Case R1 –Variable - RCC	
R2 - Variable - RCC+ Thermocol	
R3 -Variable - RCC+false Ceiling	
R4 -Variable - Filler slab	

Base case and Best design Case (Cavity wall and RCC+ thermocol insulation) comparative analysis with site, solar and wind orientations that is East-West, North South, Northeast-Southwest.

Table 11 Monthly discomfort hours and percentage for base case and best design case (Source: Author) see appendix 11

MONTHS	Base Case East-West Orientation	Best Design Case East-West Orientation	Best Design Case North-South Orientation	Best Design Case Northeast-Southwest Orientation
	Hours	Hours	Hours	Hours
JANUARY	385	432	437	433
FEBRUARY	163	196	198	196
MARCH	55	43	46	44
APRIL	75	43	44	43
MAY	350	245	246	246
JUNE	413	323	322	322
JULY	150	124	124	124
AUGUST	0	0	0	0
SEPTEMBER	45	24	24	24
OCTOBER	90	46	53	48
NOVEMBER	5	4	5	4
DECEMBER	194	223	225	223
Total	1925	1703	1724	1707

Total Comfort hours = 8760-1703 = 7057 hours = 80.5% hours annually.

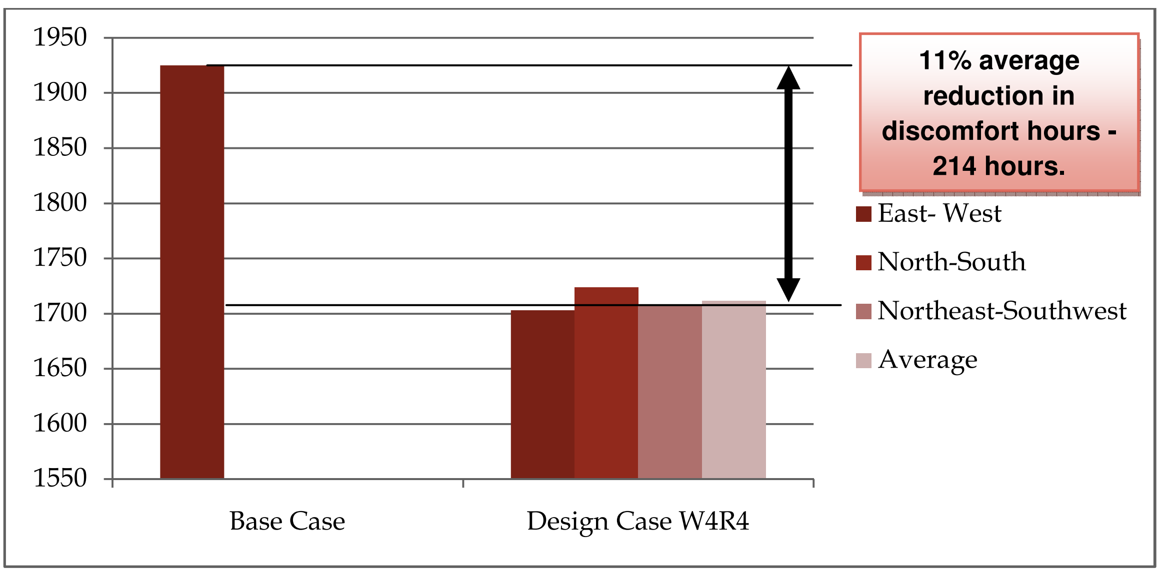


Figure 39 Graph showing reduction in discomfort hours (Source: Author) see appendix 11

The change in orientation is not making any significant difference in comfort conditions. Since the houses under consideration are naturally ventilated the preferred orientation is the wind orientation that is East-west and Northeast-Southwest and then the solar orientation North-South.

The Psychrometric Chart for Jamnagar in Figure 13 shows that only 70% hours are comfortable indoors with passive strategies. Appropriate WWR, orientation and envelope design has increased the comfort hours by 10.5% making 7057 hours that is 80.5% hours comfortable annually as seen in figure 38 and table 11.

CHAPTER 6

CONCLUSION

6. Conclusion

Chapter 6 provides recommendations of a solution set of optimized passive design strategies for rural houses built by AKPBSI in Saurashtra region. It also discusses the possibilities of further research on a similar topic for which this research would act as a source of primary data.

6.1. Solution Set

The solution set has been derived with the analysis of literature review, site study and simulation study as a guideline for bioclimatic design of rural housing in Saurashtra in general and disaster resilient housing by AKPBSI in particular.

Table 12 Solution set of Passive design strategies (Source: Author)

	Design aspect	Features	Effect
1	**Orientation**	1. Building with longer facades facing A. Northeast - Southwest; East-West B. North - South	Increase exposure to the prevailing wind direction for breeze penetration. Reduce sun exposure.
2	**Layout and Spacing**	2. Open spacing to allow cross ventilation indoors but protection from cold/hot wind 3. Spread out detached housing, low rise medium density.	Mutual shading and good potential for cross ventilation
3	**Air movement**	4. Double banked rooms with temporary provision for air movement.	Comfort ventilation
4	**Walls**	5. Heavy external and internal walls 6. Cavity wall construction. 7. Light colored whitewash or distemper applied on the exposed side of the wall. 8. In warm and humid regions, they should not exceed **2.91** W/m2-K as per Indian Standard I.S. code 3792 – 1978 (Nayak & Prajapati, 2006)	Minimize heat gain in summer.
5	**Roof**	9. Heavy roof with over 8 hours time lag. 10. Massive roof such as reinforced cement concrete (RCC) slab compared to lighter roofs such as asbestos cement sheet roofing. 11. As per Indian Standard I.S. code 3792 – 1978, maximum value of overall thermal transmittance (U-value) of a roof should not exceed **2.33 W/m2-K** in hot-dry, and warm and humid climates.	Delays the transmission of heat into the interior rooms. Increases surface reflectivity and reduces heat gain

		12. A false ceiling of insulation material below the roofs with air gaps in between. 13. Water proofing with brick bat coba and finishing with shining and reflecting material like glazed china mosaic on top of the roof. (Nayak & Prajapati, 2006) 14. Filler slab or polyethylene insulated RCC roof.	
6	**Openings**	15. Medium openings that is WWR - 20-40% on North and South Walls. 16. Avoiding openings on west walls.	Reduce direct solar heat gain, optimized day light and comfort ventilation.
7	**Spatial Organization**	17. Hierarchy of spaces like Front yard (Open), Verandah (semi-open) and multipurpose rooms (enclosed). 18. Space for outdoor sleeping like front yard and terraces is possible due to occupant lifestyle.	Flexible spaces that can be used depending upon activity, seasons and time of the day provide comfort throughout the year.
8	**Shading**	19. 45 cm horizontal overhang for windows. 20. Deciduous trees with high canopies and climbers to shade walls, outdoor open space and improve the microclimate condition around the building.	Block summer sun and allow winter sun for passive solar heating. Reducing solar heat gain and lower the building's skin temperature and also conductive and infiltration heat gain
9	**House form**	21. High ceiling with ventilators for night time cooling. 22. Chowks and courtyards also create air movement due to stack ventilation in absence of higher wind speeds. 23. Balconies and verandah for shading and catching wind.	Pre-cooling the indoors for lower next day temperatures indoors. Comfort ventilation
10	**External material and finishes**	24. Pale colors for exterior floor finish. 25. Ground cover using plants.	Reduces reflected solar radiation and glare

The adaptation to a warming world as an impact of climate change is essential along with reducing the energy demands for cooling through passive design. Design strategies that are essential in preparing the built environment to adapt to climate change (Wilson & Ward, 2009).

Design for Safety

- Avoid building in flood zones.
- Expand storm water management capacity and rely on natural systems.
- Design buildings to survive extreme winds.
- Raise buildings off the ground.
- Specify materials that can survive flooding.
- Install specialized components to protect buildings from flooding or allow flooding with minimal damage.
- Elevate mechanical and electrical equipment.
- Begin planning for rising sea levels in coastal areas.

Design for Resource Management

- Avoid new development in the driest regions.
- Specify water-efficient fixtures and appliances.
- Plumb buildings for gray water separation.
- Harvest rainwater.
- Plant native, climatically appropriate trees and other vegetation.
- Provide site-generated electricity from renewable energy.
- Provide solar hot water.
- Plan and zone communities to maintain functionality without power (Wilson & Ward, 2009).

6.2. Further research

Using passive design strategies of better envelope (walls and roof) and better orientation 80.5% comfort hours are achieved. A validation of the envelope and WWR suggested as a solution set with on site measurements of temperature and air velocity in all rooms can be done to verify the actual impact of the strategies. The energy use of the dwelling can be studied to add a list of low-cost active design strategies to the solution set and quantify the improvement in comfort conditions as a result of these.

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Appendices

1. Mahoney Table (Koenigsberger, 1975)

TABLE 1 - PART 1 AIR TEMPERATURE: °C

	J	F	M	A	M	J	J	A	S	O	N	D
MONTHLY MEAN MAX												
MONTHLY MEAN MIN												
MONTHLY MEAN RANGE												

TABLE 1 - PART 2 RELATIVE HUMIDITY %

	J	F	M	A	M	J	J	A	S	O	N	D	AMT
MONTHLY MEAN MAX													
MONTHLY MEAN MIN													
MONTHLY AVERAGE													
HUMIDITY GROUP													

RAIN AND WIND

	J	F	M	A	M	J	J	A	S	O	N	D	TOTAL
RAINFALL													
WIND PREVAILING													
WIND SECONDARY													

TABLE 2 - PART 1 DIAGNOSIS

	J	F	M	A	M	J	J	A	S	O	N	D
MONTHLY MEAN MAX												
DAY COMFORT - UPPER												
DAY COMFORT - LOWER												
MONTHLY MEAN MIN												
NIGHT COMFORT - UPPER												
NIGHT COMFORT - LOWER												
THERMAL STRESS - DAY												
THERMAL STRESS - NIGHT												

TABLE 2 - PART 2 INDICATORS

HUMID	J	F	M	A	M	J	J	A	S	O	N	D
H1 (Air Movement essential)												
H2 (Air Movement Desirable)												
H3 (Rain Protection)												
A1 (Thermal Storage)												
A2 (Out Door Sleeping)												
A3 (Cold Season problems)												

TABLE 3			**SKETCH DESIGN RECOMMENDATIONS**				
INDICATOR TOTALS FROM TABLE 2 - Part 2							**Recommendations**
H1			A1				
H1	H2	H3	A1	A2	A3		
							LAYOUT
			0-10		5-12		1. Building Oriented on east-west axis to reduce exposure to sun
			11 or 12		0-4		2. Compact Courtyard Planning
							SPACING
11 or 12							3. Open Spacing for Breeze penetration
2-10							4. As 3, but protect from cold/hot wind
0 or 1							5. Compact planning
							AIR MOVEMENT
3-12			0-5				6. Rooms single banked. Permanent provision for air movement
1 or 2	2-12		6-12				7. double banked rooms with temporary provision for air movement
0	0 or 1						8. No air movement required
							OPENINGS
			0 or 1		0		9. Large openings, 40-80% of n and S walls
			11 or 12		0 or 1		10. Very Small openings 10-20%
							11. Medium openings 20-40%
							WALLS
			0-2				12. Light Walls; short time lag
			3-12				13. Heavy external and internal walls
							ROOFS
			0-5				14. Light Insulated roofs
			6-12				15. heavy roofs; over 8 Hours time lag
							OUTDOOR SLEEPING
				2-12			16. Space for outdoor sleeping
							RAIN PROTECTION
			3-12				17. Protection from heavy rain needed

Reference tables for Mahoney tables 1,2,3

Humidity Group for Mahoney Table 1 - Part 2

Humidity Group	1	If average RH:	Below 30%
	2		30-50%
	3		50-70%
	4		Above 70%

Comfort limits based on AMT and humidity groups for Mahoney Table 2 - Part 1

		AMT over 20°C		AMT 15-20°C		AMT below 15°C	
Comfort Limits		Day	Night	Day	Night	Day	Night
Humidity Group	1	26-34	17-25	23-32	14-23	21-30	12-21
	2	25-31	14-24	22-30	14-22	20-27	12-20
	3	23-29	17-23	21-28	14-21	19-26	12-19
	4	22-27	17-21	20-25	14-20	18-24	12-18

Indicator selection table for Mahoney Table 2 - Part 2

Applicable when	Indicator	Thermal stress		Rainfall	Humidity group	Monthly mean range
MEANING:		Day	Night			
Air movement essential	H1	H			4	
		H			2,3	Less than 10°
Air movement desirable	H2	O			4	
Rain protection necessary	H3			Over 200 mm		
Thermal capacity necessary	A1				1,2,3	More than 10°
Outdoor sleeping desirable	A2		H		1,2	
		H	O		1,2	More than 10°
Protection from cold	A3	C				

2. Interview Schedule (Source: Auhor)

INTERVIEW SCHEDULE Page 1		DATE		TIME		LIST NO.
1	**House and Usability**					
1.1	How long have you lived in the house?	< 1 year	1-2 years	2-5 years	5+	
1.2	How many people are residing in the house?	1 to 2 persons	3 to 4	5 to 6	6+	
1.3	How much time do you spend in the house?	10 hours	14	18	24	
	What time and for what activities are the following spaces used?	Verandah	Room 1	Room 2	Terrace / Frontyard	
1.4	TIME	Morning Afternoon Evening Night	Morning Afternoon Evening Night	Morning Afternoon Evening Night	Morning Afternoon Evening Night	
1.5	ACTIVITY - 1.Socializing. 2.Resting/Sleeping. 3.Studying/Reading. 4.Household. 5.Eating 6.Playing. 7. Others					
2	**Construction**					
2.1	What type of Roof is preferred by you and why?	Sloping	Flat	Other	Durability Aesthetics Availability Affordability	
2.2	What type of flooring is preferred by you and why?	IPS	Ceramic/ Vitrified Tile	Kota/Natural Stone	Durability Aesthetics Availability Affordability	
2.3	What type of Window is preferred by you and why?	Wooden Frame	Precast Frame	Marble/Granite Frame with aluminum sliding window	Durability Aesthetics Availability Affordability	
2.4	What type of wall finish is preferred by you and why?	Mud Plaster	Cement Plaster	Others	Durability Aesthetics Availability Affordability	
3	**Daylight**					
3.1	Is the day light enough during the day in the following rooms?	Kitchen	Verandah	Room 1	Room 2	
3.2	Which spaces require artificial light during the day?	Kitchen	Verandah	Room 1	Room 2	

INTERVIEW SCHEDULE Page 2		DATE		TIME		LIST NO.
4	**Thermal Comfort**					
4.1	Which part of the day is the most comfortable?	Morning 6 am to11 am	Afternoon 11 am to 4 pm	Evening 4 pm to 9 pm	Night 9 pm to 6 am	
4.2	Which is the most comfortable season inside the house?	Summer March to May	Monsoon June to September	Post Monsoon October-November	Winter December to February	
4.3	When is it more comfortable outside the house?	Morning 6 am to11 am	Afternoon 11 am to 4 pm	Evening 4 pm to 9 pm	Night 9 pm to 6 am	
4.4	Does your house have any mechanical means of creating controlled climate? If yes then what are the means, what time of the day do you use it?	Fan Morning Afternoon Evening Night	Cooler Morning Afternoon Evening Night	A.C. Morning Afternoon Evening Night	Others Morning Afternoon Evening Night	
5	**Thermal Discomfort & Adaptability**					
5.1	What is the most uncomfortable element?	Temperature/ Heat	Humidity/ Sweat	Air Movement/ Breeze	Rain	
5.2	Which is the most uncomfortable season during the year?	Summer March to May	Monsoon June to September	Post Monsoon October-November	Winter December to February	
5.3	Which part of the day is the most uncomfortable?	Morning 6 am to11 am	Afternoon 11 am to 4 pm	Evening 4 pm to 9 pm	Night 9 pm to 6 am	
5.4	What do you do to overcome it?	Open windows	Use Fan	Shut the windows	Other	
5.5	What changes have you made to the house to make it more comfortable?					
6	**Satisfaction**					
6.1	How satified are you with your new house	Very Satisfied	Satisfied	Not Satisfied	Reasons	

3. Calibration certificate of instruments (Source: Auhor)

CALIBRATION LABORATORY FOR ELECTRO-TECHNICAL, TEMPERATURE, MECHANICAL-DIMENSIONAL & PRESSURE INSTRUMENTS, TORQUE, MASS & VOLUME

- MOBILE : 9921102900, 9822001300, 9225603898
- E-MAIL : universalinstru@vsnl.net
- Web : www.universalinstruments.co.in

NABL C-1113 C-1116 C-1117

Universal Instruments (TM)

AKSHAY COMPLEX, THERMAX CHOWK SAMBHAJINAGAR, PLOT NO. G/P-64, 'G' BLOCK, M.I.D.C., CHINCHWAD, PUNE - 411019.

CALIBRATION CERTIFICATE

01 of 01

Calibrated For:	SANA DHARANI 701-702,ROYAL MANOR, ST ROQUE ROAD,BANDRA (WEST), MUMBAI-400 050, Maharashtra,India	Certificate No. Date Of Calibration Calibration Due on Received Dt & Condition Calibrated at	: UI/160503/4/002 : 03.05.2016 : 02.05.2017 : 03.05.2016 / GOOD : Universal Instruments Lab

DETAILS OF UNIT UNDER CALIBRATION

Nomenclature	: DIG.HUMIDITY & TEMP METER	Id. No.	: --
Make	: HTC		
Sr. No.	: 201404177		

Environmental Conditions:- Temperature - (25 ± 4)°C & Humidity(RH) - (50± 20)%

PARAMETERS FOR CALIBRATION

Sr No	Parameter	Range	Least Count	Accuracy
1	TEMPERATURE	-40 TO 70 ° C	0.1 °C	± 1 °C
2	HUMIDITY	0 TO 100 % RH	0.1 % RH	± 3 % RH

STANDARD USED FOR CALIBRATION

Sr. No.	Instrument Sr. No./Name	Certificate No.	Calibrated by	Validity
1	TH758012015 (HUMIDITY & TEMP. INDICATOR)	5015163	BELZ CALIBRATION LAB	22/02/2017

OBSERVATIONS

1) TEMPERATURE

S. No.	Master Instruments (° C)	Unit Under Calibration (° C)	Error in ° C	Expanded Uncertainty of measurement at 95 % CL k=2,(± ° C)
1	25.4	25.9	0.50	0.32

2) HUMIDITY @ 25 °C

S. No.	Master Instruments (%RH)	Unit Under Calibration (% RH)	Error in %RH	Expanded Uncertainty of measurement at 95 % CL k=2,(± % RH)
1	40.1	39.2	-0.90	3.09

Calibration procedure no. : T-09

Remarks : 1) Overall deviation is within specified accuracy.
2) All Measurements standards used for calibration are traceable to National Standards with unbroken chain.

Calibrated By : (Cal. Engg .)

Approved By : K. M. Bhosale (Technical Manager)

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AKSHAY COMPLEX, THERMAX CHOWK
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CALIBRATION CERTIFICATE

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Calibrated For:	SANA DHARANI 701-702,ROYAL MANOR, ST ROQUE ROAD,BANDRA (WEST), MUMBAI-400 050, Maharashtra,India	Certificate No. Date Of Calibration Calibration Due on Received Dt & Condition Calibrated at	: UI/160503/4/001 : 03.05.2016 : 02.05.2017 : 03.05.2016 / GOOD : Universal Instruments Lab

DETAILS OF UNIT UNDER CALIBRATION

Nomenclature : DIG.HUMIDITY & TEMP METER Id. No. : --
Make : HTC
Sr. No. : 201404184

Environmental Conditions:- Temperature - (25 ± 4)°C & Humidity(RH) - (50± 20)%

PARAMETERS FOR CALIBRATION

Sr No	Parameter	Range	Least Count	Accuracy
1	TEMPERATURE	-40 TO 70 ° C	0.1 °C	± 1 °C
2	HUMIDITY	0 TO 100 % RH	0.1 % RH	± 3 % RH

STANDARD USED FOR CALIBRATION

Sr. No.	Instrument Sr. No./Name	Certificate No.	Calibrated by	Validity
1	TH758012015 (HUMIDITY & TEMP. INDICATOR)	5015163	BELZ CALIBRATION LAB	22/02/2017

OBSERVATIONS

1) TEMPERATURE

S. No.	Master Instruments (° C)	Unit Under Calibration (° C)	Error in ° C	Expanded Uncertainty of measurement at 95 % CL k=2,(± ° C)
1	25.2	25.9	0.70	0.32

2) HUMIDITY @ 25 °C

S. No.	Master Instruments (%RH)	Unit Under Calibration (% RH)	Error in %RH	Expanded Uncertainty of measurement at 95 % CL k=2,(± % RH)
1	37.8	39.8	2.00	3.09

Calibration procedure no. : T-09

Remarks : 1) Overall deviation is within specified accuracy.
2) All Measurements standards used for calibration are traceable to National Standards with unbroken chain.

Calibrated By : Nagtap
(Cal. Engg .)

Approved By :
K. M. Bhosale
(Technical Manager)

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DETAILS OF UNIT UNDER CALIBRATION

Nomenclature	: DIG.LUX METER	Id. No.	: --
Make	: HTC	Range	: 0 TO 200000 LUX
Sr. No.	: 2107489	Least Count	: 0.1 LUX (0 TO 199.9 LUX) 10 LUX (2000 TO 19990 LUX) 100 LUX (20000 TO 200000 LUX)
		Accuracy	: ± 4 % RDG + 0.5 %FS

Environmental Conditions:- Temperature - (25 ± 4) °C & Humidity(RH) - (50± 20)%

STANDARD USED FOR CALIBRATION

Sr. No.	Instrument Sr. No./Name	Certificate No.	Calibrated by	Validity
1	051106789 (Dig. Lux Meter)	PTH/E/15-16/C-011	PILOT TEST HOUSE, MUMBAI	14/10/2016

OBSERVATIONS

S. No.	Master Instruments (LUX)	Unit Under Calibration (LUX)	Error in % RDG
1	117.3	117.2	-0.085
2	351	350	-0.285
3	529	527	-0.378
4	793	790	-0.378
5	915	912	-0.328
6	1191	1187	-0.336
7	1325	1320	-0.377
8	1531	1525	-0.392
9	1755	1749	-0.342
10	1934	1925	-0.465

Calibration procedure used : ET-26

Remarks : 1) Measured values have been reported.
2)Expanded Uncertainty of measurement : ± 1.58 Lux at approximately 95 % CL, k=2
3) All Measurements standards used for calibration are traceable to National Standards with unbroken chain.

Calibrated By : (Cal. Engg.)

Approved By : K. M. Bhosale (Technical Manager)

4. Sun angles for 21st June and 22nd December (Source:Auhor)

Tabulated Daily Solar Data

Latitude: 22.5°
Longitude: 70.1°
Timezone: 82.5° [+5.5hrs]
Orientation: 0.0°

Date: 21st June
Julian Date: 172
Sunrise: 06:09
Sunset: 19:32

Local Correction: -51.2 mins
Equation of Time: -1.6 mins
Declination: 23.4°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA
06:30	(05:38)	66.4°	4.2°	66.4°	10.5°
07:00	(06:08)	68.9°	10.7°	68.9°	27.6°
07:30	(06:38)	71.2°	17.2°	71.2°	43.8°
08:00	(07:08)	73.3°	23.8°	73.3°	56.8°
08:30	(07:38)	75.2°	30.4°	75.2°	66.5°
09:00	(08:08)	76.9°	37.2°	76.9°	73.4°
09:30	(08:38)	78.5°	43.9°	78.5°	78.3°
10:00	(09:08)	80.0°	50.7°	80.0°	81.9°
10:30	(09:38)	81.3°	57.6°	81.3°	84.5°
11:00	(10:08)	82.4°	64.4°	82.4°	86.4°
11:30	(10:38)	83.2°	71.3°	83.2°	87.7°
12:00	(11:08)	83.0°	78.2°	83.0°	88.5°
12:30	(11:38)	78.1°	85.0°	78.1°	89.0°
13:00	(12:08)	-64.8°	87.8°	-64.8°	89.0°
13:30	(12:38)	-82.1°	81.0°	-82.1°	88.8°
14:00	(13:08)	-83.3°	74.1°	-83.3°	88.1°
14:30	(13:38)	-82.8°	67.3°	-82.8°	87.0°
15:00	(14:08)	-81.8°	60.4°	-81.8°	85.4°
15:30	(14:38)	-80.6°	53.5°	-80.6°	83.1°
16:00	(15:08)	-79.2°	46.7°	-79.2°	80.0°
16:30	(15:38)	-77.6°	39.9°	-77.6°	75.6°
17:00	(16:08)	-75.9°	33.2°	-75.9°	69.6°
17:30	(16:38)	-74.1°	26.5°	-74.1°	61.2°
18:00	(17:08)	-72.1°	19.9°	-72.1°	49.6°
18:30	(17:38)	-69.9°	13.3°	-69.9°	34.5°
19:00	(18:08)	-67.4°	6.9°	-67.4°	17.4°
19:30	(18:38)	-64.7°	0.5°	-64.7°	1.2°

Figure 40 21st June Solar data for Jamnagar from ECOTECT 2011

Tabulated Daily Solar Data

Latitude: 22.5°
Longitude: 70.1°
Timezone: 82.5° [+5.5hrs]
Orientation: 0.0°

Date: 22nd December
Julian Date: 356
Sunrise: 07:29
Sunset: 18:06

Local Correction: -48.0 mins
Equation of Time: 1.6 mins
Declination: -23.5°

Local	(Solar)	Aziumuth	Altitude	HSA	VSA
07:30	(06:42)	115.6°	0.1°	115.6°	179.7°
08:00	(07:12)	118.7°	6.3°	118.7°	167.1°
08:30	(07:42)	122.1°	12.3°	122.1°	157.8°
09:00	(08:12)	126.0°	18.0°	126.0°	151.1°
09:30	(08:42)	130.5°	23.4°	130.5°	146.3°
10:00	(09:12)	135.7°	28.5°	135.7°	142.8°
10:30	(09:42)	141.7°	33.1°	141.7°	140.3°
11:00	(10:12)	148.6°	37.1°	148.6°	138.5°
11:30	(10:42)	156.3°	40.3°	156.3°	137.2°
12:00	(11:12)	165.0°	42.6°	165.0°	136.4°
12:30	(11:42)	174.3°	43.8°	174.3°	136.0°
13:00	(12:12)	-176.2°	43.9°	-176.2°	136.0°
13:30	(12:42)	-166.8°	42.9°	-166.8°	136.3°
14:00	(13:12)	-158.0°	40.8°	-158.0°	137.1°
14:30	(13:42)	-150.0°	37.8°	-150.0°	138.2°
15:00	(14:12)	-143.0°	33.9°	-143.0°	139.9°
15:30	(14:42)	-136.8°	29.5°	-136.8°	142.2°
16:00	(15:12)	-131.5°	24.5°	-131.5°	145.5°
16:30	(15:42)	-126.9°	19.1°	-126.9°	150.0°
17:00	(16:12)	-122.8°	13.4°	-122.8°	156.2°
17:30	(16:42)	-119.3°	7.5°	-119.3°	165.0°
18:00	(17:12)	-116.2°	1.4°	-116.2°	176.9°

Figure 41 22nd December Solar data for Jamnagar from ECOTECT 2011

Table 13 HSA and VSA angles for all orientations for 21st June

21st JUNE - ECOTECT			North wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	76.9	37.2	76.9	73.4
11:00	82.4	64.4	82.4	86.4
13:00	-64.8	87.8	-64.8	89.1
15:00	-81.8	60.4	-81.8	85.4
17:00	-75.9	33.2	-75.9	69.6
21st JUNE - ECOTECT			East wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	76.9	37.2	-13.1	37.9
11:00	82.4	64.4	-7.6	64.6
13:00	-64.8	87.8	-154.8	-88.0
15:00	-81.8	60.4	-171.8	-60.7
17:00	-75.9	33.2	-165.9	-34.0
21st JUNE - ECOTECT			South wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	76.9	37.2	-103.1	-73.4
11:00	82.4	64.4	-97.6	-86.4
13:00	-64.8	87.8	-244.8	-89.1
15:00	-81.8	60.4	-261.8	-85.4
17:00	-75.9	33.2	-255.9	-69.6
21st JUNE - ECOTECT			West wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	76.9	37.2	166.9	-37.9
11:00	82.4	64.4	172.4	-64.6
13:00	-64.8	87.8	25.2	88.0
15:00	-81.8	60.4	8.2	60.7
17:00	-75.9	33.2	14.1	34.0

Table 14 HSA and VSA angles for all orientations for 22nd December June

22nd DECEMBER - ECOTECT			North wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	126	18	126	-28.93
11:00	148.6	37.1	148.6	-41.54
13:00	-176.2	43.9	-176.2	-43.96
15:00	-143	33.9	-143	-40.08
17:00	-122.8	13.4	-122.8	-23.74
22nd DECEMBER - ECOTECT			East wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	126	18	36	21.88
11:00	148.6	37.1	58.6	55.44
13:00	-176.2	43.9	-266.2	-86.06
15:00	-143	33.9	-233	-48.15
17:00	-122.8	13.4	-212.8	-15.82
22nd DECEMBER - ECOTECT			South wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	126	18	-54	28.93
11:00	148.6	37.1	-31.4	41.54
13:00	-176.2	43.9	-356.2	43.96
15:00	-143	33.9	-323	40.08
17:00	-122.8	13.4	-302.8	23.74
22nd DECEMBER - ECOTECT			West wall	
TIME	Solar Azimuth IN DEGREES	Solar Altitude IN DEGREES	H.S.A. IN DEGREES	V.S.A. IN DEGREES
9:00	126	18	216	-21.88
11:00	148.6	37.1	238.6	-55.44
13:00	-176.2	43.9	-86.2	86.06
15:00	-143	33.9	-53	48.15
17:00	-122.8	13.4	-32.8	15.82

5. Monthly upper and lower air temperature comfort limits for Jamnagar

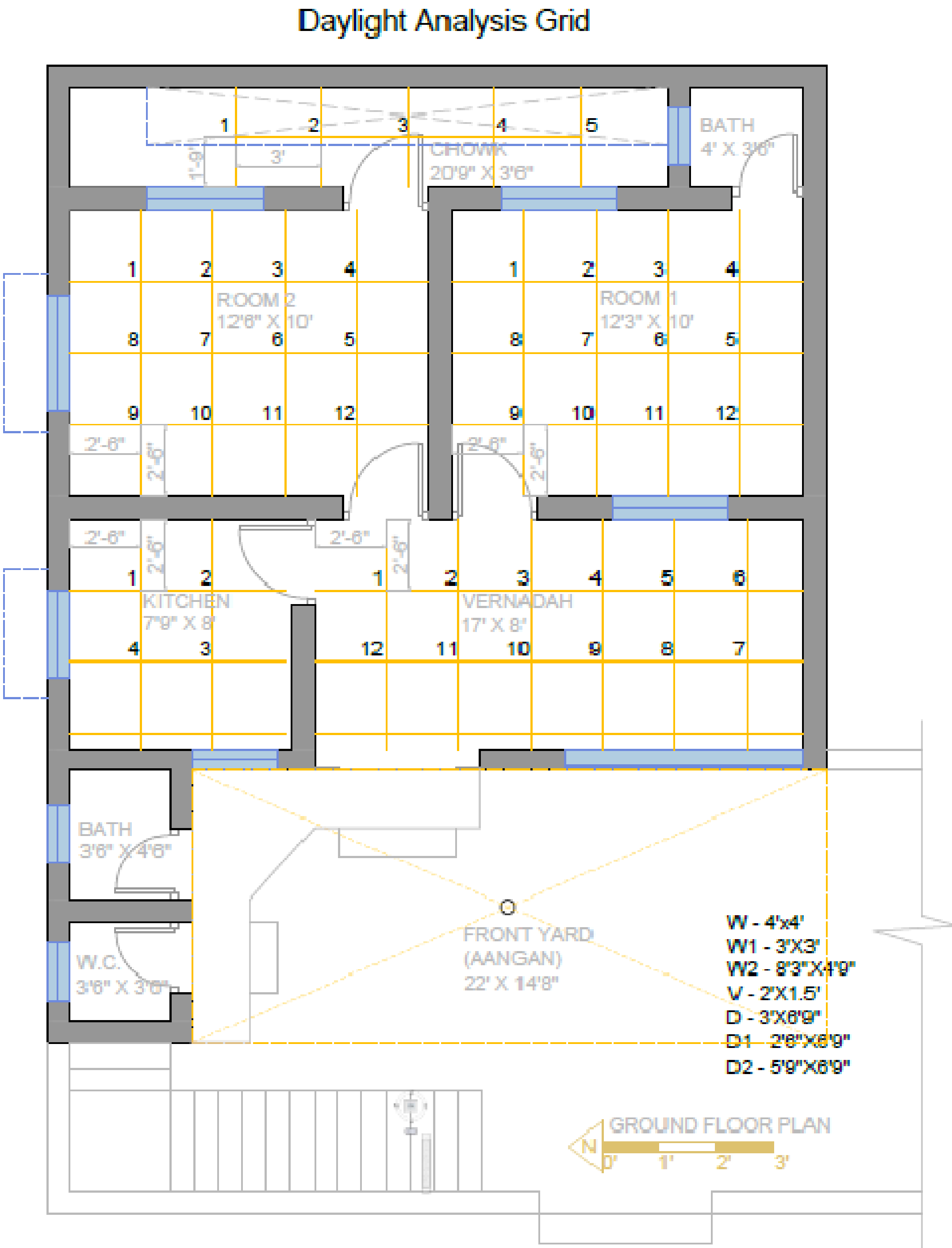
MONTHS	Air temperatures for 90% ACCEPTIBILITY for Naturally Ventilated buildings Adaptive Thermal Comfort IMAC 2014 model by Center for Advanced Research in Building Science, CEPT	
	Upper limit in degrees	Lower
JANUARY	25.57	**20.81**
FEBRUARY	25.77	21.01
MARCH	27.24	22.48
APRIL	29.26	24.5
MAY	30.79	26.03
JUNE	**31.58**	26.82
JULY	31.26	26.5
AUGUST	30.36	25.6
SEPTEMBER	29.99	25.23
OCTOBER	30.25	25.49
NOVEMBER	29.09	24.33
DECEMBER	27.16	22.4

Annual comfort band = 20.81°C to 31.6°C

6. Monthly outdoor wind velocity at site

MONTHS	OUTDOOR avg. WIND SPEED from Climate Consultant 5.5	OUTDOOR WIND SPEED at 8' factor = 0.65 ((Brown & DeKay, 2001) pg. 15)
JANUARY	3	1.95
FEBRUARY	2	1.3
MARCH	3	1.95
APRIL	5	3.25
MAY	6	3.9
JUNE	8	5.2
JULY	6	3.9
AUGUST	5	3.25
SEPTEMBER	4	2.6
OCTOBER	2	1.3
NOVEMBER	2	1.3
DECEMBER	3	1.95
Average	4.1	**3.0**

7. Daylight log sheet and readings on Grid



Log sheet for recording lux levels			
Verandah		**Room 1**	
Point No.	Lux Level	Point No.	Lux Level
1	1400	1	236
2	1360	2	410
3	1550	3	205
4	1760	4	105
5	1620	5	106
6	1700	6	200
7	1820	7	315
8	1920	8	280
9	1720	9	298
10	1500	10	250
11	1900	11	195
12	1900	12	115
Average	**1679**	**Average**	**226**
Kitchen		**Room 2**	
Point No.	Lux Level	Point No.	Lux Level
1	370	1	685
2	330	2	635
3	555	3	750
4	520	4	850
Average	**444**	5	580
Chowk		6	580
1	7380	7	620
2	7750	8	1080
3	7480	9	560
4	7680	10	518
5	6900	11	475
Average	**7438**	12	580
Outdoor	**145000**	**Average**	**659**

8. Hourly RH and temperature data recorded at site

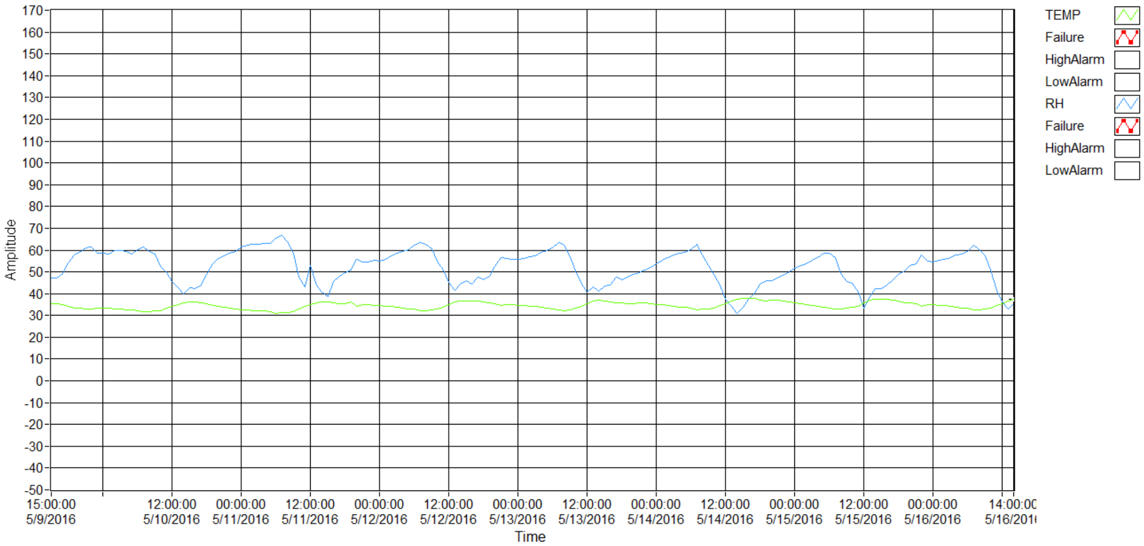


Figure 42 Indoor temperature and humidity recorded at site using data logger

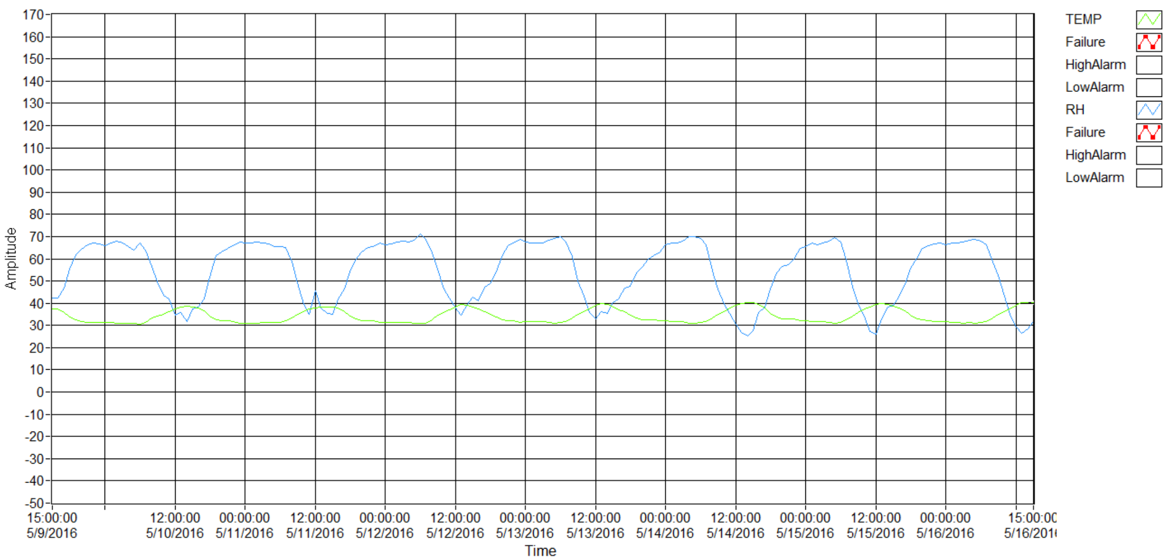


Figure 43 Outdoor temperature and humidity recorded at site using data logger

Table 15 Hourly temperature and humidity recording by indoor data logger

NO	Date and time	RH	Temperature
0	5/9/2016 15:00	47	35.3
1	5/9/2016 16:00	47.2	35.4
2	5/9/2016 17:00	49.2	34.9
3	5/9/2016 18:00	54.2	34
4	5/9/2016 19:00	57.7	33.4
5	5/9/2016 20:00	59.1	33.3
6	5/9/2016 21:00	61	32.8
7	5/9/2016 22:00	61.6	32.8

8	5/9/2016 23:00	58.7	33.5
9	5/10/2016 0:00	58.4	33.4
10	5/10/2016 1:00	58.3	33.2
11	5/10/2016 2:00	60	33
12	5/10/2016 3:00	59.9	32.8
13	5/10/2016 4:00	59.5	32.6
14	5/10/2016 5:00	58.1	32.4
15	5/10/2016 6:00	60.3	32.1
16	5/10/2016 7:00	61.5	31.7
17	5/10/2016 8:00	59.5	31.7
18	5/10/2016 9:00	58.1	32
19	5/10/2016 10:00	52.4	32.3
20	5/10/2016 11:00	49.5	33.4
21	5/10/2016 12:00	45.4	34.1
22	5/10/2016 13:00	42.9	35.1
23	5/10/2016 14:00	39.7	35.8
24	5/10/2016 15:00	42.8	36.1
25	5/10/2016 16:00	42.4	36.2
26	5/10/2016 17:00	43.9	35.7
27	5/10/2016 18:00	48.9	35.4
28	5/10/2016 19:00	53.6	34.7
29	5/10/2016 20:00	56	34.1
30	5/10/2016 21:00	57.4	33.9
31	5/10/2016 22:00	58.7	33.5
32	5/10/2016 23:00	59.5	33.1
33	5/11/2016 0:00	61.6	32.4
34	5/11/2016 1:00	62.3	32.4
35	5/11/2016 2:00	62.7	32.3
36	5/11/2016 3:00	62.8	32.2
37	5/11/2016 4:00	63.1	32
38	5/11/2016 5:00	62.9	31.6
39	5/11/2016 6:00	65.5	30.9
40	5/11/2016 7:00	66.6	31.4
41	5/11/2016 8:00	63.9	31.4
42	5/11/2016 9:00	58.7	31.9
43	5/11/2016 10:00	47.8	32.9
44	5/11/2016 11:00	43.1	34
45	5/11/2016 12:00	52.9	35
46	5/11/2016 13:00	43.9	35.7
47	5/11/2016 14:00	40.6	36.1
48	5/11/2016 15:00	38.6	36.3
49	5/11/2016 16:00	45.7	36
50	5/11/2016 17:00	47.9	35.6

51	5/11/2016 18:00	49.8	35.6
52	5/11/2016 19:00	50.9	36.1
53	5/11/2016 20:00	55.8	34.2
54	5/11/2016 21:00	54.4	35.1
55	5/11/2016 22:00	54.7	35.1
56	5/11/2016 23:00	55.3	34.7
57	5/12/2016 0:00	55.1	34.6
58	5/12/2016 1:00	55.8	34.3
59	5/12/2016 2:00	57.3	34
60	5/12/2016 3:00	58.5	33.7
61	5/12/2016 4:00	59.3	33.4
62	5/12/2016 5:00	60.4	33.1
63	5/12/2016 6:00	62.3	32.8
64	5/12/2016 7:00	63.5	32.1
65	5/12/2016 8:00	62.8	32.2
66	5/12/2016 9:00	60.6	32.6
67	5/12/2016 10:00	54.9	33
68	5/12/2016 11:00	51	33.8
69	5/12/2016 12:00	45	35.1
70	5/12/2016 13:00	41.3	36.2
71	5/12/2016 14:00	44.5	36.7
72	5/12/2016 15:00	46.1	36.8
73	5/12/2016 16:00	44.3	36.6
74	5/12/2016 17:00	47.4	36.5
75	5/12/2016 18:00	46.4	36.1
76	5/12/2016 19:00	48.1	35.7
77	5/12/2016 20:00	52.4	35.3
78	5/12/2016 21:00	56.4	34.6
79	5/12/2016 22:00	56	35
80	5/12/2016 23:00	55.8	34.9
81	5/13/2016 0:00	55.8	34.7
82	5/13/2016 1:00	56.2	34.5
83	5/13/2016 2:00	56.9	34.2
84	5/13/2016 3:00	57.5	34
85	5/13/2016 4:00	59	33.7
86	5/13/2016 5:00	59.8	33.3
87	5/13/2016 6:00	61.2	33.1
88	5/13/2016 7:00	63.6	32.4
89	5/13/2016 8:00	62.2	32.3
90	5/13/2016 9:00	57.1	32.7
91	5/13/2016 10:00	50.3	33.4
92	5/13/2016 11:00	44.4	34.2
93	5/13/2016 12:00	40.8	35.5

94	5/13/2016 13:00	43.3	36.7
95	5/13/2016 14:00	40.9	37.1
96	5/13/2016 15:00	43.7	36.8
97	5/13/2016 16:00	43.9	36.3
98	5/13/2016 17:00	47.8	35.7
99	5/13/2016 18:00	46.4	36
100	5/13/2016 19:00	47.6	35.3
101	5/13/2016 20:00	49	35.5
102	5/13/2016 21:00	49.5	35.8
103	5/13/2016 22:00	50.8	35.7
104	5/13/2016 23:00	51.9	35.4
105	5/14/2016 0:00	53.7	35.1
106	5/14/2016 1:00	55.5	34.8
107	5/14/2016 2:00	56.5	34.5
108	5/14/2016 3:00	57.7	34.2
109	5/14/2016 4:00	58.5	33.8
110	5/14/2016 5:00	59.1	33.6
111	5/14/2016 6:00	60.2	33.3
112	5/14/2016 7:00	62.6	32.5
113	5/14/2016 8:00	57.8	32.9
114	5/14/2016 9:00	52.9	33.1
115	5/14/2016 10:00	48.8	33.3
116	5/14/2016 11:00	44.1	34.4
117	5/14/2016 12:00	37.6	35.6
118	5/14/2016 13:00	34.1	36.5
119	5/14/2016 14:00	31.1	37.3
120	5/14/2016 15:00	33.7	37.7
121	5/14/2016 16:00	37.4	37.8
122	5/14/2016 17:00	40.1	37.9
123	5/14/2016 18:00	44.2	36.9
124	5/14/2016 19:00	45.8	36.5
125	5/14/2016 20:00	46.1	37.1
126	5/14/2016 21:00	47.1	36.9
127	5/14/2016 22:00	48.4	36.6
128	5/14/2016 23:00	50.1	36.2
129	5/15/2016 0:00	51.6	35.9
130	5/15/2016 1:00	52.7	35.5
131	5/15/2016 2:00	53.6	35.1
132	5/15/2016 3:00	55.2	34.7
133	5/15/2016 4:00	56.7	34.3
134	5/15/2016 5:00	58.5	33.9
135	5/15/2016 6:00	58.7	33.5
136	5/15/2016 7:00	56.6	33.1

137	5/15/2016 8:00	49.1	33
138	5/15/2016 9:00	45.6	33.3
139	5/15/2016 10:00	44.6	33.6
140	5/15/2016 11:00	40.8	34.2
141	5/15/2016 12:00	33.2	35.7
142	5/15/2016 13:00	38.8	37
143	5/15/2016 14:00	42.5	37.3
144	5/15/2016 15:00	42.2	37.4
145	5/15/2016 16:00	43.9	37.4
146	5/15/2016 17:00	46.5	37.1
147	5/15/2016 18:00	49	36.6
148	5/15/2016 19:00	50.5	36
149	5/15/2016 20:00	52.8	35.8
150	5/15/2016 21:00	53.9	35.3
151	5/15/2016 22:00	57.6	34.1
152	5/15/2016 23:00	54.8	35
153	5/16/2016 0:00	54.6	34.9
154	5/16/2016 1:00	55.3	34.7
155	5/16/2016 2:00	55.7	34.4
156	5/16/2016 3:00	56.4	34.1
157	5/16/2016 4:00	57.8	33.8
158	5/16/2016 5:00	58.3	33.5
159	5/16/2016 6:00	59.2	33.3
160	5/16/2016 7:00	62.2	32.4
161	5/16/2016 8:00	60.2	32.5
162	5/16/2016 9:00	57.2	32.8
163	5/16/2016 10:00	51	33.4
164	5/16/2016 11:00	41.7	34.5
165	5/16/2016 12:00	36.1	35.5
166	5/16/2016 13:00	33.1	36.6
167	5/16/2016 14:00	35.5	37.4

Table 16 Hourly temperature and humidity recording by outdoor data logger

NO	Date and time	RH	Temperature
0	5/9/2016 15:00	42.4	37.3
1	5/9/2016 16:00	42.4	37.4
2	5/9/2016 17:00	46.8	36
3	5/9/2016 18:00	55.3	33.7
4	5/9/2016 19:00	61.8	32.5
5	5/9/2016 20:00	64.3	31.9
6	5/9/2016 21:00	66.4	31.5
7	5/9/2016 22:00	67.3	31.4

8	5/9/2016 23:00	66.8	31.4
9	5/10/2016 0:00	66	31.5
10	5/10/2016 1:00	67.2	31.2
11	5/10/2016 2:00	68.1	31.1
12	5/10/2016 3:00	67	31
13	5/10/2016 4:00	65.5	31.1
14	5/10/2016 5:00	64	30.8
15	5/10/2016 6:00	67.3	30.4
16	5/10/2016 7:00	63.8	31.5
17	5/10/2016 8:00	56.4	33.2
18	5/10/2016 9:00	49.6	34.1
19	5/10/2016 10:00	43.6	35.1
20	5/10/2016 11:00	41.9	36.3
21	5/10/2016 12:00	34.7	37.3
22	5/10/2016 13:00	35.8	38.1
23	5/10/2016 14:00	31.8	38.8
24	5/10/2016 15:00	37.5	38.3
25	5/10/2016 16:00	38.1	37.8
26	5/10/2016 17:00	41.8	36.7
27	5/10/2016 18:00	51.7	34.3
28	5/10/2016 19:00	61.5	32.6
29	5/10/2016 20:00	63.1	32.2
30	5/10/2016 21:00	64.6	32
31	5/10/2016 22:00	66	31.6
32	5/10/2016 23:00	67.5	31.1
33	5/11/2016 0:00	67.3	31.1
34	5/11/2016 1:00	67.3	31.1
35	5/11/2016 2:00	67.6	31.1
36	5/11/2016 3:00	67	31.2
37	5/11/2016 4:00	66.6	31.3
38	5/11/2016 5:00	65.4	31.2
39	5/11/2016 6:00	65.6	31.3
40	5/11/2016 7:00	65	32
41	5/11/2016 8:00	58.7	33.4
42	5/11/2016 9:00	49.4	35
43	5/11/2016 10:00	39.4	36.2
44	5/11/2016 11:00	34.8	37.6
45	5/11/2016 12:00	45.5	37.9
46	5/11/2016 13:00	37.9	38.1
47	5/11/2016 14:00	35.2	38.2
48	5/11/2016 15:00	35	38.1
49	5/11/2016 16:00	42.1	37.7
50	5/11/2016 17:00	46.5	36.2

51	5/11/2016 18:00	54.2	34
52	5/11/2016 19:00	59.8	32.9
53	5/11/2016 20:00	62.9	32.2
54	5/11/2016 21:00	64.9	32.1
55	5/11/2016 22:00	65.6	32
56	5/11/2016 23:00	67.2	31.4
57	5/12/2016 0:00	66.3	31.5
58	5/12/2016 1:00	66.8	31.5
59	5/12/2016 2:00	67.5	31.5
60	5/12/2016 3:00	68.1	31.3
61	5/12/2016 4:00	67.6	31.4
62	5/12/2016 5:00	68.5	31.1
63	5/12/2016 6:00	71	30.8
64	5/12/2016 7:00	68.8	31.1
65	5/12/2016 8:00	62.7	32.5
66	5/12/2016 9:00	55.3	34.4
67	5/12/2016 10:00	46.4	35.8
68	5/12/2016 11:00	42.3	37.1
69	5/12/2016 12:00	37.7	38.2
70	5/12/2016 13:00	34.7	39.3
71	5/12/2016 14:00	39.3	39
72	5/12/2016 15:00	42.6	38.3
73	5/12/2016 16:00	41	37.6
74	5/12/2016 17:00	47.1	36.4
75	5/12/2016 18:00	48.9	34.9
76	5/12/2016 19:00	54	33.7
77	5/12/2016 20:00	61	32.7
78	5/12/2016 21:00	65.7	32.2
79	5/12/2016 22:00	67	32
80	5/12/2016 23:00	68.8	31.5
81	5/13/2016 0:00	67.7	31.6
82	5/13/2016 1:00	67	31.7
83	5/13/2016 2:00	67.2	31.6
84	5/13/2016 3:00	67.2	31.6
85	5/13/2016 4:00	68.2	31.3
86	5/13/2016 5:00	69.1	31.1
87	5/13/2016 6:00	69.9	31.2
88	5/13/2016 7:00	67.4	31.7
89	5/13/2016 8:00	61	33.2
90	5/13/2016 9:00	50	35
91	5/13/2016 10:00	43.3	36.3
92	5/13/2016 11:00	35.9	37.6
93	5/13/2016 12:00	33.1	39.1

94	5/13/2016 13:00	36.4	39.8
95	5/13/2016 14:00	35.4	39.6
96	5/13/2016 15:00	40.1	38.2
97	5/13/2016 16:00	42.1	37.2
98	5/13/2016 17:00	46.8	36.2
99	5/13/2016 18:00	47.8	34.5
100	5/13/2016 19:00	53.6	33.3
101	5/13/2016 20:00	56.3	32.7
102	5/13/2016 21:00	59.7	32.5
103	5/13/2016 22:00	61.4	32.6
104	5/13/2016 23:00	63.1	32.3
105	5/14/2016 0:00	66.4	32
106	5/14/2016 1:00	67	31.9
107	5/14/2016 2:00	67.3	31.7
108	5/14/2016 3:00	67.9	31.6
109	5/14/2016 4:00	69.9	31
110	5/14/2016 5:00	69.9	30.9
111	5/14/2016 6:00	69.2	31.2
112	5/14/2016 7:00	66.5	31.8
113	5/14/2016 8:00	54.5	33.4
114	5/14/2016 9:00	46.4	35
115	5/14/2016 10:00	39.5	36.4
116	5/14/2016 11:00	35.2	37.8
117	5/14/2016 12:00	30.6	39
118	5/14/2016 13:00	27	39.8
119	5/14/2016 14:00	25.1	40.4
120	5/14/2016 15:00	27.6	40.3
121	5/14/2016 16:00	35.8	39.3
122	5/14/2016 17:00	38.2	37.9
123	5/14/2016 18:00	46.2	35.6
124	5/14/2016 19:00	53.6	33.8
125	5/14/2016 20:00	56.4	33
126	5/14/2016 21:00	57.5	33.1
127	5/14/2016 22:00	60	33
128	5/14/2016 23:00	64.7	32.3
129	5/15/2016 0:00	65.5	32.2
130	5/15/2016 1:00	67.3	31.7
131	5/15/2016 2:00	66.4	31.7
132	5/15/2016 3:00	67.1	31.7
133	5/15/2016 4:00	68.1	31.4
134	5/15/2016 5:00	69.7	31.1
135	5/15/2016 6:00	67.7	31.3
136	5/15/2016 7:00	59.2	32.4

137	5/15/2016 8:00	47.3	34.1
138	5/15/2016 9:00	39.7	35.7
139	5/15/2016 10:00	34	37.3
140	5/15/2016 11:00	27.1	38.4
141	5/15/2016 12:00	25.9	39.6
142	5/15/2016 13:00	33	39.8
143	5/15/2016 14:00	38.3	39.3
144	5/15/2016 15:00	39.2	38.6
145	5/15/2016 16:00	42.9	38
146	5/15/2016 17:00	48.5	36.6
147	5/15/2016 18:00	55.8	34.5
148	5/15/2016 19:00	60.3	33.1
149	5/15/2016 20:00	64.5	32.4
150	5/15/2016 21:00	65.9	32.1
151	5/15/2016 22:00	66.9	31.9
152	5/15/2016 23:00	67.1	31.8
153	5/16/2016 0:00	66.2	31.8
154	5/16/2016 1:00	67.3	31.5
155	5/16/2016 2:00	67.2	31.3
156	5/16/2016 3:00	67.7	31.1
157	5/16/2016 4:00	68.2	31.2
158	5/16/2016 5:00	68.6	30.8
159	5/16/2016 6:00	67.8	31.2
160	5/16/2016 7:00	66.4	31.7
161	5/16/2016 8:00	58.6	33.2
162	5/16/2016 9:00	52.5	35
163	5/16/2016 10:00	43.3	36.3
164	5/16/2016 11:00	34.8	37.6
165	5/16/2016 12:00	29.5	38.9
166	5/16/2016 13:00	26.5	40.1
167	5/16/2016 14:00	28.4	40.3

9. Data input for thermal analysis - material properties

Themo-physical Properties		Density	Specific heat	Conductivity	Source
	Material	kg/m3	J/kg.K	W/m. K	
1	Air	1	1005	0.026	(Krishnan, 2001)
2	Burnt Brick	1820	880	0.811	(SP:41, 1988)
3	Brick tiles	1892	880	0.798	(SP:41, 1988)
4	Cement Mortar	1648	920	0.719	(SP:41, 1988)
5	Cement Plaster	1762	840	0.721	(SP:41, 1988)
6	Screed	1200	840	0.41	(Krishnan, 2001)
7	Ceramic Tile	1900	800	0.84	(Krishnan, 2001)
8	Clay Roof Tiles	1900	800	0.84	(Krishnan, 2001)
9	CSEB	2050	850	0.635	Auroville Earth institute
10	Limestone	2180	840	1.5	(Krishnan, 2001)
11	Mud Phuska	1622	880	0.519	(SP:41, 1988)
12	Plywood	640	1760	0.174	(SP:41, 1988)
13	RCC Slab	2288	880	1.58	(SP:41, 1988)
14	EPS	25	1400	0.035	(Krishnan, 2001)

10. Simulation data for outdoor and Room 2 indoor temperatures from 10th to 15th May.

HOURLY TEMPERATURES - 10th May			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	29.4	25.4	4
1	28.8	24.6	4.2
2	28.7	24.6	4.1
3	28.5	24.4	4.1
4	28.8	24.6	4.2
5	28.7	25	3.7
6	29.1	26.3	2.8
7	29.9	28	1.9
8	31.8	30.3	1.5
9	32	32.2	-0.2
10	33	34	-1
11	33.2	35	-1.8
12	33.4	35.8	-2.4
13	33.5	36	-2.5
14	33.6	36.1	-2.5
15	33.7	35.4	-1.7
16	33.5	34.4	-0.9
17	33.5	32.6	0.9
18	32.8	30.8	2
19	32.3	29	3.3
20	31.7	28.1	3.6
21	31.2	27.5	3.7
22	30.8	27.4	3.4
23	30.3	27	3.3
HOURLY TEMPERATURES - 11th May			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	29.8	26.7	3.1
1	29.4	25.8	3.6
2	29.2	25.2	4
3	29	24.5	4.5
4	29	25.4	3.6
5	29.2	25.6	3.6
6	29.6	26.7	2.9
7	30.3	28.4	1.9
8	32.2	30.7	1.5
9	32.7	32.9	-0.2

10	33.1	34.6	-1.5
11	33.6	35.3	-1.7
12	33.5	35.3	-1.8
13	33.2	34.6	-1.4
14	33.1	33.9	-0.8
15	33.1	33.1	0
16	33.3	32.6	0.7
17	33.2	31.9	1.3
18	33.3	31.2	2.1
19	32.9	30.2	2.7
20	32.1	29.2	2.9
21	31.8	28.3	3.5
22	30.5	27.6	2.9
23	30.2	27.1	3.1
HOURLY TEMPERATURES - 12th May			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	29.5	26.8	2.7
1	29.4	26.4	3
2	29.2	26.1	3.1
3	29	25.6	3.4
4	29.4	26.8	2.6
5	29.2	26.6	2.6
6	29.4	27.1	2.3
7	29.9	28	1.9
8	31.4	29.8	1.6
9	32	31.4	0.6
10	32	33	-1
11	32.4	33.5	-1.1
12	32.5	33.7	-1.2
13	32.3	33	-0.7
14	32.2	32.6	-0.4
15	32.2	31.7	0.5
16	32.5	31	1.5
17	31.8	29.8	2
18	31.4	28.8	2.6
19	30.7	27.6	3.1
20	30.8	27.1	3.7
21	30.1	26.7	3.4
22	30.1	26.8	3.3
23	29.8	26.7	3.1

HOURLY TEMPERATURES - 13th May			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	29.2	26.9	2.3
1	29.1	26.8	2.3
2	29.2	27	2.2
3	29.1	26.8	2.3
4	28.4	25	3.4
5	28.7	25.8	2.9
6	29.2	27	2.2
7	29.9	28.4	1.5
8	31.1	29.7	1.4
9	31.6	30.8	0.8
10	32	31.6	0.4
11	31.7	32.1	-0.4
12	31.8	32.3	-0.5
13	31.8	32.2	-0.4
14	31.7	31.8	-0.1
15	32.1	31.3	0.8
16	32	30.4	1.6
17	31.5	29.4	2.1
18	30.9	28.4	2.5
19	30.6	27.6	3
20	30.5	27	3.5
21	29.8	26.6	3.2
22	29.5	26.4	3.1
23	29.5	26.2	3.3
HOURLY TEMPERATURES - Monday 14th May (134)			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	28.7	25.8	2.9
1	28.4	25.4	3
2	28.1	24.9	3.2
3	28.1	24.8	3.3
4	28.8	26.4	2.4
5	28.9	26.8	2.1
6	29.2	27.4	1.8
7	30.4	28.6	1.8
8	30.8	30	0.8
9	31.9	31.6	0.3
10	32	33	-1
11	32.3	34.1	-1.8
12	32.3	34.4	-2.1

13	32.3	34.2	-1.9
14	32	33.2	-1.2
15	31.9	32.3	-0.4
16	32.3	31.2	1.1
17	32.3	30.6	1.7
18	32	29.9	2.1
19	31.4	29.4	2
20	30.9	28.6	2.3
21	30.4	27.8	2.6
22	29.6	27	2.6
23	29.1	26.6	2.5
HOURLY TEMPERATURES - Tuesday 15th May (135)			
HOUR	INSIDE	OUTSIDE	TEMP.DIF
	(C)	(C)	(C)
0	29	26.3	2.7
1	29	26.4	2.6
2	28.9	26.3	2.6
3	28.9	26.4	2.5
4	27.8	23.6	4.2
5	27.9	24.2	3.7
6	28.4	25.5	2.9
7	29.4	27.6	1.8
8	30.9	29.8	1.1
9	31.6	31.7	-0.1
10	31.9	32.8	-0.9
11	31.9	33.1	-1.2
12	31.7	32.7	-1
13	31.5	32	-0.5
14	31.8	31.2	0.6
15	31.8	30.7	1.1
16	32	30.4	1.6
17	32	30.2	1.8
18	31.7	29.7	2
19	31.5	29	2.5
20	30.9	28	2.9
21	29.8	27	2.8
22	29.6	26.2	3.4
23	28.9	25.8	3.1

11. Monthly indoor discomfort hours for Room 2 using thermal analysis in ECOTECT 2011

W1R1

DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	385	385
Feb	0	163	163
Mar	28	27	55
Apr	75	0	75
May	350	0	350
Jun	413	0	413
Jul	150	0	150
Aug	0	0	0
Sep	45	0	45
Oct	90	0	90
Nov	0	5	5
Dec	0	194	194
TOTAL	1151	774	1925

W1R2

DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	435	435
Feb	0	206	206
Mar	12	36	48
Apr	52	0	52
May	260	0	260
Jun	324	0	324
Jul	124	0	124
Aug	0	0	0
Sep	28	0	28
Oct	55	0	55
Nov	0	7	7
Dec	0	227	227
TOTAL	855	911	1766

W1R3

DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	451	451
Feb	0	229	229
Mar	17	56	73
Apr	54	0	54
May	260	0	260
Jun	310	0	310
Jul	120	0	120
Aug	2	0	2
Sep	30	0	30
Oct	64	0	64
Nov	0	12	12
Dec	0	248	248
TOTAL	857	996	1853

W1R4

DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	420	420
Feb	0	194	194
Mar	15	34	49
Apr	58	0	58
May	287	0	287
Jun	347	0	347
Jul	131	0	131
Aug	0	0	0
Sep	30	0	30
Oct	63	0	63
Nov	0	7	7
Dec	0	224	224
TOTAL	931	879	1810

W2R1
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	380	380
Feb	0	159	159
Mar	29	27	56
Apr	78	0	78
May	353	0	353
Jun	416	0	416
Jul	152	0	152
Aug	0	0	0
Sep	46	0	46
Oct	94	0	94
Nov	0	5	5
Dec	0	194	194
TOTAL	1168	765	1933

W2R2
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	433	433
Feb	0	202	202
Mar	13	35	48
Apr	52	0	52
May	257	0	257
Jun	323	0	323
Jul	125	0	125
Aug	0	0	0
Sep	28	0	28
Oct	57	0	57
Nov	0	7	7
Dec	0	227	227
TOTAL	855	904	1759

W2R3
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	450	450
Feb	0	230	230
Mar	20	55	75
Apr	56	0	56
May	259	0	259
Jun	307	0	307
Jul	122	0	122
Aug	2	0	2
Sep	30	0	30
Oct	62	0	62
Nov	0	12	12
Dec	0	249	249
TOTAL	858	996	1854

W2R4
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	416	416
Feb	0	191	191
Mar	15	34	49
Apr	59	0	59
May	287	0	287
Jun	346	0	346
Jul	130	0	130
Aug	0	0	0
Sep	30	0	30
Oct	63	0	63
Nov	0	7	7
Dec	0	224	224
TOTAL	930	872	1802

W3R1
ISCOMFORT
PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	383	383
Feb	0	161	161
Mar	30	27	57
Apr	77	0	77
May	351	0	351
Jun	415	0	415
Jul	152	0	152
Aug	1	0	1
Sep	45	0	45
Oct	92	0	92
Nov	0	5	5
Dec	0	194	194
TOTAL	1163	770	1933

W3R2

DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	434	434
Feb	0	204	204
Mar	13	36	49
Apr	54	0	54
May	261	0	261
Jun	325	0	325
Jul	125	0	125
Aug	0	0	0
Sep	30	0	30
Oct	57	0	57
Nov	0	7	7
Dec	0	227	227
TOTAL	865	908	1773

W3R3
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	450	450
Feb	0	229	229
Mar	19	54	73
Apr	55	0	55
May	262	0	262
Jun	308	0	308
Jul	122	0	122
Aug	2	0	2
Sep	31	0	31
Oct	65	0	65
Nov	0	12	12
Dec	0	248	248
TOTAL	864	993	1857

W3R4
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	419	419
Feb	0	195	195
Mar	15	34	49
Apr	58	0	58
May	287	0	287
Jun	347	0	347
Jul	132	0	132
Aug	0	0	0
Sep	31	0	31
Oct	64	0	64
Nov	0	7	7
Dec	0	223	223
TOTAL	934	878	1812

W4R1
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	378	378
Feb	0	154	154
Mar	22	26	48
Apr	72	0	72
May	351	0	351
Jun	421	0	421
Jul	149	0	149
Aug	0	0	0
Sep	37	0	37
Oct	83	0	83
Nov	0	4	4
Dec	0	192	192
TOTAL	1135	754	1889

W4R2 EAST WEST
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	432	432
Feb	0	196	196
Mar	12	31	43
Apr	43	0	43
May	245	0	245
Jun	323	0	323
Jul	124	0	124
Aug	0	0	0
Sep	24	0	24
Oct	46	0	46
Nov	0	4	4
Dec	0	223	223
TOTAL	817	886	1703

W4R3
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	454	454
Feb	0	225	225
Mar	15	49	64
Apr	49	0	49
May	247	0	247
Jun	305	0	305
Jul	118	0	118
Aug	0	0	0
Sep	26	0	26
Oct	57	0	57
Nov	0	10	10
Dec	0	244	244
TOTAL	817	982	1799

W4R4
DISCOMFORT PERIOD
DISCOMFORT DEGREE
HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	416	416
Feb	0	184	184
Mar	13	30	43
Apr	55	0	55
May	282	0	282
Jun	344	0	344
Jul	130	0	130
Aug	0	0	0
Sep	29	0	29
Oct	55	0	55
Nov	0	5	5
Dec	0	220	220
TOTAL	908	855	1763

W4R2 NORTH SOUTH
DISCOMFORT PERIOD
DISCOMFORT DEGREE HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	437	437
Feb	0	198	198
Mar	12	34	46
Apr	44	0	44
May	246	0	246
Jun	322	0	322
Jul	124	0	124
Aug	0	0	0
Sep	24	0	24
Oct	53	0	53
Nov	0	5	5
Dec	0	225	225
TOTAL	825	899	1724

W4R2 NORTHEAST SOUTHWEST
DISCOMFORT PERIOD
DISCOMFORT DEGREE HOURS

MONTH	TOO HOT (Hrs)	TOO COOL (Hrs)	TOTAL (Hrs)
Jan	0	433	433
Feb	0	196	196
Mar	12	32	44
Apr	43	0	43
May	246	0	246
Jun	322	0	322
Jul	124	0	124
Aug	0	0	0
Sep	24	0	24
Oct	48	0	48
Nov	0	4	4
Dec	0	223	223
TOTAL	819	888	1707