CLIMATE RESPONSIVE VERNACULAR ARCHITECTURE: JHARKHAND, INDIA

by

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Abstract

This research aims to explore and assess passive solar design techniques that promote high thermal comfort in vernacular houses of the state of Jharkhand in India. The study of these houses provides useful insights for designing energy efficient houses that provide thermally comfortable conditions. An analysis of these houses in Ranchi, the capital city of Jharkhand, India provides a context for the field research.

Jharkhand predominantly has two different styles of vernacular houses: huts and havelis. These houses were constructed, without any mechanical means, in such a manner as to create micro-climates inside them to provide high thermal comfort levels. Hence the study of thermal comfort levels in these buildings in relation to built environment in today's context is significant. As part of data collection, interviews were conducted with the occupants of ten houses in Ranchi, in June 2007. Two houses of each (huts and havelis) were selected for detailed experimental analysis.

Experiment results indicated that all the four selected houses exhibited lower ambient temperature than outside during the day and a higher ambient temperature at night. *Brick bat coba* and lime mortar were the key materials used for constructing high thermal-mass walls. Adequate ventilation is significant in creating conditions that are comfortable. Aperture to volume ratio of less than 0.051 is not adequate enough to cool the thermal mass of these houses. These houses also use attic space to mitigate the heat gain from the roof. Courtyards and other exterior spaces form an integral part of these houses and influence the thermal conditions in and around the houses. The case studies show that there is a scope for more relaxation of comfort temperature range based on culture and phenomenon of acclimatization. A universal approach in understanding and defining comfort condition fails because the users of these houses were comfortable in conditions defined as uncomfortable by ASHRAE and Nicol.

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Preface

Before the advent of the industrial age, and the invention of mechanical heating and cooling, bio-climatic means were exclusively used to achieve moderately comfortable climates inside buildings. Today, active heating and cooling devices ensure interior comfort, but require major energy inputs. However, given the dual challenge of a growing fuel crisis and concerns of global warming, the amount of energy used to provide thermal comfort levels will become unsustainable. Sustainable, ecological, and climate-adaptable architecture offers possible solutions to these challenges. Many architectural publications advocate that traditional and vernacular homes form the basis of environmentally conscious design (Meir & Roaf, 2006).

Design lessons learned from traditional and vernacular architecture can help in designing an eco-friendly future. Ancient Indian buildings use the environment, climate-responsive design, and local and sustainable materials in their design and construction. Once built, these building forms embodied an important strategy of environmentally friendly homes: minimal use of energy (Jadhav, 2007). However, industrialization and urbanization changed the approach to building into an efficient, expedient industry that is not particularly responsive to the environment. According to a study by Tombazis (2001), worldwide building stock today on average uses more than half of the total world's energy, and in developing countries like India, it accounts for a much higher percentage. Substituting passive means to achieve thermal comfort for buildings, then, can be of great significance to worldwide energy use.

A burgeoning population and rapid urbanization in India in recent years has also affected quality of life in cities. Even smaller cities are facing huge problems in accommodating the growing population, and this, in turn, has resulted in rapid replacement of heritage and traditional buildings with modern construction. The city of Ranchi in Jharkhand is a classic example of these changing patterns.

Since the Iron Age, Jharkhand has been a land of thirty different tribes on the Chotanagpur plateau (www.jharkhandonline.gov.in). Before British colonization in 1870, Jharkhand had an agrarian society. Huts made of mud walls and thatched roofs were the standard construction. Along with a thermally-responsive construction, the architecture of Jharkhand also responded to interactive social life by creating community courtyards. The continued popularity of these buildings is evident: data informs us that these buildings constituted 48% of total residential construction until 1960 (Das & Pushplata, 2005).

During the mid 19th century, Jharkhand became a popular summer retreat for the British. During early colonization from 1870s till 1940s, a new vernacular architecture emerged in the region, more grandiose in nature and heavily influenced by western ideals. The architecture from those times in this region was efficient, bearing the heat of summer and tackling the cold weather of the plateau.

The state of Jharkhand was also known for its abundance of natural resources, particularly coal and iron ore. The abundance of natural resources attracted industry to the region, and after independence in 1947, a large influx of people from various parts of the country looking for work occurred.

With industrial development continuing into the late 1960s, the urbanization of Jharkhand was inevitable, bringing with it a high demand for new housing to accommodate the growing population. The new style of architecture rapidly forsook the precedents of the region, adopting instead new westernized high-rise apartment construction (see Figure 0.1).

With the formation of the new state Jharkhand in 2000, the region witnessed more exponential growth in population and the real estate sector market (http://www.indianrealtynews.com/indian-states/jharkhand/). To accommodate the expansion, old buildings are being replaced by contemporary architecture.

Figure 0.1 Photograph of a typical street in Ranchi. (Photograph by Saikat Mukhopadhyay)

Thus, we see two prevalent styles of vernacular architecture in Jharkhand, huts and havelis. The huts provided shelter to very low-income families, while the havelis, based on colonial plantation homes, were popular with prosperous classes. These prototypes adopt different passive strategies to achieve comfort levels for their users.

Structure of Thesis

The purpose of the study is to discover potential strategies for contemporary buildings that passively promote thermal comfort in these buildings, thereby reducing the need for external energy inputs and increasing the quality of life for occupants. This research intends to seek ways to document the traditional vernacular principles to promote a sustainable community. Last but not least, the study intends to test the assumption that vernacular houses of Jharkhand have high thermal comfort levels without using any mechanical means.

This thesis is divided into three broad sections. The first section is the literature review that discusses the significance and background for the research. This section is subdivided into three chapters. Chapter 1 deals with vernacular architecture and thermal comfort. Chapter 2 focuses on the climatic conditions of Jharkhand. Chapter 3 describes the two prevalent styles of vernacular architecture of Jharkhand, its social, economic, and cultural attributes, and discusses the potential to adapt the vernacular architecture to contemporary architecture.

The second section of the thesis encompasses an in-depth research study of specific cases of vernacular architecture in Jharkhand. This section is divided into two chapters: Chapter 4 describes the framework, limitations, and methodology adopted to carry out the research while Chapter 5 contains the data collected from the study and an analysis of the findings.

The final section contains the analysis and conclusions of the research. Chapter 6 also suggests ways to promote and apply traditional vernacular architecture principles in today's construction. Finally, this last chapter suggests future studies that could broaden the results drawn from this study.

Figure 0.2 Structure of thesis

CHAPTER 1 - Vernacular architecture and thermal comfort

> *Vernacular buildings record lifestyles of the past when people had to find a sustainable way of life or perish, just as we will have to now. The new importance of vernacular building is that it has vital ecological lessons for today.*
>
> - (Pearson, 1994)

> *Vernacular architecture is our starting point and is similar to the flora and fauna of a region. It springs from the ground like the wild flowers, perfect in its use of material, sitting and taming of the weather. It also embodies the local lifestyle and its process of evolution is completely unconscious.*
>
> - (Kamiya, 2003)

These quotes describe some of the salient attributes of vernacular buildings. Vernacular is strongly tied to cultural and social traditions. It responds to ambient environmental conditions, and it is, in a way, a naturally evolving process. This chapter defines vernacular architecture and thermal comfort. The chapter first introduces vernacular architecture and the way it responds to climate. The second section of this chapter defines thermal comfort and then summarizes studies that illustrate the climate responsiveness of vernacular architecture. The last section of the chapter describes the ecological importance of vernacular architecture in present day context.

Vernacular architecture comprises all buildings, not just dwellings and relates to environmental contexts and available resources. These are customarily owner or community built and use traditional technologies. Vernacular architecture is built to meet specific needs, while accommodating the values, economies, and ways of life of the cultures that produce them (Oliver, 1987). The word '*vernacular*' derives from the Latin word '*vernaculus*' which means native. Hence vernacular architecture refers to '*native* *science of building.'* Vernacular architecture is both regionally and socially specific. Each community over the years develops a prototype that responds to local needs and carries it forward through generations (Oliver, 2006).

Rapoport (1969) introduces vernacular architecture as a folk tradition that is a '*direct and unself-conscious translation into physical form of a culture, its need and values – as well as the desires, dreams and passions of the people.*' Rapoport categorizes this folk tradition into pre-industrial vernacular and modern/post-industrial vernacular. However, these two types of vernacular architecture cannot be compared for thermal comfort levels. Pre-industrial vernacular architecture refers to buildings built by the community and involves no specialized trades. It is a direct response of the community that understands its own needs and requirements; solutions to these problems are handed down through verbal transfer of knowledge through generations. The outcome of the response tends to be very tradition oriented, and the houses follow a uniform model. Most of these houses are self-built. The construction is clear and simple, adhering to the rules drafted by ancestors (Rapoport, 1969).

Post-industrial vernacular architecture differs considerably in its conception, design, and construction. As specialized building trades emerged, the occupants sought help from them to construct buildings. The occupants of these kinds of houses, although not active participants in the construction, are not just mere users but provide inputs to the design and construction of the house. Individual variability is thus witnessed in these houses; however, because a society is bound by traditions, the differences fall within a frame of common heritage and values. These often lack ostentatious aesthetic display as they try to solve problems in the simplest possible manner, working with the site and micro-climate, respecting other members of the community and the environment (Rapoport, 1969).

From the very beginning, shelters have been guided by the climate of the region. Vernacular solutions show a variety of designs related to the conditions that surround it, responding to the nature, culture, symbolic interpretations, and definition of comfort in that area (Rapoport, 1969). These solutions vary from place to place, usually being governed by culture even while responding to the similar conditions: the definition of comfort changes from culture to culture. Hence, understanding thermal comfort is important because it varies from person to person (Foss & Rohles, 1982).

Thermal comfort

Thermal comfort is defined by ASHRAE Standard 55-2004 as "*the condition of mind that expresses satisfaction with the thermal environment.*" The thermal environment is those characteristics of the environment which affect a person's heat loss or gain. According to Fanger (1970), the following variables affect the thermal comfort most:

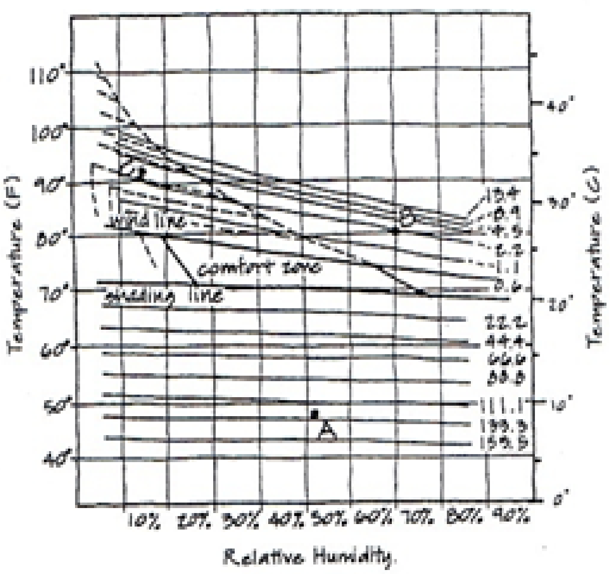
- Activity level (heat produced in the body)
- Thermal resistance of the clothing (clo-value)
- Air temperature
- Mean radiant temperature
- Relative air velocity
- Water vapor pressure in the ambient air

Activity level is directly related to the metabolism of the body, which in turn produces heat. For example, the body of an exercising person will be hotter than a sleeping person. Hence, the activity directly relates to the thermal level of the body and to the thermal comfort temperature. Clothing also affects body temperature and exposure to air. All other things being equal, a person wearing a woolen jacket will be warmer-than someone wearing a t-shirt; i.e., the jacket has a higher clo-value, a measure of clothing insulation. Apart from keeping the body warm, the clothing also affects evaporative cooling by preventing convective air from moving over the body surface. Air temperature refers to the sensible temperature of the air, i.e., temperature that the sensory mechanism of humans can recognize. Radiant temperature refers to the area-weighted mean temperature of all the objects surrounding the body. Even though not in direct contact with body, hot or cold objects affect the perception of temperature as they exchange radiant energy. Air movement is very important for comfort. It can either create comfort or discomfort depending on climatic conditions. In hot enclosed spaces, no air movement leads to stuffiness; while in cold conditions, even the slightest air movement may cause discomfort (draftiness). Humidity is another major variable that affects the comfort condition. Humans automatically sweat to maintain body temperature; higher humidity reduces the ability of sweating to maintain homeostasis; sweat no longer evaporates to cool the body.

Many studies, summarized in Olgyay (1963) have defined thermal comfort conditions. Vernon concluded that 18.94°C (66.1°F) in summer and 16.72°C (62.1°F) in winter were ideal temperatures with air movement of 50 fpm or less. Bedford stated the ideal temperature was 18.16°C (64.7°F) in winter, and 13.22°C (55.8°F) to 23.16°C (73.7°F) was the comfort zone. According to Markham, 15.55°C (60°F) to 24.44°C (76°F) is the ideal range with relative humidity at noon between 40 to 70%. Brooks stated that British comfort zone varies between 20.55°C (69°F) and 26.66°C (80°F) with relative humidity between 30 and 70%. According to ASHRAE Standard 55-2004, a range of 19.4°C (67°F) and 27.77°C (82°F) is ideal for thermal comfort.

Humans feel comfortable half way between temperature they can tolerate in winter without being grossly uncomfortable and the temperature that makes the person's circulatory and sweat secretion system apply effort in order to adapt to the heat (Olgyay, 1963). Olgyay (1963) defined thermal comfort using a chart known as the bioclimatic chart (see Figure 1.1). The chart combines temperature and relative humidity to define the human comfort zone and gives recommendations for points that lie within the defined boundary. The chart also incorporates wind speed and radiant temperature.

Figure 1.1 Bio-climatic chart. (Source: Coates, nd.)



Nicol (2001) proposed a new theory relating comfort temperatures to humans. This new theory, an adaptive model of thermal comfort, relates comfortable indoor conditions to outdoor conditions. According to the theory of adaptive comfort, humans adapt themselves to the average indoor temperature. An advantage of variable comfort temperature is that it changes with the outside temperature and hence will require less energy to achieve than a fixed comfortable temperature. In summer, the comfort temperature increases, thereby decreasing the cooling load, and decreases in winter, in turn, decreasing the heating load.

Though metrics have been developed to quantitatively define thermal comfort, it is inherently subjective. Humphrey in 1981derived a mathematical relationship between the comfort temperature (T_c) and outdoor temperature (T_o) for a passive building: $T_c = 12.1 + 0.53\ T_o$ (Nicol, 2001). He collected data from comfort surveys from all across the world and plotted the temperature reported as comfortable against outdoor temperatures for the month of survey. Later, Nicol and others (2001) concluded after similar research in the Indian sub-continent: $T_c = 17.0 + 0.38\ T_o$.

The difference between the two formulas is the subjective nature of thermal comfort. Thermal comfort varies because of social conditions, acclimation to geographic locations, and culture (Foss & Rohles, 1982). Thermally comfortable buildings respond to these variables to create comfortable conditions for users. Passive, thermally comfortable buildings use different strategies to create such conditions.

> *Our modern solutions to climatic problems often do not work, and our homes are made bearable by means of mechanical means whose cost sometimes exceeds that of the building shell...Primitive and pre-industrial builders cannot take this attitude, since they lack the technology to allow them to ignore climate in design…they solve their problems by collaborating with nature.*
> - (Rapoport, 1969)

The above quote emphasizes that comfort conditions are achieved in vernacular houses without using mechanical means. Beng (1994) and Cooper & Dawson (1998) state that vernacular architecture evolves over time after trial and error, and the final form that emerges in a particular culture is highly responsive to climate and available resources. These successful solutions to the problems of the climate did not come from deliberate scientific reasoning but from countless experiments and accidents and the experience of generations of builders who continued to use what worked and rejected what did not (Fathy, 1986). In many regions, vernacular forms can be traced back over hundreds or thousands of years, providing occupants with comfortable conditions. Dr. Walter B. Cannon (in Olgyay, 1963) stated "*the development of a nearly thermo-stable state in our buildings should be regarded as one of the most valuable advances in the evolution of buildings.*"

Studies show that vernacular architecture uses less energy than contemporary architecture. Vyas (2005) studied the principles of traditional Indian architecture. After examining different cases from different regions of the Indian subcontinent for their climatic context, he concluded that vernacular buildings have less need for energy than contemporary buildings. Much research needs to be done to verify this assertion. Behailu (1997), whose study in Ethiopia on the differences between traditional, vernacular, and modern buildings in material used, concluded that contemporary buildings neglect some essential environmental human requirements. He suggests variables that could be used in modern architecture to lower external energy requirements in the house. Our study hopes to show a similar result and advocate the use of thermally beneficial strategies in contemporary buildings under similar climatic conditions to make them more climatically responsive.

Some studies have suggested that vernacular architecture has high thermal performance, creating comfortable indoor conditions. Krishnan and others (1996) studied climatically responsive indigenous buildings and settlements in the two desert conditions of India, i.e., hot-dry desert of Jaisalmer and cold-dry desert of Leh. Their study found high thermal performance among these buildings. Another study by P. R. Reddy and B. Lefebvre (1993) showed that traditional mud houses create thermal comfort. The study investigates thermal comfort attitudes of those dwelling in traditional mud houses. Their survey shows that 90.6% inhabitants of mud houses find them to be comfortable without artificial cooling and ventilation. The study also shows that, due to the high maintenance, these dwelling in mud houses would prefer burnt clay bricks over traditional mud walls.

Studies have even showed that vernacular homes use various passive strategies to create comfortable conditions inside them. For example, courtyard homes in Kolkata use geometry to capitalize on shade and ventilation. Das (2006) conducted a study in Kolkata on the courtyard houses specifically focusing on the roles of solar shading and natural ventilation in courtyards.

Given the properties noted above, vernacular architecture has ecological implications for architecture today, i.e., vernacular architecture is inherently sustainable. Sustainable architecture can help address the coming energy crisis and potentially global warming as well. With the energy crisis deepening, the role of the built environment becomes more significant because buildings use nearly 50% of the energy produced (Steele, 1997). One solution to the depletion of oil and other fossil fuels is to adopt a sustainable way of life. As defined by Edward Mazria, a sustainable house should be able to “*collect, transfer, store and ultimately convert naturally occurring environmental phenomena into a safe, healthy and comfortable indoor living environment, within the prescribed human comfort zone, for at least thirty generations*” (www.2010imperative.org/forum.html). These values are some of the salient features of vernacular architecture.

With the evidence that vernacular architecture is likely to be passively comfortable, and that using vernacular techniques will further the objectives of sustainability, this thesis intends to study two vernacular types of architecture in Jharkhand. This paper posits that these building types will be thermally comfortable. First, the paper will identify the ambient thermal conditions of Jharkhand and identify passive strategies in general that create comfort conditions in that climate.

CHAPTER 2 - Climate of Jharkhand

The morphology of a built environment is a consequence of a whole range of natural environmental factors: topography, climate, water and vegetation, modified by particular social, cultural and economic realities. Among the natural factors shaping the environment, climate is the most crucial and its effect on the form and structure of a settlement are the most noticeable.

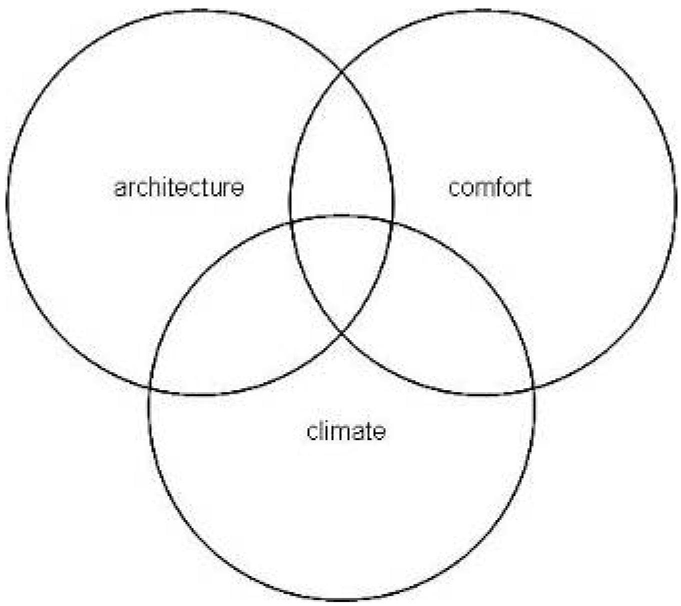
- (Gabriel & Garda, 1989)

As Gabriel and Garda state, climate has a strong impact on architecture. Shelter makes humans comfortable in adverse climate conditions; the body acclimatizes to adverse climatic conditions only to a limited extent (Vyas, 2005). In vernacular buildings, passive thermal strategies provide comfortable conditions. These passive thermal strategies are intimately tied to climate. An understanding of the attributes of climate in a region is important to the analysis of the performance of vernacular architectural types as different climates have their own reflection on culture and architectural traditions of the region (Nicol, 2001).

Rapoport (1969) outlines the different variables of climate to which a building needs to respond. These variables are temperature, humidity, wind, rain, radiation, and light. Different combinations of these variables create different climates. Worldwide, climate can be grouped into, among others, cold, hot arid, hot humid, temperate, Mediterranean, tropical, maritime. Depending on the climate, the variables become desirable or undesirable in creating comfortable conditions.

Vitruvius in his Book VI of "Ten Books on Architecture" explains the fundamental relationships among climate, comfort, and architecture using the '*tri-partite model of environment*' (see Figure 2.1). He states that the comfort, climate, and architecture are all closely linked to each other and architecture can create comfortable spaces in uncomfortable climatic conditions. Strategies that work with the climate rather than against it have always existed in vernacular buildings. In vernacular homes, mechanical systems work with passive design strategies to control the climate inside the house to make it comfortable. These passive design strategies vary from the region to region. These strategies keep the building warm in cold regions, cold in hot seasons, keeping water from destroying the building in water rich or uncontrolled areas, allowing cool winds to cool buildings in hot humid areas among other strategies depending on the climate.

Figure 2.1 Vitruvian tri-partite model of environment. (Reproduced from Hawkes, 1996)



Applying different passive solar design strategies depends on the relationship between the building and the environment, which may be either selective or exclusive. An exclusive mode isolates the building's indoor environment from the outdoors to achieve comfortable conditions, while a selective mode allows interaction between the two spaces (Hawkes, 1996). The exclusive mode seals buildings, and mechanical systems work inside them to create comfortable conditions. The selective mode uses passive strategies and allows selected climate variables to enter the building to create comfortable conditions. Vernacular houses work by allowing selective and limited elements of climate inside a house to create comfortable conditions.

Various studies have examined different passive design strategies in buildings and their effect on indoor climate. Both prototypes of the vernacular houses under investigation in this study exhibit high thermal mass as passive design strategy (see Chapter 3). Some research has studied the relationship between comfort and use of thermal mass with air movement as solar passive design strategies.

Under proper conditions, wind driven airflows can offset solar heat gains by replacing warm indoor air with cool outside air. This cools down the structure by carrying away the sensible heat stored in the thermal mass, thus lowering the radiant temperatures in the space, cooling the building occupants directly by increasing convective and evaporative heat loss from the occupants' body surfaces (Ernest, 1991). Shaviv (2001) suggested using high thermal mass materials in buildings along with natural ventilation at night to keep buildings cool. Peleg and Robinson (1964) stated that thermal comfort levels can be achieved inside a house with rational use of natural ventilation: preventing hot air from penetrating the house during hot hours of the day and allowing exchange of air and heat during the cool outdoor hours. Thulasi Narayan (nd) concluded that high thermal mass creates a shift in thermal lag and keeps the heat out in summer months. Narayan also concluded that high thermal mass, natural ventilation and evaporative cooling are good passive strategies to achieve thermal comfort in extremely warm climates. All these studies suggest using natural ventilation to cool the structure at night and using high thermal mass to keep heat out of the structure during the day.

The next section of this chapter outlines the climate of Jharkhand and the passive strategies that create comfortable conditions inside houses in that particular climate.

Climatic zones in India

Vyas (2005) divides India into six climatic zones: hot and dry, warm and humid, composite, cold and cloudy, cold and sunny, and moderate (see Figure 2.2). In Figure 2.2, Jharkhand shows a moderate climate. The weather data for Ranchi, capital of Jharkhand, was taken from Department of Meteorology, Birsa Agriculture University, Ranchi, India.

Figure 2.2 Climatic zones in India. (Source: Vyas, 2005)

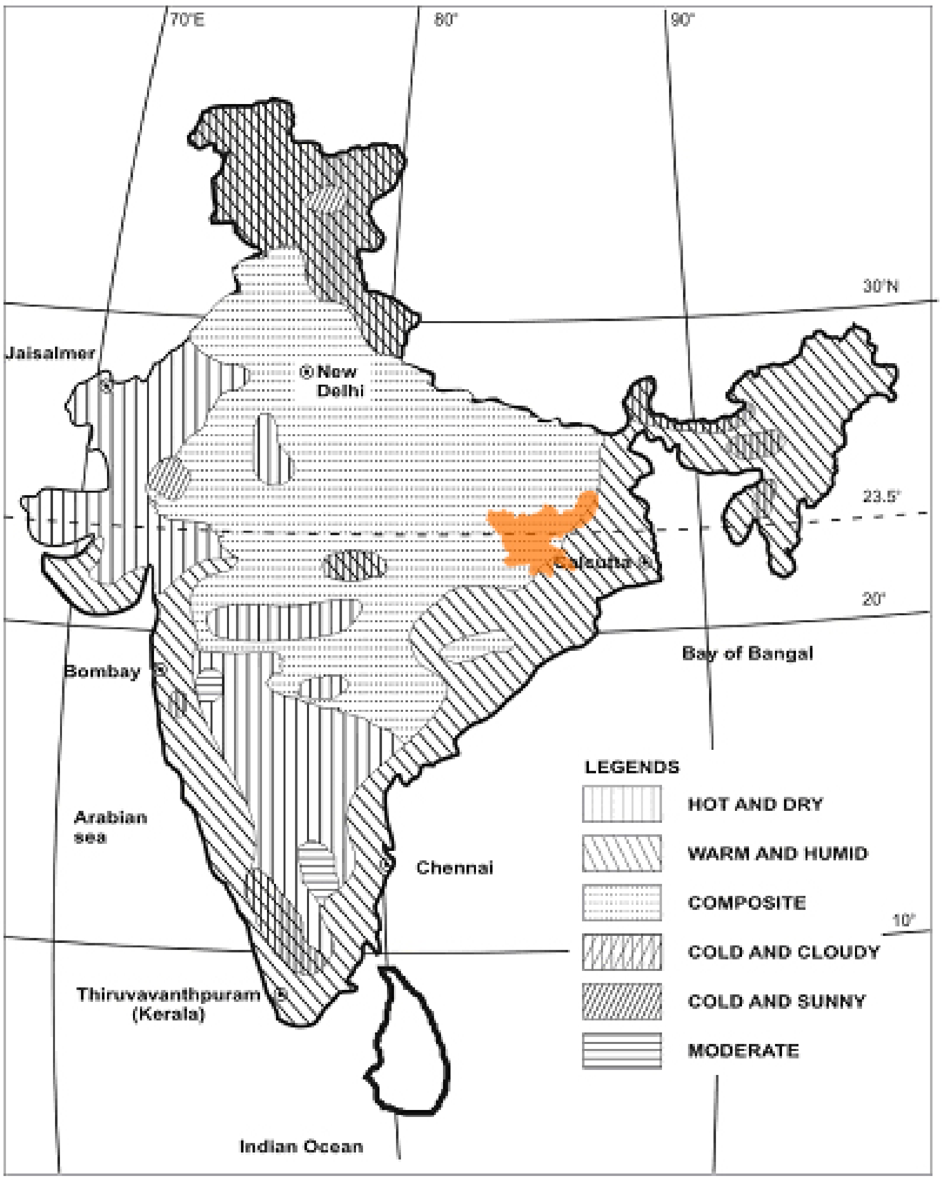


Figure 2.3 Weather data for Ranchi, Jharkhand for 2007. (Source: BAU, Ranchi)

Months	**Temperature (˚C)**		**RH (%)**		**Rainfall**
	MAX	**MIN**	**7 am**	**2 pm**	**(mm)**
Jan	23.3	6.1	87.3	48.5	0
Feb	24.3	10.9	88.7	60.9	121.2
Mar	28.1	13.6	89.0	51.5	58.7
Apr	35.4	18.6	85.0	33.2	32.8
May	35.0	21.7	80.8	40.9	36.3
Jun	34.0	23.3	81.0	51.9	129.8
Jul	29.5	22.5	88.0	68.6	364.1
Aug	29.5	22.3	88.7	72.6	324.3
Sep	28.9	22.0	88.5	75.3	300.7
Oct	28.8	15.9	88.6	53.3	11.6
Nov	25.6	11.8	87.8	60.7	0.8
Dec	23.2	6.3	86.5	52.8	0

The climate of Ranchi falls into five seasons: summer, monsoon, fall, winter, and spring. Summer is typically between April and mid-June with average maximum temperature of 34.8°C, average minimum temperature of 21.2°C, and monthly mean maximum relative humidity of 62.13%. Monsoons are typically between mid-June and September with average maximum temperature of 30.48°C, average minimum temperature of 22.53°C, and monthly mean maximum relative humidity of 76.83%. During this time, Ranchi receives more than 1000mm of rain. Fall is typically between October and November with average maximum temperature of 27.2°C, average minimum temperature of 13.85°C, and monthly mean maximum relative humidity of 72.6%. Winter is typically between December and January with average maximum temperature of 23.25°C, average minimum temperature of 6.2°C, and monthly mean maximum relative humidity of 68.78%. Spring is typically between February and March with average maximum temperature of 26.2°C, average minimum temperature of 12.25°C, and monthly mean maximum relative humidity of 72.53%. July, August, and September are the prime months for rainfall.

There are indications that the weather in Jharkhand has recently changed. Comparing the weather data of Ranchi for the year 1986, 1987, 1996, 1997, 2006, and 2007 (refer to Appendix A), we find that the temperature has increased.

The climate in Ranchi comprises extreme conditions in summer, monsoon, and winter while fall and spring are moderate. Days are hot, and nights are cool in summer; heavy rains come during monsoon; and in winter, both days and nights are cold. According to Brown and DeKay (2001), the main strategies to create comfort in this climate include:

Summers:

Use evaporative cooling.

Protect against summer heat gain.

Keep the sun out in summers to reduce heat gain and glare.

Flatten day-to-night temperature swings to reduce cooling in summers.

Use vegetative cover to prevent reflected radiation and glare.

Expand use of outdoor spaces during the night.

Night time flush ventilation to cool thermal mass.

Winter:

Let the winter sun in to reduce heating needs.

Protect from cool winter winds to reduce heating.

Expand use of outdoor spaces during the day.

Spring:

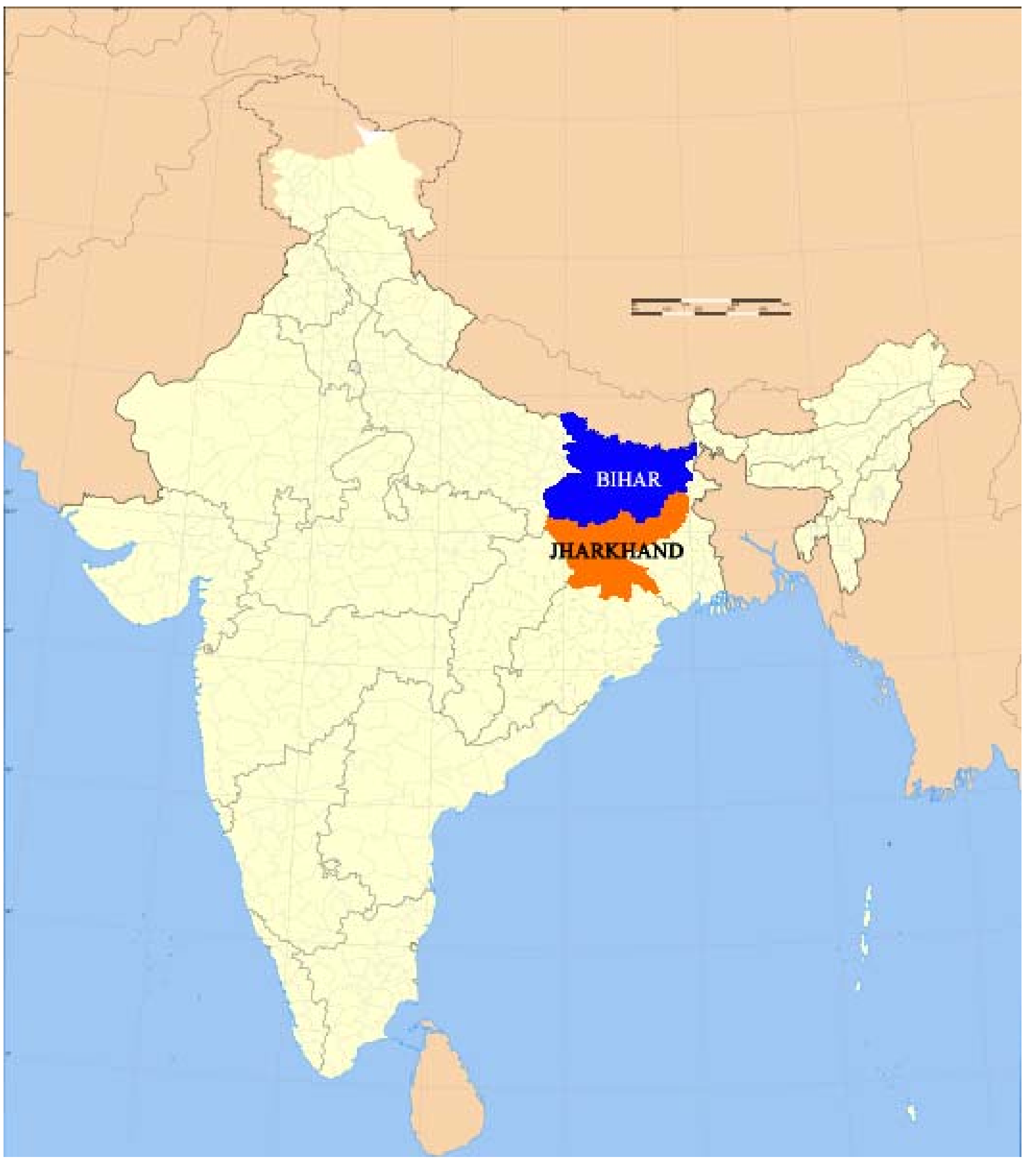
Use natural ventilation to cool in spring.

In part, the specific climate of Jharkhand has given rise to particular vernacular types. These types will be explored in the next chapter.

CHAPTER 3 - Vernacular architecture of Jharkhand

Jharkhand, earlier a part of Bihar, is a small state in eastern India (see Figure 3.1). It split from Bihar in 2000 owing to significant differences in the culture of the people of these two regions.

Figure 3.1 Location of Jharkhand. (Modified from: http://upload.wikimedia.org/wikipedia/commons/thumb/7/79/India_Jharkhand_locator_map.svg/530px-India_Jharkhand_locator_map.svg.png)



Originally Jharkhand was the land of the tribes of the Chotanagpur plateau. It later became a summer retreat for the British from 1765 to 1947 when British rule ended in India. One third of the state is covered with forest which is reflected in its name; Jharkhand in local dialect means 'land of the woods' (www.ranchiexpress.com/maindocs/history.htm). After independence, this region, being rich in minerals, became the heart of mining activities in India. People from different regions were attracted to Jharkhand, and many have become permanent residents.

Two distinct and quite different vernacular architectural styles exist in this region: small huts or hutments (see Figure 3.2) and havelis (large mansions) (see Figure 3.3). The hutments were originally built of mud, sticks, grass, and pebbles. These houses were mostly self-built by family members, sometimes aided by neighbors. Their modest beauty lies in being less influenced by self-conscious decorative attempts than from pure, practical shapes produced by adapting local material as economically as possible to mitigate hostile environmental elements and to use beneficial ones (Cooper & Dawson, 1998).

The havelis are of more recent origin. During the late eighteenth and early nineteenth century, under the influence of British, the region saw prosperity due to increase in trade and commerce. The local merchants became affluent. In order to exhibit their wealth, a new architecture style evolved that was meant to display the wealth of these merchants. Their mansions were built of burnt clay brick and were highly influenced by western motifs. These houses were built of local materials and by local craftsmen. The buildings that resulted from this process are quite different from the earlier type, combining traditional with modern, but they are still vernacular because they are the outcome of local vernacularization of modernity (Vellinga, 2006). Though more refined, the havelis are still made primarily of high thermal mass materials.

Figure 3.2 A hut in Ranchi, Jharkhand. (Photograph by Shishir Sinha)

Figure 3.3 A haveli in Ranchi, Jharkhand. (Photograph by Shishir Sinha)

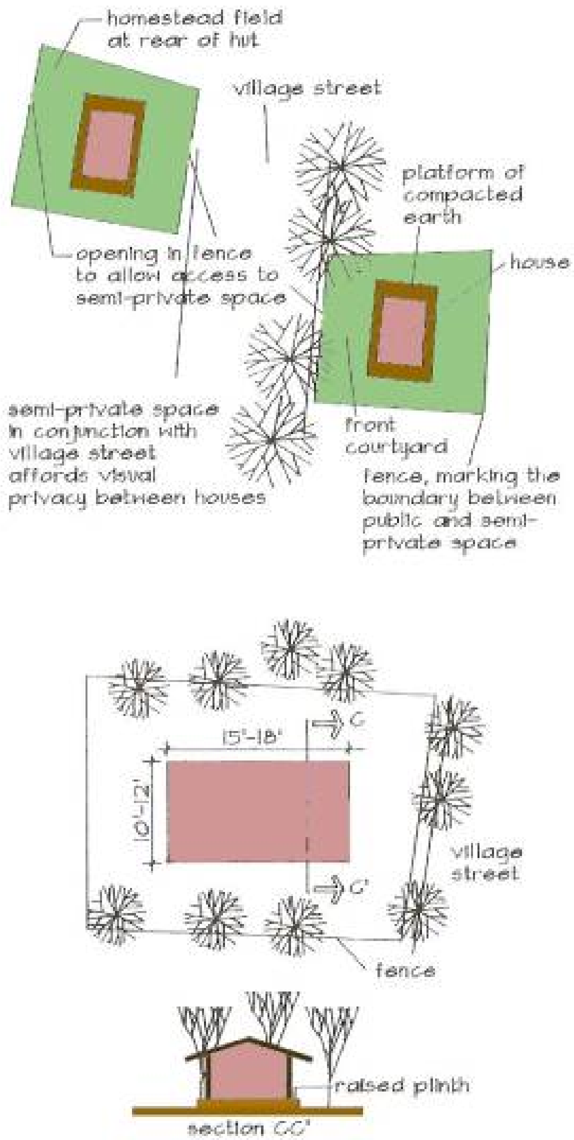
Traditional huts

Both vernacular forms were heavily influenced by social and cultural factors. The hutments consisted primarily of two distinct "cultural spaces." The conception of space in the hutments began with a single cell shelter. This single cell was then either divided to create different space, or several single cells were added to create a large space (Jain & Jain, 2000). Both these features exist in the huts of Jharkhand (see Figure 3.4). The primary element was a single interior living space, which may have been sub-divided, multiplied, or otherwise modified. Second, an external space adjacent to or surrounded by the dwelling was emphasized by use of elements such as low platforms or verandahs.

An average hut measured approximately 5 to 6 meters (15 to 18 feet) long and 3 to 4 meters (10 to 12 feet) wide (Dhar, 1992). These huts were arranged in a linear pattern along the main street of a village, usually amidst a group of bamboo trees. The houses were normally surrounded by a fence made of bamboo, shrubs, or twigs that defined the boundary between the public street and the semi-public courtyard area in front and at the rear of the hut. This open-to-sky courtyard acted a prime space for the house, especially during the day in winter and in the evenings in summer. Most day to day activities occurred in this space. Often there was a well in this courtyard that served as the source for water for drinking, bathing, washing, and cooking. People used this courtyard to dry clothes, crops, and eatables during the day time. The aged of the house used this as a rest area, supervising the children at play.

The house sat on a raised platform made of compacted earth. The high thermal mass helped keep the house cool in the evenings in summer which made it pleasant for people to rest in the evenings. The huts normally had minimal fenestration. Often the only opening on the external walls was the main door. Some houses had windows, but they were small and placed high to ventilate the indoors while, at the same time, acting as a visual barrier for the private spaces. The small windows also served to keep the hot summer sun and cold winter winds out.

Figure 3.4 Typical plan of a hut in Jharkhand. (Reproduced from Dhar, 1992)



Traditional architecture developed its individuality by tapping nearby resources and exploiting them to confront problems posed by the local environment (Cooper & Dawson, 1998). The huts were made of local materials. Timber, bamboo, clay, straw, cow dung, and a special variety of grass were used to build houses (Dhar, 1992).

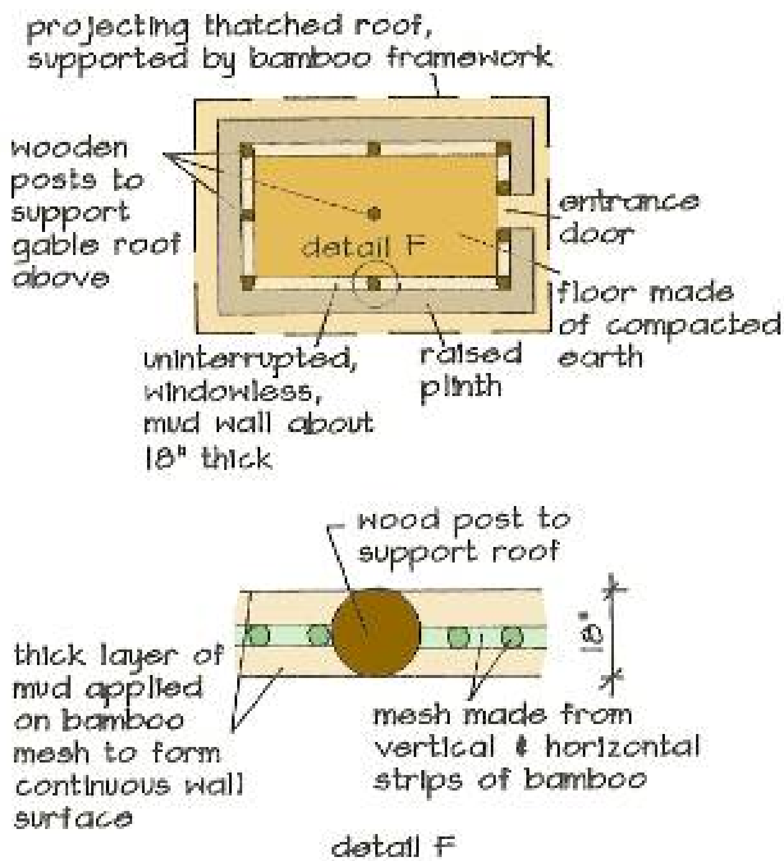
The walls were made of a special type of mud obtained by souring earth by adding vegetable waste and leaving it to mature (see Figure 3.5). The decaying waste produced tannic acid and other organic colloids, greatly improving the mud’s plasticity

(Cooper & Dawson, 1998). This mud was then mixed with cow dung, chopped straw, and gravel or stones to make the raw material for the walls. The walls were formed by applying a thick coat of the mixture on both sides of bamboo mesh that wrapped around the posts (see figures 3.6 and 3.7). Sometimes the mesh was made of wooden logs obtained from saal trees that grow in abundance in this region. The walls were approximately 450 mm (18 inches) thick and bulky (Dhar, 1992).

Figure 3.5 Special mud blocks left with vegetable waste matter to mature for wall construction.

Figure 3.6 Mud wall with wooden posts of typical hut.

Figure 3.7 Typical hut construction. (Reproduced from Dhar, 1992)



The roof rested on nine wooden posts erected in three rows, with three posts per row, as shown in Figure 3.7 (Dhar, 1992). These posts were sunk into the raised platform and tied with wooden beams and purlins that supported the roof structure. The huts usually had a gabled thatch roof. Bamboo sticks formed the mullions to support the thatch. The thick thatch used as roofing material prevented rain from entering the house and at the same time provided insulation to the building. While providing some benefits to the house, thatch had its own drawbacks. It tended to house parasites, rodents, and birds (see Figure 3.8). Over time, as an effect of industrial hybridization, the thatch in the huts was replaced by sun-dried or burnt clay Mangalore tiles (named for their place of manufacture) that are today more commonly used as roofing material for the huts.

Figure 3.8 View of decayed thatch roof in a hut over a period of time.

Slight variations occurred in architectural styles from village to village; however, the basic composition remained the same. The walls were decorated with blocks of red and yellow ochre. Relief designs were common. Some were textural arcs made with a broom; others were patterns made by finger and handprints. Usually these designs depicted nature and folklore (see Figure 3.9).

Figure 3.9 Painting on the wall of a hut. (Source: http://www.marcusleatherdale.com/images/jharkhand/fullsize/jharkhand_07_fs.jpg)

Havelis (mansions) of early twentieth century

In these hot countries a house is considered beautiful if it be capacious, and if the situation be airy and exposed on all sides to the wind, especially to the northern breeze. A good house has its courtyards, garden, trees, basins of water, small jets d'eau in the hall or at the entrance and handsome subterranean apartments which provided with large fans…no handsome dwelling is ever seen without terraces on which the family must sleep at night.

- Francois Bernier (quoted by Cooper & Dawson, 1998)

Indian architecture as it stands today is a pluralistic body of production of various cultures influenced by political, religious, or ideological powers (Oliver, 2006). In various parts of the country, both the original and the influenced forms of vernacular architecture can be seen.

The British rule in India transformed the country in many respects, and architecture was no exception. Under British rule, the country saw a sudden growth in trade, and native merchants prospered. Under British patronage, this segment of the society sought ways to distinguish itself from the rest. One of the consequences was a new form of architecture, governed by the local culture but also influenced by British architecture. The newly created spaces and forms were purposefully transformed into usable spaces according to the cultural and ritualistic norms of the society (Bandhopadhyay & Merchant, 2006). Mansions (see Figure 3.10) became popular among the wealthy. Cultural connotation meant the honor of the owner depended on the number of people staying in it, so these houses were large (Cooper & Dawson, 1998).

Figure 3.10 A haveli in Ranchi, Jharkhand. (Photograph by Vanjul Vinit)

These mansions may have mimicked English architecture, but this traditional urban domestic architecture harmonized with the regional climate (Cooper & Dawson, 1998). A courtyard is an important feature of these houses, which is a major difference between these houses of Jharkhand and those of the English. In these houses, the outdoor space is captured and included in the residential volume, thus becoming the heart of its morphology (Poster, 1989).

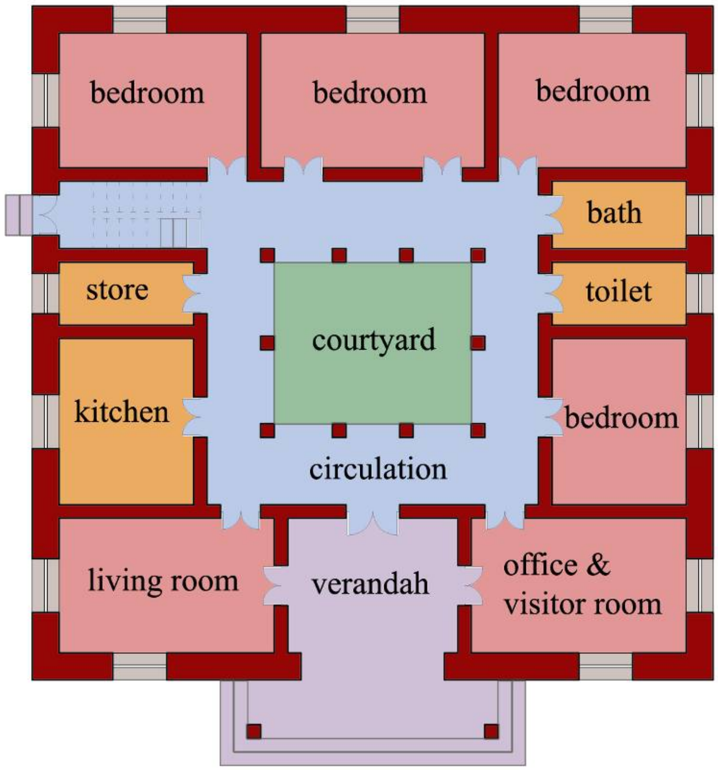
The environmental benefits made courtyards an important aspect of houses in a hot arid climate. In winter, the courtyard provided sunlight at the center of the house enabling heat to be available to most of the house. During night time in winters, this space radiated the heat to the adjoining rooms mitigating the cold. During summers, the courtyard acted as a thermal chimney to let the warm air escape the house and draw the cooler winds into the house (Raydan et al., 2006).

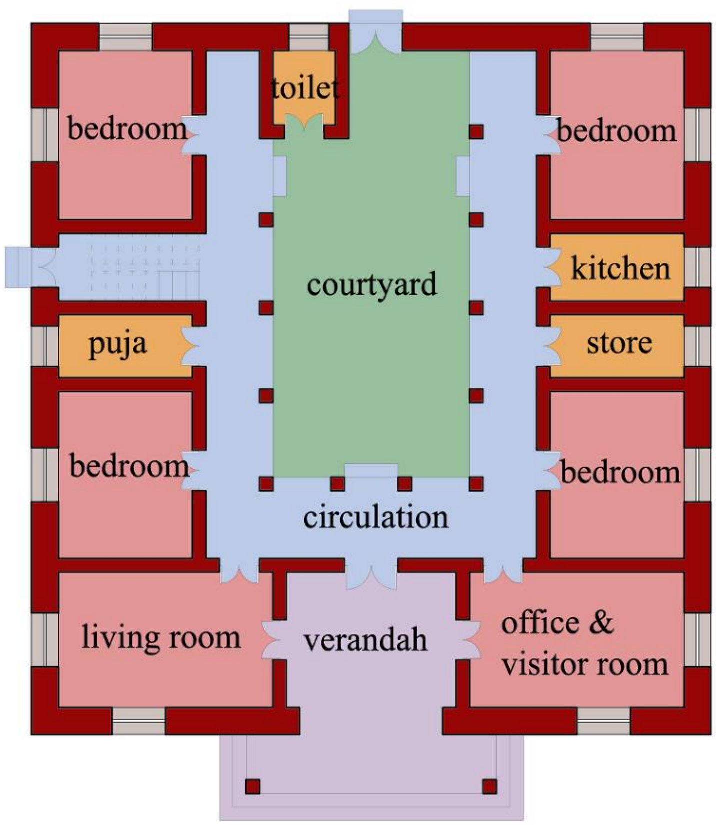
Although courtyards benefited the houses climatically, their evolution responded more to culture than to the necessity to mediate climate. Courtyards evolved from the cultural imperative for a private area for the women of the household to congregate. Typically the front room of the house was used as a business room for the merchants where they carried out day-to-day trade. The courtyard separated the spaces for outsiders and women (see Figure 3.11).

As in the huts, most of the day-to-day activities occurred in the courtyard. It acted as a safe playground for the children who could be watched by the women of the house as they carried out chores. Because the space was thermally comfortable, the aged of the house used the courtyard to rest. Often a small raised brick platform with a small '*tulsi*' plant (holy basil) was present and was incorporated in Morning Prayer according to religious custom. Washing and drying of clothes was also done in this courtyard. In most of the houses, coal and wood were used as fuel for cooking, which created smoke in the house. To overcome this, in most houses, cooking was also done in the courtyard whenever possible. Apart from cooking, eating, and washing, some people used the courtyard for sleeping during summer nights.

An eave ran along the front facade to shade the entrance. This space was used to receive visitors. Only the privileged were allowed to sit in the separate living room of the house. Rooms were arranged on both sides of the courtyard with a narrow raised verandah in front. These houses showed two variations in the arrangement of rooms. The first type had a wall on the back side of the house with the toilet against it, while in the second type, rooms were found even on the back wall and space for toilet was made on one side. Prayer space and kitchen were opposite the toilet.

Figure 3.11 Plan of typical haveli with two variations in Jharkhand.





These houses were built of burnt brick, timber, iron, and lime plaster. Walls were often massive to allow further construction on the floor above. These thick walls acted as high thermal mass for the house, helping flatten day and night temperature swings. Above the rooms, beams supported closely spaced joists, the gap bridged by flat bricks (see Figure 3.12) on which a thick layer of mortar and rubble was laid (Cooper & Dawson, 1998). The roof was finished with lime plaster and *brick bat coba* which serves as waterproofing. Apart from waterproofing, *brick bat coba* acted as a good thermal insulator (Rangaswamy, 2004).

Figure 3.12 View of roof with beams and joists. (Photograph by Ashok Kumar)

The havelis had many windows to allow ventilation. These windows have wooden shutters that were manually operated to control the entry of sun and wind into the house.

These houses were primarily whitewashed inside. Slaked lime in water was used to whitewash the inside. Whitewash served the dual purpose of reflecting heat as well as controlling insects and vermin (http://www.buildingconservation.com/articles/lwdistempers/lwdistempers.htm).

Process and Product

Rapoport (1990) defined vernacular architecture on the basis of process characteristics and product characteristics. In 1969, Rapoport developed these characteristics to distinguish vernacular architecture from popular and folk, a very difficult task. Process characteristics refer to ways in which an environment is created while the product characteristics describe the environment. The former provides information on characteristics of the house that describes its evolution and formation, including the identity of the designer, while the latter provides information on the qualities and attributes of the architecture such as materials and aesthetics. The table shows the contrast between the two styles, huts and havelis, based on the characteristics of vernacular architecture as defined by Rapoport.

The table shows that the two vernacular styles studied here share many process and product characteristics as defined by Rapoport, but differ in a few ways. The users of the houses designed the huts while havelis were designed by specialists along with the users. The main intent of the design in the huts was to abide by tradition, fulfill the user's needs, and maintain a group identity by resembling the rest of the community. The havelis, on the other hand, identify an individual who wants to make distinct impression while still satisfying the needs of the dwellers. The degree of anonymity of the designers in the huts is high while in that of havelis it tends to be a bit lower; some of the designers of the havelis are well-known. Both the prototypes rely on a single model, but some variations in the courtyards and decorative elements occur in the havelis. The degree of congruence relates to the effectiveness of the environment as a setting for behavior and lifestyle. Both types exhibit a high degree of congruence because the environment fits closely with the lifestyle and activities as shaped by the users or part time specialists along with the users. Both prototypes follow unwritten design guidelines; however, they do follow specific rules passed on orally from one to the next generation. Both the prototypes have remained fairly consistent over time. Almost all the houses of these two prototypes display a similar solid-to-void relationship, fenestration pattern, volume, massing, materials, color, and texture.

Table 3.1 Process and product characteristics of vernacular architecture.

	process and product characteristics	huts	havelis
1	Identity of designers	users	users and part-time specialist
2	intentions and purpose of designers	tradition, use, group identity	use, individual identity, status, impressiveness
3	degree of anonymity	highly anonymous	mostly anonymous
4	reliance on a model with variations	yes	yes
5	presence of single model	single model with limited variations	single model with variations
6	extent of sharing of the model	high	medium
7	use of single model	yes	often
8	degree of congruence	high	high
9	use of implicit/unwritten design criteria	high	high
10	degree of constancy over time	high	high
11	degree of cultural and place specificity	high	low
12	use of specific materials	earth, straw, timber, burnt clay tiles	burnt clay brick, lime, timber, iron
13	use of specific color, texture	white inside and outside; rough texture	white inside but colorful outside; smooth texture

Rapoport (1990) suggests that the vernacular architecture responds very effectively to the local climate. He concludes that vernacular architecture resolves climatic conflicts not only by creating thermally acceptable environments but also by responding to meaning and cultural variables like privacy.

The next chapter describes the methodology adopted to test the climate responsiveness of the two different vernacular architectures of Jharkhand.

CHAPTER 4 - Research Methodology

The primary goal of this thesis is to identify the passive architectural strategies used in the vernacular buildings of Jharkhand that contribute to the thermal comfort of their occupants. A comparative case study approach will help in analyzing the buildings in situ and understanding their bioclimatic responsiveness. The case studies were selected after an initial survey. Seeking a representative sample, but recognizing challenges to accessibility of the sample area, were guiding factors in selecting buildings. Data collection was carried out on site in June 2007 during a visit to India. Kansas State's IRB (Institutional Review Board) granted approval for the study before the study (see Appendix B). Two detailed case studies were carried out for each of the two building types: huts and havelis. The research tools include extensive surveys of the building users, photography, building measurement, on-site data collection, and computer-assisted data analysis. These tools helped address the research questions on the qualitative and quantitative aspects of these types of vernacular architecture. The research, divided into survey, observation, and data collection, are discussed in detail in this chapter.

Survey design

One component of the study was a survey of occupants of the two building types. The survey research was divided into two stages: preliminary and detailed. The preliminary survey was used to select the case studies for detailed on-site data collection. During this part of the research, a short questionnaire was given to the head of the family or the person who spent the most time in the house.

The purpose of the preliminary questionnaire was to:

i. Identify the inhabitant to be surveyed.
ii. Get their consent on the informed consent template.
iii. Find out how old their house was and how long they have lived there. Find out the demographics of the household.
iv. Identify the thermal comfort perception of the users in the house.

v. Select from completed surveys a representative sample for further investigation.

As a part of the survey, the researcher cross checked for the following:

- architectural style of the house,
- time of visit,
- date of visit,
- signature on the informed consent form,
- permission and date for further data collection,
- photographic documentation of the house under investigation.

Survey questions from two previous studies were used to formulate the questions for this study. Rohles et al. (1989) studied indoor environment acceptability and developed a rating scale to judge the same. Their study involved using a survey in which the indoor environment was divided into acoustics, air quality, light, and thermal levels. The acoustical environment was judged on loudness, pitch, and distracting sounds. The air quality was judged on odor, dust, and tobacco smoke present. The lighting conditions were judged on brightness, glare, and shadows while the thermal conditions were judged on temperature, humidity, and air movement. Their study showed that temperature and light were the major constituents in the indoor environment acceptability criteria. The preliminary survey for this study incorporates similar survey questions to estimate the acceptability of indoor conditions to the occupants. Das (2006) conducted research in Kolkata on the courtyard house type, examining the roles of solar shading and natural ventilation in the courtyard. The methodology of this study involved surveying and on-site data collection to record the temperature, humidity, and air movement inside the houses. Our research used similar methodology with some modifications. In addition, the preliminary survey questions in our study were based on the parameters developed by Das.

A second, more detailed survey provided perspective for the on-site data collected from the selected buildings in relation to the research question. The interview questionnaire for the occupants covered demographic and general information, the house and its usability, thermal comfort, discomfort, adaptability, and other indoor environmental conditions. Most importantly, the survey attempted to gather the user's perception of thermal comfort in their home. The survey is reproduced in its entirely in Appendix C.

Observation

Personal observation is an important research tool in much research. Phuong and Groves, using only personal observation, studied Hanoi architecture in 2006. Jorgensen (1989) describes participant observation as one of the most important and successful methods for research on humans. Along with the preliminary survey, the researcher made personal observations on a wide range of factors at both the scale of the building and its context. The context included information on the following:

Neighborhood Scale:

i. Location of the house with respect to the neighborhood and its solar orientation.
ii. Description of the neighborhood.
iii. Description of the width and orientation of the street providing access to the house.
iv. Location of adjoining buildings, other structures, and vegetation next to the house especially for solar access and prevailing winds, including estimates of height and other dimensions as well as orientation.
v. Estimate of the economic status of the neighborhood.

Building Scale:

i. Condition of the house.
ii. Landscaping around the house.
iii. Presence of a water body near the house.
iv. Number of rooms in the house.
v. Location of different rooms with respect to the entry.
vi. Solar orientation of the different rooms and openings/windows.
vii. Structural continuity between the different rooms.
viii. Type of the cooking appliance.
ix. Presence of active cooling means in various rooms.

x. Type and wattage of light fixtures.

Element and Detailing Scale:

i. Construction materials of the floor, walls, roof, and shading devices.
ii. Colors of the wall, floor, roof, shading devices.
iii. Number of windows on the exterior and interior walls of the house.
iv. Location, number, and dimensions of the windows, including solar orientation.
v. Windows being open or closed during the time of visit.
vi. Type of shading devices used.
vii. Thickness of the walls, shading devices, floor, and ceiling.
viii. Presence of rat-traps, screening, and other vermin control.
ix. Activities of the habitants during the time of visit.
x. Clothing of the habitants.
xi. Types of furniture and furnishings.

Personal Experience:

i. Hottest and coolest parts of the house at the time of visit.
ii. Social interaction in the different spaces.
iii. Acoustical quality of the house.
iv. Comfort level inside the house as compared to the outside.
v. Ambiance of the place.

Data measurements

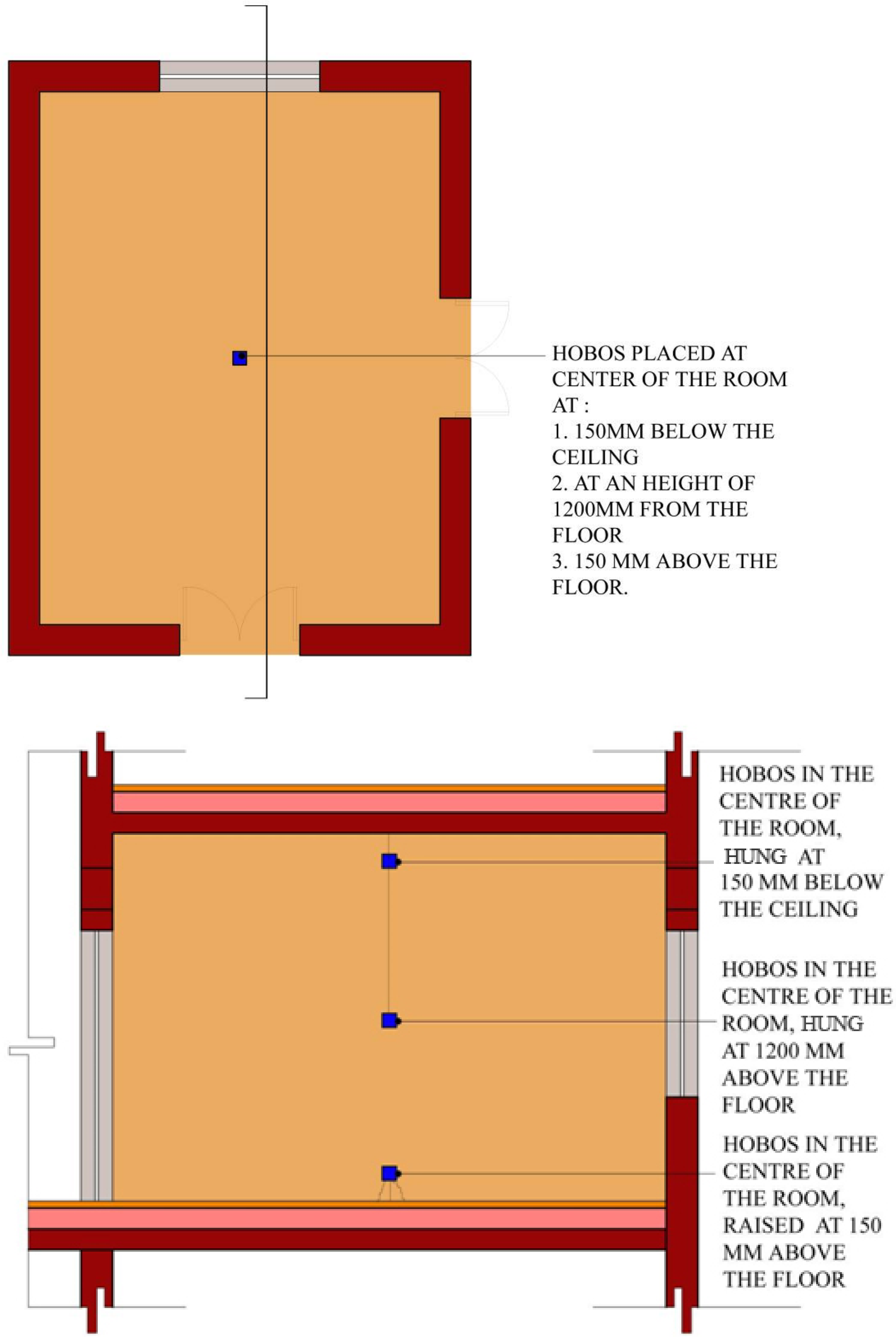
Based on the preliminary analysis, two houses of each prototype were selected to carry out detailed on-site data measurements. The on-site measurements helped correlate the perceived subjective human comfort levels of the occupants with objective data. Data on temperature, humidity, light intensity, and air movement was gathered in the four selected houses over two days with the help of instruments borrowed from the Department of Architecture at Kansas State University. A description of the instruments follows.

HOBO:

Four Three-channel Hobo data loggers (see Figure 4.1) collected data on humidity, temperature, and light intensity to study variations over a day. These data loggers were installed at the center of the room at a height of 1-1.5m, 150mm above finished floor level, and 150mm below the ceiling level (see Figure 4.2). The height of 1-1.5m is based on the average human height while sitting or standing (Das, 2006). To collect the ambient temperature data, another HOBO data logger was installed on the outside wall in shade. The external data port of the device at 150mm below the ceiling collected the ceiling temperature. The external port was placed so that a thermal conductor was in contact with the ceiling while the HOBO was 150 mm below the ceiling. Another HOBO was placed on the wall at the height of 1.5m with a thermal conductor connected to its external data port to record the thermal mass temperature of the external wall. This external data port was taped to the surface. All data were automatically sampled at an interval of 30 minutes.

Figure 4.1 HOBO data logger. (Source: www.onsetcomp.com)

Figure 4.2 Diagram showing typical locations of the data logger installed to gather climatic data in a room.



Raytek handheld infrared thermometer:

A Raytek thermometer (see Figure 4.3) was used to record temperature instantaneously on different surfaces. Surface temperature of the walls, roof, and floor were recorded at an interval of 30 minutes. This data provided information on the temperature stratification on the different facades and the thermal properties of different building materials.

Figure 4.3 Raytek Gun. (Source: www.lasertools.com.au/images/raytekmt6.jpg)

Anemometer and velocity stick:

Anemometer (see Figure 4.4) and Velocity Stick (see Figure 4.5) recorded the wind speed at the center of the room at a height of 1-1.5m. Readings for wind speed at the windows were also recorded. The wind speed helps determine evaporative and convective cooling of the thermal mass of the house. All observations were recorded at an interval of 30 minutes to coincide with the data set from the HOBO data loggers.

Figure 4.4 Anemometer. (Source: www.anemometers.co.uk/anemometer_kestrel_1000_anemometers.html)

Figure 4.5 Velocity Stick. (Source: www.skcgulfcoast.com/images/products/specialty/velocitystick1.jpg)

Metric measuring tape:

Measuring different parameters in the house is essential to document the house under investigation. Dimensions of the different elements and spaces helped in comparing the different architectural variables under investigation. A metric measuring tape was used to measure the dimensions of rooms and windows. In houses with sloping roofs the ceiling heights at the walls and at the ridge were measured. All measurements were made from the finished floor level.

Magnetic compass:

Orientations of the houses under investigation were identified to act as a control variable. A magnetic compass corrected for declination was used to determine the orientation of the building.

Data analysis

Statistical analysis will be carried out on the collected data to derive relationships among the different variables. Ghisi and Felipe Massignani (2007) calculated correlation between external and internal temperatures, and correlation between temperature differences and thermal properties to study the thermal performance of bedrooms in a multi-storey building in southern Brazil. A factor of correlation was used to measure the dependence of one variable on the other. Similarly factor of correlation will be calculated between different variables in this study to analyze the data collected.

Factor of correlation between the interior and exterior temperatures will be calculated to see their interdependency. A low correlation between the two will lead to conclude the structure being a good thermal barrier. Correlation will also be calculated between the different temperatures inside the house to see their relationship to height. It is expected that the temperatures at different heights will have high correlation with each other in low ceiling space and vice versa. In a high ceiling space, due to stack ventilation there can be a low correlation between the air temperatures in the living zone and next to the ceiling. Since radiant temperatures influence thermal comfort, correlation between the surface temperature and temperature near the different surfaces will be calculated to check if they influence each other. If the thermal mass has high thermal capacity the correlation between the external temperature and the internal surface temperature of these surfaces would be less and vice versa. Variance will be calculated to measure the consistency of the data collected. The data was collected every half hour for two days, so the average of the data measured will be used to calculate a single value for further analysis.

Limitations of the research design

There are some inherent limitations in this research study. Among the limitations were distance between the locations for case studies and the university, which limited time for actual site visits. The instruments were not water-proof, which may have skewed the results. A complicating factor was the difficulty of obtaining permission from the occupants of the buildings to participate in the research.

The research constrained itself by studying limited numbers of variables both in passive solar design strategies, architectural elements, and the building type. The study was limited to two building types: huts and haveli style mansions. Time and resource constraints limited the architectural variables to aperture and ceiling heights along with estimates of features such as thermal mass, material, and orientation. Also in defining thermal comfort, the study was limited to the variables of temperature, humidity, ventilation and does not explicitly address personal user factors such as age, culture, thermal performance of clothing, nor the user's metabolism/activity level.

The study was conducted for a limited time and within a particular season, so the validity of the results applies only to that season; generalizing results to the entire year cannot be accurate. Summer was preferred as the season to collect the on-site data as personal observation of the climate of Ranchi shows the climate becoming hotter over recent years. Moreover, the Hobos collecting data were not waterproof, so on-site data had to be collected before the onset of the monsoon. The advantages of collecting data during this season include results from the hottest time of the year, so a reasonable extrapolation would be that thermal conditions during most of the rest of the year would be similarly or more comfortable. However, data was not collected for winter, so the performance of the houses under cooler conditions cannot be tested.

The homes selected for the case studies had instruments installed in them for the duration of the study period. Out of respect for the privacy of the participants, the researcher did not remain on-site during the night. The researcher has ensured to the best of his ability that the data collected and used in this report is authentic. The havelis selected for on-site data collection and detailed study had servants (mostly uneducated) and children, and the selected huts had children whose behavior was not under the control of the researcher. Hence, there is no guarantee that instruments were not mishandled. As a part of reliability verification, the instrument heights and location were checked when retrieving them from the site to ensure that they had not been relocated or tampered with.

The survey questions were designed in English but were translated into Hindi to conduct the survey. Answers were given in Hindi and translated into English for this study. Survey answers are subjective in nature; the responses given may well have been influenced by personal thermal attributes and uncertainties of exact English-Hindi measuring.

The next chapter discusses the case studies in detail.

CHAPTER 5 - Case Studies

As described in Chapter 4, this research uses case studies to examine the research question. This chapter contains analysis of survey and on-site data collected for the study. The chapter has two sections: a) survey, and b) on-site data analysis.

Survey analysis

As discussed in Chapter 4, in June 2007, a survey identified a representative sample for onsite data collection for detailed case studies. The survey attempted to gather users' perceptions of thermal comfort in their home. For this purpose, the survey was divided into six sections (see appendix C for questions and responses). Five houses of both the types were surveyed. The houses were numbered 1 to 10 (see appendix D for photographs of all the houses surveyed); henceforth their respective numbers are used to address them individually. The following is the analysis of the survey.

Demographic and general information:

This section of the survey (see tables C.1 and C.7) attempted to gather information on the house and occupants. Questions based on the period that the user had stayed in Ranchi and in the house were asked to ensure that the occupants had stayed long enough in Ranchi and the house to answer some of the questions that required observations over a long time. The time when the house was built was used to check that the houses under investigation were not new construction. Nine out of ten houses surveyed showed that the occupants had been living in their homes for more than 30 years. All houses under investigation were at least 35 years old. One hut selected for detailed case study was more than 100 years old, while the other was approximately 50 years old. The havelis selected for detailed case study were approximately 75 years old.

House and its use:

This section of the survey (see tables C.2 and C.8) attempted to gather information on the usage pattern of the house on a diurnal and seasonal basis. These questions helped us correlate usage of space based on the thermal comfort levels in those areas to determine the most used space by the occupants. Thus instruments could be set up in that space to collect weather data. Time spent by the occupant inside the house was needed to relate their perception of thermal comfort conditions inside the house with the outside. On average, the occupants surveyed remained in the house for more than half the day, which ensured their responses would be comparable to the data collection period. In the huts and one house of the havelis, we saw a seasonal shift in space usage. The occupants of huts migrated from indoor space during the summer to outdoor space in winters. We saw a diurnal shift in space usage from indoor to outdoor in only two houses belonging to the pre industrial type. The occupants of these two huts moved outdoors during the evenings in summers because of air movement; air movement inside the house was nearly non-existent. Occupants of other huts preferred to stay indoors in summers even in the evenings. Despite spending most of their time indoors, washing, bathing, drying of clothes, praying were done in the courtyard early in the morning when the temperature outside was cooler than in the afternoon. The users slept inside the huts throughout the year. The occupants of the havelis indicated no seasonal migration in space usage and preferred staying indoors throughout the year. Like the courtyards of the huts, courtyards of these houses were also used for praying, washing, cooking at times, and playing. The owners of these houses mentioned changes in the function of the courtyard over the years. The havelis courtyards used to be the center of all kinds of activities even in summer, but recently sleeping, sitting at leisure hours, daily cooking, gatherings have shifted indoors due to security and weather conditions.

Comfort exterior:

Perceived comfort conditions were the main focus of this section of survey (see tables C.3 and C.9); the responses were correlated with the on-site measured data. All ages and genders had similar responses to the relative thermal comfort of their homes. Occupants of all the houses felt more comfortable all day inside the house during summer because it was relatively cooler inside than out. Users of huts (80%) said spring to be the best season outside the house, while all haveli occupants said winters were most comfortable outside. Occupants of two huts used a ceiling fan to circulate air in summers to make it comfortable inside the house while the occupants of rest of the three huts depended on air movement for circulation of air. Occupants of all the havelis surveyed used ceiling fans throughout the day in summer. Occupants of the huts believed the attic made the hut more thermally comfortable while occupants of the havelis believed thermal mass and high ceilings were the main reason their houses were more thermally comfortable.

Discomfort exterior:

This section of the survey (see tables C.4 and C.10) gathered information on the discomfort levels as perceived by the occupants of the houses surveyed. The intention was to compare occupant responses to the data collected. As the research was carried out for a limited time these responses also helped us understand their perceptions for the entire year. Occupants said temperature was most uncomfortable in summer and winter. They also felt humidity and lack of air movement were uncomfortable in summer. Occupants (80%) of the huts said that the rainy season was the most uncomfortable season because they could not perform day-to-day activities as usual. Occupants (60%) of havelis found winters most uncomfortable due to reduced light and heat from the sun; the windows were usually closed throughout the day to keep the chilly wind out.

Adaptability:

As discussed in Chapter 2 and Appendix A, the climate of Ranchi has changed over the years. This section of the survey (see tables C.5 and C.11) gathered responses to changes in climatic conditions and their perception of thermal comfort inside the house over the years, as well as to determine what changes, if any, had been made to the homes from their original condition. All the occupants surveyed said that the climate in Ranchi had changed over the years, becoming hotter. Occupants of 80% of the huts and 60% of the mansions felt no difference in the comfort of the house. Moreover, all the houses are in their original state and only repair work to keep the house in good condition has been done. The occupants added that, except for adding ceiling fans in the house, no other measures were taken to create comfortable conditions inside the house over the years.

Additional indoor environmental factors:

The last section of the survey (see tables C.6 and C.12) addressed additional environmental factors that create comfortable conditions inside these houses. The survey questionnaire and rating system developed by Rohles (1989) was used. This section covered acoustics, light, air quality, thermal environment, and pest control. The thermal environment inside the houses was highly rated. The occupants said that indoor thermal levels were more comfortable than outside and were highly satisfied by their houses' performance. Occupants of all these houses rated the acoustical quality of their house highly on loudness, pitch, and audibility of distracting sounds. Occupants (60%) of the houses surveyed rated the air quality high, with odor, dust, and smoke inside the house not a problem. Occupants of 60% of the huts and 80% of the havelis rated the light quality inside the house satisfactory, given shadows and brightness. The light quality (glare) was also high. Occupants (90%) rated the indoor environment quality poor for pests. In all, occupants of 80% of the huts and 100% of havelis were highly satisfied with the overall comfort level inside their houses. The remaining 20% occupants of the huts surveyed rated their indoor environment quality acceptable.

On-site data analysis

Occupants of these houses said their houses had high thermal comfort, but only four houses were selected for detailed on-site data collection. House 1 and house 4 were selected from the huts while house 6 and house 7 were selected from havelis. Permission from the occupants and the researcher's instinct for the safety of instruments in the houses were the guiding factors in selecting these houses. Occupant responses to survey were used to correlate the measured data and verify results.

House 1 (hut)

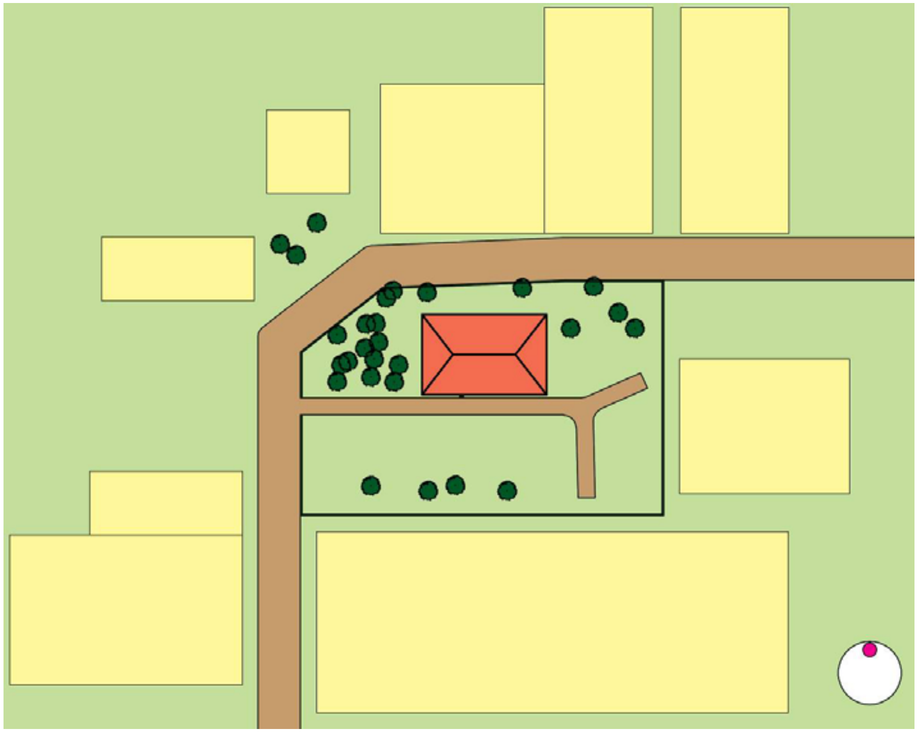
The house is next to the main downtown road in the center of the town. It faces south and is east-west elongated. Houses with shops on the first floor neighbor the house. The street connecting the house to the road is oriented east-west and is 3 meters wide. There are trees on the north and west sides of the house about 7 meters away. On the east and south lies an open area of about 15 meters square. The house sits in a lower middle class neighborhood. The walls are in good shape; however, the roof appears to need some maintenance. Trees grow on the north and the west side of the house. On the south side, a small bush 1.2 meters high sits 3 meters away. No surface water lies near the house. The house has two living spaces, a kitchen, a toilet, a study, two storage areas, and a verandah on the east and south sides. The primary entry door opens to the family room from the verandah on the south side of the house. Two other doors remained closed throughout the time the data was collected. The house also has two windows on the north side (see Figure 5.1). The ceiling of the living space is 4 meters high. The unglazed windows of the living room (1.2x1.2 meters) have wooden shutters which remained open during the visit, but the doors were closed, and there was very little movement of air inside the house (see figures 5.14 and 5.15).

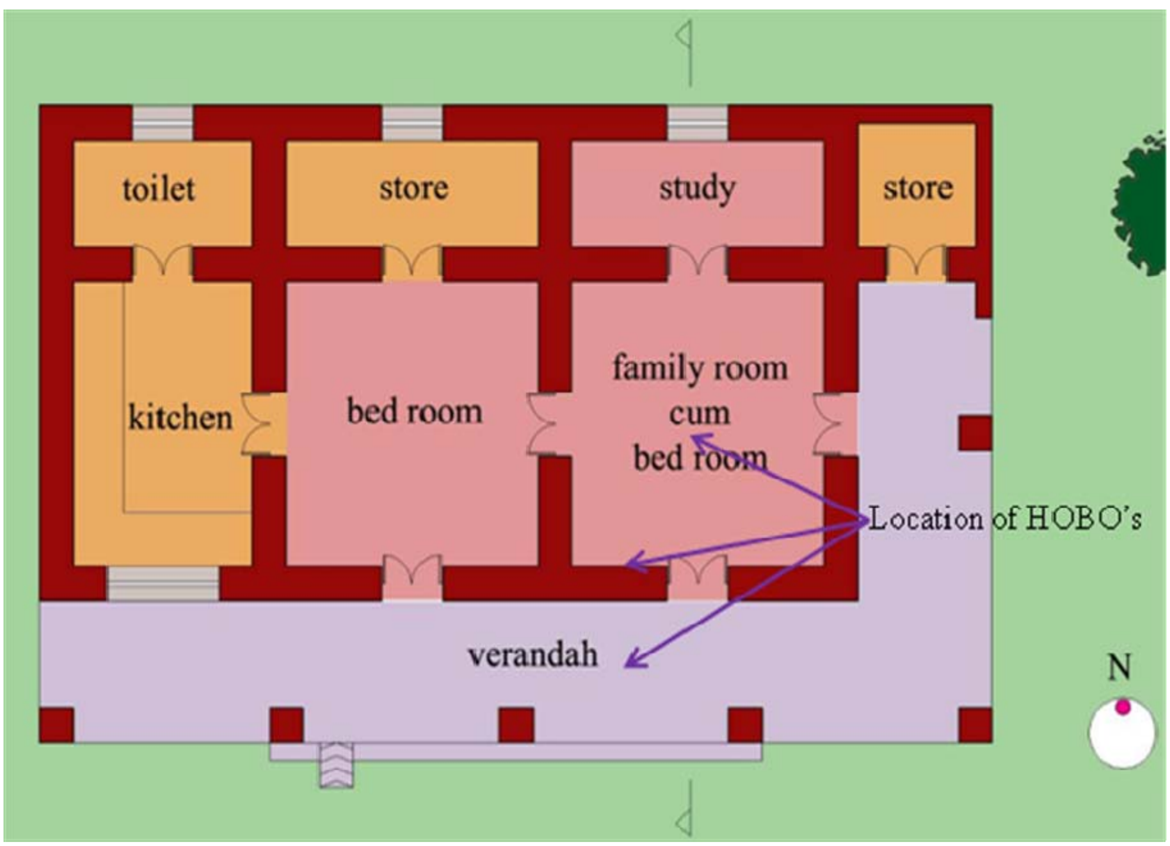
Adobe bricks and lime mortar were used to construct walls and exterior columns, all of which are approximately 0.6 meters thick. The floor and walls are finished with lime plaster. The roof is made of burnt clay tiles laid over wooden rafters. An intermediate ceiling lies below the roof and is made of mud tiles laid over wooden rafters and plastered with lime. There are no external shading devices over the windows. The walls and the ceiling are white while the floor is grey (see Figure 5.2). The wooden doors and the windows are painted green.

Liquefied petroleum gas is used as cooking fuel in the kitchen; hence, there is no smoke inside the house, which was verified by the survey results. The family room has a ceiling fan for air circulation, which is used during summer afternoons. Each room is lit by a single compact fluorescent lamp, which minimizes the heat from the lighting. There are rat traps on the external doors. No screening exists on the windows, and the residents wish to add them to prevent insects entering the house.

The owner of the house rested during the initial visit and wore a t-shirt and trousers as the outside temperature was high. Personal observations suggest the kitchen is the hottest area and family room the coolest, which is supported by the survey results. The house was relatively much cooler than outside during the afternoon hours in summer, which is verified by the collected data.

Figure 5.1 Site Plan, plan and section of house # 1.





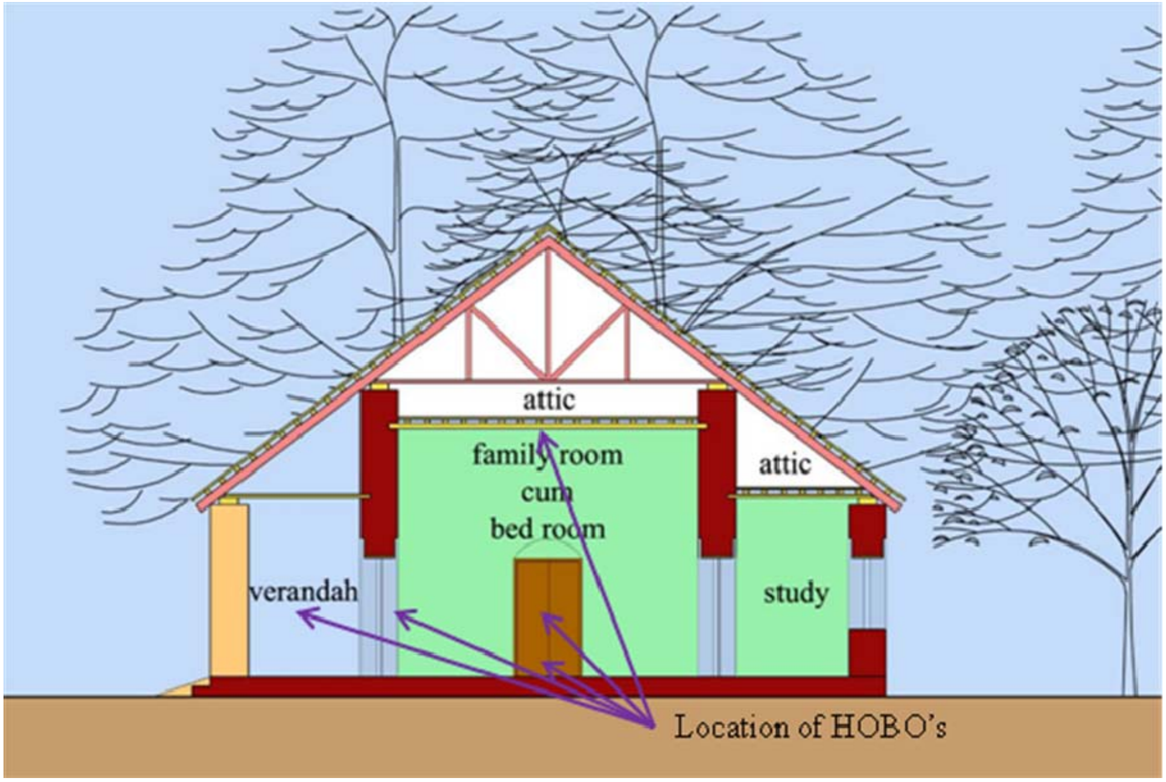


Figure 5.2 View of house # 1.

House 1: Data Collected

While the surveys were very helpful in determining perception of comfort, this component was supported by objective measurements. A variety of instruments determined ambient external and interior conditions for forty-eight hours as described in Chapter 4.

Figure 5.3 House 1, temperature: external, internal, degrees C.

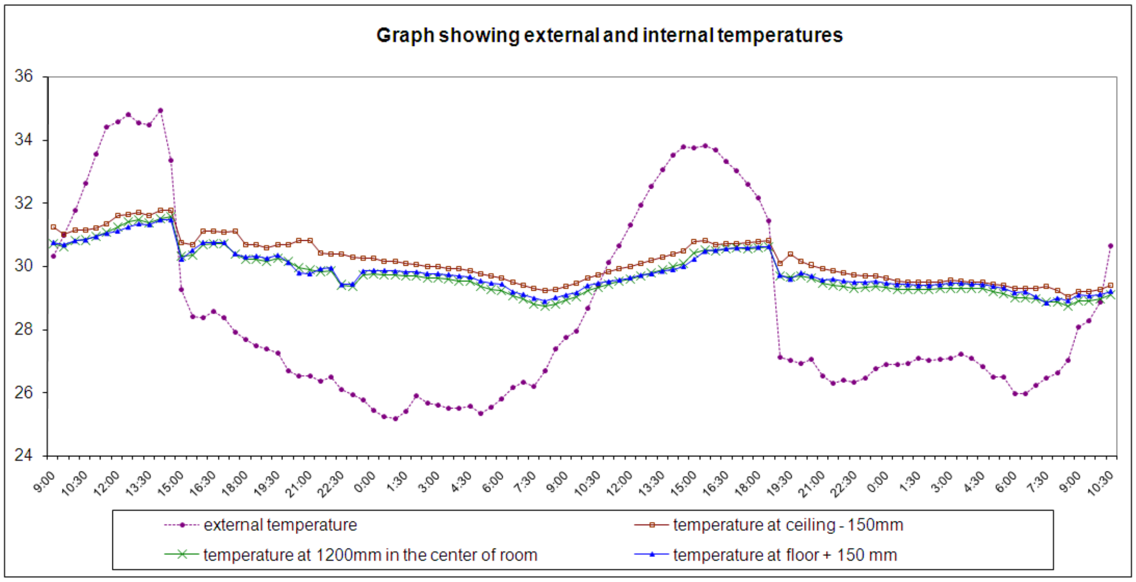


Figure 5.3 shows the external temperature and internal air temperatures. The graph shows a higher exterior diurnal temperature swing than inside the hut. While the temperature variation outside the house was 9.75°C (from 34.94°C to 25.18°C), interior temperature at 1200mm high remained stable within a range of 2.81°C (between 28.74°C and 31.56°C). The internal temperature did not follow the external temperature curve. The graph also shows that the temperature inside the house remained lower during the day and higher at night than the outside temperature. In the survey, the residents verified this by preferring to stay indoors during the day. The temperature of air near the ceiling was higher than the air temperature at 1200mm high inside the house, because hot air rises, thereby allowing cool air to settle down in the living zone and create comfortable conditions in summer. The graph also shows that the air near the floor remains much cooler than the air at sitting height. The average difference between the temperatures at

floor level and at the sitting height was 0.07°C; the high thermal mass of the floor absorbed the heat from the air near it making it much cooler than the air at 1200mm high.

Figure 5.4 House 1, temperatures: air at 1200mm near the external wall, internal surface of the external wall at 1200mm height, degrees C.

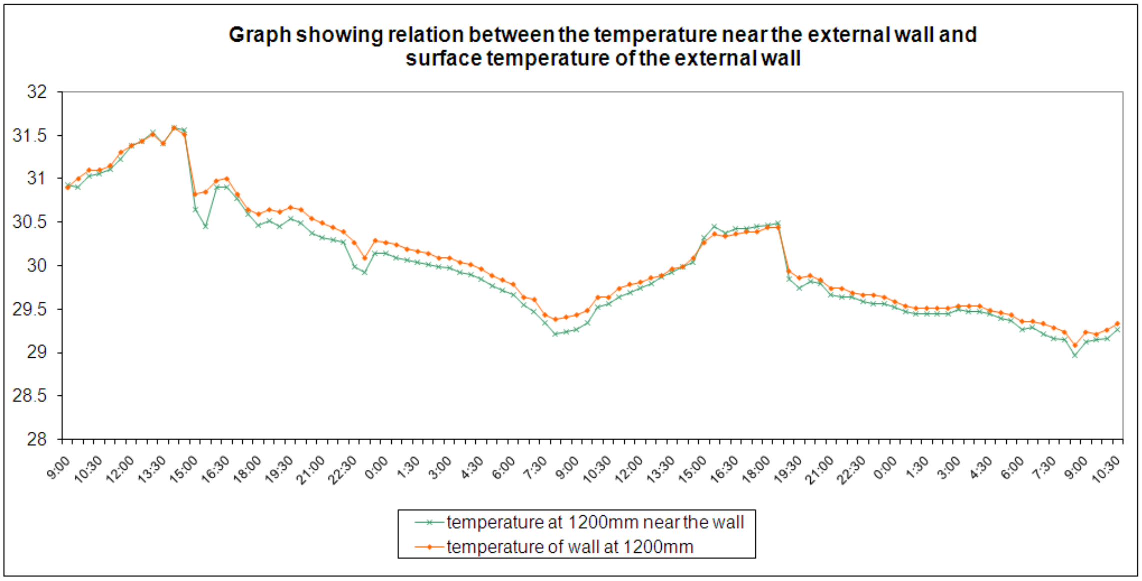


Figure 5.4 compares the air temperature near the external wall and the surface temperature of the external wall. The surface temperature of the external wall and the air temperature near the external wall tracked each other closely, with a correlation between them of 0.99. The correlation between the external air temperature and the surface temperature of the wall was 0.55, showing that these two temperatures were not closely related. This leads to the conclusion that that air temperature inside the building is influenced more by the walls than by external conditions. During the afternoon, the air temperature rose above the surface temperature of the wall indicating the high thermal capacity of the walls. Also, the external wall temperature did not track external air temperature. The thermal retention capacity of the walls was high, so the surface temperature of wall remained stable even when the outside air temperature changed significantly.

Figure 5.5 House 1, temperature: air near the ceiling, surface of the ceiling, degrees C.

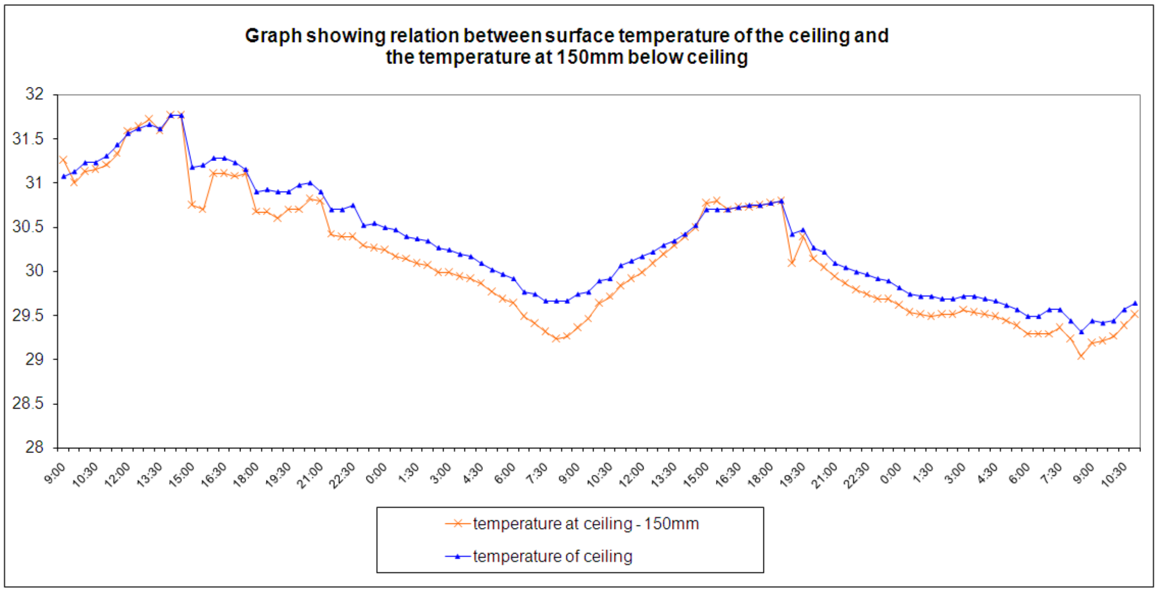


Figure 5.6 House 1, temperature: external, comfort as defined by Nicol, comfort range as per ASHRAE, internal at a height of 1200mm, degrees C.

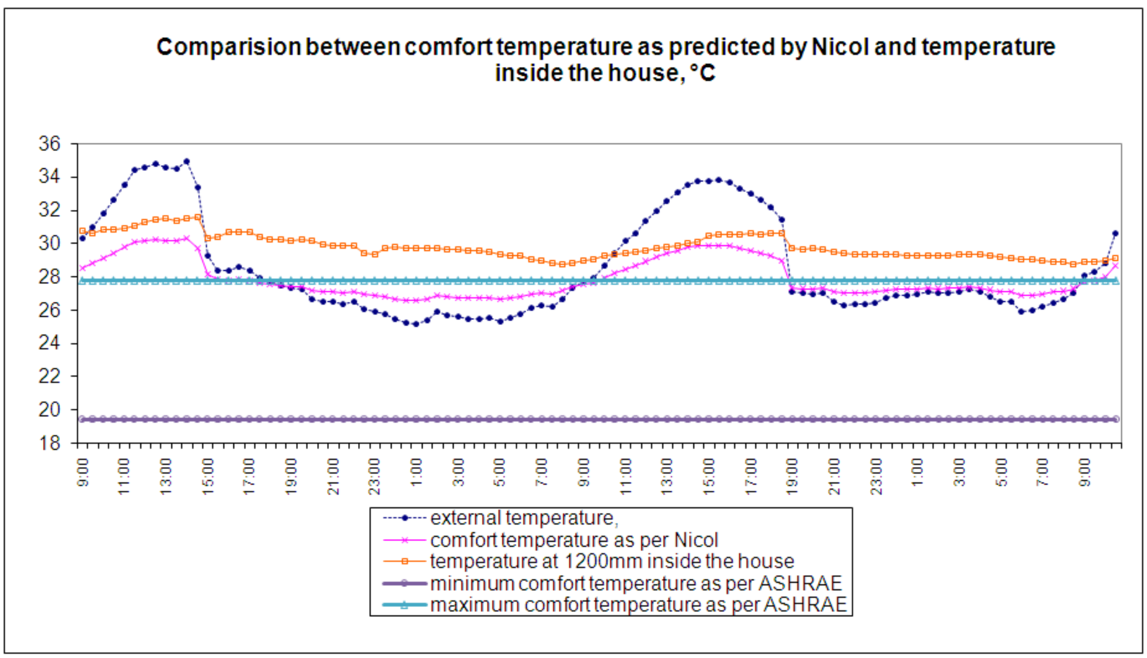


Figure 5.5 compares the air temperature near the ceiling and the surface temperature of the ceiling. The surface temperature of the ceiling and the air temperature

near the ceiling traced each other closely, with a correlation of 0.98. The ceiling received heat from both the hot air trapped in the attic and from inside the room. However, the thermal capacity of the ceiling is high, so its temperature does not increase dramatically. The external roof of the hut kept the sun rays from falling directly onto the ceiling and hence the ceiling temperature did not increase as much as it could have. The surface temperature of the ceiling did not track the external air temperature, and the correlation between them was 0.55.

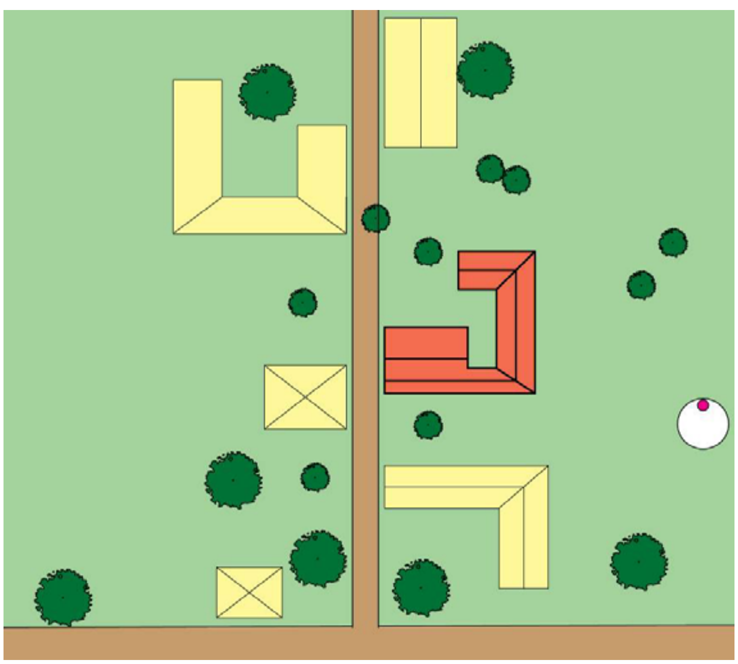
Figure 5.6 compares comfort temperatures and temperature inside the house at 1200mm high. The temperature inside the house was always higher than the thermal comfort temperature as predicted by Nicol. When the outside temperature was high, the inside air temperature is much closer to this predicted comfort temperature than when the outside air temperature is low. Moreover, the external air temperature lay within the ASHRAE comfort temperature range from evening until morning while the air temperature inside the house at this hour was in the discomfort zone. This contrasts survey results (see tables C.3 and C.6) and on-site data: occupants considered the temperature inside the house comfortable throughout the 24 hours.

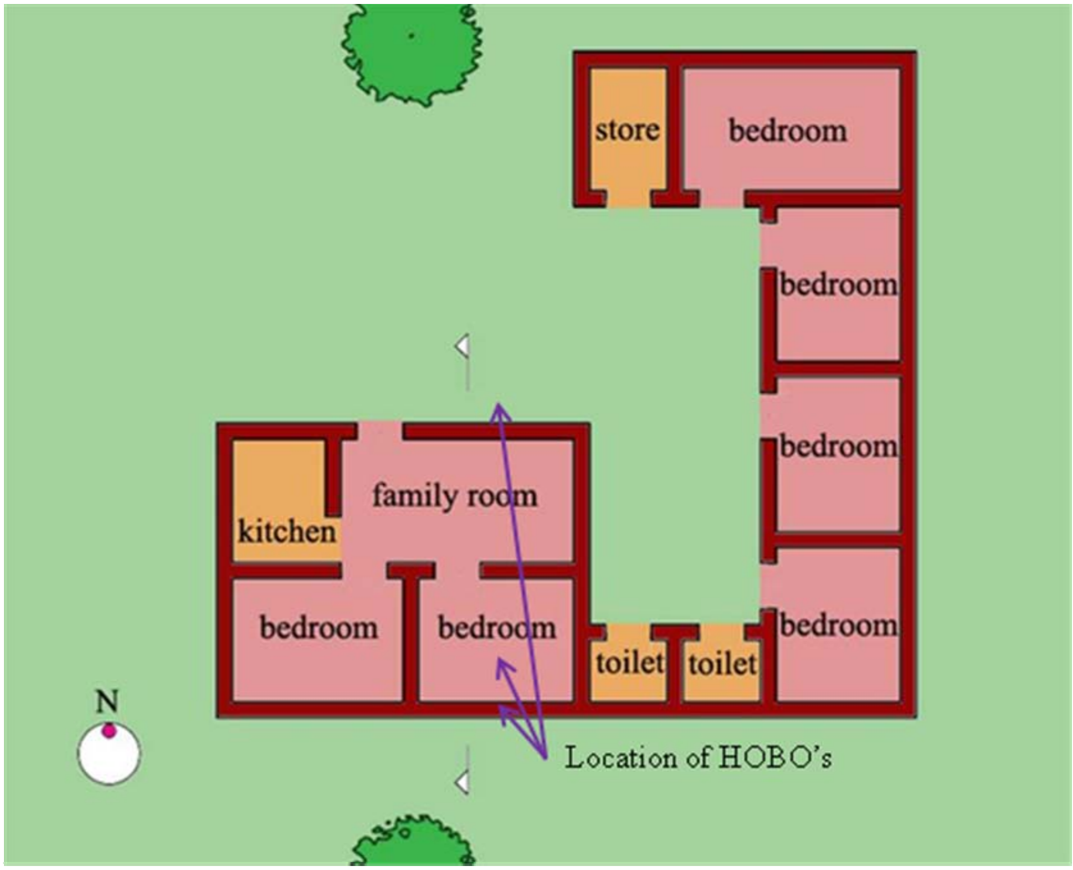
House 4 (hut)

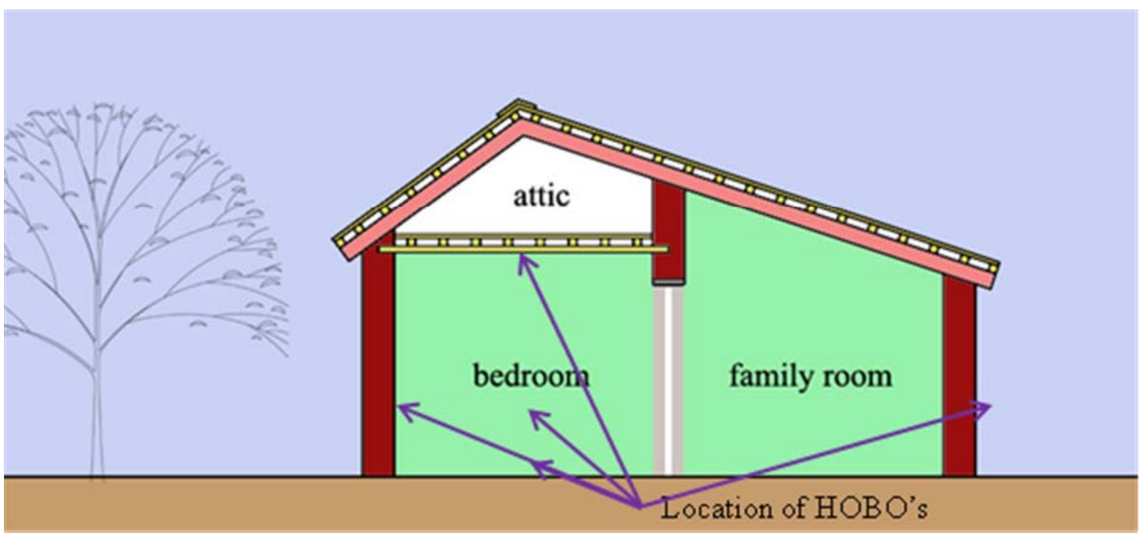
The house is in the suburbs of the city, in a lower class neighborhood with similar homes. A 3 meter wide mud road runs east-west next to the house; connecting the house to the main road. There are trees 9 meters north of the house. On the east and south lies an open area about 6 meters wide. The walls and the roof of the house are in good shape compared to others nearby. There is a 4 meter diameter well on the north side of the house 6.5 meters away. The house is L-shaped and has 6 living rooms, a kitchen, a storeroom, a toilet, and a bath. The doors of all the rooms except two open onto a common courtyard. The remaining two rooms have the family room between them and the court. The family room has the only window of the house, unglazed and without shutters. The doors remained open during the day, but our measurements showed very little movement of air inside the house (see figures 5.11 and 5.12). The floor and walls are finished with mud plaster. The house has 450mm thick mud walls. The ceiling of the living space is 2.1 meters high (see Figure 5.8). The roof has burnt clay tiles laid over wooden rafters. The house originally had two bedrooms, a kitchen, and a toilet. Later on, as the number of family members increased, 4 bedrooms, another toilet, and a storeroom were added, creating a semi-enclosed courtyard. The new construction was similar to the old construction.

Figure 5.7 View of house # 4.

Figure 5.8 Site plan, plan and section of house # 4.







Liquefied petroleum gas is used as cooking fuel in the kitchen, so there is no smoke inside the house as verified by the survey results. The rooms have no mechanical means to circulate the air. All the rooms have one lamp, so the heat from the lighting is negligible. There are no rat traps and no screens on the window to prevent insects entering the house.

The owner of the house rested during the time of the visit and wore a vest and a wrapped cloth around his waist as it was too hot outside the house. Personal observation suggested no significant difference in the thermal conditions inside various rooms of the house. The house was also relatively much cooler than outside during the time of visit, which was verified by the on-site data.

House 4: Data Collected

As with House 1, objective measurements in House 4 complemented the results of the survey. The same instruments and a similar method was used to collect these data (refer to Chapter 4). The section below presents these data collected from House 4.

Figure 5.9 House 4, temperature: external, internal, degrees C.

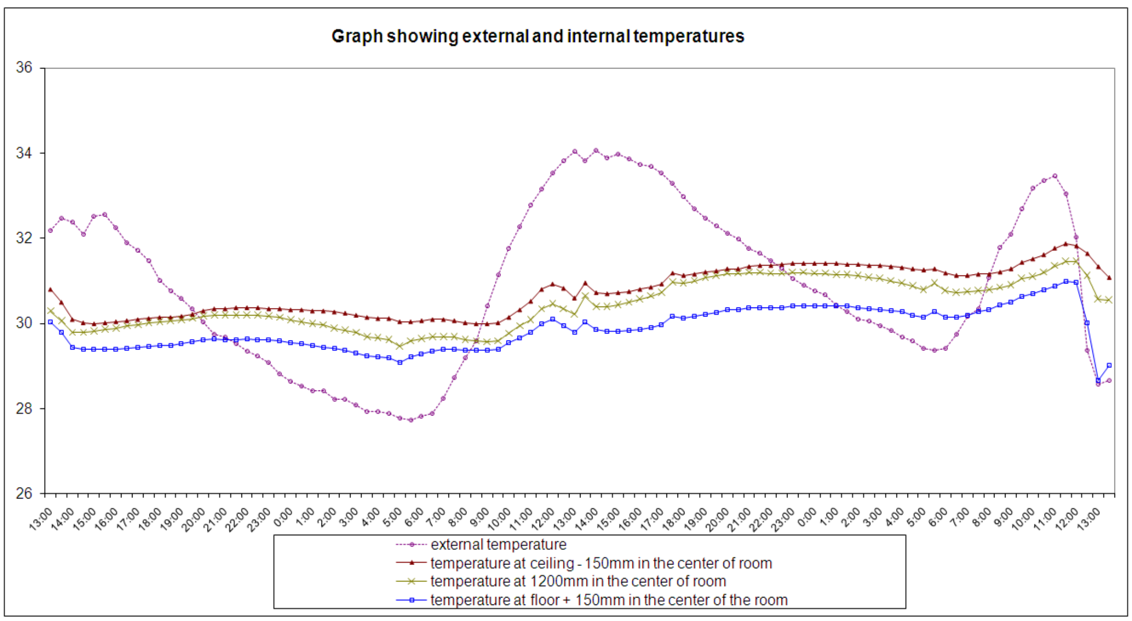


Figure 5.9 shows the external air temperature and internal air temperature. The exterior diurnal temperature swing was higher than inside the hut. While the temperature variation outside the house was 6.34°C (from 27.72°C to 34.07°C), the interior temperature remained more stable within a range of 1.99°C (between 29.46° C and

31.45°C). The graph shows the external and internal air temperatures were not closely related to each other and changes in external air temperature barely affected the internal air temperature. The correlation between the external air temperature and the air temperature at 1200mm high inside the house was 0.38. However, the indoor air temperatures at different heights tracked each other closely. A low ceiling does not allow temperature stratification, so the three indoor air temperatures at different heights were highly correlated. The factor of correlation between the air temperatures at 1200 and 150mm below the ceiling was 0.97 and that between 150mm above floor and 1200 mm high is 0.9. Also, the correlation between air temperatures at 150mm below the ceiling and 150mm above floor was 0.87, which suggests that these three air temperatures were interdependent. The graph also shows that the air temperature inside the house remained cooler during the day and warmer at night than the outside air temperature. The residents verified this, mentioning their preference to stay indoors than outdoors during the day in the survey.

Figure 5.10 House 4, temperature: air at 1200mm near the external wall, internal surface of external wall at 1200mm height, degrees C.

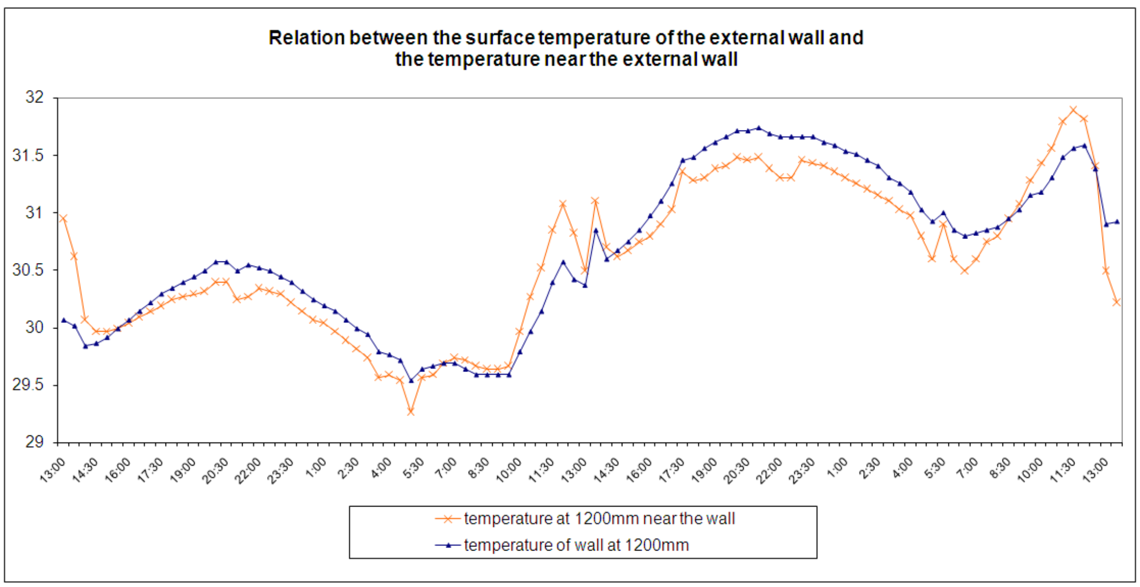


Figure 5.11 House 4, wind velocity: first day, ft/min.

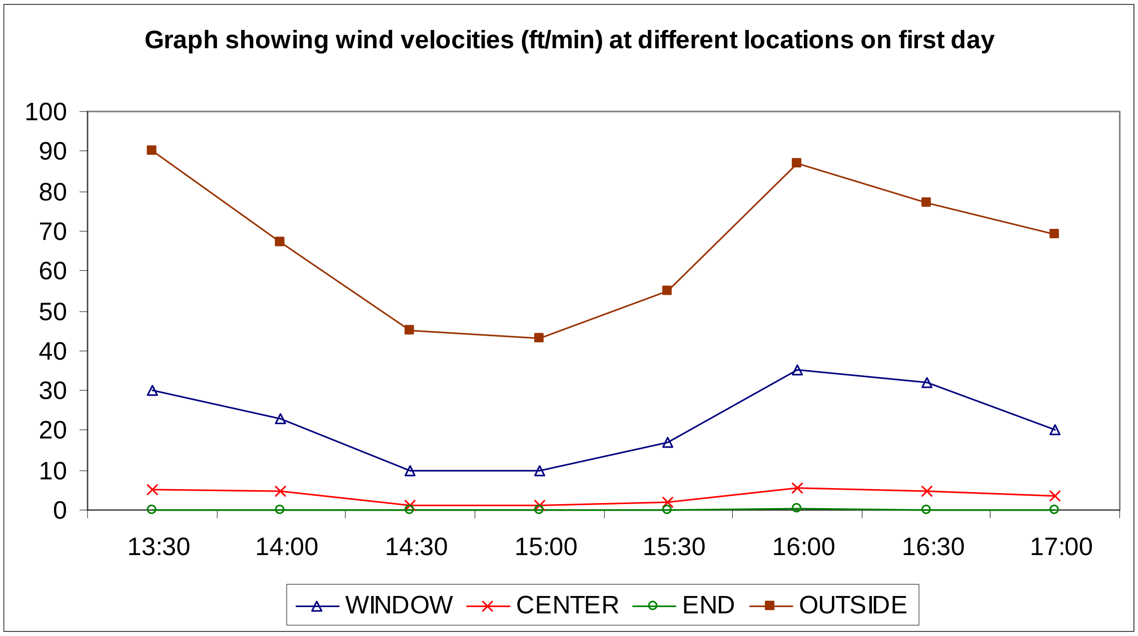


Figure 5.12 House 4, wind velocity: second day, ft/min.

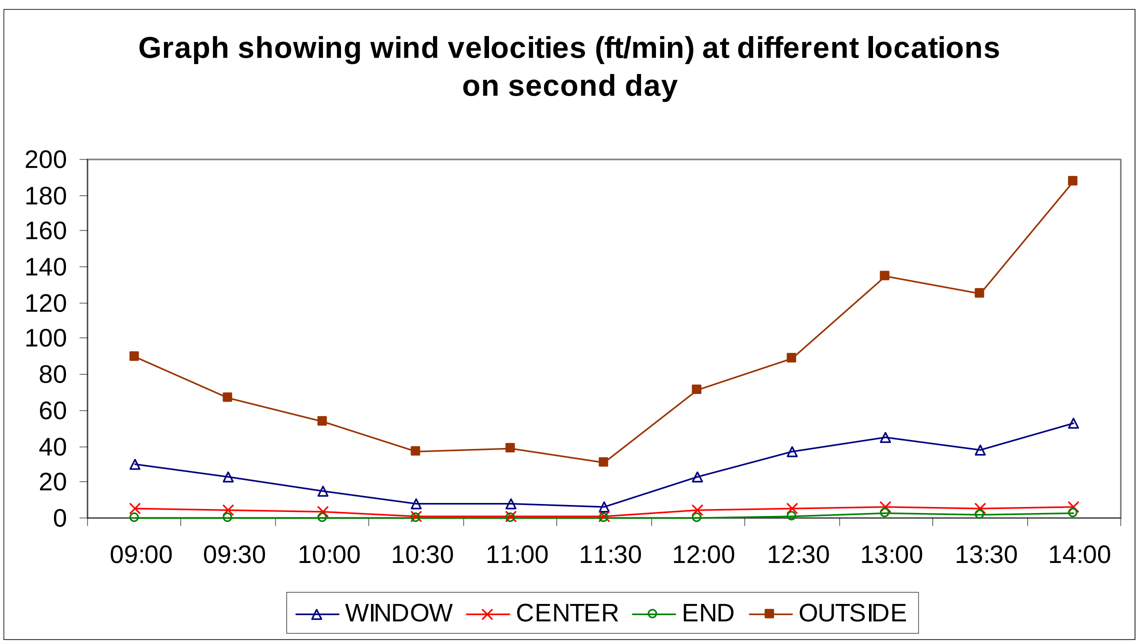


Figure 5.10 compares the air temperature near the external wall and the surface temperature of the external wall. The surface temperature of the external wall and the air temperature near the external wall tracked each other closely; the statistical correlation is

0.93. Moreover, the external wall temperature did not track the external air temperature. The thermal retention capacity of the walls was high, so its temperature remained stable even when the outside air temperature changed significantly. The correlation between the external air temperature and the wall temperature is 0.37, which shows that these two temperatures are not closely related. The temperature of the wall itself was higher than the temperature of air near the wall from afternoon until morning because the walls absorbed heat from the sun but took relatively more time to lose heat because there was very little air movement (see Figures 5.11 and 5.12).

Figure 5.13 House 4, temperature: air near the ceiling, surface of the ceiling, degrees C.

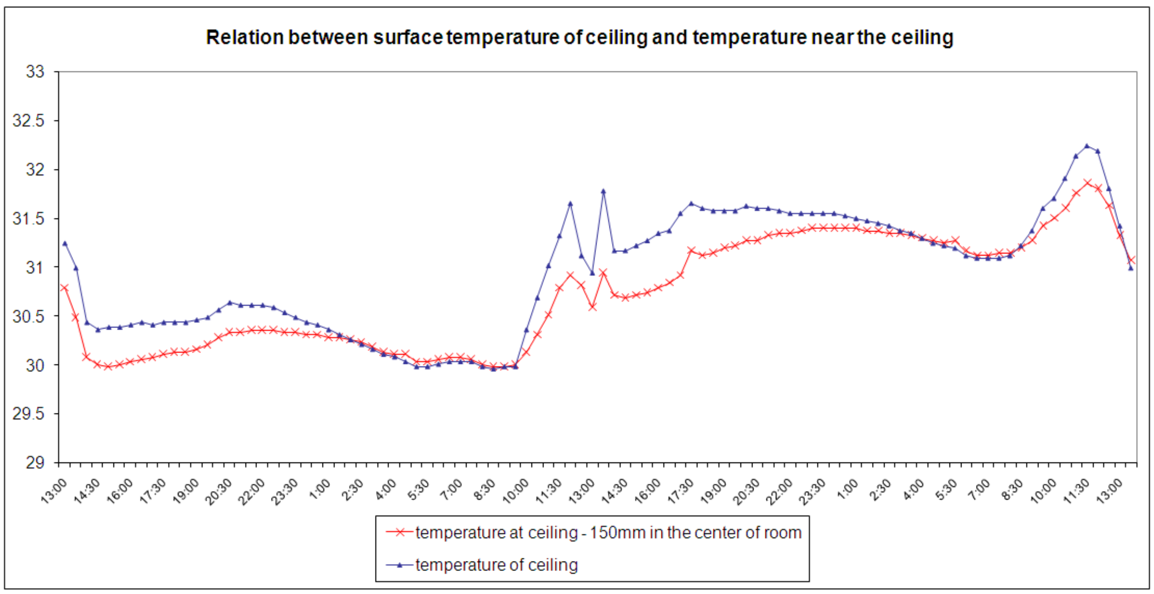


Figure 5.13 compares the air temperature near the ceiling and the surface temperature of the ceiling. The surface temperature of the ceiling and the air temperature near the ceiling tracked each other closely, correlating statistically at 0.94. The ceiling received heat from both sides, from the hot air trapped in the attic and inside the room. However, the thermal capacity of the ceiling is high, so its temperature did not increase dramatically. The external roof of the hut kept the sun rays from falling directly onto the ceiling and hence its temperature did not increase as it would have otherwise. Therefore, the surface temperature of the ceiling did not follow the external air temperature, showing

a correlation of 0.58. The ceiling temperature remained higher than the air temperature near the ceiling from afternoon until evening. The trapped air in the attic accounted for heating the ceiling during the daytime, but in the evening, when the sun set and the hot air in the attic was replaced by cool outside air, the surface temperature of the ceiling was reduced. However, the air temperature near the ceiling remained higher than the ceiling temperature as the hot trapped air inside the house has no aperture to escape.

Figure 5.14 House 4, temperature: external, comfort as defined by Nicol, comfort range as per ASHRAE, internal at a height of 1200mm, degrees C.

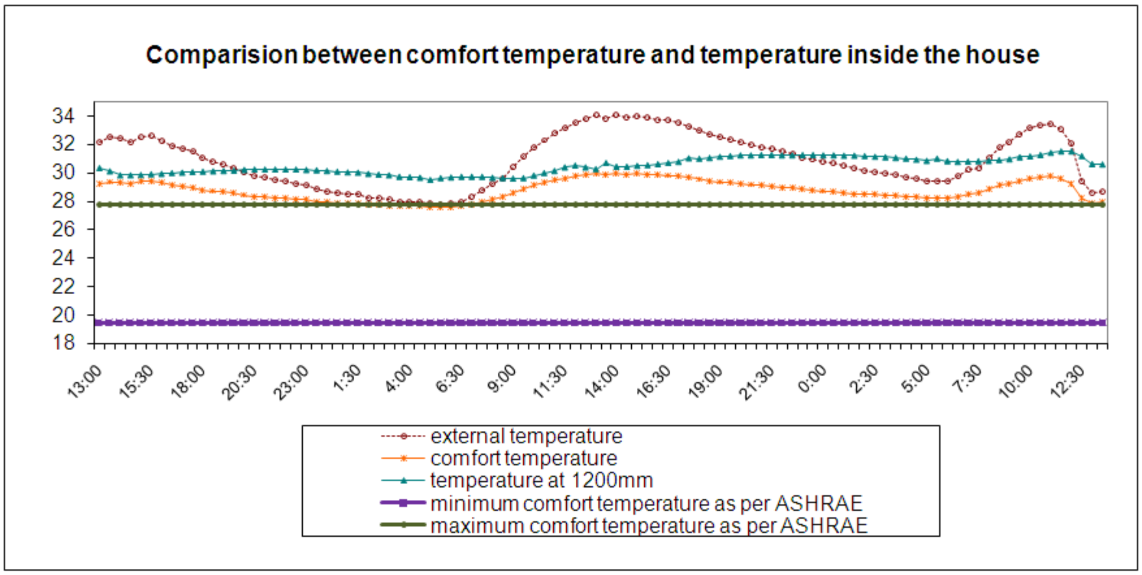


Figure 5.14 compares the comfort temperature as predicted by Nicol, comfort temperature range according to ASHRAE standards and the air temperature inside the house at 1200mm height. The air temperature inside the house at 1200mm high from the floor was always higher than the thermal comfort temperature as predicted by Nicol. When the outside air temperature was high, the inside air temperature was much closer to the comfort temperature as predicted by Nicol than when the outside air temperature was low. The correlation between the comfort temperature and the air temperature at 1200mm high inside the house was 0.38, which suggests a weak relationship between the two. Moreover, the air temperature inside the house was above the comfortable temperature range as defined by ASHRAE. Despite being higher than the predicted comfort

temperature, as per the survey results the temperature inside the house felt comfortable to the occupants (see tables C.3 and C.6).

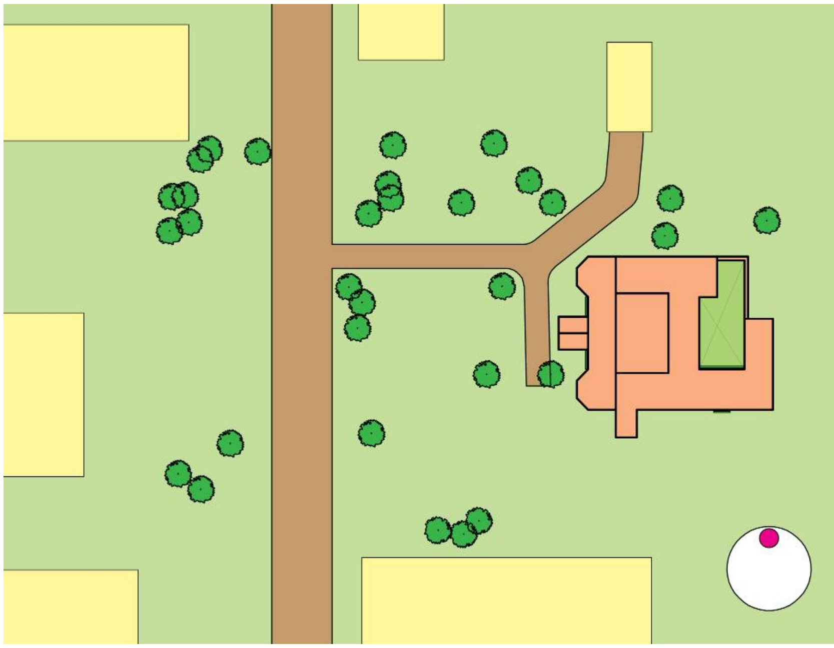
House 6 (haveli)

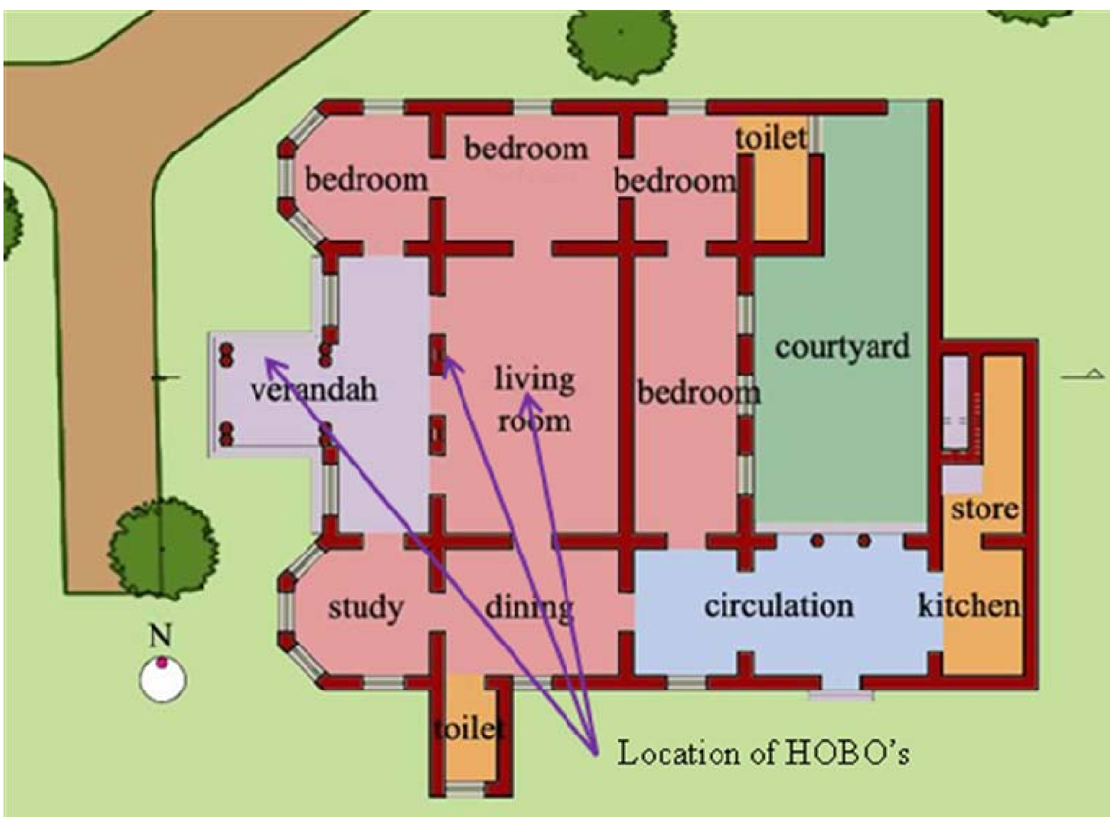
This house is in the center of the town with similar houses in the neighborhood. A 3 meter wide street runs east-west next to the house; connecting the house to the main street. There are trees on the north side of the house 6.5 meters away. On the east, west, and south is an open area for about 15 meters. The house is east-west elongated. The walls and the roof of the house are in good shape. The house has 8 rooms and a kitchen, a courtyard, and a toilet (see Figure 5.16). The ceiling of the living space was 6 meters high in the living room and 4 meters high in the other rooms.

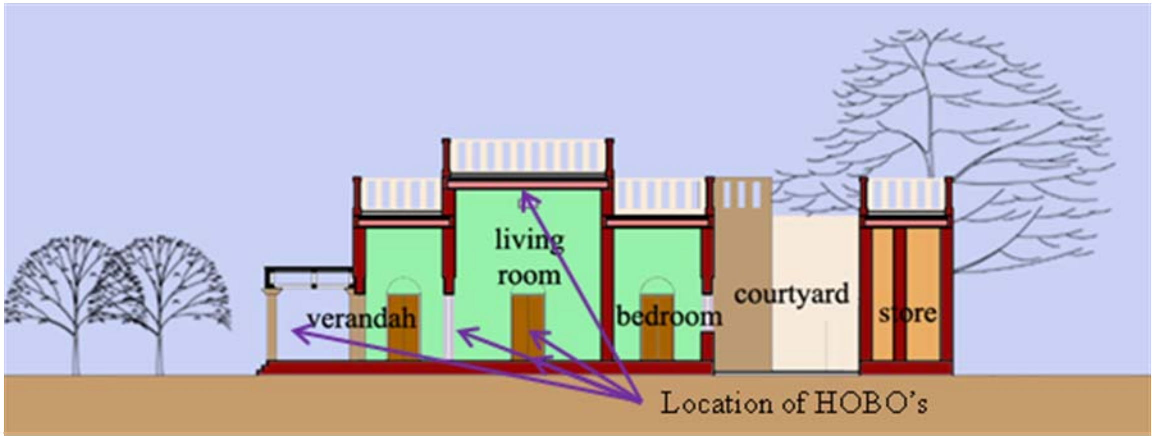
Figure 5.15 Photograph of house # 6.

The floor and walls are finished with lime plaster. The walls of the house are made of burnt clay bricks and are 400 mm thick. The exterior of the house is painted white and red. The interior walls and the ceiling are white while the floor is red. The wooden doors and the windows are painted yellow. The doors and windows are unglazed and have wooden shutters. There are no external shading devices on the windows.

Figure 5.16 Site plan, plan and section of house # 6.







Liquefied petroleum gas was used as cooking fuel; hence, there is no smoke inside the house, which is verified by the survey. All rooms have ceiling fans for air circulation. All rooms have compact fluorescent lamps, so the heat from lighting is negligible. There are no rat traps and no screenings on the windows to prevent insects entering the house.

The owner of the house rested during the time of the visit and wore a shirt and trousers as the outside temperature was high. The house had minimal furniture with very little upholstery as would be expected in a hot climate. No significant differences in the thermal conditions inside various rooms of the house were observed, but according to the occupants, the family room was a bit cooler than other spaces. Personal observation suggested the house was relatively much cooler than outside, which was verified by the on-site data collected.

House 6: Data Collected

As with houses 1 and 4, objective measurements were made in House 6 to complement the results of the survey. The same instruments and a similar method was used to collect these data (refer to Chapter 4). The section below presents these data.

Figure 5.17 House 6, temperature: external, internal, degrees C.

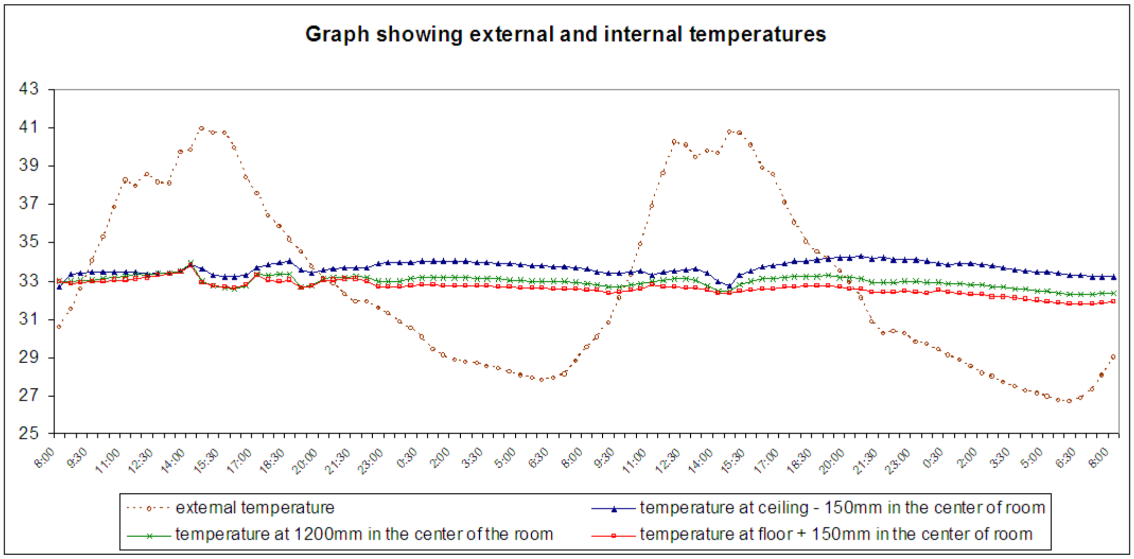


Figure 5.17 compares external air temperature and internal air temperatures. The graph shows a larger exterior diurnal temperature swing than inside the house. While the temperature variation outside the house was 14.2°C (from 26.72°C to 40.92°C), the interior temperature at 1200mm high remained in a range of 1.66°C (between 32.27°C and 33.94°C). The various internal air temperatures did not track the external air temperature with a correlation for the 1200mm high measurement inside the house of 0.35. The air temperature inside the house remained cooler during the day and warmer at night than outside. In the survey, the residents reported preferring to stay indoors during the day. The air temperature near the floor tracked the air temperature measured at 1200mm high much more closely than the air temperature near the ceiling. A high ceiling allows temperature stratification. The statistical correlation between the air temperatures at 1200mm high and 150mm below the ceiling is 0.47 and that between 150mm above the floor and 1200 high is 0.87. The correlation between air temperatures at 150mm below the ceiling and 150mm above floor is 0.11. The graph also shows that the external air temperature was higher than the internal air temperature from 9:30 in the morning till 9:30 at night and lower from 9:30 at night till 9:30 in the morning.

Figure 5.18 House 6, temperature: air at 1200mm near the external wall, internal surface of the external wall at 1200mm height, degrees C.

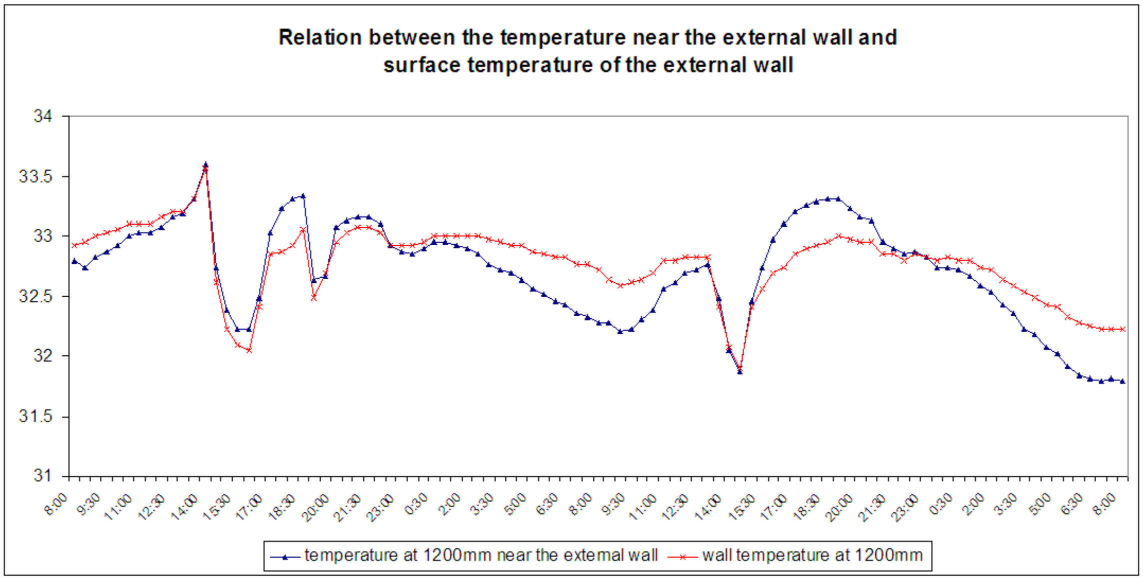


Figure 5.19 House 6, temperature: air near the ceiling, surface of the ceiling, degrees C.

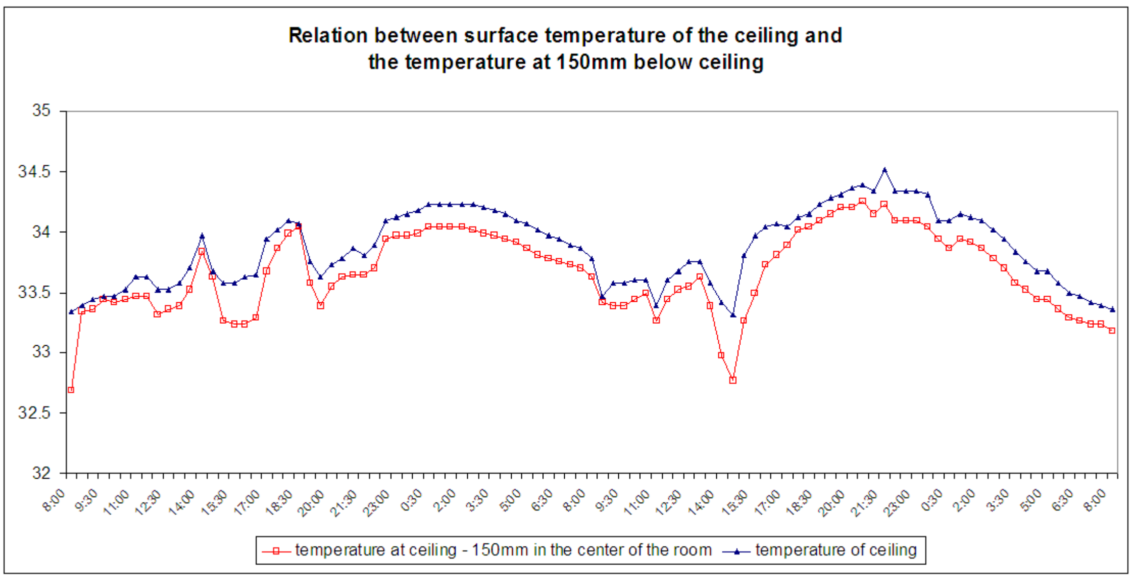


Figure 5.18 compares the air temperature near the external wall and the surface temperature of the external wall. The surface temperature of the external wall and the air temperature near the external wall tracked each other closely with a statistical correlation of 0.84. The internal surface temperature of the external wall temperature did not track

the external air temperature. The correlation between the external air temperature and the internal surface temperature of external wall temperature is 0.02, showing that these two temperatures do not depend on each other. The thermal retention capacity of the walls was high, so its temperature remained stable even when the outside air temperature changed significantly.

Figure 5.19 compares the air temperature near the ceiling and the surface temperature of the ceiling. The surface temperature of the ceiling and the air temperature near the ceiling tracked each other closely with a statistical correlation of 0.95. The thickness and materials of the ceiling helped keep the air temperature inside the house lower than the outside air temperature. Thus, the surface temperature of the ceiling did not track the external air temperature with a correlation of 0.29.

Figure 5.20 House 6, temperature: external, comfort as defined by Nicol, comfort range as per ASHRAE, internal at a height of 1200mm, degrees C.

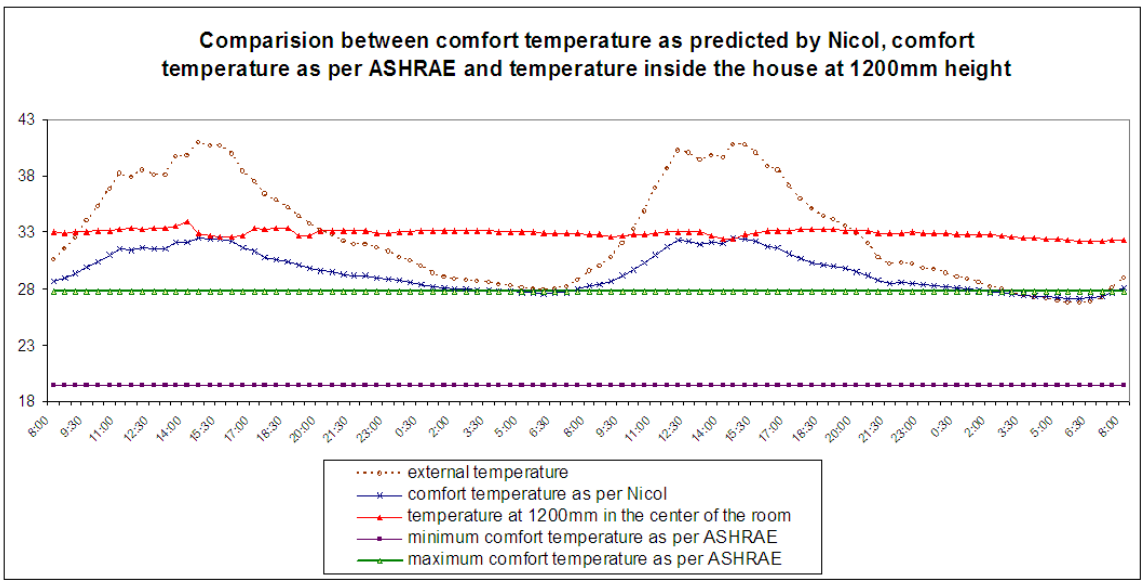


Figure 5.20 compares the comfort temperature as predicted by Nicol, comfort temperature range according to the ASHRAE standard, and the air temperature inside the house at 1200mm high. The air temperature inside the house at 1200mm high was always higher than the thermal comfort temperature as predicted by Nicol. When the outside air

temperature was high, the inside air temperature was much closer to the comfort temperature predicted by Nicol than when the outside air temperature was low. The survey seconded this, with residents preferring to stay indoors during the afternoon hours when the outside heat was unbearable. The air temperature inside the house at 1200mm high remained higher than the maximum comfortable temperature according to the ASHRAE standard. However, the occupants felt comfortable with the temperature inside the house (see tables C.9 and C.12).

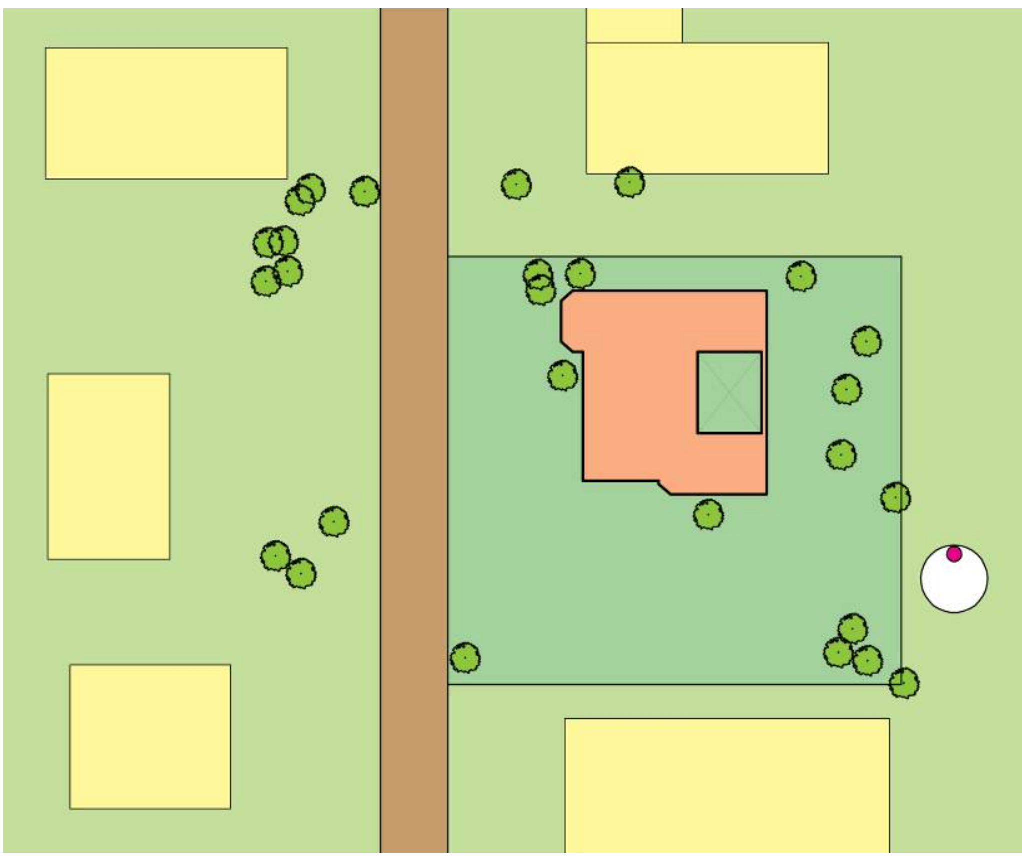
House 7 (haveli)

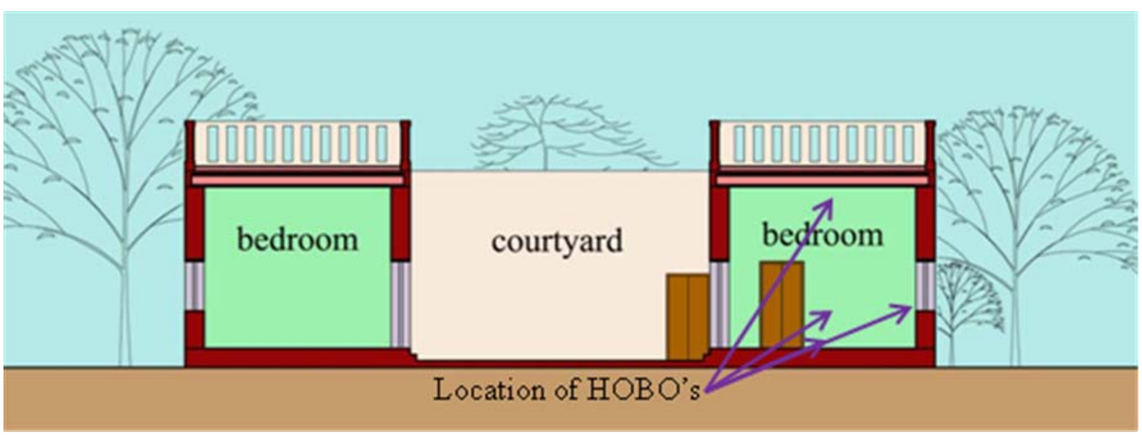
The house is in a residential area of the town with similar houses in the neighborhood. A 3 meter wide metallic street runs north-south next to the house that connects the house to the main metallic street. There are trees 6 meters away on the east side of the house. On the east and south side of the house is an open area for about 10 meters. The walls and the roof of the house are in good condition. The house is rectangular with 7 rooms, a kitchen, and a toilet and a courtyard at the back. The ceiling of the living space is 4 meters high (see Figure 5.22). The doors and windows have wooden shutters. During data collection, the doors remained open during the day although the measurement showed little air movement inside the house.

The floor and walls were finished with lime plaster. Adobe bricks and lime plaster were used to construct the walls, which are 450mm thick. There are no external shading devices over the windows. The walls and the ceiling are white while the floor is grey. The wooden doors and the window shutters are painted brown.

Figure 5.21 Photograph of house # 7.

Figure 5.22 Site plan, plan and section of house # 7.





Liquefied petroleum gas was used for cooking; hence, there was no smoke inside the house as verified by the survey. There were fans in the rooms for air circulation. All the rooms had compact fluorescent lamps; hence, the heat from the lighting was negligible. There were no rat traps and no screenings on the window to prevent insects entering the house.

The owner of the house rested during the time of the visit and wore a shirt and trousers as it was very hot outside. The house had minimal furniture. No significant difference in the thermal conditions inside various rooms of the house was observed. The house is relatively much cooler than outside, again as verified by on-site data.

House 7: Data Collected

As for houses 1, 4, and 6, objective measurements were taken in House 7 to complement the survey results. The same instruments and a similar method were used to collect these data (refer to Chapter 4). The section below presents the data collected from House 7.

Figure 5.23 House 7, temperature: external, internal, degrees C.

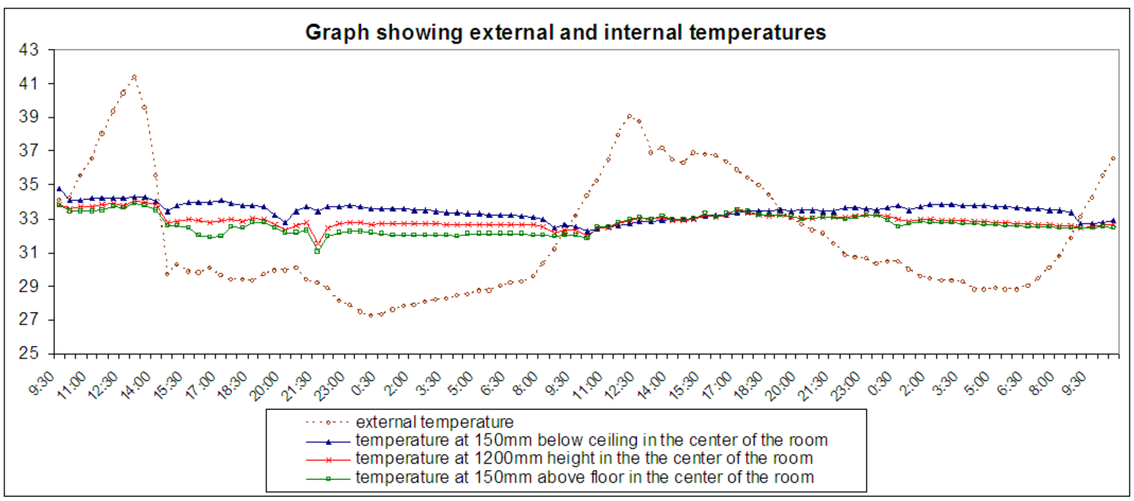


Figure 5.23 compares external air temperature and internal air temperatures. The graph shows higher exterior diurnal temperature swing than inside the house. While the temperature variation outside the house was 14.13°C (from 27.25°C to 41.38°C), the interior air temperature at 1200mm high remained more stable within a range of 2.53°C (between 31.48°C and 34.01°C). The internal air temperatures did not track the external air temperature with a correlation between the external and internal air temperatures of

0.53. The air temperature inside the house remained cooler during the day and warmer at night than outside.

Figure 5.24 House 7, temperature: air at 1200mm near the external wall, internal surface of the external wall at 1200mm height, degrees C.

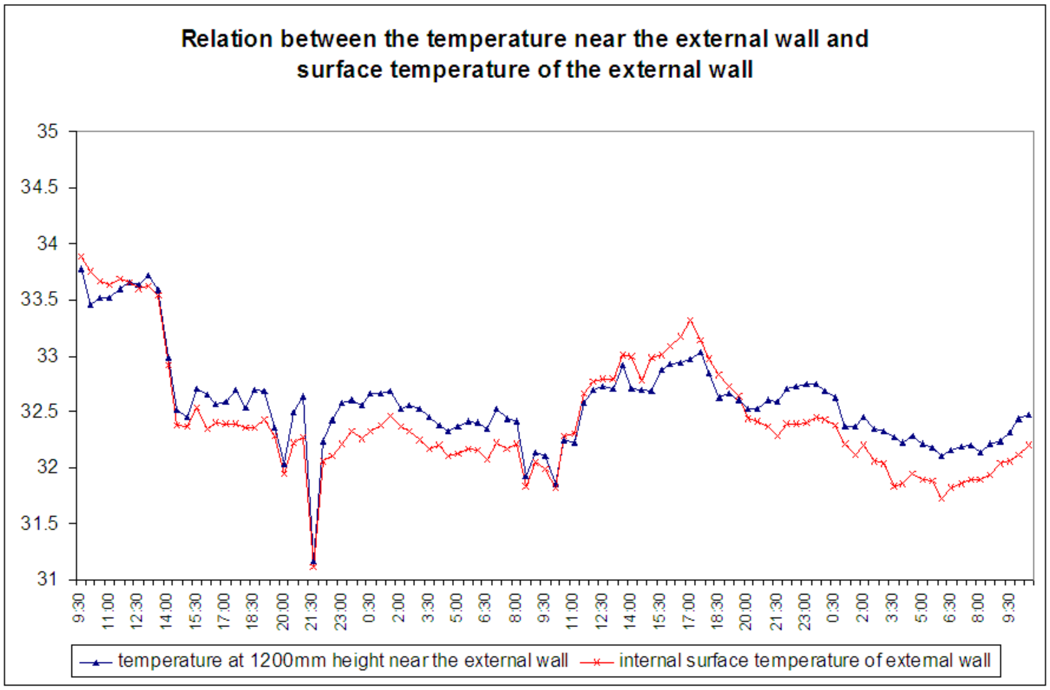


Figure 5.24 compares the air temperature near the external wall and the surface temperature of the external wall inside the house. The surface temperature of the external wall and the air temperature near the external wall tracked each other closely, having a statistical correlation of 0.94. The surface temperature of the external wall inside the house remained lower than the air temperature near it except during the afternoon when the walls had absorbed the heat from the sun and the temperature of the walls had risen considerably, however, even then due to high thermal mass of the walls the air temperature inside the house remained less than outside air as the walls did not radiate much heat inside the house.

Figure 5.25 House 7, temperature: air near the ceiling, surface of the ceiling, degrees C.

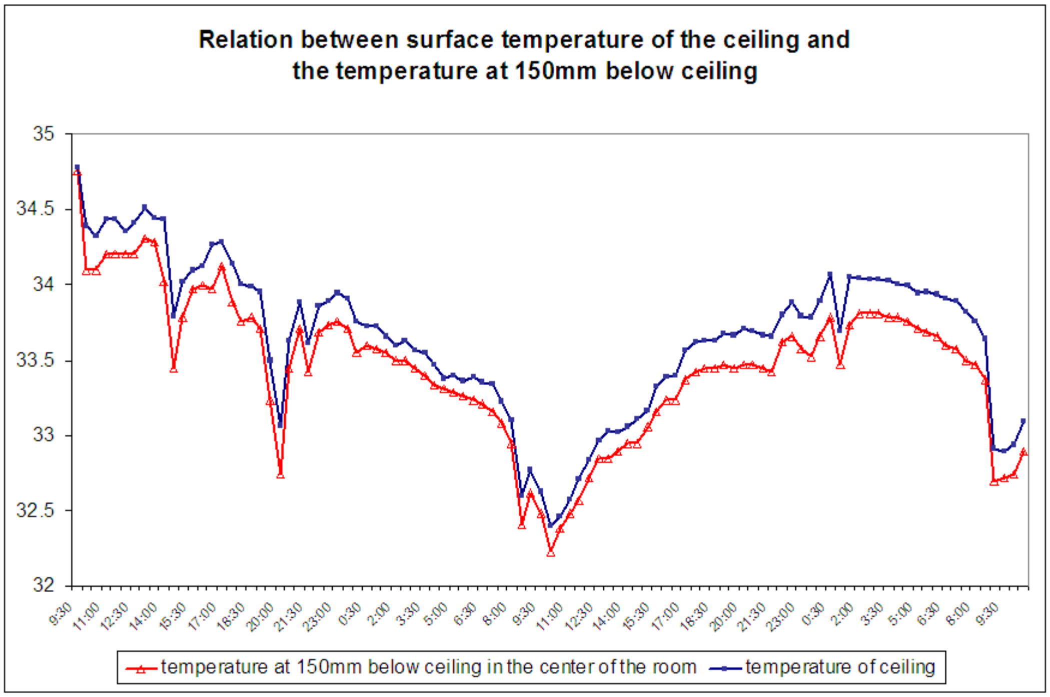


Figure 5.25 compares the air temperature near the ceiling and the surface temperature of the ceiling. The surface temperature of the ceiling and the air temperature near the ceiling tracked each other closely, having a statistical correlation of 0.99. As with house 6, the thickness and materials of the ceiling helped keep the air temperature inside the house lower than the outside air temperature, so the surface temperature of the ceiling did not track the external air temperature. The correlation observed between them was 0.16.

Figure 5.26 House 7, temperature: external, comfort as defined by Nicol, comfort as per ASHRAE standard, internal at a height of 1200mm, degrees C.

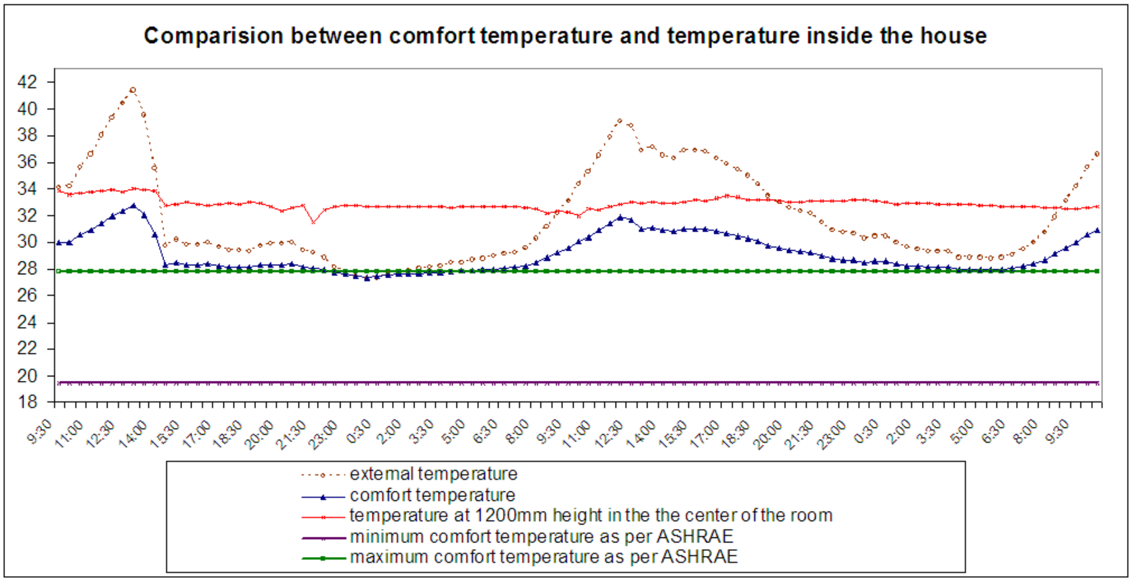


Figure 5.26 compares the comfort temperature as predicted by Nicol and the air temperature inside the house at 1200mm high. The air temperature inside the house at 1200mm high was always higher than the thermal comfort temperature as defined by Nicol and ASHRAE standard. When the outside air temperature was high, the air temperature inside the house is much closer to the comfort temperature established by Nicol than when the outside air temperature is low. However the occupants felt comfortable in these conditions (see tables C.9 and C.12).

Analysis

Despite the four houses being somewhat different from each other, similar results were obtained from the survey, on site data measurements, and personal observations. The table below compares some of the variables of the four detailed case studies.

Table 5.1 Table showing different variables of the case studies.

	HOUSE 1	HOUSE 4	HOUSE 6	HOUSE 7
wall thickness in meters	0.6	0.3	0.4	0.45
wall material	burnt clay bricks, lime plaster	mud	burnt clay bricks, lime plaster	burnt clay bricks, lime plaster
ceiling height in meters	4	2.1	6	4
ceiling material	burnt clay tiles on wooden rafters	burnt clay tiles on wooden rafters	*Brick bat coba,* lime plaster, I joists	*Brick bat coba*, lime plaster, I joists
aperture area in the room in which on-site data was collected, $meter^2$.	4.57	1.95	11.38	6.59
floor area of the room in which the on-site data was collected, $meter^2$.	22.29	7.43	33.44	17.07
aperture area/volume	0.051	0.125	0.057	0.097
window	unglazed with wooden shutters	unglazed with no shutters	unglazed with wooden shutters	unglazed with wooden shutters
wall color	white inside, white outside	white inside, white outside	white inside, red outside	white inside, yellow outside

Figure 5.27 Internal and external temperature swings in all houses, degrees C.

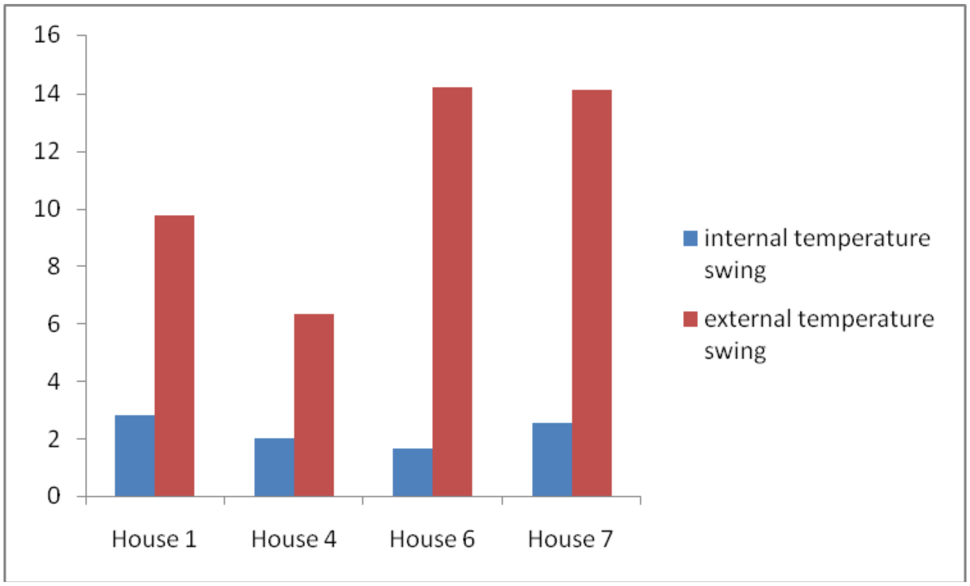
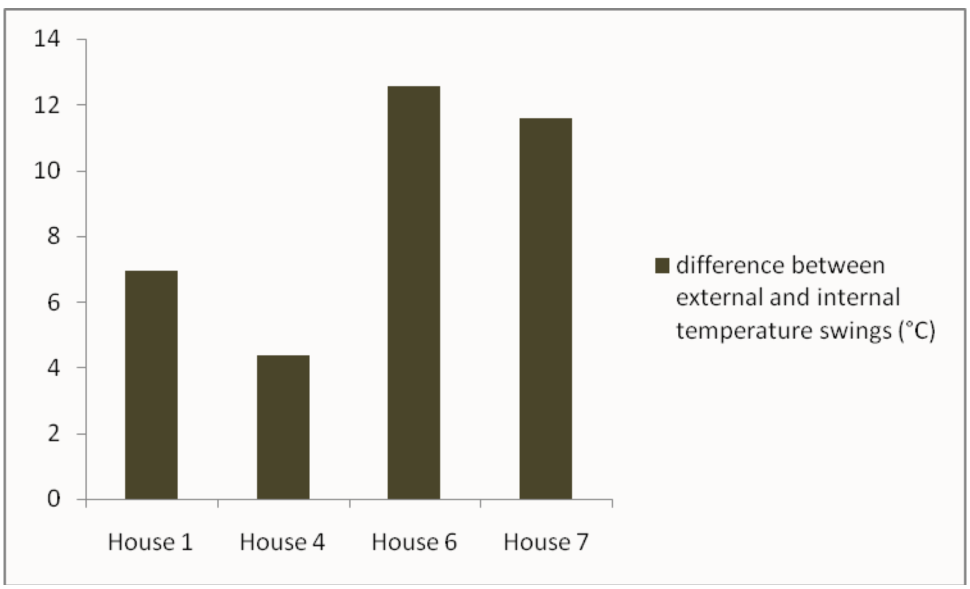
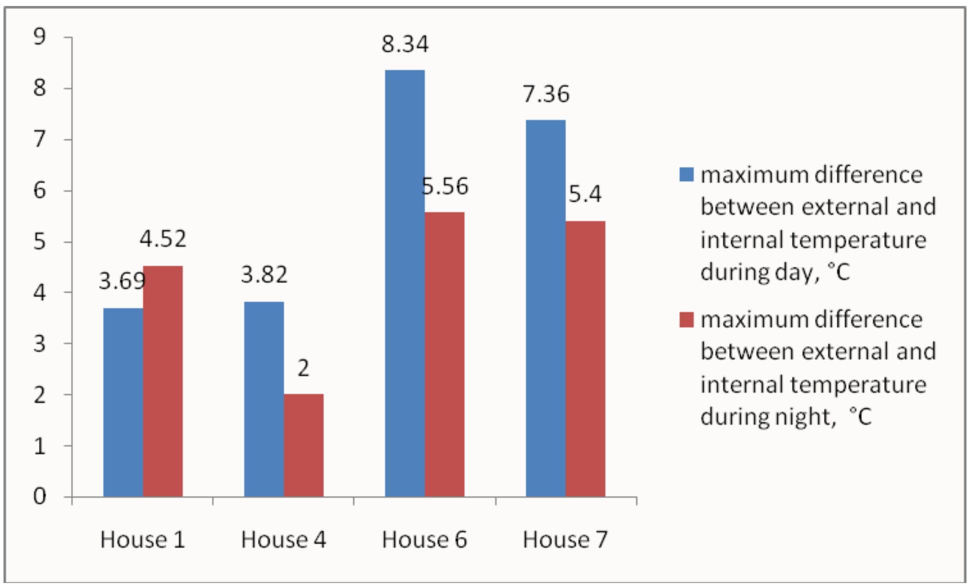


Figure 5.28 Difference between internal and external temperature swings in house 1, 4, 6, and 7, degrees C.



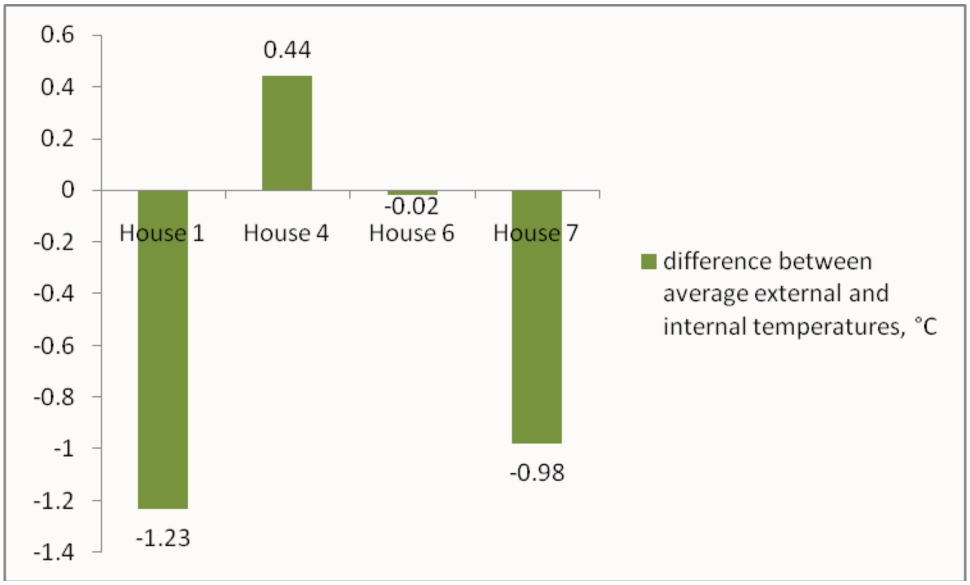
The diurnal temperature swing inside all four houses is less than outside the house (see figures 5.27 and 5.28). The diurnal temperature swing in house 1 was 2.81°C when the swing in external temperature was 9.75°C. The diurnal temperature swing in house 4 was 1.99°C when the swing in external temperature was 6.34°C. The diurnal temperature swing in house 6 was 1.66°C when the swing in external temperature was 14.2°C. The diurnal temperature swing in house 7 was 2.53°C when the swing in external temperature was 14.13°C. The different studies cited in Chapter 2 on high thermal mass in buildings thus explain the flattening of high day/night temperature swings of all the four houses. High thermal mass of the houses under investigation helped create more stable thermal conditions inside the house. The diurnal shift in temperature was reduced by high thermal mass: high thermal mass absorbed heat during the day and released it at night, flattening the temperature range. High thermal mass construction enabled the houses to separate internal temperature from external temperature so that drastic changes in the external environment were not reflected inside the house.

Figure 5.29 Maximum difference between day time and night time external/ internal temperatures, degrees C.



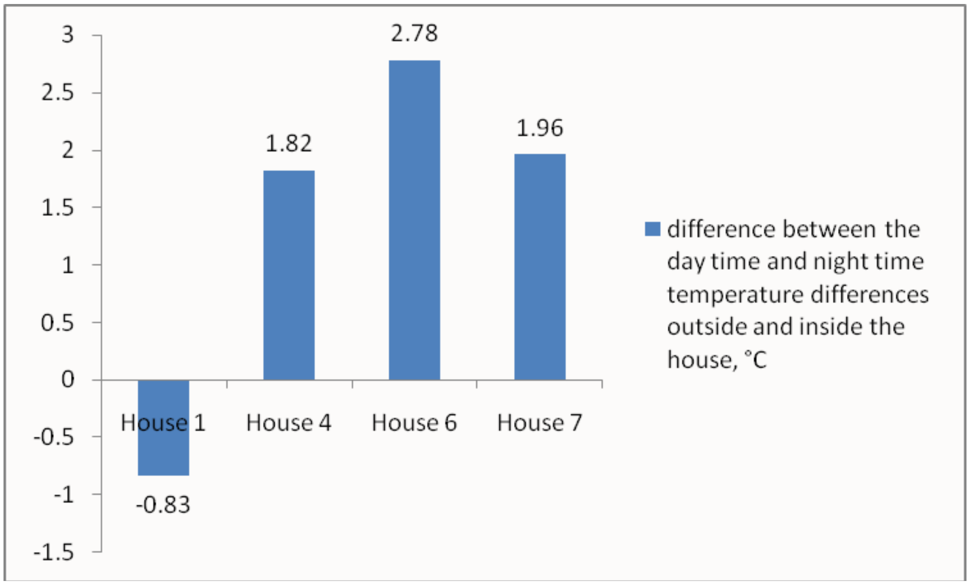
For all four houses, the air temperature inside the house remained lower during the day and higher at night than the outside air temperature (see Figure 5.29). Figure 5.30 shows that except for house 4 the average external air temperature was always lower internal air temperature. However, it cannot be concluded that house 4 created best comfort conditions as survey results show occupants of all the houses to be equally satisfied by the thermal conditions in their homes (see tables C.3, C.6, C.9 and C.12).

Figure 5.30 Difference between average external and internal temperatures, degrees C.



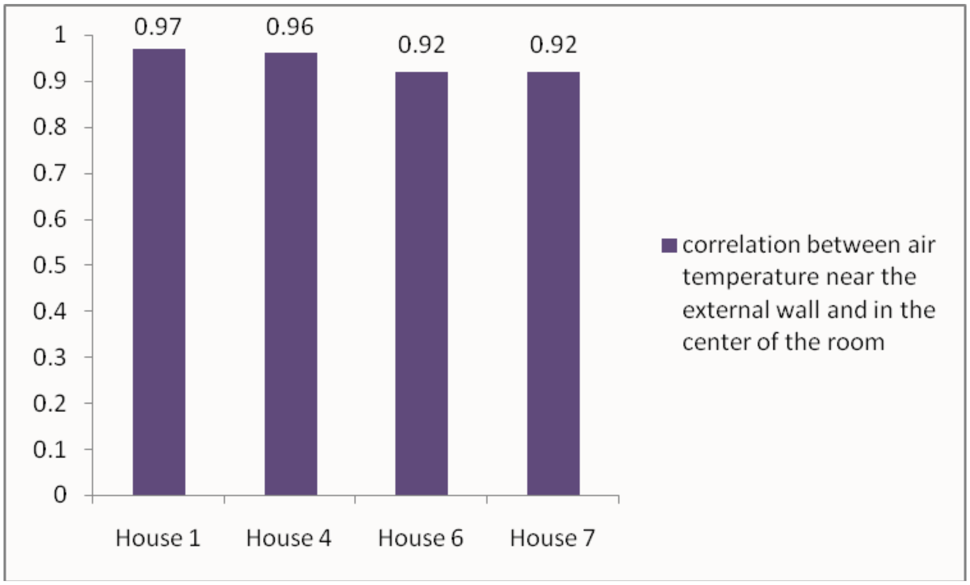
Air movement inside all the four houses was negligible due to lack of openings. Studies (see Chapter 2) on the effect of natural ventilation and high thermal mass have shown that the temperature of thermal mass cools down in the night through adequate ventilation. Thus, during night time the internal air temperature was higher than the external air temperature in all the four homes because of the lack of ventilation on the thermal mass. Figure 5.31 shows that House 1 was much cooler in the night than day as compared to rest of the houses. With less ventilation to cool the thermal mass inside the house at night, the temperature inside all the houses did not drop to comfort levels. The maximum aperture to volume ratio in the case studies was 0.125, which was not enough to cool the thermal mass at night and reduce the internal temperature to comfortable levels as the windows remained closed.

Figure 5.31 Difference between day time and night time external/ internal temperatures, degrees C.



Air temperatures at different heights at the same time inside houses 1, 6, and 7 correlated less while the air temperatures at different heights at the same time inside house 7 correlated highly. The heights at which these temperatures are taken are important; hot air rises and cold air sinks. The ceiling heights in houses 1 and 7 were both 4 meters high, house 6 had ceilings 6 meters high, but the ceiling height of house 4 was 2.1 meters only. The three readings were taken at 150mm above the finished floor, at 1200mm above finished floor, and at 150mm below the ceiling. House 1, house 6, and house 7 have high ceilings, so temperature stratification occurs, and hot air from the living zone rises upwards, displaced by relatively cool air. This makes the air temperature at the living zone comparatively lower that than just below the ceiling. House 4, with a low ceiling, showed less temperature stratification, so air temperatures at different heights correlated highly to each other. With no windows, the house trapped hot air inside and the air temperature remained high in the living zone creating. This can act as an advantage in winter when high temperature in the living zone is desirable.

Figure 5.32 Correlation between air temperatures near the external wall and in the center of the room.



Temperatures near the wall and in the center of the room are similar in all the four houses, with correlations of 0.97, 0.96, 0.92, and 0.92 in house 1, house 4, house 6, and house 7, respectively (see Figure 5.32). Thus, thermal conditions across the room in which measurements were taken were nearly the same. It is expected that the temperature near the external wall to be higher than in the center of the room due to radiant heat from the walls but these case studies showed the air temperature in the center of the room and near the external wall to be nearly the same, suggesting that the external wall had high thermal capacity and radiated less heat inside the house.

Correlation between the external air temperatures and air temperatures inside the houses are: 0.72, 0.38, 0.35, and 0.53 for house 1, house 4, house 6, and house 7, respectively (see Figure 5.33) while the correlation between the inside surface temperature of the external wall and the external air temperature are: 0.55, 0.37, 0.02, and 0.71 for house 1, house 4, house 6, and house 7, respectively (see Figure 5.34). This suggests that the walls act as a strong barrier between the external and internal environments. The walls absorb heat from the sun but do not dissipate the heat rapidly inside the house; the surface temperatures of the walls were higher than the air temperature near them inside the house only for a few hours in the afternoon. They lose their heat to the outside environment as the outside becomes lower than the internal temperature at night.

Figure 5.33 Correlation between external and internal air temperatures.

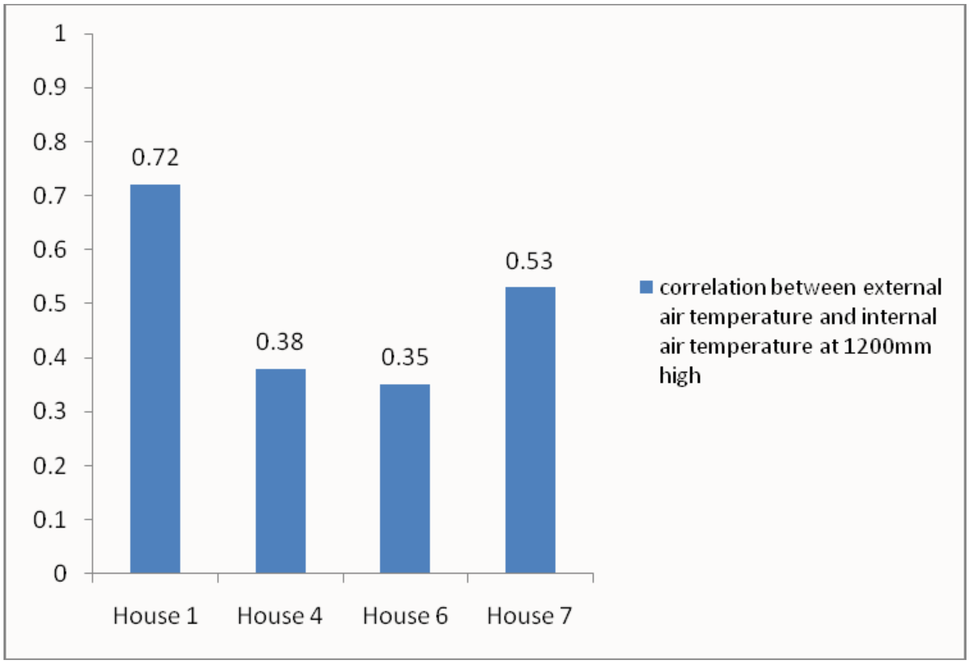


Figure 5.34 Correlation between external air temperature and surface temperature of external wall.

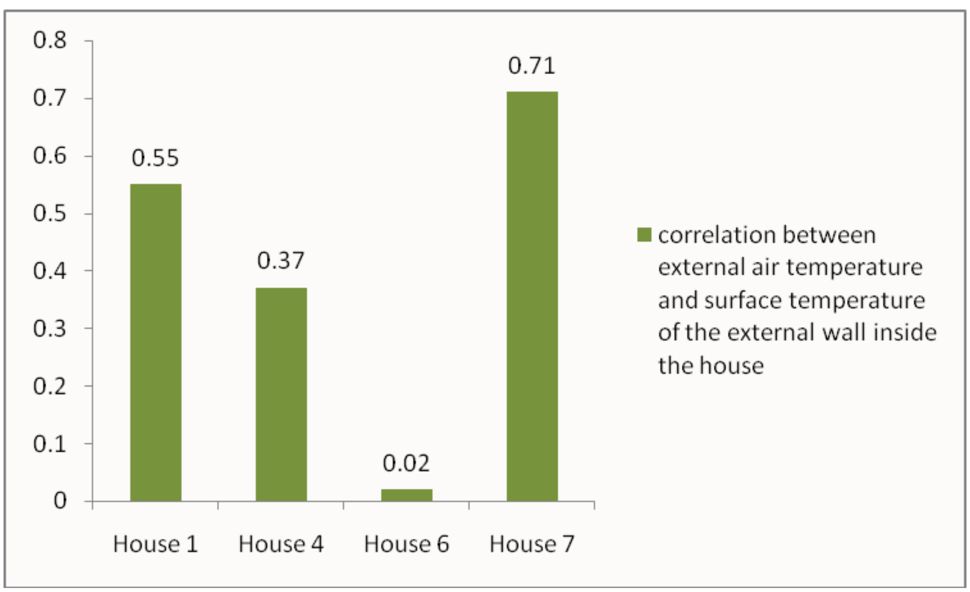
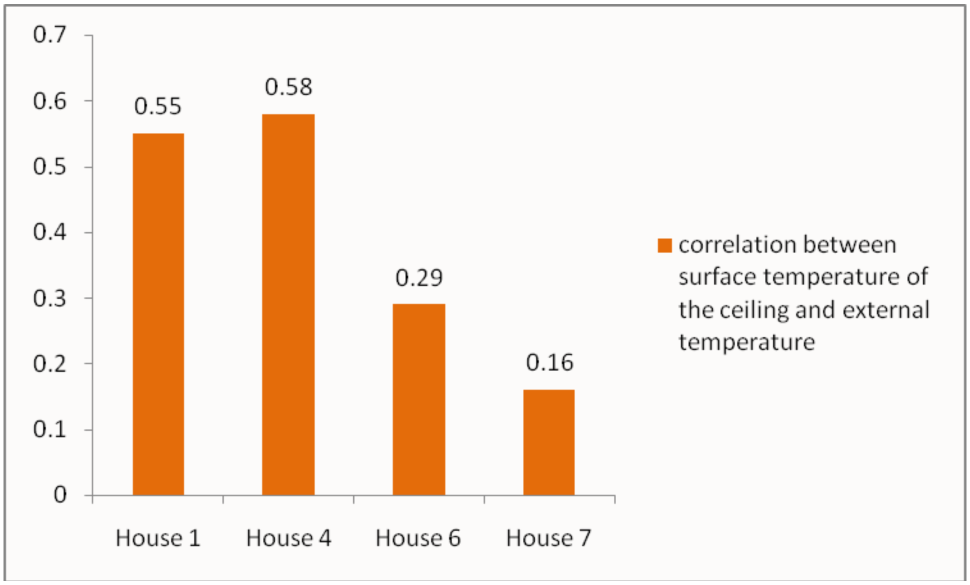


Figure 5.35 Correlation between external air temperature and surface temperature of ceiling.



The inside surface temperature of the ceiling and the external air temperature also did not correlate: 0.55 and 0.58 for house 1and house 4, respectively (see Figure 5.35). This suggests that less heat traveled from outside to the inside at the roof and then to the inside of the ceiling because these houses have attic space. The correlations between the inside surface temperature of the ceiling and the external air temperature in house 6 and house 7 were 0.29 and 0.16, respectively (see Figure 5.35), suggesting that the ceiling material (*brick bat coba* and lime plaster) acted as a good heat barrier.

All four houses had high thermal comfort levels according to both survey (see tables C.3, C.6, C.9 and C.12) and personal observation. However, site measurements showed the internal air temperature in the living zone of each of the houses was higher than the comfort temperatures recommended by Nicol and ASHRAE, and the onsite data from the case studies showed that the homes are warmer than ambient temperatures at night (see figures 5.6, 5.14, 5.20 and 5.26). None of the houses have high thermal comfort by the current standards. However, the subjective evidence (from the surveys) shows that residents feel comfortable in the houses. It is easy to assume that the indication of comfort from the residents may be due to the degree of difference between daytime exterior temperatures and interior temperatures. It can also be postulated that people in hot climates perceive higher temperatures to be comfortable than recommended by ASHRAE and Nicol.

The analysis of these different case studies, using surveys, personal observations, and on site data, shows that these houses do not create completely thermally comfortable conditions according to the present comfort standards as defined by ASHRAE and Nicol; however the occupants of these houses felt comfortable in those conditions. The following chapter provides the conclusions drawn from these case studies.

CHAPTER 6 - Conclusions

The previous chapter presented the survey results, on-site data measurements, and personal observations in investigating the hypothesis that vernacular homes in Jharkhand promote high thermal comfort levels inside them. The occupant surveys indicated that they were quite satisfied with the perceived thermal conditions of their homes. The objective on-site data collected from these houses showed they had a relatively lower temperature inside than outside during the day. These houses have some inherent characteristics that help them provide comfortable climate levels to their occupants without external energy inputs during the day in summer. However, the preponderance of data collected indicated that occupants should be uncomfortable. At night, the temperature inside was higher than outside, which is not desirable. Moreover, the comfort temperature as predicted by Nicol and according to ASHRAE standards was lower than the temperatures inside the houses. This indicates that the houses were somewhat uncomfortable according to these standards. In spite of this, the residents were highly satisfied with the temperatures inside their homes. What then causes the discrepancy between pre-determined notions of comfort and the stated experience of the home occupants?

These case studies point towards a dichotomy in defined and experienced comfort conditions. Although the conditions inside the different case studies are thermally comfortable to the users, they are noticeably beyond the comfort range defined by ASHRAE and those predicted by Nicol. This implies that one cannot take a universal approach in understanding and defining comfort condition. There is a potential for gauging comfort temperature ranges based on culture and the phenomenon of acclimatization. Today most buildings are cooled and heated according to ASHRAE standards but these case studies indicate there are comfort temperatures beyond its range. A more corrective comfort temperature definition will decrease the need for elaborate, costly, energy intensive solutions to a problem that may not exist. This is crucial because it gives a more meaningful human depth to the understanding of comfort conditions unlike the conventional definition which is largely a derivative of the perception of a small sample group.

Some of the most prevalent design elements of vernacular buildings are passive comfort strategies honed over successive generations. The homes examined in this study are no different and the strategies helped create comfortable conditions. These homes were designed some decades ago and have provided comfortable conditions during the day in summer, saving energy that could be used elsewhere. The analysis provides some recommendations for future design of houses in Jharkhand.

Jharkhand’s climatic conditions are such that high thermal mass in buildings helps create more stable conditions inside the buildings, and the diurnal shift in day-night temperature swing can be reduced by its use. The case studies validate the use of high thermal mass as a passive cooling strategy in these climatic conditions. In spite of lack of data for winters, it is expected that these high thermal mass also help create comfort conditions in winters by absorbing the sun’s heat during the day and radiating it in the night thereby increasing the temperature inside. Hence, high thermal mass should be used in houses where diurnal temperatures are extreme to create comfortable conditions inside buildings. The walls of houses 1, 6, and 7 and the ceiling of houses 6 and 7 were made of brick, *brick bat coba* and lime plaster. The walls of house 4 were made of mud. All these surfaces displayed high thermal capacity and acted as a strong barrier between the external and internal environment. All these materials are locally available and can be used even in contemporary use.

The minimum aperture to volume ratio in the case studies was 0.051, which was not enough to cool the thermal mass at night and lower the internal temperature during summer as most of the openings remained closed during the night. The maximum aperture to volume ratio in the case studies was 0.125 but cannot be accounted for as they remained closed at night. Hence, effective aperture to volume ratio of more than 0.051 would definitely be required to help cool the thermal mass. Windows should be opened at night to allow breezes to ventilate and cool the thermal mass. The windows remained closed in the houses under investigation during the night to prevent insect intrusion, so placing screens on all openings would ensure ventilation without the added discomfort of pests. With adequate ventilation to cool the thermal mass, high night time temperatures in summer inside houses can be reduced, thereby creating comfortable conditions at night. Also incorporation of glazing on the windows can ensure the house to gain from sun's heat in winter and keep the cold winds out. In monsoon, the glazed window will serve the purpose of keeping the rain out but allowing sunlight inside the house, thereby saving energy.

The huts validate the use of attic space not only as a storage space but by acting as a barrier between the hot summer sun and the living space. Attic space helps reduce the temperature of the ceiling of the living zone in summer; however, this can act as a constraint in winter when the heat from the sun is desirable to heat the ceiling. Hence, a right balance in the provision of attic space is crucial for creation of comfort condition year round.

The case study approach adopted for this research makes it clear that these houses have inherent benefits, especially in terms of climatic response, and thus lessons to be learned in designing for the future. Both the huts and the havelis studied here are molded to respond to the climate of the region, and the design principles inherent in them can contribute valuable insights to contemporary architecture. One indication of their success is that both the types have been in continuous use and promise continued use in the future as well. Unfortunately, as the city has modernized, the inherent value of these established house types has become marginalized. High real estate values in Jharkhand means these vernacular houses are being torn down to provide land for new construction. In less than six years after Jharkhand was formed, more than fifty percent of the vernacular houses had been demolished to make room for multi-storied apartments that not only do not respond to the lifestyle of the people but also require high external energy inputs to create comfortable thermal conditions inside (see Figure 6.1). Typically these apartment buildings have no community spaces and are built of non-local materials like cement manufactured in west India some thousand kilometers away. No evidence of traditional architectural features can be seen in these structures.

Figure 6.1 Photograph showing present day architecture in Jharkhand. (Photograph by Saikat Mukhopadhyay)

> *There is a clear need to further develop the traditional systems based on natural resources. Before inventing or proposing new mechanical solution, traditional solutions in vernacular architecture should be evaluated, and then adopted or modified and developed to make them compatible with modern requirements.*
>
> \- (Fathy, 1986).

As Fathy has said, a sustainable future society requires using traditional architecture along with modern technology. In developing countries, where most of the population remains in rural areas using traditional buildings and technologies, the only feasible way to provide them with better living conditions is to upgrade traditional and vernacular homes (Meir & Roaf, 2006). In such a context, preserving vernacular buildings in Jharkhand should not focus just on faithfully restoring individual buildings but on revitalizing and improving the neighborhood to maintain their livability today and ensure their relevance in the future. Reinvesting in these successful vernacular types, updating house features and amenities to provide for contemporary needs, is indeed appropriate.

Both types of houses under investigation could be improved by proper sanitation facilities, modern electrical features, and pest control. The huts lack basic toilet facilities, so equipping them with sanitary fixtures will help improve the standard of life of the occupants. Both types of houses lack pest control, which means the doors and windows remain closed during the night. Providing occupants with nets will allow the windows to remain open, allowing cool winds to circulate in the house at night and reduce nighttime internal temperature in summer. Lighting inside the huts is poor, so providing electricity will enhance occupants' quality of life. Community participation in planning and development, coupled with concessions from governmental agencies like exemptions on income tax, estate duty, property tax, gift tax, and wealth tax to people who contribute to restoring these buildings, will help revive vernacular architecture. Finally, educating current and future generations about their rich architectural heritage will help preserve these building types.

Future directions

This research concentrated on understanding vernacular architecture and using its design intelligence to design for the future. Present day construction in Jharkhand uses mechanical means to create comfortable conditions. This research investigated whether vernacular houses created comfortable conditions for its residents without the use of any mechanical means. Further studies would support these conclusions and encourage using passive means to create comfortable conditions.

This research also acknowledged the cultural values embedded in these vernacular houses in Jharkhand. The huts and the havelis both have high cultural and social value, but poor economic conditions means these buildings have deteriorated. The owners of these types of houses are selling out to real estate agents who are constructing new apartments. This research raises the ethical issue of why these structures should be preserved.

This research focused particularly on thermal conditions inside these vernacular structures. The research used case studies to test its hypothesis, using post occupancy surveys and instruments to collect climatic data. This research also demonstrated practical application of the state of the art toolkit assembled by the Agents of Change in naturally ventilated buildings. The approach of relating real time climatic data to post occupancy survey responses helped strengthen the findings and conclusions in this research.

Other than measuring the surface temperature of the thermal mass, this research did not investigate its properties in detail. House 4 had mud walls while rest of the houses under investigation had burnt clay brick walls. House 4 exhibited maximum thermal resistance. The type and thickness of thermal mass has huge implications for the climatic conditions inside the house, so future studies should investigate those implications. The limited number of case studies became a constraint on strongly asserting the conclusions. Further studies can further test the hypothesis and strengthen the validity of the findings.

These case studies question the conventional notion and definition of comfort condition. Hence there is an obvious need for further studies to find variance in the comfort conditions and develop comfort ranges based on culture and other human responses. Finally, this research is just a beginning with potential for many future research investigations.

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Appendix A - Climatic charts of Ranchi, Jharkhand

The data for these charts was provided by Birsa Agriculture University, Ranchi. The following charts show the temperature and humidity for six years over thirty years. These charts help explain the climate of Ranchi and any changes in the last two decades. Figure A.1 shows that the maximum average temperature of Ranchi has increased over the last two decades for the months January, February, May, July, September, October, November, and December. Figure A.2 shows that the average minimum temperature to have increased all throughout the year except in May and July. Figure A.3 shows that the average maximum humidity of Ranchi has increased except for the months July, August and September. Similarly, Figure A.4 shows that the average minimum humidity to have decreased for the months July, August, September and November. It should be noted that probably in all cases, the maximum humidity takes place at night, with the possible exception of the monsoon season. Relative humidity is directly related to temperature, and goes up as temperature goes down.

Figure A.1 Average maximum temperature data for 1986, 1987, 1996, 1997, 2006, and 2007.

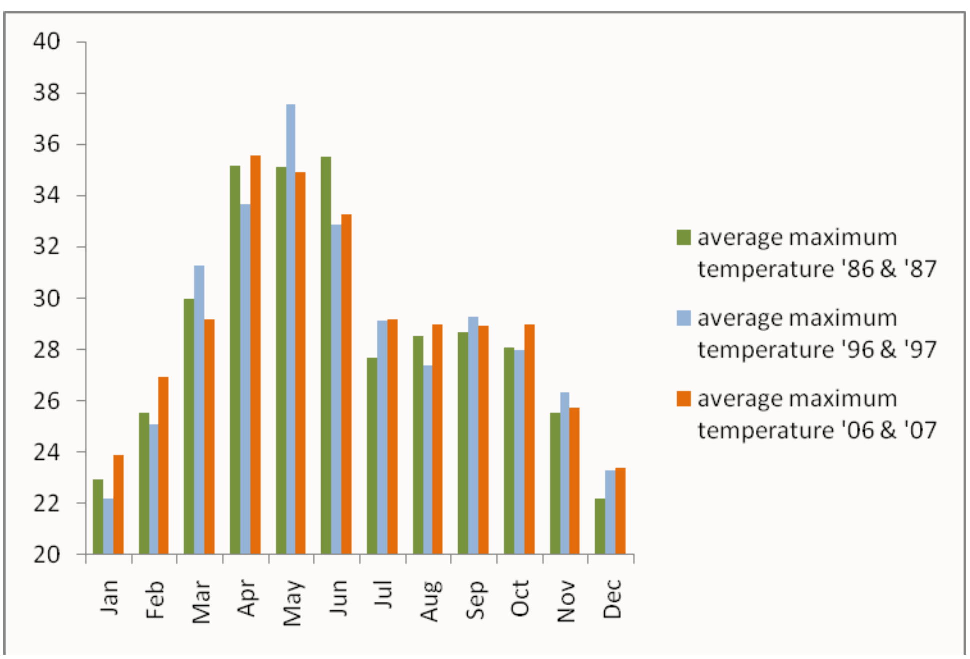


Figure A.2 Average minimum temperature data for 1986, 1987, 1996, 1997, 2006, and 2007

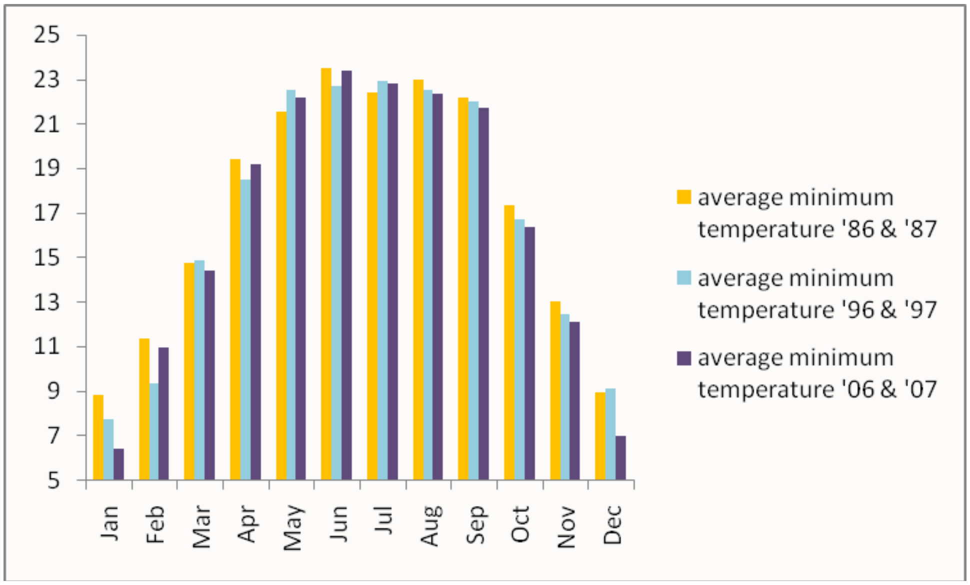


Figure A.3 Average maximum monthly relative humidity of Ranchi for 1987, 1996, 1997, 2006, and 2007.

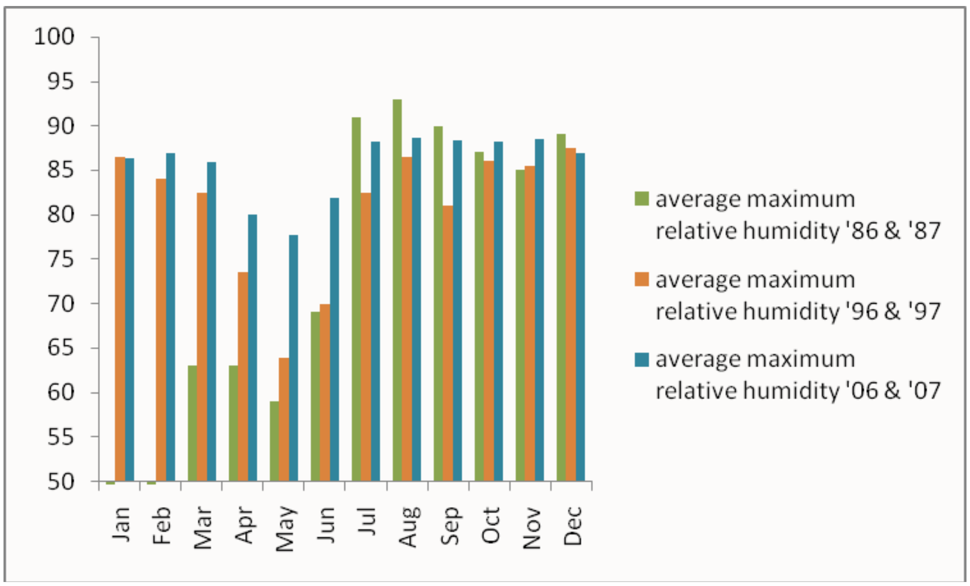
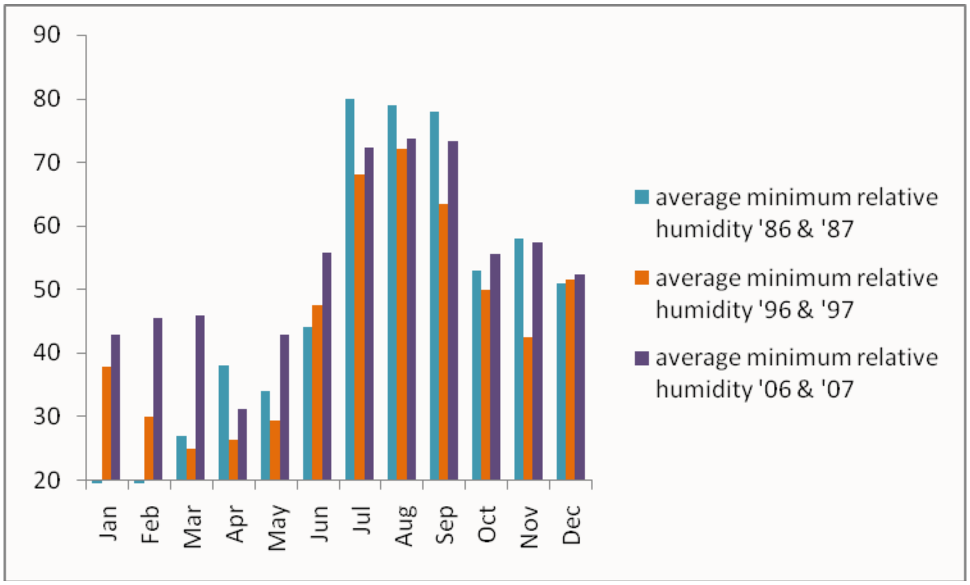


Figure A.4 Average minimum monthly relative humidity of Ranchi for 1987, 1996, 1997, 2006, and 2007.



Appendix B - IRB application

FOR OFFICE USE ONLY: IRB Protocol # ___________________ Application Received: ____________
Routed: ________ Training Complete: __________________

Committee for Research Involving Human Subjects (IRB)

Application for Approval Form

Last revised on March 2007

ADMINISTRATIVE INFORMATION:

- **Title of Project:** (if applicable, use the exact title listed in the grant/contract application)
  Climate Responsive Vernacular Architecture: Jharkhand, India

- **Type of Application:**
  ☒ **New,** ☐ **Addendum/Modification,**

- **Principal Investigator:** (must be a KSU faculty member)

Name:	**Prof. R. Todd Gabbard**	**Degree/Title:**	**Assistant Professor**
Department:	**Architecture**	**Campus Phone:**	**785-532-1129**
Campus Address:	**201B Seaton Court**	**Fax #:**	**785-532-6722**
E-mail	rtodd@ksu.edu		

- **Contact Name/Email/Phone for Questions/Problems with Form:** **R. Todd gabbard, rtodd@ksu.edu, 785-532-1129**
  Avinash Gautam, agautam@ksu.edu, 609-649-4462

- **Does this project involve any collaborators not part of the faculty/staff at KSU?** (projects with non-KSU collaborators may require additional coordination and approvals):
  ☒ **No**
  ☐ **Yes**

- **Project Classification** (Is this project part of one of the following?):
  ☒ **Thesis**
  ☐ **Dissertation**
  ☐ **Class Project**
  ☐ **Faculty Research**
  ☐ **Other:** ____________________

- **Please attach a copy of the Consent Form:**
  ☒ **Copy attached**
  ☐ **Consent form not used**

- **Funding Source:** ☒ **Internal** ☐ **External (identify source and attach a copy of the sponsor's grant application or contract as submitted to the funding agency)**
  ☐ **Copy attached** ☒ **Not applicable**

- **Based upon criteria found in 45 CFR 46 – and the overview of projects that may qualify for exemption explained at http://www.ksu.edu/research/comply/irb/about/exempt.html, I believe that my project using human subjects should be determined by the IRB to be exempt from IRB review:**
  ☐ **No**
  ☒ **Yes** **(If yes, please complete application including Section XII. C. 'Exempt Projects'; remember that only the IRB has the authority to determine that a project is exempt from IRB review)**

If you have questions, please call the University Research Compliance Office (URCO) at 532-3224, or comply@ksu.edu

Last revised on March 2007

Human Subjects Research Protocol Application Form

The KSU IRB is required by law to ensure that all research involving human subjects is adequately reviewed for specific information and is approved prior to inception of any proposed activity. Consequently, it is important that you answer all questions accurately. If you need help or have questions about how to complete this application, please call the Research Compliance Office at 532-3224, or e-mail us at **comply@ksu.edu**.

Please provide the requested information in the shaded text boxes. The shaded text boxes are designed to accommodate responses within the body of the application. As you type your answers, the text boxes will expand as needed. After completion, print the form and send the original and one photocopy to the Institutional Review Board, Room 203, Fairchild Hall.

Principal Investigator:	**R. Todd Gabbard**
Project Title:	**Climate Responsive Vernacular Architecture: Jharkhand, India**
Date:	**04/27/2007**

NON-TECHNICAL SYNOPSIS (brief narrative description of proposal easily understood by nonscientists):

Study to find passive solar design techniques that promote high thermal comfort in the vernacular homes in Jharkhand, India.

I. BACKGROUND (concise narrative review of the literature and basis for the study):

Jharkhand is located on the eastern part of India. Santals (tribal of Chota-Nagpur plateau) are the original inhabitants of the state. Climate is clearly one of the prime factors taken into consideration the built form. The traditional architecture of Jharkhand is vernacular in the sense that it is a product of well tried local craftsmanship and use of local materials. The houses range from a traditional jhonpri (hutment) to haveli (large mansions) built by the rich merchants later during the 19th and early 20th century. The hutments were originally kuccha (Hindi for raw, unripe, incomplete) in nature built of mud, sticks, grass and pebbles. These houses were mostly built by the family members and sometimes aided by neighbors. The beauty of kaccha architecture lies in its self-conscious attempts to adapt local material as economically as possible to encounter hostile environmental elements and to utilize beneficial ones. During the late eighteenth and early nineteenth century, the architecture style changed and mansions made of burnt clay brick came into prevalence. Technological advancement all over the world made its impression in this remote part of India too. Houses now built were pucca (Hindi for proper, cooked, ripe) in nature. The new houses were also built judiciously with the use of local materials and by local craftsman. These houses provide high thermal comfort levels. With the advance of global warming and the fuel crisis, study of vernacular buildings could provide solutions to achieve thermal comfort levels without mechanical means. In such a scenario there is a need to study these buildings and understand the passive soalr design techniques employed in them.

II. PROJECT/STUDY DESCRIPTION (please provide a concise narrative description of the proposed activity in terms that will allow the IRB or other interested parties to clearly understand what it is that you propose to do that involves human subjects. This description must be in enough detail so that IRB members can make an informed decision about proposal).

The study shall involve surveying the users of the selected houses to obtain information regarding the thermal comfort levels inside the house. Also the study shall use instruments that shall be deployed in the house to measure temperature, humidity, and air movement inside them.

III. OBJECTIVE (briefly state the objective of the research – what you hope to learn from the study):

To discover potential strategies for contemporary buildings that passively promote thermal comfort, thereby reducing need for external energy inputs and increasing quality of life for occupants.

IV. DESIGN AND PROCEDURES (succinctly outline formal plan for study):

A. Location of study: **Ranchi, Jharkhand, India**

B. Variables to be studied: **aperture, orientation, thermal mass, ceiling height, temperature, humidity, air movement**

C. Data collection methods: (surveys, instruments, etc – **PLEASE ATTACH**) **Surveys, HOBO data loggers, Raytek gun, anemometer, compass, measurement tape,**

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	digital camera, velocity stick.
D. List any factors that might lead to a subject dropping out or withdrawing from a study. These might include, but are not limited to emotional or physical stress, pain, inconvenience, etc.:	**None**
E. List all biological samples taken: (if any)	**None**
F. Debriefing procedures for participants:	**Thesis copy shall be made available to them**

V. RESEARCH SUBJECTS:

A. Source:	**Users of the selected house**
B. Number:	**20 houses**
C. Characteristics: (list any unique qualifiers desirable for research subject participation)	**Residents of vernacular houses in Ranchi**
D. Recruitment procedures: (Explain how do you plan to recruit your subjects? Attach any fliers, posters, etc. used in recruitment. If you plan to use any inducements, ie. cash, gifts, prizes, etc., please list them here.)	**By request**

VI. RISK – PROTECTION – BENEFITS: The answers for the three questions below are central to human subjects research. You must demonstrate a reasonable balance between anticipated risks to research participants, protection strategies, and anticipated benefits to participants or others.

A. **Risks for Subjects:** (Identify any reasonably foreseeable physical, psychological, or social risks for participants. State that there are "no known risks" if appropriate.)

None

B. **Minimizing Risk:** (Describe specific measures used to minimize or protect subjects from anticipated risks.)

n/a

C. **Benefits:** (Describe any reasonably expected benefits for research participants, a class of participants, or to society as a whole.)

Knowledge of passive solar design techniques

In your opinion, does the research involve **more than minimal risk** to subjects? ("Minimal risk" means that "the risks of harm anticipated in the proposed research are not greater, considering probability and magnitude, than those ordinarily encountered in daily life or during the performance of routine physical or psychological examinations or tests.")

☐ **Yes** ☒ **No**

VII. CONFIDENTIALITY: Confidentiality is the formal treatment of information that an individual has disclosed to you in a relationship of trust and with the expectation that it will not be divulged to others without permission in ways that are inconsistent with the understanding of the original disclosure. Consequently, it is your responsibility to protect information that you gather from human research subjects in a way that is consistent with your agreement with the volunteer and with their expectations. If possible, it is best if research subjects' identity and linkage to information or data remains unknown.

Explain how you are going to protect confidentiality of research subjects and/or data or records. Include plans for maintaining records after completion.

User name will not be disclosed

VIII. INFORMED CONSENT: Informed consent is a critical component of human subjects research – it is your responsibility to make sure that any potential subject knows exactly what the project that you are planning is about, and what his/her potential role is. (There may be projects where some forms of "deception" of the subject is necessary for the execution of the study, but it must be carefully justified to and approved by the IRB). A schematic for determining when a waiver or alteration of informed consent may be considered by the IRB is found at http://www.ksu.edu/research/comply/irb/images/slide1.jpg and at http://ohrp.osophs.dhhs.gov/humansubjects/guidance/45cfr46.htm#46.116. Even if your proposed activity does qualify for a waiver of informed consent, you must still provide potential participants with basic information that informs them of their rights as subjects, i.e. explanation that the project is research and the purpose of the research, length of study, study procedures, debriefing issues to include anticipated benefits, study and administrative contact information, confidentiality strategy, and the fact that participation is entirely voluntary and can be terminated at any time without penalty, etc. Even if your potential subjects are completely anonymous, you are obliged to provide them (and the IRB) with basic information about your project. See informed consent example on the URCO website at http://www.ksu.edu/research/comply/irb/app.html). It is a federal requirement to maintain informed consent forms for 3 years after the study completion.

Yes	No	Answer the following questions about the informed consent procedures.
☒	☐	a. Are you using a written informed consent form? If "yes," include a copy with this application. If "no" see b.
☐	☒	b. In accordance with guidance in 45 CFR 46, I am requesting a waiver or alteration of informed consent elements (See Section VII above). If "yes," provide a basis and/or justification for your request.
☒	☐	c. Are you using the online Consent Form Template provided by the URCO? If "no," does your Informed Consent document has all the minimum required elements of informed consent found in the Consent Form Template? (Please explain)
☐	☒	d. Are your research subjects anonymous? If they are anonymous, you will not have access to any information that will allow you to determine the identity of the research subjects in your study, or to link research data to a specific individual in any way. Anonymity is a powerful protection for potential research subjects. (An anonymous subject is one whose identity is unknown even to the researcher, or the data or information collected cannot be linked in any way to a specific person).
☒	☐	e. Are subjects debriefed about the purposes, consequences, and benefits of the research? Debriefing refers to a mechanism for informing the research subjects of the results or conclusions, after the data is collected and analyzed, and the study is over. (If "no" explain why.)

*** It is a requirement that you maintain all signed copies of informed consent documents for at least 3 years following the completion of your study. These documents must be available for examination and review by federal compliance officials.**

IX. PROJECT INFORMATION: (If you answer yes to any of the questions below, you should explain them in one of the paragraphs above)

Yes	No	Does the project involve any of the following?
☐	☒	a. Deception of subjects
☐	☒	b. Shock or other forms of punishment
☐	☒	c. Sexually explicit materials or questions about sexual orientation, sexual experience or sexual abuse
☐	☒	d. Handling of money or other valuable commodities
☐	☒	e. Extraction or use of blood, other bodily fluids, or tissues
☐	☒	f. Questions about any kind of illegal or illicit activity

Yes	No		
☐	☒	g.	Purposeful creation of anxiety
☐	☒	h.	Any procedure that might be viewed as invasion of privacy
☐	☒	i.	Physical exercise or stress
☐	☒	j.	Administration of substances (food, drugs, etc.) to subjects
☐	☒	k.	Any procedure that might place subjects at risk
☐	☒	l.	Any form of potential abuse; i.e., psychological, physical, sexual
☒	☐	m.	Is there potential for the data from this project to be published in a journal, presented at a conference, etc?
☒	☐	n.	Use of surveys or questionnaires for data collection **IF YES, PLEASE ATTACH!!**

X. SUBJECT INFORMATION: (If you answer yes to any of the questions below, you should explain them in one of the paragraphs above)

Yes	No		Does the research involve subjects from any of the following categories?
☐	☒	a.	Under 18 years of age (these subjects require parental or guardian consent)
☐	☒	b.	Over 65 years of age
☐	☒	c.	Physically or mentally disabled
☒	☐	d.	Economically or educationally disadvantaged
☐	☒	e.	Unable to provide their own legal informed consent
☐	☒	f.	Pregnant females as target population
☐	☒	g.	Victims
☐	☒	h.	Subjects in institutions (e.g., prisons, nursing homes, halfway houses)
☐	☒	i.	Are research subjects in this activity students recruited from university classes or volunteer pools? If so, do you have a reasonable alternative(s) to participation as a research subject in your project, i.e., another activity such as writing or reading, that would serve to protect students from unfair pressure or coercion to participate in this project? If you answered this question "Yes," explain any alternatives options for class credit for potential human subject volunteers in your study.
☐	☒	j.	Are research subjects **audio** taped? If yes, how do you plan to protect the recorded information and mitigate any additional risks?
☐	☒	k.	Are research subjects **video** taped? If yes, how do you plan to protect the recorded information and mitigate any additional risks?

XI. **CONFLICT OF INTEREST:** Concerns have been growing that financial interests in research may threaten the safety and rights of human research subjects. Financial interests are not in them selves prohibited and may well be appropriate and legitimate. Not all financial interests cause Conflict of Interest (COI) or harm to human subjects. However, to the extent that financial interests may affect the welfare of human subjects in research, IRB's, institutions, and investigators must consider what actions regarding financial interests may be necessary to protect human subjects. Please answer the following questions:

Yes	No		
☐	☒	a.	Do you or the institution have any proprietary interest in a potential product of this research, including patents, trademarks, copyrights, or licensing agreements?
☐	☒	b.	Do you have an equity interest in the research sponsor (publicly held or a non-publicly held company)?
☐	☒	c.	Do you receive significant payments of other sorts, eg., grants, equipment, retainers for consultation and/or honoraria from the sponsor of this research?
☐	☒	d.	Do you receive payment per participant or incentive payments?
		e.	If you answered yes on any of the above questions, please provide adequate explanatory information so the IRB can assess any potential COI indicated above.

XII. PROJECT COLLABORATORS:

A. KSU Collaborators – list anyone affiliated with KSU who is collecting or analyzing data: (list all collaborators on the project, including co-principal investigators, undergraduate and graduate students)

Name:	Department:	Campus Phone:
Avinash Gautam	Architecture	785-532-0659

B. Non-KSU Collaborators: (List all collaborators on your human subjects research project not affiliated with KSU in the spaces below. KSU has negotiated an Assurance with the Office for Human Research Protections (OHRP), the federal office responsible for oversight of research involving human subjects. When research involving human subjects includes collaborators who are not employees or agents of KSU the activities of those unaffiliated individuals may be covered under the KSU Assurance only in accordance with a formal, written agreement of commitment to relevant human subject protection policies and IRB oversight. The Unaffiliated Investigators Agreement can be found and downloaded at (http://www.ksu.edu/research/comply/irb/forms/invagree.pdf). The URCO must have a copy of the Unaffiliated Investigator Agreement on file for each non-KSU collaborator who is not covered by their own IRB and assurance with OHRP. Consequently, it is critical that you identify non-KSU collaborators, and initiate any coordination and/or approval process early, to minimize delays caused by administrative requirements.)

Name:	Organization:	Phone:

Does your non-KSU collaborator's organization have an Assurance with OHRP? (for Federalwide Assurance and Multiple Project Assurance (MPA) listings of other institutions, please reference the OHRP website under Assurance Information at: http://ohrp.osophs.dhhs.gov/polasur.htm).

☐ **No**
☐ **Yes** **If yes, Collaborator's FWA or MPA #** ______

Is your non-KSU collaborator's IRB reviewing this proposal?

☐ **No**
☐ **Yes** **If yes, IRB approval #** ______

C. Exempt Projects: 45 CFR 46 identifies six categories of research involving human subjects that may be exempt from IRB review. The categories for exemption are listed on the KSU research involving human subjects home page at http://www.ksu.edu/research/comply/irb/about/exempt.html. If you believe that your project qualifies for exemption, please indicate which exemption category applies (1-6). Please remember that only the IRB can make the final determination whether a project is exempt from IRB review, or not.

Exemption Category: ______

XIII. CLINICAL TRIAL ☐Yes ☒No
(If so, please give product.)

Post Approval Monitoring: The URCO has a Post-Approval Monitoring (PAM) program to help assure that activities are performed in accordance with provisions or procedures approved by the IRB. Accordingly, the URCO staff will arrange a PAM visit as appropriate; to assess compliance with approved activities.

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INVESTIGATOR ASSURANCE FOR RESEARCH INVOLVING HUMAN SUBJECTS

(Print this page separately because it requires a signature by the PI.)

P.I. Name: R. Todd Gabbard

Title of Project: Climate Responsive Vernacular Architecture: Jharkhnad, India

XII. ASSURANCES: As the Principal Investigator on this protocol, I provide assurances for the following:

A. **Research Involving Human Subjects:** This project will be performed in the manner described in this proposal, and in accordance with the Federalwide Assurance FWA00000865 approved for Kansas State University available at http://ohrp.osophs.dhhs.gov/polasur.htm#FWA, applicable laws, regulations, and guidelines. Any proposed deviation or modification from the procedures detailed herein must be submitted to the IRB, and be approved by the Committee for Research Involving Human Subjects (IRB) prior to implementation.

B. **Training:** I assure that all personnel working with human subjects described in this protocol are technically competent for the role described for them, and have completed the required IRB training modules found at: http://www.ksu.edu/research/comply/irb/training/index.html. I understand that no proposals will receive final IRB approval until the URCO has documentation of completion of training by all appropriate personnel.

C. **Extramural Funding:** If funded by an extramural source, I assure that this application accurately reflects all procedures involving human subjects as described in the grant/contract proposal to the funding agency. I also assure that I will notify the IRB/URCO, the KSU PreAward Services, and the funding/contract entity if there are modifications or changes made to the protocol after the initial submission to the funding agency.

D. **Study Duration:** I understand that it is the responsibility of the Committee for Research Involving Human Subjects (IRB) to perform continuing reviews of human subjects research as necessary. I also understand that as continuing reviews are conducted, it is my responsibility to provide timely and accurate review or update information when requested, to include notification of the IRB/URCO when my study is changed or completed.

E. **Conflict of Interest:** I assure that I have accurately described (in this application) any potential Conflict of Interest that my collaborators, the University, or I may have in association with this proposed research activity.

F. **Adverse Event Reporting:** I assure that I will promptly report to the IRB / URCO any unanticipated problems involving risks to subjects or others that involve the protocol as approved.

G. **Accuracy:** I assure that the information herein provided to the Committee for Human Subjects Research is to the best of my knowledge complete and accurate.

________________________________ ________________

(Principal Investigator Signature) (date)

Appendix C - Survey responses

The tables below show occupants' response to the various questions asked to gather their perception of thermal comfort in their home. A detailed analysis of the survey is presented in Chapter 5.

Table C.1 Huts: Demographic and general information

Questions		Huts				
		House 1	House 2	House 3	House 4	House 5
A. Demographic and general information						
1.1	When where you born?	1949	1973	1972	1969	1974
1.2	Gender	Male	Male	Male	Male	Male
1.3	Religion	Hindu	Hindu	Hindu	Hindu	Christian
1.4	How long have you lived in Ranchi?	more than 30 years	more than 30 years	more than 30 years	more than 30 years	more than 30 years
1.5	How long have you lived in this house?	more than 30 years	more than 30 years	more than 30 years	more than 30 years	more than 30 years
1.6	When was this house built?	1902	1953	1969	1962	1962
1.7	How many people reside in this house?	2	10	8	6	4
1.8	Are they all family members?	Yes	Yes	Yes	Yes	Yes
1.9	Prime Occupation	Retired	Agriculture	Unemployed	Gardener	Builder
1.10	Annual Income	No response	No response	No response	No response	No response

Table C.2 Huts: House and its usability

Questions		Huts				
		House 1	House 2	House 3	House 4	House 5
B. House and its Usability						
2.1	How much time do you spend in the house?	21-24	13-16	9-12.	9-12.	13-16
2.2	What times of the day you stay at home?	6-9, 9-12, 12-3, 3-6, 6-9, night	6-9. 12-3, 3-6, 6-9, night	6-9, 6-9, night	6-9, 6-9, night	6-9, 12-3, 6-9, night
2.3	Which part of the house is mostly used? Do you change the prime used space from season to season? If yes, then why and from which space to which?	Family room. Yes. From family room to verandah during winter.	Courtyard and bedroom. Yes. From courtyard to inner bedroom during summer.	Living space. Yes. Move to kitchen in winter.	Family room and courtyard. From room in summer to courtyard in winter.	Bedroom. No.
2.4	Do you change the prime used space from morning to night? If yes, then why and from which space to which?	No.	No.	Yes. From inside to outside to get some air movement.	Yes. Summer evening courtyard and winter evening inside the house.	No.
2.5	What are the most common activities performed in the prime used space?	Sitting, eating, sleeping.	Sleeping.	Cooking, sleeping.	Cooking, eating, resting, and sleeping.	Sleeping, spending time.
2.6	Which family member uses the prime used space most?	Both.	Old People.	all	all	wife and children
2.7	Which is your most preferred season in the prime used space?	Summer.	Whole year	winter	Summer, winter.	Spring, summer, autumn, winter.

2.8	Do you use some specific part of the house only for a particular season? If so which space, why and in which season?	No.	Yes. Courtyard to gain heat from sun.	Yes. Kitchen in winter to gain heat from stove.	No.	No.

Table C.3 Huts: Comfort

Questions		Huts				
		House 1	House 2	House 3	House 4	House 5
C. Comfort.						
3.1	Which part of the day is the most comfortable in the most used place? Please explain why.	Entire day as it is cold inside the house as compared to outside.	9-12, 12-3. During these hours the room is cold as compared to outside.	Entire day as it is cold inside the house as compared to outside.	12-3, 3-6. Living style makes these hours free.	6-9, 9-12. It is pleasant inside the house.
3.2	Which is more comfortable season inside the house?	Spring, summer, rainy.	Entire year.	Summer	Summer	Summer
3.3	When is it more comfortable outside the house? Please explain why.	Spring as it is comfortable throughout the day.	Winter. As there is plenty of sun in the courtyard.	Spring when it is neither cold nor hot outside.	Winter. As there is plenty of sun in the courtyard.	Spring and Autumn as it is not cold and not hot during these times.
3.4	Does your house have any mechanical means of creating controlled climate? If yes, then what means and what time of the day and season do you use them?	Yes. Fan. Use during summer afternoon.	No.	No.	No.	Yes. Fan. Used in summer afternoons.

3.5	How do you relate to thermal comfort inside the house?	Cold.	Cold.	Cold.	Cold.	Cold.
3.6	What do you think makes the most preferred space thermally comfortable? Why?	Double ceiling.	Double ceiling traps sun and hot air from entering the house. Also mud walls keep the house cold.	Ceiling allows air flow through it.	High thermal mass and double ceiling.	Ceiling helps in air circulation and wooden shutters prevent sun from entering the house.
3.7	How do you relate to thermal comfort outside the house?	warm	too warm	too warm	warm	too warm
3.8	Do all the users of the house experience nearly the same thermal comfort levels? If there is a difference, please explain.	Yes.	Yes.	Yes.	Yes.	Yes.

Table C.4 Huts: Discomfort

Questions		Huts				
		House 1	House 2	House 3	House 4	House 5
D. Discomfort.						
4.1	What is the most uncomfortable element? Temperature, humidity, or air movement. Why?	Humidity as it makes it sweaty.	Air movement in winter and temperature in summers.	Temperature as it makes it unable to work outside.	Temperature as it is too hot in summers and too cold in winters.	Humidity as it makes it sweaty.

4.2	When does it get most uncomfortable?	Rainy as one can't go out. Winter as there is no sun.	No response	Rainy.	Rainy.	Rainy.
4.3	What do you do to overcome it?	Wear warm clothes.	No response	nothing	No response	Use plastic sheets to keep the rain out from entering the house.
4.4	When was the most uncomfortable day? What did you do to make yourself comfortable?	No response	No response	During 10-3 daily in summers as it is hot during these hours. Sleep during these hours to avoid being uncomfortable.	No response	No response
4.5	Which part of the day is the most uncomfortable in the most used place?	Summer from 3-6 as sometimes there is no air movement.	No response	Rainy. As there is leakage of rain through the ceiling.	No response	Rainy. As there is leakage of rain through the ceiling.

Table C.5 Huts: Adaptability

Questions		Huts				
		House 1	House 2	House 3	House 4	House 5
E. Adaptability						
5.1	Is there any change in the climate of the place?	Yes.	Yes.	Yes.	Yes.	Yes.
5.2	What change you observe in the climate?	It has become hotter.	It has become hotter.	It has become hotter.	It has become hotter.	It has become hotter.

5.3	Is the house in its original state (as it was built)?	Yes.	Yes.	Yes.	Yes.	Yes.
5.4	What are the changes incorporated over the years in the built form? And why?	None.	None.	None.	Added electricity.	Added a metal frame door for security.
5.5	In the time that you've lived in this house, have you perceived changes in the comfort level?	No.	Yes.	No.	No.	Yes.
5.6	What changes do you observe?	None.	Slight increase in temperature inside the house.	None.	None.	Water seeps through the ceiling more often.
5.7	What changes have you incorporated in the house to make it more comfortable?	None.	None.	None.	Added electricity to provide light.	Added a plastic sheet below the ceiling.
5.8	What changes have you incorporated in your lifestyle to make it more comfortable?	None.	None.	None.	None.	None.
5.9	If you were to make any change to make the house more comfortable what would you be doing?	Add windows with glass to enable outside vision.	Repair ceiling and mud plaster the walls.	Add more windows to increase the air movement inside the house.	Raise floor to avoid water entering during rains.	Repair ceiling.

Table C.6 Huts: Indoor Environment

Questions		Pre Industrial Vernacular Architecture				
		House 1	House 2	House 3	House 4	House 5
F. Indoor Environment						
6.1	How do you rate the acoustical environment on the basis of loudness inside the house?	6	6	6	7	6
6.2	How do you rate the acoustical environment on the basis of pitch inside the house?	7	6	6	7	6
6.3	How do you rate the acoustical environment on the basis of distracting sounds from outside the house?	6	6	7	7	4
6.4	How do you rate the air quality on the basis of odor inside the house?	6	6	6	6	5
6.5	How do you rate the air quality on the basis of dust inside the house?	6	4	6	4	4
6.6	How do you rate the air quality on the basis of smoke inside the house?	7	6	4	4	4
6.7	How do you rate the light quality on the basis of brightness inside the house?	7	6	5	4	6

6.8	How do you rate the light quality on the basis of glare inside the house?	7	7	7	7	6
6.9	How do you rate the light quality on the basis of shadows inside the house?	5	7	5	4	6
6.10	How do you rate the thermal environment inside the house on the basis of temperature?	7	7	7	7	6
6.11	How do you rate the thermal environment inside the house on the basis of humidity?	7	6	7	7	6
6.12	How do you rate the thermal environment inside the house on the basis of air movement?	4	6	6	6	6
6.13	How do you rate the indoor environment quality on the basis of pests inside the house?	2	3	3	4	2
6.14	Do you have any pests in the house?	Yes	Yes	Yes	Yes	Yes
6.15	What are the pests present inside the house and what precautions/care do you take?	mosquito	mosquito and other insects	termite	mosquito and other insects	mosquito and other insects

6.16	What measures would you take to improve the acoustics, light, air quality, thermal environment and pest control inside the house?	net	repair ceiling and lime plaster	pesticide and waterproof the ceiling	pesticide	pesticide, add exhaust in kitchen and waterproof the ceiling
6.17	How do you rate the overall comfort level inside the house?	7	5	7	6	5

Table C.7 Havelis: Demographic and general information

Questions		Havelis				
		House 6	House 7	House 8	House 9	House 10
A. Demographic and general information						
1.1	When where you born?	1964	1955	1975	1976	1956
1.2	Gender	Male	Male	Male	Male	Female
1.3	Religion	Hindu	Hindu	Hindu	Hindu	Hindu
1.4	How long have you lived in Ranchi?	more than 30 years	26-30	more than 30 years	more than 30 years	more than 30 years
1.5	How long have you lived in this house?	more than 30 years	26-30	more than 30 years	more than 30 years	more than 30 years
1.6	When was this house built?	1925	1952	1939	1942	1953
1.7	How many people are residing in this house?	5	6	30	11	3
1.8	Are they all family members?	Yes	Yes	Yes	Yes	Yes
1.9	Prime Occupation	Advocate	Professor	Business	Business	Housewife
1.10	Annual Income	No response	No response	No response	No response	No response

Table C.8 Havelis: House and its usability

Questions		Havelis				
		House 6	House 7	House 8	House 9	House 10
B. House and its Usability						
2.1	How much time do you spend in the house?	13-16	17-20	9-12.	17-20.	21-24
2.2	What times of the day you stay at home?	6-9, 3-6, 6-9, night	6-9, 3-6, 6-9, night	6-9, night	6-9, 9-12, 12-3, 6-9, night	6-9, 9-12, 12-3, 6-9, night
2.3	Which part of the house is mostly used? Do you change the prime used space from season to season? If yes, then why and from which space to which?	Living room. Yes. From bedroom on East to one on North in summers.	Bedroom. No.	External verandah and courtyard. No.	Kitchen. No.	Living Room. No.
2.4	Do you change the prime used space from morning to night? If yes, then why and from which space to which?	No.	No.	No.	No.	No.
2.5	What are the most common activities performed in the prime used space?	Eating, watching TV, general sitting	Sleeping, watching TV, reading	sitting, spending time, nearly everything except sleeping	cooking and eating	Sleeping, sitting, eating
2.6	Which family member uses the prime used space most?	all	all	all	Mother	all
2.7	Which is your most preferred season in the prime used space?	Summer	Summer	Whole year	Winter	Spring

2.8	Do you use some specific part of the house only for a particular season? If so which space, why and in which season?	Yes, Porch in winters.	No	No	Yes. To living room	No

Table C.9 Havelis: Comfort

Questions		Havelis				
		House 6	House 7	House 8	House 9	House 10
C. Comfort.						
3.1	Which part of the day is the most comfortable in the most used place? Please explain why.	12-3, 3-6. Living style makes these hours free.	9-12, 12-3, 3-6. it is cool in summer	Entire day. Less hot as compared to outside and good ventilation helps in feeling comfortable.	12-3 as living room is cold during these hours when the heat outside is unbearable.	6-9, 9-12,6-9, night
3.2	Which is more comfortable season inside the house?	Summer	Summer	Summer	Summer	Summer
3.3	When is it more comfortable outside the house? Please explain why.	Winter. Mostly clear sky conditions enable gain from sun's heat.	Winter. Mostly clear sky conditions enable gain from sun's heat.	Morning and evening in summers. Daytime in winters.	Winters as summers are too hot.	Spring

3.4	Does your house have any mechanical means of creating controlled climate? If yes, then what means and what time of the day and season do you use them?	Yes. Fan used in summers throughout the day.	Yes. Fan used in summers during daytime.	Yes. Fan used in summers during daytime.	Yes. Fan used in summers throughout the day.	Yes. Fan used in summers from noon to evening
3.5	How do you relate to thermal comfort inside the house?	Cold.	Cold.	Cold in summers. Warm in winters.	Cold.	Cold.
3.6	What do you think makes the most preferred space thermally comfortable? Why?	High ceiling height, thermal mass, and lime surkhi construction.	Thermal mass, high ceiling height, sun on the walls only on the west façade. Second floor construction.	Thermal mass, central location on the site and large windows enabling ventilation.	Thermal mass and high ceiling.	thermal mass, high ceiling
3.7	How do you relate to thermal comfort outside the house?	warm	warm	warm	too warm	warm
3.8	Do all the users of the house experience nearly the same thermal comfort levels? If there is a difference, please explain.	Yes.	Yes.	Yes.	Yes.	Yes.

Table C.10 Havelis: Discomfort

Questions		Havelis House 6	House 7	House 8	House 9	House 10
D. Discomfort.						
4.1	What is the most uncomfortable element? Temperature, humidity or air movement. Why?	Air movement. No air movement in some rooms which makes it uncomfortable.	Humidity	No response	No response	Temperature.
4.2	When does it get most uncomfortable?	Winter.	Winter.	Never only when there are no winds in summer.	Never.	Winter.
4.3	What do you do to overcome it?	Use blanket inside the house and utilize the sunspace during sunny hours.	No response	Use fan.	No response	warm clothes
4.4	When was the most uncomfortable day? What did you do to make yourself comfortable?	One day nearly eight years ago in summers it was highly humid.	No response	No response	No response	No response
4.5	Which part of the day is the most uncomfortable in the most used place?	Winter. As there is no sun inside the room.	Winter. No sun in the room.	No response	No response	Winter nights as it is cold.

Table C.11 Havelis: Adaptability

Questions		Havelis				
		House 6	House 7	House 8	House 9	House 10
E. Adaptability						
5.1	Is there any change in the climate of the place?	Yes.	Yes.	Yes.	Yes.	Yes.
5.2	What change you observe in the climate?	It has become hotter.	It has become hotter.	It has become hotter.	It has become hotter.	It has become hotter.
5.3	Is the house in its original state (as it was built)?	Yes.	Yes.	Yes.	Yes.	Yes.
5.4	What are the changes incorporated over the years in the built form? And why?	Nothing except for maintenance.	Nothing.	3rd and 4th floor added later in 1960.	Repair over the years to keep the house in shape.	added plumbing system
5.5	In the time that you've lived in this house, have you perceived changes in the comfort level?	Yes.	Yes.	No.	No.	No.
5.6	What changes do you observe?	It was much cooler inside a few decades back.	More comfortable earlier as there was more greenery around and plenty of open spaces that enabled a beautiful view and didn't stop winds.	None.	None.	None.

5.7	What changes have you incorporated in the house to make it more comfortable?	Attached toilet to the house and added electricity,	Nothing.	None.	Repair over the years to keep the house in shape.	Bought new electrical gadgets to make lifestyle more comfortable.
5.8	What changes have you incorporated in your lifestyle to make it more comfortable?	Food habits. Eat food in the morning and then at night to suit to daily routine.	Use of more warm clothes.	None.	Spend most of the time in house.	Adopted use of technology in life.
5.9	If you were to make any change to make the house more comfortable what would you be doing?	Attach toilet to rest of the bedrooms.	Make rest of the spaces adjacent to this house similar to those as in past.	None.	For aesthetic purpose reduce the number of doors and windows.	Add mosquito net in the windows.

Table C.12 Havelis: Indoor Environment

Questions		Havelis				
		House 6	House 7	House 8	House 9	House 10
F. Indoor Environment						
6.1	How do you rate the acoustical environment on the basis of loudness inside the house?	6	7	7	6	7
6.2	How do you rate the acoustical environment on the basis of pitch inside the house?	6	7	7	6	7

6.3	How do you rate the acoustical environment on the basis of distracting sounds from outside the house?	6	7	7	7	7
6.4	How do you rate the air quality on the basis of odor inside the house?	7	7	7	7	6
6.5	How do you rate the air quality on the basis of dust inside the house?	6	3	7	7	7
6.6	How do you rate the air quality on the basis of smoke inside the house?	7	3	7	7	7
6.7	How do you rate the light quality on the basis of brightness inside the house?	7	2	7	6	7
6.8	How do you rate the light quality on the basis of glare inside the house?	7	6	7	7	7
6.9	How do you rate the light quality on the basis of shadows inside the house?	7	2	7	6	5

6.10	How do you rate the thermal environment inside the house on the basis of temperature?	7	7	7	7	7
6.11	How do you rate the thermal environment inside the house on the basis of humidity?	7	3	7	7	7
6.12	How do you rate the thermal environment inside the house on the basis of air movement?	7	7	7	7	5
6.13	How do you rate the indoor environment quality on the basis of pests inside the house?	3	2	7	5	3
6.14	Do you have any pests in the house?	Yes	Yes	Yes	Yes	Yes
6.15	What are the pests present inside the house and what precautions/care do you take?	mosquitoes, flies, lizards, cockroaches, rats	mosquitoes, lizards, cockroaches	mosquitoes	mosquitoes	mosquitoes, lizards, flies, cockroaches

6.16	What measures would you take to improve the acoustics, light, air quality, thermal environment and pest control inside the house?	pest control	pest control	net	mosquito coil	net
6.17	How do you rate the overall comfort level inside the house?	6	6	7	7	6

Appendix D - Photographs of houses surveyed

Figure D.1 House 1: Trees to shade the west wall.

Figure D.2 House 1: Light colored walls to reflect heat.

Figure D.3 House 1: Interlocking burnt clay tiles.

Figure D.4 House 1: Light colored ceiling inside the living room with a fan.

Figure D.5 House 1: Front verandah used for sitting in winter and to shade the light colored exterior walls.

Figure D.6 House 1: Door and window placed opposite to each other for cross-ventilation.

Figure D.7 House 2: View from entrance showing light colored walls to reflect heat.

Figure D.8 House 2: Storage area with low ceiling.

Figure D.9 House 2: View of attic space.

Figure D.10 House 2: Interlocking burnt clay tiles to prevent rain from entering the house.

Figure D.11 House 3: View from entrance with its occupants in front.

Figure D.12 House 3: Light colored attic space to reflect heat.

Figure D.13 House 4: Entrance showing light colored walls to reflect heat.

Figure D.14 House 4: Attic space used as storage area.

Figure D.15 House 4: Low availability of light in the house due to lack of windows.

Figure D.16 House 4: Light colored walls to reflect the heat.

Figure D.17 House 4: Thick ceiling made with wooden beams and mud.

Figure D.18 House 4: Use of courtyard for drying clothes and food.

Figure D.19 House 5: Entrance.

Figure D.20 House 5: Roof with interlocking burnt clay tiles to block rain from entering the house.

Figure D.21 House 5: Thick mud walls to increase the thermal capacity of the walls.

Figure D.22 House 5: Like the kitchen area shown here in the photograph, rest of the spaces too lack windows which reduces heat gain inside the house but hinders night time flush ventilation of the thermal mass, making the space warmer than outside.

Figure D.23 House 6: View from entrance showing large number of windows.

Figure D.24 House 5: Main living area with high ceiling, bare tile floor, fan to circulate air, and a ventilator at top to ensure stack ventilation.

Figure D.25 House 7: View of house from entrance.

Figure D.26 House 7: Large windows with wooden shutters to block sun during daytime in summers.

Figure D.27 House 7: Door and windows are placed opposite to each other to cross ventilation.

Figure D.28 House 8: View from entrance.

Figure D.29 House 8: View of courtyard showing the railings with fenestrations to enable wind movement through it.

Figure D.30 House 8: Room with large windows, high ceiling and fans.

Figure D.31 House 8: View of courtyard from top showing a child playing.

Figure D.32 House 9: View from entrance.

Figure D.33 House 8: View of living room with light colored high ceiling, light colored walls and fan.

Figure D.34 House 10: View from entrance.

Figure D.35 House 10: View of house showing many windows with wooden shutters to bock sun in summer and allow sun in the winter.

Figure D.36 House 10: View of main living room with light colored walls and high ceiling.