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Energy efficient house

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ABSTRACT
On one hand Pakistan is facing severe energy crises, and on the other the planet earth is going through global warming. The only solution for both is low carbon planning. The purpose of this dissertation is to show the benefit of low energy residential designs. This research has taken into account analysis of three case studies of eco houses designed with considerations of energy efficiency and traditional methods; which has been examined in regard with economy, material, and techniques. It is normally believed that closely controlled conditions equate with better comfort. Analysis of field surveys and adaptive comfort theories have made it clear that while closely controlled is one way of achieving comfort it is not the only way. It is a comparison of two types of houses. Firstly there is a complete analysis of an existing house in UET staff colony that adopts traditional methods of achieving comfort through energy consumption. On the other hand there is another house where comfort is accommodated through alternative means. The calculations are made on the basis of utility bills. The later house is an Eco-House design proposal for which creative design decisions are discussed in detail namely, selection of material, comfort levels, space utilization, and site development; according to the sun path diagrams. This Eco-House is based on precedent conducted studies. It is supposed to be within usual comfort limits by the use of shading and thermal mass to control the range of the temperature. The two prong strategy was devised for both the houses, separately. A comparative analysis of the radiation penetration through fenestrations for the two houses was conducted on two typical days. One is the longest day of the year i.e. 22nd of June and the other is the shortest day of the year i.e. 22nd of December. In closely controlled case firstly the analysis was made creating model based graphs of radiation statistics. And secondly for the same conditions ECOTECT software was used to study the sun path patterns and sunlight penetrations. The results obtained provide us the substance to statistically show the benefits of low energy designs. Moreover, the findings highlight an importance by providing an insight for the architects to pay attention towards as well as adopt the measures for designing low energy buildings.

Key works: sustainability, eco- green house, 0- Energy, Energy efficient House.

1. INTRODUCTION

The world today is facing depleting energy resources Mohamed et al (2006). For a country like Pakistan the case is even worse, where the gap between generation and consumption is constantly rising Wood et al (2012). Therefore, it is needed to efficiently utilize the scarce energy resources. Thus, the architects should pay attention to design and build such constructions that consume comparatively lesser amount of energy McLennan (2004). The much acclaimed solution is the constructions of eco buildings Kibert et al (2012). This research addresses the said issue.

2. RESEARCH STATEMENT / HYPOTHESIS

The statement below best describes this dissertation:

"An Eco-House* can provide same or even more (i.e. variable degree) level of comfort for residential buildings as that of high energy consumption houses" (*"Eco-House," an energy efficient home which uses the surrounding natural resources to heat, cool, and power all of its major energy needs. The home should employ a variety of alternative energy technologies, such as solar panels, a wind turbine, and battery packs to meet the energy needs of sustainable living.)

3. OBJECTIVES

The main/primary objectives of this dissertation can be stated as:

- To provide a low energy residential design solution for architects by making creative design decisions regarding the selection of building materials, comfort levels, space utilization, process flows and circulation, control and operation of the facility, and site development.
- To use an appropriate and well defined method to solve climate problems creatively by testing the alternatives against a set of well defined criteria.
- The other/secondary objectives of this dissertation can be stated as:
- Image, the visual concept of the building refers to and the ways of the building attracting attention to itself. The form of the building and the symbolic attributes
- Community refers to how the building and its site represents a better neighborhood and identity in terms of safety, security, and privacy.
- Efficient functionality is an attribute in which the building is able to respond to the work which is held in process in it; and flow of people, equipment, and material.
- Security here is defined as the level to which the building can segregate sensitive functions from one another and prevent the entry of people to restricted areas.
- Expansion refers to the ability of the building to grow to meet the growth of the family without disturbing the existing functions.
- Flexibility is defined as the degree to which the building plan can be rearranged to conform to revised work progress and personnel changes.
- Technical Performance refers to how the building operated in terms of mechanical systems, electrical systems and industrial processes.
- Human performance is defined as how the building provides a physically and psychologically comfort to the residence, to work and live.

4. METHODOLOGY AND DESIGN

The discussion below explicitly reveals the methodology used for this dissertation. It can be summarized as:

- Taking the existing plan of a typical house at UET, calculate the energy by analyzing the utility bills.
- Redesigning the house to minimize the energy consumption
- Calculating and comparing the radiation penetration through fenestrations
- Calculating the energy loads on ECOTECT software for the new design

Rapid societal change means that designers must switch more and more from random creativeness to deliberate and focused creativeness. With shorter amount of time to solve increasingly complex problems, a systematic process is necessary if ideas are to be produced on purpose (S. J. Kirk, 1988)[1]. Thus, the logical sequence for decision process of this dissertation comprises as below:

- Identify the problem to be solved
- Gather information
- Analyze the data
- Produce alternative solutions
- Evaluate ideas and allow time for additional ideas to occur
- Synthesize ideas into a whole
- Verify the proposed solution through evaluation[2]

5. RESEARCH DESCRIPTION AND DISCUSSION

The study is primarily based upon the residential sector's low energy architecture design. The issue of comfort is often directly related to the energy consumption i.e. higher the energy consumption, higher the comfort level. This dissertation however, shows that although high energy consumption is one way of achieving the comfort it is not the only way. There are other unexplored or less utilized alternatives available; some of them are discussed in this study. This dissertation shows another way of attaining comfort levels i.e. by constructing the *Eco House*. It is basically a comparison of two houses of a residential colony of UET Lahore. First house is already built and the data is gathered from the existing facts collected for statistical analysis. The second house is an Eco-House; a purpose-built model that can be used as a proposed design for the futuristic constructions. Both the houses are similar i.e. their architecture, their number of inhabitants, income groups, life styles, and the energy consumption patterns (Maheshwari, 2015); all of them have been chosen to have a similarity before the start of, and during the time period of this study.

The dissertation includes seven chapters; all of them address separate but important and relevant topics covering the subject of low energy architecture design. Briefly stated as:

1. The opening chapter provides the information about the optimal use of sunlight and reducing radiation.
2. The second chapter revolves around three different case studies from three different parts of the world respectively.
3. The third chapter discusses about the use of software named *ECOTECT;* a computer program to take the advantage of modern technologies for creative architecture designs.
4. The fourth chapter is the study of an existing house in a UET staff colony that uses the controlled methods for comfort.
5. The fifth chapter describes the different design approaches to be used for an energy efficient house.
6. The sixth chapter discusses a model house considered as an Eco-House designed to take the advantage of green landscapes for obtaining the varying degree comfort levels as with the controlled methods.
7. The final chapter has summarized the results and detailed conclusions are formed.

"Eco-House," is an energy efficient home which uses the surrounding natural resources to heat, cool, and power all of its major energy needs. The home should employ a variety of alternative energy technologies, such as solar panels, a wind turbine, and battery packs to meet the energy needs of sustainable living. This dissertation highlights the importance of the ecological architecture, to optimize comfort, and minimize energy consumption; by taking an example of a house of UET staff colony. The reduced energy consumption is found to be half or even less than half of the amount consumed by the comparative house.

Along with others, the study has taken into account three case studies of different traditional but eco houses. The first case study is of a house situated in the same city of Lahore. This house has used water circulation and air circulation by absorbing the external heat and ultimately cooling it before being circulated inside the premises. Also the external walls of the houses were more than 80 percent covered with greenery and landscape. The second case study is of a house in Iran that has open-able double roofs. The roofs open up in winter for sunlight penetration, whereas in summer they can be closed as an insulation against the strong beams of incoming sunlight radiation. The third and the last case study is of an American house. The shading devices of the western windows of the house are designed in such a way that they can adjust themselves according to the angle of the sun automatically; throughout the day and throughout the year Moreover this house is made up of several portable components that were carried individually to the site to be assembled ultimately as one cohesive unit within two days.

Furthermore, to demonstrate, simulate and analyze the environmental performance of buildings a software named *ECOTECT* is used. The basic function of the software is analysis of different elements namely, solar, thermal, acoustics, and lighting. Also it conducts the thermal simulations on the models of the buildings.

Moreover, the descriptive statistics is used to analyze the radiation of sun penetrations in the two principal houses of the study. The extensive study is carried out to gather the data of the different radiation aspects of the two houses. This data as well as the calculations are further analyzed in detail to produce the findings and make suggestions for the future. Both the graphical as well as the tabular presentations of the dissertation provide a deep insight to show the importance of the ecological architecture. The results clearly indicate the difference of energy consumption between the two houses.

5.1. Sunlight and Radiation

The chapter discusses the importance of efficient and optimal use of sunlight by architects for designing the buildings. On the one hand it discusses the pros and cons of sunlight. On the other it provides the information for architects to design buildings in such a way that they avoid or minimize the sunlight radiations Santamouris et al (2013).

5.2. Sunlight

As we all know that Sun is the brightest star in the solar system. It gives us light which is a valuable source of heat energy. It can be considered as the 'life blood' for all living things on the planet and without which, almost all the living organisms would fail to exist. The sun also creates few problems for living beings. For example, extreme heat which is often undesirable for it causes an increase in temperature. Therefore people have found ways over time to use the power of sun and reduce its negative effects. Nevertheless, the architects have also played role in maneuvering this source intelligently (Sustainable Design Guide, 2008)[1].

5.2.1. Radiation

The architects can best utilize the sunlight by minimizing the radiation effects. It is the ultraviolent radiant energy emitted by Sun as a result of its nuclear fusion reactions. When this ultraviolent radiation is not absorbed by the atmosphere or other protective coating, it can cause adverse effects for humans in general and the overall climate in particular.

Unless it is properly calculated, it would be difficult to minimize the radiation. For the purposes of this dissertation, the calculations on the longest day of the year i.e. June 22nd and the shortest day of the year i.e. December 22nd were made. These calculations were subject to the orientations of the building. The following formula can be used for radiation calculations.

$$\text{Cos}(\theta) = \text{Cos}(A) \times \text{Cos}(WSA)$$

Where,

A = Angle of Altitude* and

WSA = Wall Solar Azimuth**

(*Altitude is the angular distance above the horizon measured perpendicularly to the horizon. It has a maximum value of 90° at the zenith, which is the point overhead)

(**Azimuth the angular distance measured along the horizon in a clockwise direction. The number of degrees along the horizon corresponds to the compass direction. Azimuth starts from exactly north, at 0 degrees, and increases clockwise)

The angular positions for different degrees of radiation can be given as below:

- For maximum radiation:

A = 0° (For North Orientation)

WSA = 0° (For North Orientation)

- And for minimum radiation:

A = 90° (For East Orientation)

WSA = 90° (For East Orientation)

To measure the angle of the sun in its motion across the sky, we need to take its altitude and azimuth reading. (Lee Jin You, Roger et-al, 2009)[2].

The figure 1 explains the angle of azimuth and altitude that is used for the preparation of the tables shown in chapter 5 & 6.

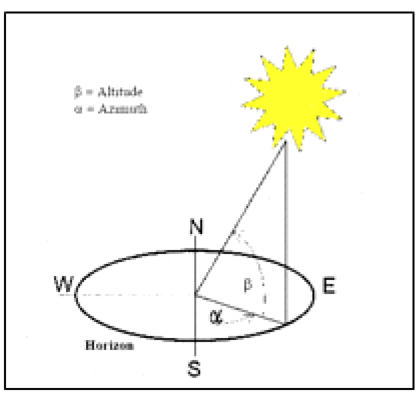


Figure 1

Angles of altitude and azimuth

Source: Heavenly Mathematics GEK 1506 Sun and Architecture.

5.3. Site of the building for solar accessibility

Careful site selection and building orientation are important for maximum daylight and solar utilization. The following main considerations should be made for the said purpose.

1. Is the site receiving unobstructed solar radiation between the hours of 0900 a.m. to 1700 p.m.?
2. Are there any major obstructions which prevent the sun from reaching the site such as geologic features, trees, or adjacent buildings?

3. Is the site allowing for a longitudinal configuration along east-west configuration?
4. If not, then alter the building shape and size to maximize the potential for day lighting and solar load control.

The figure 2 shows the use of solar thermal for passive solar heating. This figure shows how direct and diffused radiation falls on the surface of the building. Moreover, it also shows how wall solar azimuth is calculated. Furthermore, this figure is used for calculations to be made for the tables given in chapter 5 & 6.

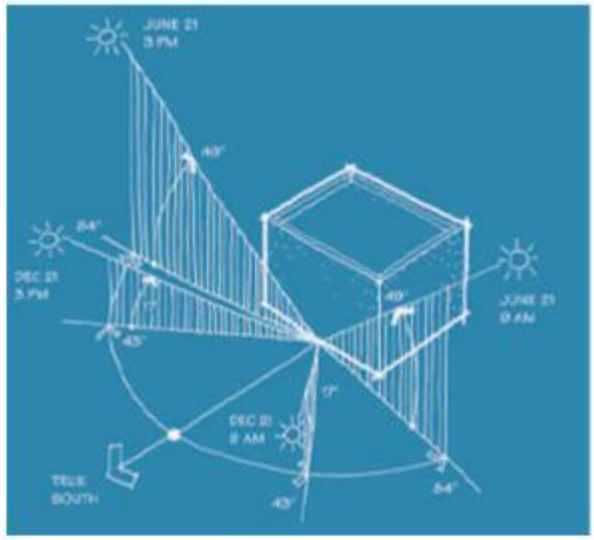


Figure 2
Solar accessibility
Source: Sustainable Building Design

5.4. Solar constant
The Solar constant is the amount of the Sun's incoming ultraviolet radiation per unit area, measured on the outer surface of earth's atmosphere. It includes all types of solar radiations, not just the visible light. The figure 3 is used for calculations in formulas used in table 5.4 to 6.10 where the radiation penetration through fenestration is measured.

$$\mathbf{I_{\circ} = 1353\ watts\ /sq\ meters}$$

Where, $I_{\circ}$ = intensity of the outer surface of the earth 'solar constant'

Note: Although $I_{\circ}$ is never constant, and it varies with the different environment conditions. But we always take an average which is solar constant

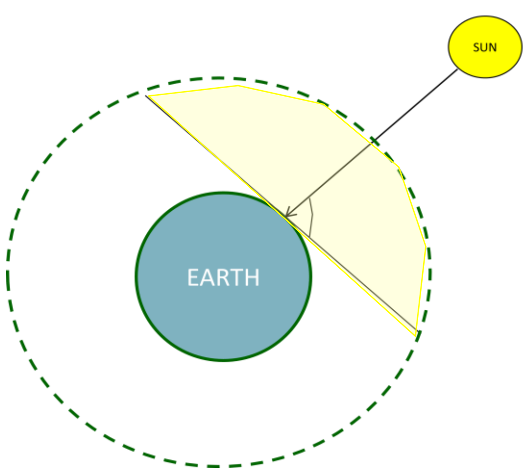


Figure 3
Solar constant intensity

5.5. Design of high-performance features and systems
The warm summers in Lahore coupled with the intense high-altitude sunshine make passive solar control*of all fenestration; one of the important design considerations. The uncontrolled solar gain results in high cooling loads and excessive illumination, and also increases glare. The first strategy in Sunlight and Radiation passive cooling is solar heat gain avoidance, which can be achieved primarily through shading and glazing selection.

(*A passive solar building is designed to maximize the use of natural systems to maintain thermal comfort for the occupants. The term "passive" implies a conceptually simple approach that uses few, if any, moving parts or input energy, requires little maintenance or user control, and results in no harmful pollution or waste by-products)

It is recommended to use solar angle charts for Lahore latitude (32° N) to design shading devices that block unwanted solar gain at specific dates and times. Glazing selection is also an important feature of consideration in window design because, it determines the visual, thermal, and optical performance of the window (Lee Jin You, Roger et-al, 2009).

This chapter deals with three case studies of different traditional but eco houses. The first case study is of a house situated in the city of Lahore. This house has used water and air circulation by absorbing the external heat and ultimately cooling it before being circulated inside the premises.

The second case study is of a house in Iran that has open-able double roofs. The roofs open up in winter for sunlight penetration, whereas in summer they can be closed as an insulation against the strong beams of incoming sunlight radiation.

The third and the last case study is of an American house. The shading devices of the western windows of the house are designed in such a way that they can adjust themselves according to the angle of the sun automatically; throughout the day and throughout the year

5.6. Study one: Dr. Shakeel Qureshi's house
This house is functional, climate responsive, cost effective and aesthetically pleasing and falls into the category of good homes. The following are the most significant features:

- This house on a small plot of 209m^2 has an accommodation of four bedrooms with all required facilities and yet has an area of 167m^2 (i.e. 80% of plot area) being green and landscaped as shown in figure 5.10 and 5.11.[1]
- In the extreme weather conditions, it remains comfortable during summers where temperature rises to 46°C without any air-conditioner; and during winter's when the temperature drops to 0°C, it remain under comfort zone without any heater
- Here economy is achieved in construction cost as well as in maintenance cost
- The house is aesthetically pleasing with interesting volumes and environment friendly materials as shown in figure 4

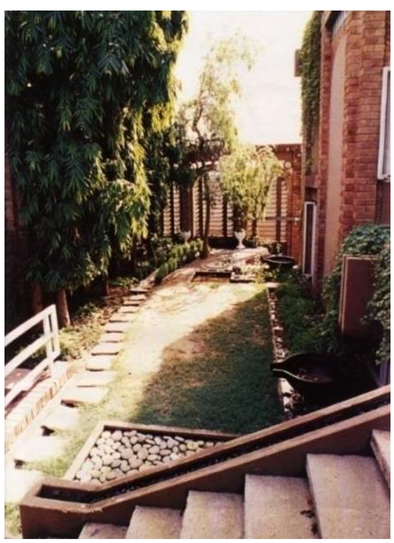


Figure 4
View from the entrance showing steps [1]

Making the house an 'Energy Efficient' and ecological was not the only a challenge for the architect but making it 'Cost Effective' and low carbon was more of a big test for him as a construction manager. Generally the cost of construction comprises of two main components, i.e., cost of materials and cost of labor.

In this house, due to functional and aesthetic reasons, the best quality local materials and best available local craftsmen were used. The search for achieving economy in the cost of construction was done by economizing the quantities of materials which led the architect to work out details with less consumption of bricks, concrete and other materials.

The owner of the house, Mr. Qureshi, himself an architect, explains about his house:
"Economy in the cost of maintenance is achieved mainly by eliminating the running expenses on air-conditioners and heaters in the house. In addition, the use of fair-face brick work in the exterior and interior of the house has substantially cut down the maintenance costs on its finishes."[1]

Figure 5 shows that the deeper we go underground, the cooler becomes the temperature. The house is constructed on the basis of the theory that the space under ground is much cooler hence air scoops are designed to take the air from the environment and make it travel under the ground for bringing the temperature down.

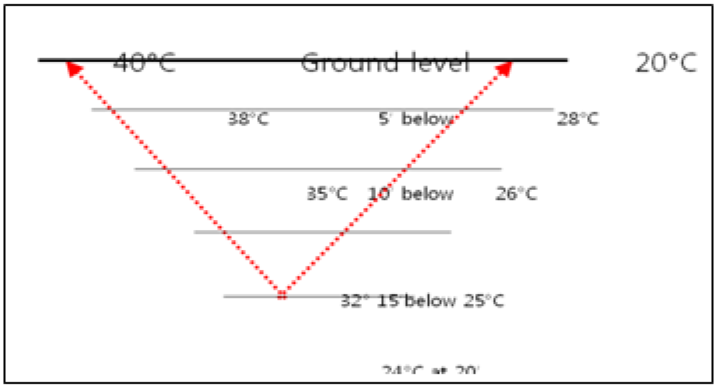


Figure 5
Relationship between temperature and depth

Figure 6 shows that the best comfort of 24°C is achieved at the depth of 20 feet, This phenomenon; used in this house; was made possible through laying an "earth cooling tube" under the floors of the house at ten feet below the road level. The total length of the tube is 180 feet, and is two feet in diameter. It was constructed in two parts: the upper half of the tube is thick pre-cast RCC*. (* Reinforces cement and concrete)

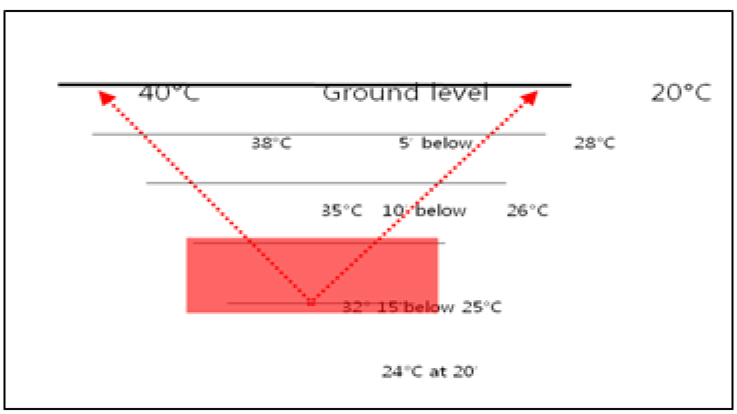


Figure 6
The best place to dwell, but less oxygen and no view

Figure 7 shows that the air of the house is guided into this tube through pressure with the help of a fan, and then recycled in all living rooms. As a result of this continuous process of recycling, the air temperature of the house becomes the same, as it exists ten feet underground.

An additional feature that reinforces and expedites the process of conditioning the air (cooling the warm air of summer season, and warming the cool air of winter season) is a galvanized iron pipe that runs along inside the earth cooling tube. In summer, the G.I pipe carries cold water. When the air passing through the earth cooling tube comes in contact with the cold surface of the pipe, the air temperature falls down. In winter, the same G. I. pipe is connected to a geyser (water heater). As a result, hot water runs through the pipe that helps to raise the temperature of the circulating cool air.

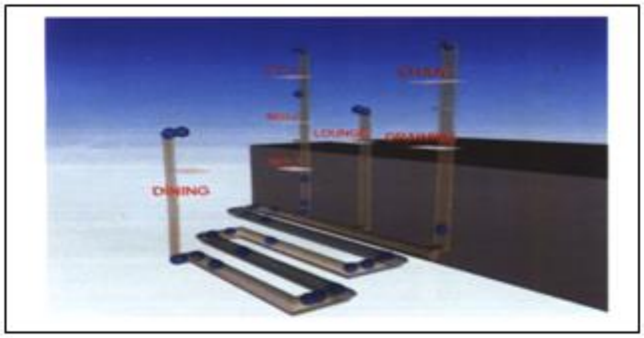


Figure 7
Underground tube system [1]

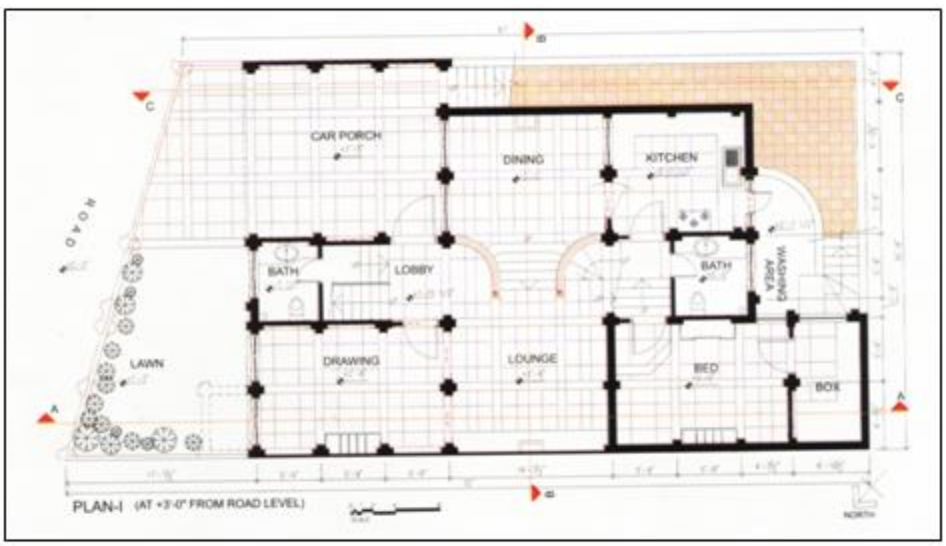


Figure 8
Shows the lower level of the house

Dr. Qureshi designed this house for his own family. Its lower level is public space, where there is drawing, dinning, kitchen, and guest bed. The figure 9 shows the plan of the private zone, where the bed rooms are located according to our cultural system. In this plan, half of the lower level is built, whereas the rest is landscaped, so that the occupants can have a good view from the window. The water channels used; to accelerate cold water circulation in winter; are also is shown here in the plan. This plan at the upper level is more or less symmetrical, with stair case at the both side.

This plan at the upper level is more or less symmetrical, with stair case at the both side. There are more openings at the northern elevation as compared to the east, where there is harsh sun in the morning times. On the southern side there are more windows as compared to the east and west orientation. In figure 10 and 11 we can see the massing of the whole house; which is of orthogonal setting and the beautiful red brick combination with the green natural material.

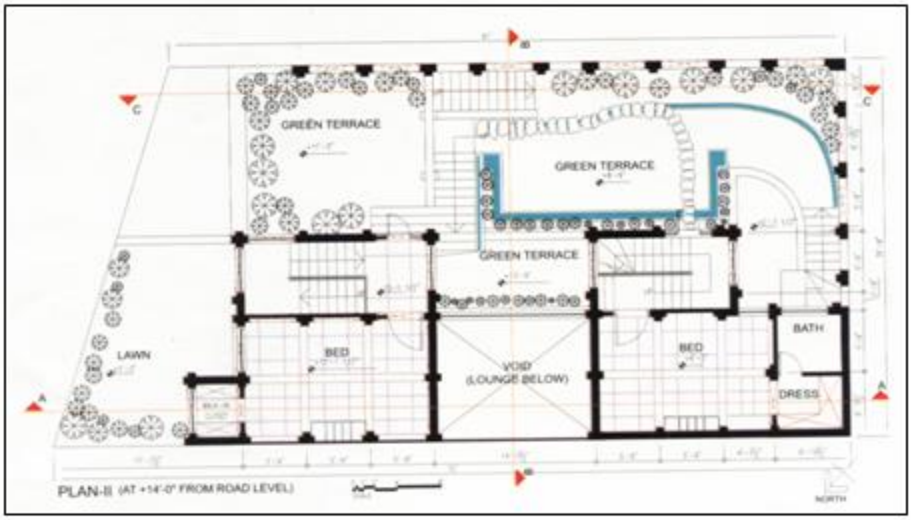


Figure 9
Upper level plans of the house Shakeel Qureshi[1]

Figure 10: Axonometric[1] **Figure 11**: Entrance view[1]

5.7. Case study two

Ali Sodagaran Competition for Eco House, Oxford University, 2004

The house shown in figure 12; located in Tehran; is an eco house, uses similar concept as is discussed in case study one. In this case also the internal underground tube system is used where air comes over a water pond thereby getting cooler, before it is passed through the house.

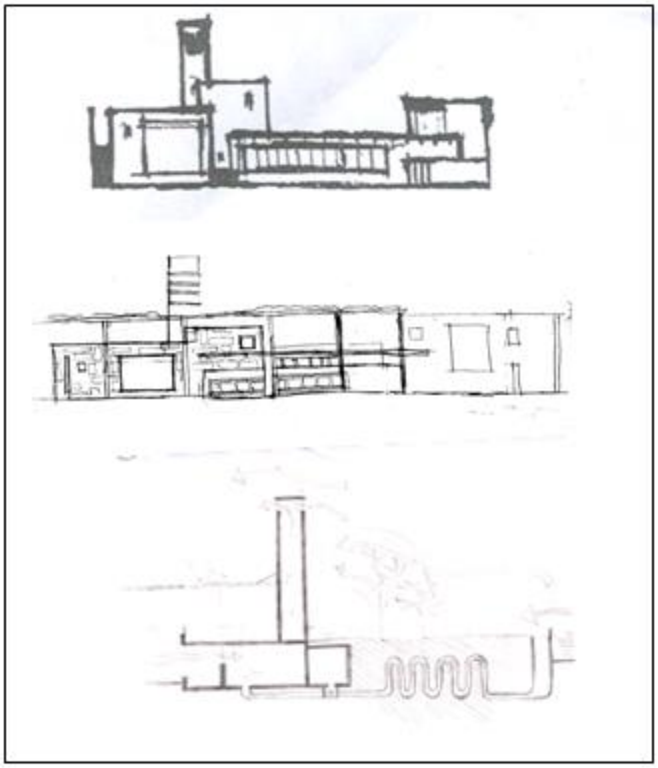


Figure 12
Section and elevation of the Eco House

The air chimney is used to enhance further circulation of the air. There is double skin for the house, the second skin is green skin, which is dried out in winter, and in summer it grows back. The roof is open able that is closed in summer to keep sun out, and in winter is opened up to invite sun in to provide heat.

Figure 13: Detailed model made by the author

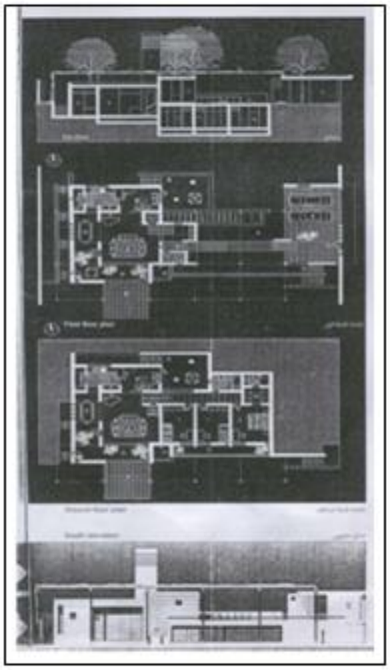


Figure 14: Drawing of the house

The figure 13 shows the details of the model. There are green trees for the shades and the house is compact with sun light penetrating right through inside the building, till basement. The massing is beautifully laid down with double skin of greenery. The section; as shown in the figure; is also very well designed; with complete understanding of eco systems and thermal heating systems.

This project was made by Iranian students of Harvard University. It was a project designed by them and has won a competition of project design. Figure 14 shows the drawings made by the students.

The figure 15 further explains this project. This shows how the sunlight enters inside the house in winter. During winter the leaves of especially planted trees fall down, such that the sun is invited which is at the lower angle. In the basement thermal heating system is used, where insulated stones are kept to absorb the heat throughout the summer and then this heat is radiated away during winter.

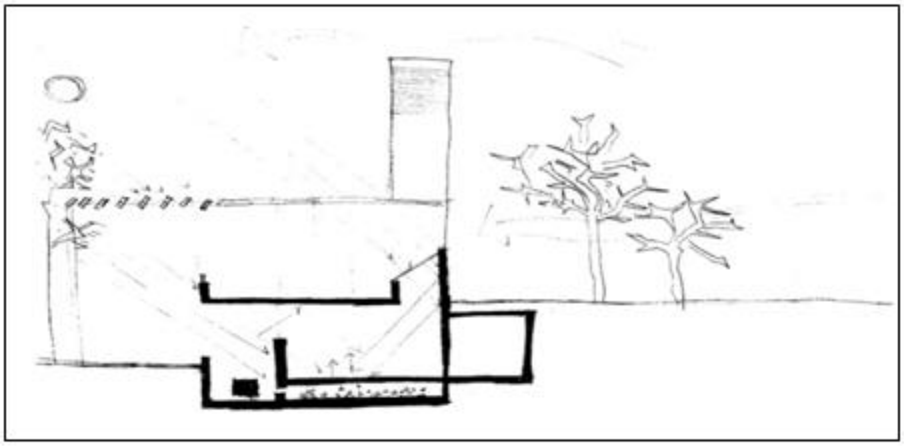


Figure 15
Sketch of the case study

The massing is very clear in the model; figure 16; constructed by the author for this study. The elevation is very well planned, with small windows to view. In figure 16, the beautiful orthogonal design can be seen in the model, which is made to understand the massing constructed by studying the sun path and the light penetration. [2]

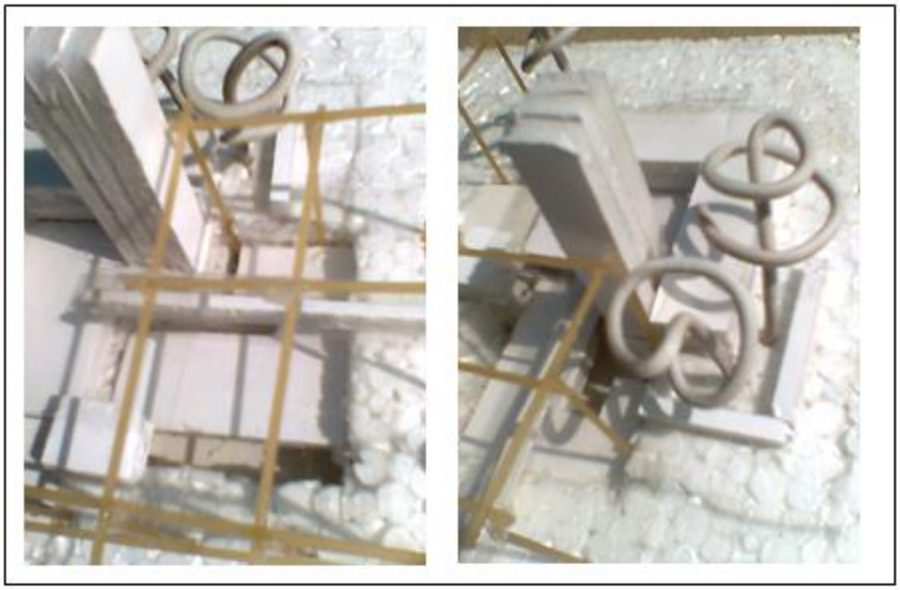


Figure 16
Model of the case study

5.8. Case study three

Loblolly House: Kieran Timberlake Associates (KTA), Taylors Island, Maryland, USA

This case study is about an American house, which basically tells us the following:

- Discusses the approaches to prefabricated housing
- Describes the component approach to house building
- Compares component process building to standard house building

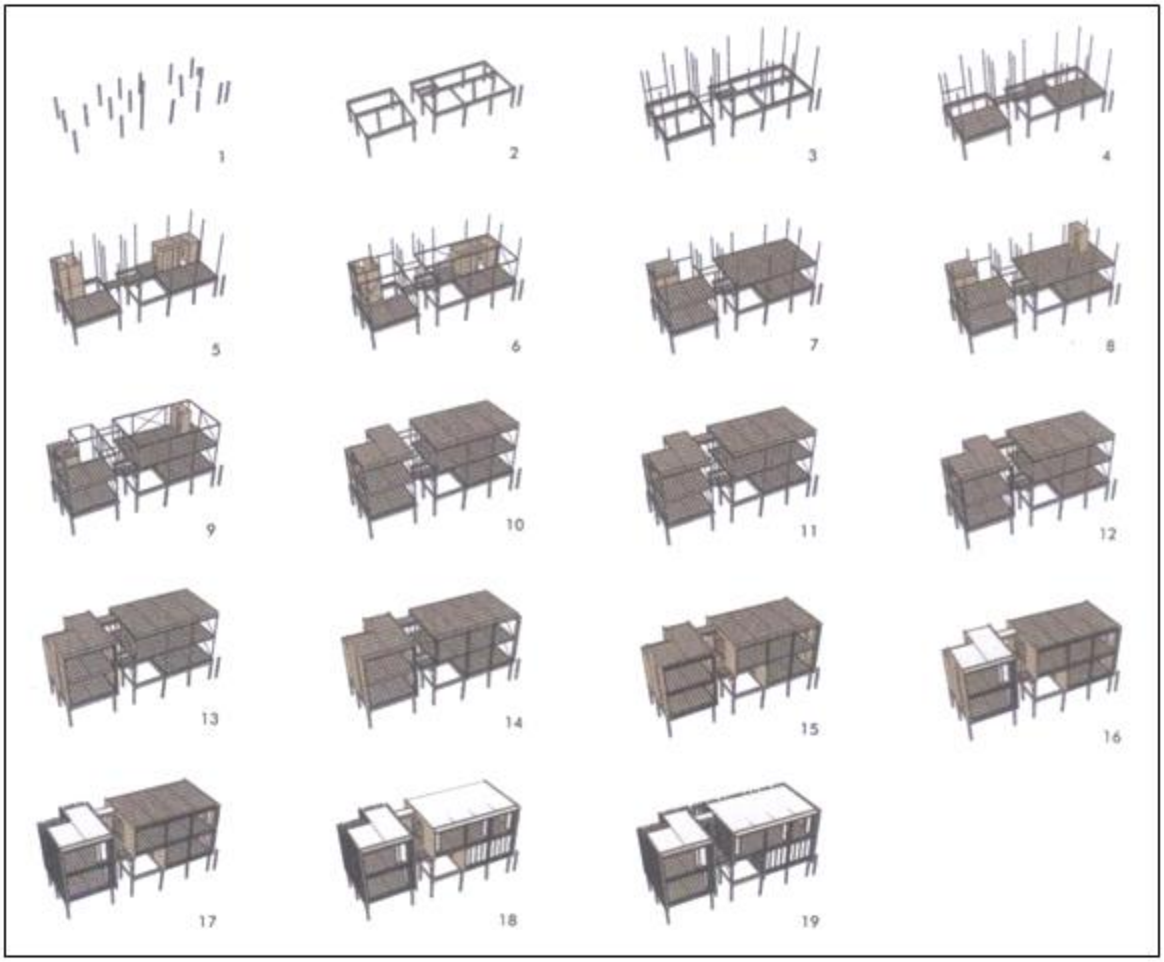


Figure 17

Evolutional model of the house

The figure 17 shows the evolution model of the house. It presents the sequential procedure in 19 steps to assemble the house on site. The entire Loblolly House cold be fitted on two tractor trailers to be delivered ultimately onto the site. The architects reformulated typical house design into larger elements that combine a variety of building materials into simple units, such as floor cartridges, that could easily be installed on the site. The figure 18 shows the different components for installation. The main components are:

1. Green roof (Sailor, 2008)
2. Cedar cladding panelized
3. Prefab boxes for bathroom and kitchen aluminum frame
4. Prefab coffer floor system
5. Structural pilings
6. Double west wall skin
7. Bosch Rexroth structural [3]

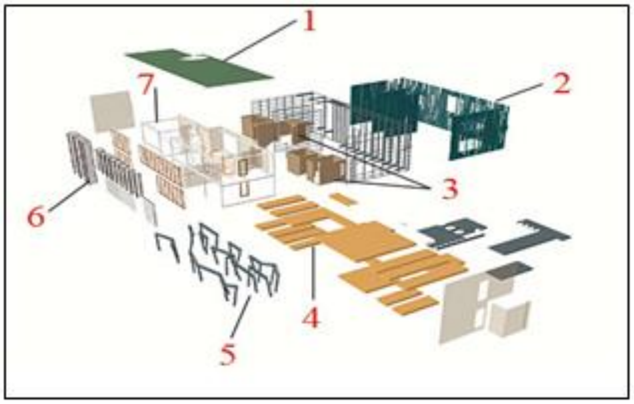


Figure 18
Components of the house

The division of the house can be seen in the figure 18, where every component is separate. It is then assembled on the site. In figure 19 there is a view of the house underground. In figure 20 side elevation is shown. In figure 21 there is a study of the house, by the architect, to understand the sitting and the orientation of the house.

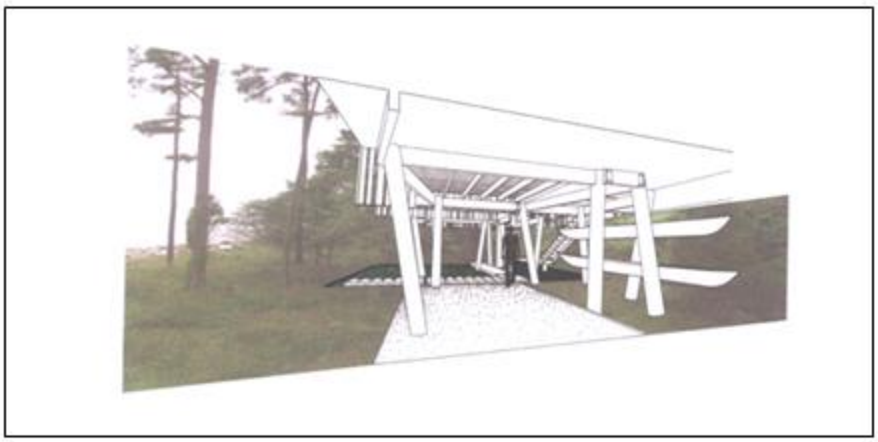
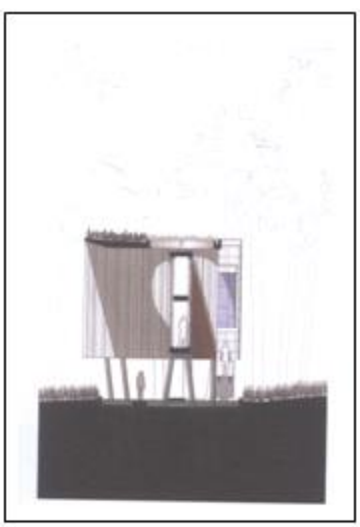


Figure 19
Schematic sketches for the development



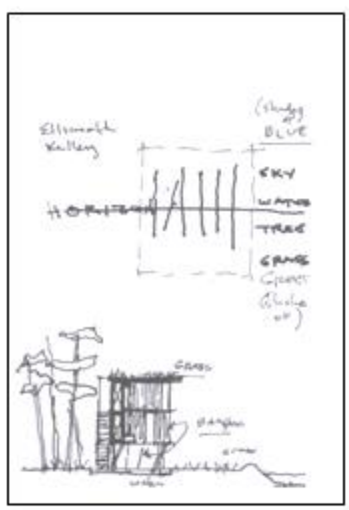


Figure 20: Elevation of the house **Figure 21**: Sketches for the project
Source: Duran. S.C.,2008

5.9. Window insulation system

In figure 22, the windows insulation system is understood, where the sun placement throughout the day is considered, as well as the angle throughout the year are incorporated throughout the year. The windows are designed to shade the window according to the sun movement Ganse (1980).

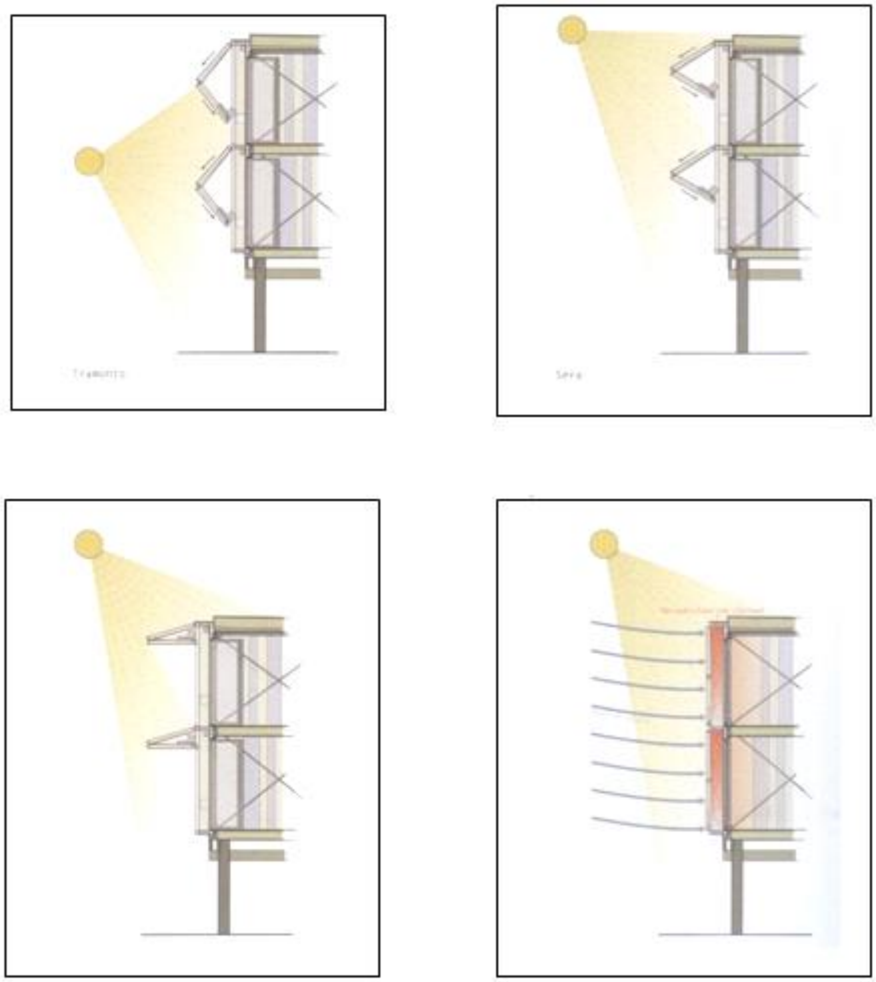


Figure 22

The window details according to the sun movement

5.10. Redefining comfort standards

- Up until now the comfort standards have been concerned with accurate measurement and definition of indoor conditions on the basis that this equates with accurate measurement of 'comfort', e.g. house one, P-120
- In the process it has become accepted that tightly controlled conditions equate with better comfort
- Analysis of field surveys and adaptive comfort theory have made it clear that whilst close control is one way of achieving comfort it is not the only way
- At the same time close control is an expensive strategy in terms of energy
- New standards are needed which reflect the need for low-carbon futures
- We want to define a standard which encourages NOT high energy buildings but LOW energy buildings
- They must be comfortable or they are not sustainable
- There is no temperature at which everyone will feel comfortable, comfort is a psychological state defined by climate, culture and economic circumstances

6. CONCLUSION

This research article basically deals with the issue of comfortable living. A living that can satisfy the emotional feelings of the occupants by two ways. Firstly, by the aesthetics i.e. the tangible aspects, and secondly, by the monetary compensation i.e. the economical energy consumption aspects of an affordable accommodation.

All the seven chapters of the dissertation revolve around the core theme of *Eco House*, which is discussed here as a viable alternative of low carbon, environmental friendly, and healthy living. The beauty of this solution is its sustainability. Not only this solution provides low energy consumption for the present dwellers but also this is considered to be essential for preserving resources for the future generations.

The concept of Eco House is explained well in dissertation statement, i.e.

"An Eco-House can provide same or even more (i.e. variable degree) level of comfort for residential buildings as that of high energy consumption houses".

To strengthen this idea the research was primarily focused upon the residential sector. There are three different examples discusses individually. The two houses are non eco houses. One of them uses passive solar techniques. However, the third house is an Eco House design, proposed by the author of this dissertation. This idea is not the new one, and the three case studies from three different parts of the world are explained at length to support this argument.

The research has provided in detail the Eco-House design proposal for which creative design decisions are discussed in detail namely, selection of material, comfort levels, space utilization, and site development; according to the sun path diagrams. This Eco-House is based on precedent conducted studies. It is supposed to be within usual comfort limits by the use of shading and thermal mass to control the range of the temperature.

Furthermore, the Eco House proposal discusses following main characteristics:

1. Building should allow *occupants to control* their environment by having opening windows, adjustable shades to keep sun out, fans for increased air movement, and so on.
2. Where possible occupants should *feel free* to adjust clothing, move to more comfortable places, and so on.
3. Environment should be within *usual comfort limits* by use of shading, thermal mass (to control range of temperature) and so on.
4. Good low-carbon buildings will provide
   - Appropriate indoor conditions
   - Possibilities for adjustment
   - Freedom to adapt

The Eco House proposal is designed with the help of modern state of the art software ECOTECT. This software provides a complete informative list about the latest products and appropriate building materials to be used in the building which the architects should select according to their choices. There is a complete wealth of options for graphic representation contained in this software along with the visual information which is explained and illustrated with graphic material during the modelling procedure in appendix.

Although there are certain limitations of the Eco-Houses, yet on the average it is the most suitable option that the architects of today should pay attention towards while designing the new houses. The concept will even further be explored in future studies by the author and the invitation is open to all the architecture students to discuss and debate this subject.

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