LOW-ENERGY PASSIVE SOLAR RESIDENCE IN AUSTIN, TEXAS

A Thesis

by

ARUNABHA SAU

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2010

Major Subject: Architecture

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Approved by:

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	José L. Fernández-Solís
Committee Member,	Charles H. Culp
Head of Department,	Glen Mills

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ABSTRACT

Low-energy Passive Solar Residence in Austin, Texas. (August 2010)

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Co-Chairs of Advisory Committee: Dr. Jorge Vanegas
Dr. José L. Fernández-Solís

From the various studies, it can be concluded that the excessive summer heating and the humidity are one of the major problems of the hot, humid climatic region. The literature review for this study shows that natural ventilation alone cannot meet year long optimum indoor comfort in buildings. This research, through a design exercise, intends to verify whether a naturally ventilated house, in hot humid region of Austin, TX, can enhance its passive cooling potential through double-walled wind catcher and solar chimney.

In this research, a passive solar residence has been designed. Two designs have been explored on the chosen site: a basecase design without the wind catcher and solar chimney and another design with wind catcher and solar chimney. In the designcase, the placement of the wind catcher and the solar chimney has been designed so that a thermal siphon of airflow inside the building can be created. The design might show that there will be a natural airflow during the time of the year when natural wind does not flow. Moreover, the double walled wind catcher will resist the cool winter wind due to its shape and orientation. In the design, the placement of the wind catcher and the solar chimney has been done so that a thermal siphon inside the building can be created. Therefore, inside the home, there will be a natural airflow during the time of the year when natural wind does not flow. The double walled wind catcher has been designed and placed according to the orientation of the building in order to achieve the optimum wind flow throughout the year. The solar chimney has been placed in a certain part of the building where it can get maximum solar exposure.

By comparing two cases, it can be clearly said that there will some kind of changed indoor comfort level. Since the potential of the design has been judged through perception, a computational fluid dynamics simulation analysis for a year is to be done.

DEDICATION

To *ma* and *pa*

ACKNOWLEDGEMENTS

Study nature, love nature, stay close to nature. It will never fail you.

- Frank Lloyd Wright

I want to thank Prof. Larry Degelman, retired professor of Texas A&M, for his unconditional help. Special mentions to Architect Peter Pfeiffer for letting me use his design as Basecase. My thankful note goes to Dr. Rosangela Tenorio. His PhD dissertation (University of Queensland, St. Lucia, Brisbane 4067, Australia) on dual mode house helped me to frame my thesis-structure.

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I extend my special thanks to my friends Anindya, Sandeep, Mini, John, Jennifer, Vahid, Pasquale, Jenny, Ian, DeSilva, Saif and all my other friends who corrected those grammatical errors. Their help in my thesis is, honestly, more than friendship. Simply, I love y'all.

I don't want to enchant the great support from my family, back home in India because neither a thanks nor an acknowledgement can be reply for their love and support.

NOMENCLATURE

ACH	Air Change per Hour
ASHRAE	American Society of Heating and Air-conditioning Engineers
CFD	Computational Fluid Dynamics
CFL	Compact Fluorescent Lamp
DOE	Department of Energy, USA
DSF	Double Skin Façade
IAQ	Indoor Air Quality
IESNA	Illuminating Engineering Society of North America
LEED	Leadership in Energy and Environmental Design (A rating system/tool for building to measure how sustainable/energy efficient it is)
NOAA	National Oceanic and Atmospheric Administration
NatVent	Natural Ventilation
PDEC	Passive Downdraft Evaporative Cooling
PMV	Predicted Mean Vote (for thermal comfort)

PPD	Predicted Percentage of Dissatisfied
SBS	Sick Building Syndrome
SHGC	Solar Heat Gain Coefficient
Designcase	The residence after this research/literature review
Basecase	The residence without the design features

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1. INTRODUCTION

This section outlines the world literature concerning the current environmental concern and energy crisis, briefing the world problem and how it manifests in architecture or more specifically in residential architecture. It describes the social changes after mechanical air conditioning was invented. It also describes the social changes after the oil crisis during late seventies.

1.1 Energy and Environment

The US residential sector uses over 22% of total electricity generated (see Figure on page 4) (Annual Energy Review 2008, EIA, US DOE). In EU countries primary energy consumption by buildings represents about 40% of total energy consumption (Santamouris and Wouters, 1994).

The primary energy sources consist of fossil fuels. Unfortunately, combustion of fossil fuels emits carbon dioxide (CO2) and other greenhouse gases, as well as pollutants that have contributed to global warming, air and water pollution, and other damage to the Earth's ecosystems. Additionally, the world's energy consumption continues to increase, which exacerbates the problem of environmental detriment. In the *IEO2009* reference case, world energy consumption was projected to increase from 472 quadrillion Btu in 2006 to 552 quadrillion Btu in 2015 and 678 quadrillion Btu in 2030—a total increase of 44 percent over the projection period (Figure 1a). Total world energy use in 2030 is forecasted to be about 2 percent lower than projected in the *International Energy Outlook 2008*(*IEO2008*), largely as the

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This thesis follows the style of *Landscape Journal.*

result of a slower overall rate of economic growth in this year's reference case. From the retrieved data of US Energy Information Administration, the graph (Figure 1a.) has been drawn and it clearly says that from the year 2000, the energy usage in this world has increased by a leap.

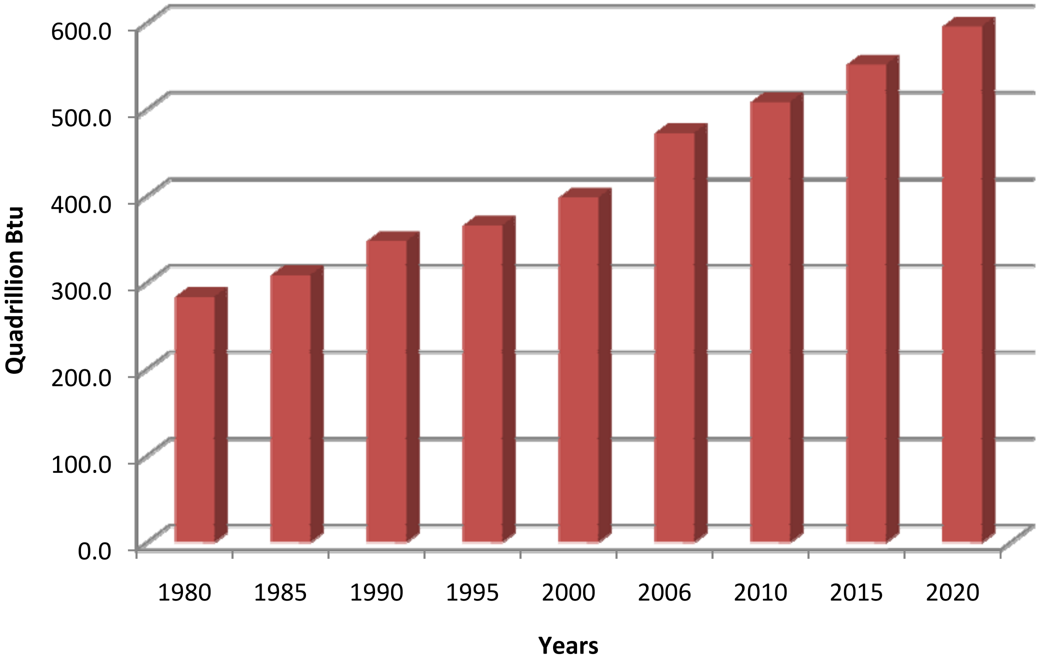


Figure 1a. World's marketed energy usage in Quadrillion Btu

Source: Energy Information Administration (EIA), International Energy Annual 2006 (June-December 2008). World Projections Plus, 2009 (EIA Report #:DOE/EIA-0484(2009))

1.2 Energy Usage in Building/Construction Sector

After the late nineties oil crisis, energy policy has been considerably changed all over the world, particularly in the western world. It has been seen that in the building sector there have been wide-reaching efforts to reduce the usage of energy. The building industry started considering its possibilities in every aspect during that phase. In the Figure 1b. there is a energy supply source and the demand sectors relation. Fossil fuel is the top most used energy source and surprisingly the renewable energy is the most low in the list of supply source. Here is this design thesis; there is a goal of not to depend upon the fossil fuel, has been tried to achieve.

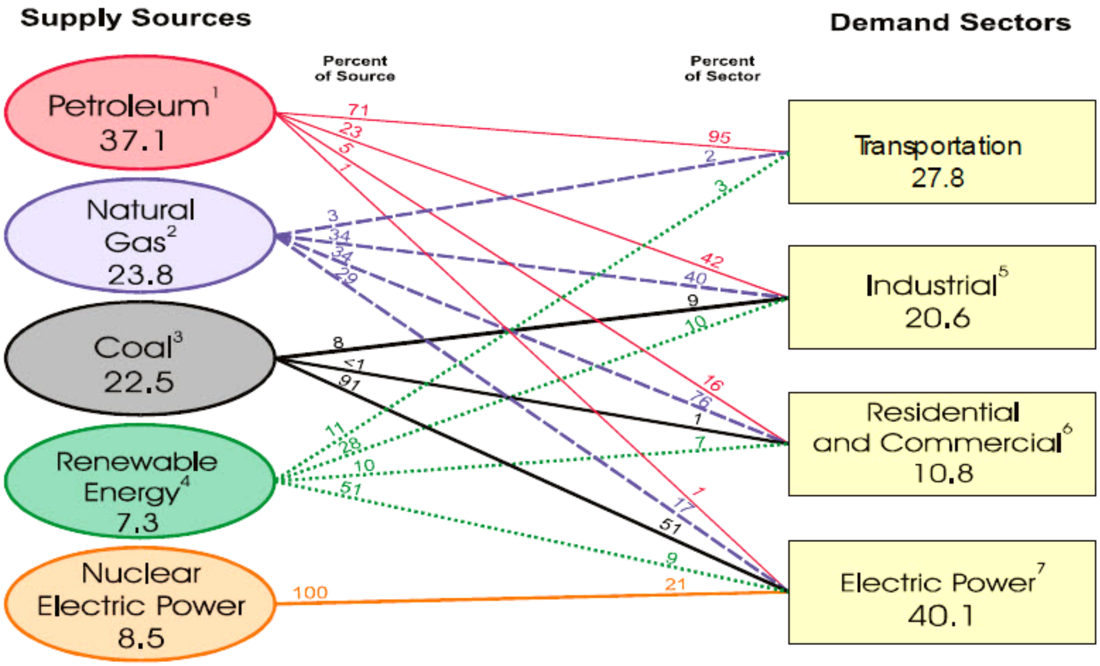


Figure 1b. U.S. primary energy consumption by source and sector, 2008 (Quadrillion Btu)

[1] Does not include the fuel ethanol portion of motor gasoline—fuel ethanol is included in "Renewable Energy."

[2] Excludes supplemental gaseous fuels.

[3] Includes less than 0.1 quadrillion Btu of coal coke net imports.

[4] Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.

[5] Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.

[6] Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.

[7] Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

In figure 1c., there is a clear picture of residential energy usage which is more than commercial sector and close to the industrial sector. Therefore, energy saving in grass root level seems like mandatory.

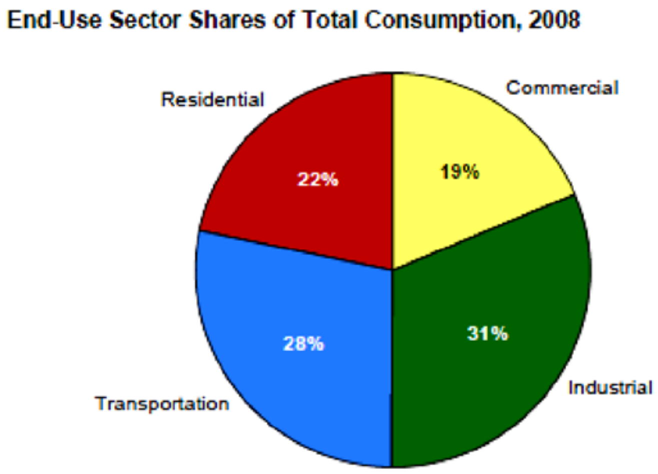


Figure 1c. End-use sector share of total energy consumption in the year 2008
(Source: Energy Consumption by Sector, 1949–2008, Table 2.1a, Annual Energy Review 2008 Report No. DOE/EIA-0384(2008))

Note**:** Sum of components may not equal 100 percent due to independent rounding.
Source: Energy Information Administration, *Annual Energy Review 2008*, Tables 1.3, 2.1b-2.1f , 10.3, and 10.4. (Annual Energy Review 2008 Report No. DOE/EIA-0384(2008))

1.3 Impact of Artificial Cooling

After the oil crisis in 1973, energy policies have been enhanced worldwide. The early 1980's energy conservation program was mainly due to concern about acid rain (SO_2 and NO_x caused pollutions) and by the virtue of time the priorities of energy policies around the world have been changed and are changing still. Though the primary goal of energy saving had not shifted, the strategies to respond global environmental crisis had been changed to sustainability of energy conservation. Kyoto Protocol has been modified internationally.

45% of all green house gas emissions are caused by the built environment (Grummer 1998). Generation of electricity, the major source of residential energy usage, is a vital cause of greenhouse gas emission. Even the hydro-electric power units indirectly cause severe environmental problems related to the construction of these power plants.

Energy consumed for space heating and conditioning represents approximately two-thirds of the total energy consumed in the typical home and roughly 11% of the total U.S. energy consumption, according to U.S department of energy data. The majority of energy that a building consumes is for heating and cooling. Household appliances, equipment, and human factors are less important in regard to energy consumption. There is a large trend of increasing use of home air conditioning systems all over the world, which leads to a high use of electricity and emission of CO_2. The trend is also observable in developing countries (i.e. India). In 1990 less than a percent of urban Chinese households owned an air conditioner; however, by 2003 this number rose to 62 percent. This evidence suggests that a similar explosion of air conditioner use in many other countries is not far behind. Room air conditioner purchases in India are currently growing at 20 percent per year, with about half of these purchases attributed to the residential sector (McNeil, Michael A., & Letschert, 2008).

Up to 50% of this energy is used in the provision of indoor climate control. Naturally ventilated buildings typically use less than half as much energy as those with air conditioning (Kolokototroni et al, 1996). Most importantly, energy consumption is completely dependent upon occupant thermal comfort. The sensitivity of occupants to the indoor climate has a great implication for how closely we need to control the environment, which is directly tied with energy savings. An occupant's thermal comfort is also closely linked with his or her perception of indoor air quality (Humphreys et al, 2002) and productivity (McCartney and Humphreys, 2002). This simply implies that an optimization in thermal comfort concerning indoor climate can leads to a low-energy building. Comfort is the one of mandatory factors in architectural design.

Air conditioners are not only a major cause of energy consumption but a potential source of hazardous CFC (Chlorofluorocarbon) emission, a harmful ozone depleting material. Intensive use of Air conditioning is the result of many processes, in particular:

- Adoption of universal style of buildings that does not consider climatic issues and increasing energy demands during the summer period.
- Increase of ambient temperature, particularly in the urban environment, owing to the heat island phenomenon, which exacerbates cooling demand in buildings.
- Change in comfort culture, consumer behavior and expectations.
- Improvement of living standards and increased affluence of consumers.
- Increase in buildings' internal load.

(Santamouris, 2007)

1.4 The Call: Social Lifestyle Change

In the 1960s and 70s, when SBS or “sick building syndrome” in offices and workplaces was brought to the public’s attention, VOCs from carpeting and furniture, inadequate air circulation, poor lighting, disgusting mold buildup and disruptive temperature variances — all were contributing to nausea, respiratory problems, skin rashes, lethargy, headaches, and numerous other health concerns, public protest over sick building syndrome led to improvement in building design and maintenance (White paper on Sustainability; Building Design & Construction Magazine, 2002).

Likewise the ‘SBS’(sick building syndrome), people are getting aware of this situation and it has been that there is huge social life style change to save energy in personal level or in organizational. Though the sales of A/C units have increased in the order of 400% from 1994-1998 (South American countries – SIESE 1999); 900% in southern Europe in the last decade (Santamouris 1996); 122% in Thailand, from 1987 – 1989 (Parker 1995) there is a huge public concern about energy saving is growing day by day. In past IEA (International Energy Agency) report, it has been said that China, India, Indonesia, Russia and Brazil will be in big financial figure in the 2020 world. Needless to be said that if the increasing use of energy still goes up then there will be a dark future and all assumption will be proved wrong. India, Indonesia and Brazil are one of the fastest growing consumers of energy, mostly located in hot humid area and on the extreme edge of A/C use. Therefore, it can be easily concluded that a passive or active approach is very much needed from grass-root level to save energy is very much needed.

Clearly it shows that the growth of population is related to economy and it is reversely proportional. Through the sudden increase of economy in developing country like India, people are getting more westernized and which indirectly implies to use more air conditioner in residential sector. In India, sustainability is widely practiced from ancient days and naturally ventilated homes were around. People are used to wear cloth accordingly. But due to sudden acceleration of economy the social call has been changed. In developing country like India, instead of searching for passive, low energy solution the installation of mechanical air conditioner has been applied as the comfort-remedy.

Although a completely antithesis has been seen in EU countries. European Union countries have been trying to save energy by all means from reducing the sizes of their cars to optimizing the energy needs of a building. A call for green is happening everywhere.

Design a passive, low energy building in hot humid is a not only a real piece of innovation but an experiment also. To control the human comfort in hot humid climate, designer must have to consider about sweating which indirectly caused by humidity. Therefore, controlling the exact amount of humidity inside home is a colossal job which can't be done not only designing a passive house but by social change. The definition of thermal comfort has been changed from last twenty years and considering the future our society needs to think back again. Therefore it's again the call for social change.

1.5 The Passive and Active Approaches

Nearly 2000 years ago, Vitruvius described elaborate HVAC systems with partial solar energy application in combination with wood as the fuel resources. Passive cooling techniques have been developed in various part of the world leading to a unique levels of development: cliff dwellings through the earth (ground cooling), wind towers (convective and mass cooling), sprinkling water with fountains (evaporative cooling), and whitewash (sun protection). All passive designs are very delicate and need to be designed properly.

In the Middle Eastern arena, in hot arid climate, evaporative cooling was applied in buildings along with a mechanically driven air supply (known as "Desert coolers"). Bahadoori describes cooling systems in Iran (incorporating wind-catchers, porous water pots and *salsabil)* which have been effective for several centuries (Bahadori, 1978). Recently, attention has returned to the potential of exploiting the benefits of direct evaporative cooling while avoiding mechanical assistance by using buoyancy or wind forces to drive the air flow. When water evaporates within a stream of ambient (outside) air, the temperature of the air is lowered and its moisture content is elevated while its “wet bulb” temperature remains constant. The cooling of the air is also reflected in an increase in density, sufficient to drive a downdraught of air through a building. In the late 1980s, a number of successful experiments were undertaken which tested the evaporation of water within a downdraught tower, hence the term Passive Downdraught Evaporative Cooling (PDEC). The adiabatic cooling that has been applied in the new law court building by Richard Meier in Phoenix, Arizona (Meier R., 2001) is very encouraging. It demonstrates confidence in the approach, both in terms of being a viable passive cooling technique in hot dry climates and in being able to resolve the potential risks and disadvantages. (Ford, Brian; 2001)

Everything changed when the miracle of mechanical cooling was discovered during 20th century. Abandoned sources of energy in developed countries never forced architects and designers to look back at old energy saving techniques. Likewise, in many parts of the world the classical vernacular of passive techniques was abandoned until last couple of decades when Energy Policy Act has been modified and the world has started rethinking about the energy-crisis.

Not only the sufficient source of natural energy but a few conditions like more comfortable mechanical thermal comfort, safety concerns, noise from outside and privacy have prevented architects to think about natural ventilation and selecting mechanical ventilation.

For an active approach, plenty of research has been done worldwide and also at Texas A&M for energy saving potential of a cool residence in hot humid climate. Active way, here, means the efficiency of HVAC and all other home equipments. Partial air conditioning use (air conditioning at night) along with light weight concrete walls with insulation on the inside wall might reduce 9.08% of energy in hot humid climate of Thailand in comparison to 4-inch conventional brick walls. A combination of improved ceiling insulation, replacement of single pane clear glass with double pane low-e glazing, exterior shading, efficient systems, lighting and refrigerators resulted in 20% energy saving. Adding solar, thermal and photovoltaic (PV) systems to the above condition can reduce annual energy saving up to 72.58% in Thailand context (Rasisuttha and Haberl, 2002).

Advance framing, decreased window area, increased insulation, windows with lower U-values and SHGC (Solar Heat Gain Coefficient), calculated overhangs and porches, lower absorptivity roofs, decreased infiltration, programmable thermostats, installation of Energy Star products for lighting and appliances, efficient heating, cooling and water heating equipment and ductwork with reduced leakage can reduce up to 75% of energy usage (Gamble et al. 2004). Gamble in his research also showed a net-zero energy use by coupling such upgrade package with PV systems, with net overall cost close to that of standard code built homes.

Kootin-Sanwu in 2004 worked in the U.S. hot and humid climate and found that modified envelope, efficient systems and landscape improvements benefited in low-income housing. Using of CFL (Compact Fluorescent Lamp) instead of conventional bulbs, use of equipment without pilot lights and having an air-conditioner with a longer-lasting stainless steel heat exchanger are the most economically favorable measures (Kootin-Sanwu, 2004).

In his thesis Chulsukon (Chulsukon, 2002) figured out that insulated walls and roof, improved glass type, light-colored exterior surfaces, increased ground reflectance and variation in thermostat setting can reduce up to 30% of annual energy usage in hot humid climate of Thailand.

Passive solar cooling (a part of solar energy applications) is not a foolproof system. “Hot” may be a relative term, but it does describe a real sensation, and it’s not what you want the inside of your to be. Still, mechanical devices that are far simpler and cheaper than air conditioner can add much to the cooling efficiency. Passive-solar design is not an exotic technology whose perfection must be awaited. While it is at this time apparently locked in competition with complex modern technologies, it is in fact a practical application of phenomena as old as the Earth. For the longest imaginable future, solar is the lifeline on which we can depend.

Passive solar refers to means of using sunlight for energy without active mechanical systems (as contrasted to active solar). Such technologies convert sunlight into usable heat (water, air, and thermal mass), cause air-movement for ventilating, or store heat for future use, without the assistance of other energy sources. A solarium on the equator-side of a building is one common example. Passive solar also is used to describe technology and design principles to reduce summer cooling requirements. Passive cooling is a subset of passive solar technology.

Technologies that use a significant amount of conventional energy to power pumps or fans are classified as active solar technologies. Some passive systems use a small amount of conventional energy to control dampers, shutters, night insulation, other devices that enhance solar energy collection, storage and usage, and reduce undesirable heat transfer.

Passive solar technologies include direct and indirect solar gain for space heating, solar water heating systems based on the thermo siphon, use of thermal mass and phase-change materials for slowing indoor air temperature swings, solar cookers, the solar chimney for enhancing natural ventilation, and earth sheltering. More widely, passive solar includes technologies such as the solar furnace and solar forge, but these typically require some external energy for aligning their concentrating mirrors or receivers, and historically have not proven to be practical or cost effective for wide-spread use. 'Low-grade' energy needs such as space and water heating have proven over time to be better applications for passive solar energy utilization.

2. Research Objectives

This section portrays the research problem, the research question, purpose, structured methodology, assumption, delimitation and the research significance. The overall approach is outlined below.

2.1 The Genesis

My childhood days were spent in a small town in West Bengal, India. I lived in a small bungalow. For long periods of time, electricity used to be cut off frequently, which used to lead life to a virtual paralysis. Summer months in the hot and humid climate would have been intolerable in the absence of adequate ventilation in those houses. Large windows on the north and the south sides of the buildings is a common design features in the region. Designing buildings climatologically and contextually is an intuitive art that is culturally rooted in the people of general hot, humid regions. Therefore, for the time being it was in my mind to design for indoor comfort without using mechanical air conditioning. Now, it is the era of energy saving. It is the time to be aware of unnecessary energy usage everywhere, including the home.

My formal training as an architect has shaped my thought process towards solving design problems, using a judicious mix of rigorous scientific analysis and case-based intuitive approach. Therefore, scientific knowledge in architecture helped me to search for the science behind the passive solar technology. My quest leads me to solve design problems globally and the inspiration can be traced back to my roots.

2.2 The Problem

Being an architect and hailing from a hot, humid, tropical country -- India, I have to conclude that summer heating is one of the problems in achieving comfort while designing a residence/building without air conditioning.

Summer heating is one of the vital problems of a hot, humid climate while designing a residence using passive techniques. In India, studies show that passively designed, naturally ventilated buildings show effective energy savings;, and except for few months in winter, naturally ventilated vernacular buildings perform quite satisfactorily in achieving thermal comfort (Singh, *et al*, 2009). In all climatic regions of the world, natural ventilation proves to be the simplest and most effective way to provide indoor comfort, except in some parts of the year (Givoni, Baruch; 1998).

Therefore, the problem identified in this thesis is as follows:
Lack of utilization of passive solar techniques (such as double-walled wind catcher, solar chimney) as design feature; and ignoring their huge potential towards reduction of energy usage and to achieve indoor comfort level throughout the year.

In this context, Givoni (1969) posited that there is a limit to lowering the indoor temperature and achieving optimum comfort level in spite of maximum ventilation. . The psychological definition of thermal comfort is not only different from person to person but also dependent upon culture and geographical location. In summary, it can be said that presently passive solar techniques are not being commonly used as a design feature to reduce energy usage as well as to achieve optimum comfort level in residential design.

2.3 The Gap

Although the Solar chimney and wind catcher have been quantified for energy saving measures, there are few complete built (or designed) residential projects where these techniques were used together. (Givoni, 1994).

Therefore, a future detailed CFD simulation of the design, which can verify the positive effect of using passive solar techniques in residential architecture, is required.

2.4 The Purpose

The primary purpose of this thesis is to create increased airflow inside the residences through passive solar design which facilitates natural ventilation as well as energy-efficiency. For the convenience of design, the climate of Austin, TX has been analyzed. The increased airflow might reduce the discomfort hours inside the house.

The result of this thesis is to be a stepping stone for the ultimate passive solar house where indoor comfort can be achieved without using mechanical air conditioning.

2.5 The Research Question

There will be two research questions for this architectural design thesis: one is for this thesis and the other is for the long term goal. Therefore, for this research, the question is that by using wind catcher and solar chimney in architectural design, can we get an improved indoor airflow situation in a double story residence?

In general for long term, the ultimate research question will be -

- Can the wind catcher and solar chimney along with natural ventilation be a substitute for air conditioning systems in designed residences in a hot, humid climate?

In the next page there is figure 2a. where the research structure for this design study has been described. The conclusion at the apex is the goal of this thesis which is a design of a passive solar house. To reach that destination there will be few steps – defining problem statement through literature study and then finding the gap which follows the fixation of set-point of departures. Set point of departure is nothing but the direction of some particular point where a special attention is needed. Here in this thesis, set points are solar chimney and double walled wind catcher.

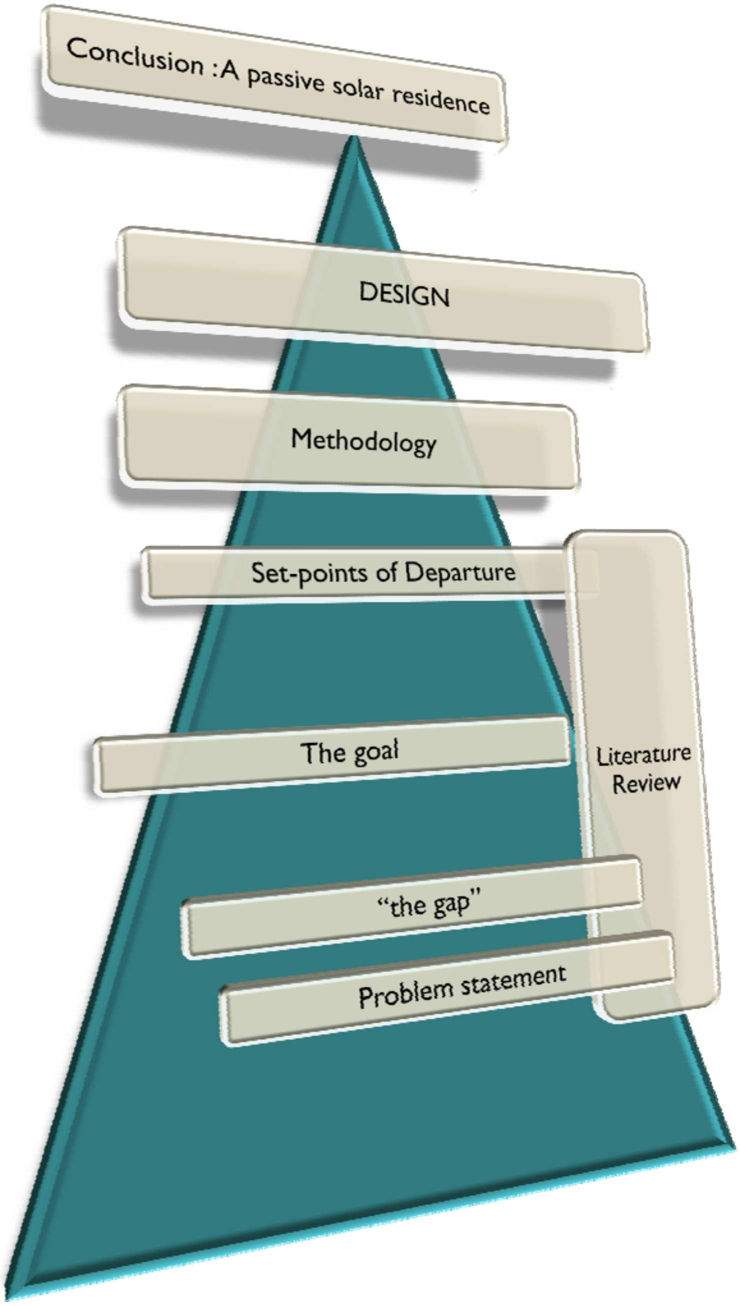


Figure 2a. The research structure

2.6 Preconceived Guidelines

There are several guidelines for this thesis that I have followed for the architectural design. These guidelines are based on the review of literature. It includes a few suggestions from analyzing the ‘wea’ weather file from the DOE in the simulation program, Climate Consultant 4.0 (Liggett *et al*, 2008).

The guidelines are as follows:

i. Indoor climatic condition (temperature and humidity) is very difficult to control only through passive technologies.
ii. Cross ventilation, (air movement, or the air change rate (ACH)) can reduce the indoor temperature up to 5^{o} F.
iii. A solar chimney is one a potential passive techniques that can be used to create the stack effect in a small area.
iv. Controlling indoor humidity is very complicated using only passive strategies.
v. Research studies shows that a high level of thermal performance can be achieved by using a different use pattern, different planning and a higher thermal mass.
vi. ASHRAE guidelines for material is time tested, therefore, could be trusted for proper insulation material.

These working guidelines are the basis of the experimental design of this thesis. The individual control and awareness of the occupants of the residence is very essential for the design to be successful.

2.7 Approach: Set Points of Departure

To accomplish the objectives of this study, the following tasks will be performed:

i. Investigate residential energy-saving passive strategies and their energy saving potential from the previous research or real completed project.
ii. Identify suitable passive solar techniques to fit in the context of a hot, humid climate.
iii. Select a set of possibly appropriate passive technologies by investigating the potential of natural ventilation to reduce the indoor temperature.
iv. Design a residence with the selected passive solar techniques.
v. Create a Basecase of the same house without those passive solar techniques.
vi. Develop generalized guidelines, based on the visual comparison of the two designs.

2.8 Methodology

To meet the objectives of the set points of departure, here is the structured methodology for this architectural design research. From different thesis, research, and case studies, it has been concluded that a wind catcher with double wall construction would be a valuable component to enhance airflow inside the building (Koronakis 1992).
The methodology is as follows:

i. Roof geometry analysis
ii. Study on the solar chimney and double wall wind catcher
iii. Architectural function finding: searching for the requirements of a small family and designing by their requirements
iv. Putting form and function together to create a design
v. Conclusion for future researches

2.9 Delimitation

The design has been done for only the hot, humid climate of Austin, TX. Therefore, no concrete conclusion can be made for the general hot, humid climate. This design needs a detail level of computational fluid dynamics analysis which can scientifically prove the justification of the thesis.

The delimitations of this research are as follows:

i. Among vast passive solar technologies, only a few have been chosen to test here. There might be a solution for excessive humidity and temperature in a hot, humid climate, using other passive solar techniques.
ii. The design is based on the weather/climate data available from Department of Energy website weather file. Wind flow data is also based on this file, although wind flow depends entirely on microclimate and the neighborhood building or buffer structure. For a complete analysis of the airflow, a complete neighborhood modeling must be done in different CFD simulation software with the exact same boundary conditions.
iii. No computer simulation or any mathematical analysis has been used here. Therefore, the design might not work as expected.

2.10 Assumption

In this thesis, few assumptions have been considered. The conclusion of this research is based on these assumptions.

i. The wind flows according to the weather file analysis.
ii. ASHRAE/IECC 2006 recommended materials for Austin weather will perform thermally perfect for this non-air conditioned house.

iii. The double-walled cavity wall and solar chimney has been considered as an optimum natural ventilation technique which has been used here as design only by intuition.

iv. Since in both cases- the Basecase and the designed case, there will be almost same amount of building errors. As a result of this comparison, therefore, a conclusion can be made.

2.11 Significance of the Research

Passive solar technologies like small solar chimney and double walled wind catcher has been used as a design feature in this research. From the visual analysis, the design seems to be working and it has demonstrated a technique to maximize building energy savings by design options. If a detailed mathematical or computer simulation had been done, then the efficiency could have been proven. The combination of energy-efficient design strategies will open future avenues for research in passive solar design principles. A further research is proposed through a detailed CFD simulation of the combined energy saving potential through solar chimney and double-walled wind catcher. The finding of the future research will facilitate the use of natural ventilation in building to achieve an optimum indoor comfort level throughout a complete year.

3. LITERATURE REVIEW

3.1 Introduction

The categories of the literature review that are most relevant to this thesis are:

1. Passive building design components that have been used somewhere in the history,
2. Characteristics of a hot, humid climate and possible passive strategies,
3. Optimized combination of strategies to return the most optimum comfort level without using an air conditioning system, and
4. Case studies of passive home research.

With these categories in mind, previous research and new technologies that reduce residential energy use were reviewed. These findings are discussed in this section with the primary focus on strategies for hot and humid climates.

A review on these topics has been done for this thesis: Problems in Hot, Humid Climates, Thermal Behavior of Buildings, Passive Solar Principles, Passive Cooling of Buildings, Natural Ventilation, Double Skin Façades, Thermal Comfort, Climatic Variables, Micro-Climate and Urban Heat Island Effect, Surrounding Landscape, and Available Simulation Tools.

Even though mechanical cooling is very recent, it successfully replaced the use of passive systems for cooling a building within a few decades. Besides the pleasant environment that air conditioning systems provide, it takes away the climatic point of view in dealing with the technical problems faced in buildings. Research for envelope design, which was entirely the job of the architect, is commonly ignored now after extensive use of mechanical cooling in buildings. In 1969, Banham an admirer of the immense possibilities of A/C said, "…we now dispose of sufficient technology to make any old standard, norm or type habitable anywhere in the world. The glass skyscraper can be made habitable in the tropics; the ranch-style split level can be made habitable anywhere in the US".

Szokolay (1987), Givoni (1994), Bansal *et al*(1994), Santamouris *et al*(1994), and Kuno (1995) are the key researchers in passive designing of buildings. In their papers they tried to prove that unfortunately, passive system cannot eliminate discomfort completely in hot humid climate. The stress caused by an environment with high humidity and temperature levels should be properly controlled, by any means of system approach whether passive or active. In this literature review, a effort to accumulate all the factors which can affect an architectural design has been tried. There are innumerable techniques which are passive solar but here the only few vital natural factors have been analyzed. In every part of the world, there are certain vernacular passive techniques which have been practiced for several years by native people and which brought comfort inside their dwelling units are yet to be proven scientifically. This literature study is more focused on the primary principles of nature not any particular specific practice.

3.2 Problems in Hot Humid Climate

Before invention of mechanical cooling, we were used to have thermal comfort in only winter days. Cooling is considered as heating today in developed countries (i.e. USA, Japan and few EU countries), in terms of comfort and indoor quality; however, much more effort has been systematically directed at the appropriate use of heating facilities (Nason, 1985).The passive fundamental design approach can be implied for successful operation and better results in fully or partially air conditioned buildings. A scientific and not just intuitive way of design is a key issue of modern passive buildings.

Among the approximate 40% of energy used for the building sector, 22% energy is used in the residential sector (EIA, USDOE website, Nov'08). Of the variety of homes in the United States, 68.9% of these residences are single family detached houses (EIA, US Department of Energy Website, Nov'08 http://www.eia.doe.gov/emeu/recs/recs2001/ce_pdf/enduse/ce1-

4c_housingunits2001.pdf). Therefore, a major portion of energy produced in the USA is consumed by single family detached houses.

A majority of the world's population lives in hot, humid climates, about 40% (Givoni, 1998). Anselm (2006) described some design implications for hot, humid climates, which are:

1. Employ lightweight materials (low mass construction).
2. Maximize external wall areas (plans with one room depth are ideal, especially for
3. residential units) to encourage movement of breeze through the building (i.e. cross
4. ventilation).
5. Shade the whole building; consider using fly-roofs and landscape trees.
6. Use reflective insulation and vapor barriers.
7. Ventilate roof spaces if possible for optimized results.
8. Consider high raked ceiling.
9. Provide screen, shaded outdoor living areas, also creating outdoor spaces (for Residential projects)
10. Design and build against windy conditions and hazards.
11. Most essentially, design for a green environment.

According to Anselm's thesis, excessive summer heating will be the most common problem of a hot, humid region. Humidity control will be the next problem in the region. From my own experience living in the city of Kolkata, India, it can be observed that high humidity levels with high temperatures make Kolkata miserable during the summer months. Unless the use of an effective dehumidifier is employed, the humidity cannot be controlled in a typical Kolkata-micro climate.

In this research thesis, the climate of Austin has been analyzed and used for simulation. From the 'epw' weather file analysis, it can be summarized that excessive summer heating for five months, below comfort range temperature for four months and moderate temperature for the rest of the year is Austin weather. Therefore, architects should be considering the facts in psychometric chart in relation with the comfort temperature range for medium activity level and the monthly solar radiation, wind flow, rainfall and relative humidity details.

3.3 Thermal Behavior of Buildings (Case Studies)

In previous sections the principles of passive and active building design in the hot, humid tropics were discussed. This section is devoted to the discussion of various simulation studies, which were carried out in the tropics according to the relevant theory earlier discussed. The studies discussed here are all related to small buildings such as houses. For simulation engines, they used different programs such as HEED, DOE-2, ESP-r, Energy-10, Ecotect, Energy Plus, ENER-WIN, and TRNSYS. On the US Department of Energy website there is a list of simulation engines along with a description of their uses and limitations. These simulation programs are some of the earlier programs; however, research and development in this sector is rapidly increasing.

Since the installation of computer simulation to analyze the climate of a building became available for most research institutions around the 1970’s, there have been attempts to model the complex thermal behavior of buildings. Fortunately, simulation programs, which can be conducted in a reasonable amount of time and run on personal computers, are more recent as reported by Delsante (1987). Despite the overwhelming number of simulation tools available today, not much has been done to enhance and test the performance of buildings in the warm, humid tropics. A major concern with these programs is the capability to model coupled thermal performance and inside airflow, as this is one of the most significant ways to improve the thermal comfort in the tropics.

For a long time period, simulation studies were focused on the argument between light weight insulation or heavy weight insulation, in terms of defining what would be the most suitable thermal enclosure for hot, humid climates. When considering the possibility of enhancing the thermal performance of buildings in hot, humid climates, the envelope and especially the building materials, were the main target to be optimized. ASHRAE has published research on materials that could be used for the perfect insulation, as well as energy saving.

Below in the Table 1a, there are list of three passive house case studies in which their design has been simulated in previous studies. These are the only few available studies in this area of research, and they have been well documented. The main purpose of reviewing these studies is to present details of the methodologies and the limits of their scope, according to the simulation tool used. A brief summary of the results is presented but there is no attempt to discuss it further.

Table 1a. Passive house case study

Project	**Simulation tool used**	**Author/Designer**	**Year**
PV-RES Florida	DOE-2.1 (Energy Gauge)	Parker et al	1998
Residential buildings in Jakarta	ENER-WIN	Soebarto, V.1.	1999
TarryTown House, Residence, Austin	NONE	Ar. Peter Pfeiffer	2002

3.3.1 The PV-RES Florida Project

This project was sponsored by the Florida Energy Office and Sandia National Laboratories. It was developed by the Florida Solar Energy Centre (FSEC), USA. FSEC is one of the oldest and prestigious institutes in the states and is famous for energy-efficiency research in buildings. The objective of this project was to test the feasibility of constructing family residence units, which are designed to save energy by means of reducing air conditioning loads to an absolute minimum so that most of the cooling and other daytime electrical needs could be accomplished by the PV component. This should apply a little net demand on the utility during the summer peak demand period. The local municipal utility, electricity, and water, operates by the PV systems in the building.

The hot-humid location of Lakeland, Florida was chosen. Two single-family homes were constructed on the site and they were duly monitored. The first house was used as the basecase model for comparisons. It was like normal single family units. The other one was the PV-integrated home (PV-RES). A number of energy efficient features were simulated before the construction to test the performance parameters and the feasibility of the project. The free-running mode was not analyzed at this study, only the conditioned one. For most Florida houses, NC is fully used during all summer months. The simulation tool used for the energy efficient design was a special version of DOE-2.1 e hourly building energy simulation: Energy Gauge USA. The project presented results for the simulated and monitored period. This review concentrates mostly on the methodology of the mounted study design features. The base model home features included current residential building practice in Central Florida. It included:

- Grey/brown asphalt shingle roofing,
- Overhangs around the perimeter of the home,
- Ceiling and wall insulation (on the interior of concrete block walls),
- Single glazed windows with aluminum frames,
- Standard appliances (electric range, refrigerator and electric dryer),

- Standard incandescent lighting (30 recessed can lights), and
- Insulated ducts located in attic.

The PVRES have a number of integral elements designed to minimize cooling loads and these specific measures have been simulated in detail and analyzed in other field projects e.g. Parker *et al* (1992, 1994, 1995, and 1996). These integral elements are described below:

- White reflective roof insulated,
- Wider overhangs of one meter around the perimeter of the building,
- Exterior insulation over concrete block system,
- Advanced solar control double-glazed windows,
- Down-sized COP 4.2 variable speed air conditioner,
- Low friction loss and sealed duct system within the conditioned space,
- Programmable thermostat,
- High efficiency refrigerator, and
- High efficiency compact fluorescent lighting.

Considering thermostat settings, both houses remained set at a constant 24.2°C temperature. The operation of the PVRES house used the concept of load shift potential. The programmable thermostat was scheduled to maintain different cooling modes. The timeframe from 12:00 to 17:00, which is the pre-cooling mode, coincides with the peak output of the PV system. The temperature was maintained on 22.2°C. After this, the temperature rose one degree each hour until 8 pm. During the monitoring periods however, the occupants found these temperatures too cold and a warmer schedule was developed. Table 1b presents the DOE-2.1E simulation predicted annual electric energy consumption for the two buildings (Control house and PVRES), which were both occupied and operated similarly.

Table 1b. Predicted energy requirements (kWh) for the PVRES and control house Florida

Case	**Heating**	**Cooling**	**Hot Water**	**Lighting**	**Refrigerat**	**Other**	**Total**
Control	1,211	10,093	3,012	2,279	1,047	5,098	22,740
PVRES	418	3,440	0*	820	659	3,152	8,489
Difference	793	6,653	3,012	1,459	388	1,946	14,251
Reduction	65%	66%	100%	64%	37%	39%	63%

*estimated annual propane energy use is 1 20L for back-up heat.

The photovoltaic (PV) solar electric generation system is grid-interactive, producing DC power which is converted into AC current and then directly fed into the local utility feeder of Lakeland Electric and Water Company. Another simulation program PVFQRM (Menicucci *et al* 1988) was also used to predict the annual performance of the PV systems and its sensitivity to the off-azimuth orientation of the west-facing sub-array.

The study also presented a detailed analysis of the project economics. The objective was to explore the maximum feasible energy savings a new Florida residence would produce when combined with PV electric power. The assessment of the economic performance was made using the DOE-2.1E building energy simulation program. The relative contribution of the various measures used in the project were assessed by tuning the model to reflect the conditions of the control house (air handler leakage from the attic, un-shaded windows, etc.) and then using the model to estimate the savings in comparison with the PVRES. As a technical research demonstration project, a number of items did not appear cost effective, but through some altered floor plan variants, it was possible to reduce the incremental cost thus improving economics while preserving the identified level of performance.

As a brief summary, the Lakeland project has demonstrated that it is feasible to construct homes in a warm, humid location, such as Central Florida, that consumes electricity for air conditioning and other appliances, at a fraction of the consumption by a standard dwelling.

Energy efficient housing, incorporating utility integrated PV power, can reduce the total electrical consumption by 70% or more over traditional housing. As the PV electric generation is being considered, such efficient construction practices demonstrate the feasibility of building homes, which exert little net impact on the utility grid during peak summer periods. During non-peak periods such homes could provide clean, renewable electricity to the utility and its customers. From the passive design point of view, especially important was the performance of the external insulation on the surface of the concrete blocks, which provided significant reduction on heat gains, as discussed in previous sections.

3.3.2 The Residential Building Study in Jakarta

Soebarto (1999) presented this paper in PLEA'99 about a simulation study relating to the controversy over lightweight versus heavyweight buildings in the tropics, followed by monitoring results to validate the analysis with the simulation tool ENER-WIN (Soebarto and Degelman 1995). The evaluation parameter was the indoor ambient temperature, giving the number of hours outside the comfort temperature range.

The US-DOE climate data for Jakarta, Indonesia was used for the study. An urban 3-bedroom single story house was simulated with a total area of 120 meters, with a ceiling height of 3 meters. The construction features of the building consist of plastered single brick walls, concrete slab-on-ground with tile flooring and un-insulated clay tile roofing with plasterboard ceiling, and the windows were fully shaded by overhangs. The internal gains were measured by the presence of five occupants. Four of them would leave the house during the day and return late in the afternoon. The lighting contributed with a load density of 10W/m^2 (incandescent), and other small equipment contributed 4W/m^2. Only the free- running (without air conditioning) mode was investigated in this research.

The monitored building had a zoning similar to the simulated building, and it was a two-and-a-half story building. The structure was reinforced concrete with plastered single brick walls, a concrete slab on the floor, and clay tile roof. The windows faced north and south and

represented around 30% of the total wall area. An hourly monitoring was conducted from November to December of 1997, registering indoor and outdoor temperature and relative humidity in two areas (ground floor and first floor).
The strategies experienced in this study are the following:

- Wall thickness and mass,
- Radiant barrier and roof insulation,
- Regime of windows,
- Building orientation, and
- Shading.

The construction materials tested for the walls were single brick, double brick, un-insulated and insulated timber frames with timber sidings. Double brick walls, performed the best during the day in the hottest week of January, but would perform the worst in the evening and early in the morning. The second variation included the use of radiant barriers and roof insulation.

The solar absorptance of the roof was changed from 0.75 (clay tiled roof) to 0.1 (radiant barrier under the roof tiles), but no change was considered to the U-value. Secondly, insulation was added above the ceiling. The results demonstrated a reduction of the indoor peak temperature by almost 7K. The third variation considered the opening of windows. For the previous run of simulations, it was assumed that 70% of the windows were opened during the day and night. However, for this section, it was assumed that 90% of windows were closed from 11:00 till 17:00 and open for the rest of the time. A reduction of 3K to 4K was achieved in indoor temperatures.

3.3.3 Tarry Town House, Residence, Austin

For a real scale measurement, I studied a mixed-mode air conditioned house in Austin, Texas, designed by architect Peter Pfeiffer of Barley & Pfeiffer Architects. According to Pfeiffer, “It does not look green or particularly unusual. It shows that GREEN homes can be fun and functional FAMILY homes in established neighborhoods”. The Tarry Town House was designed in 2002, and is not only LEED accredited, but analysis beyond the minimum LEED standards has been performed. A few significant Green Building points about the residence include:

- Received the highest point rating in the history of the Austin Green Builder Program for its environmental and energy conserving features; the oldest and most established Green Building program in North America,
- Recognized by the Fine Homebuilding magazine as being among the “greenest homes in America”,
- It is not built of Straw Bale, which is considered as cheap green building material, and
- The building has served as an excellent example and inspiration to architects, builders, and homeowners by being included on the 2004 National Green Building conference tour, the 2002 AIA Austin Homes and the 2002 USGBC International Green Building Conference Exposition tour.

By his own words, Mr. Pfeiffer describes that an architect builds his own “laboratory” to demonstrate an “up country” interpretation of the Craftsman architectural style infused with superior technology construction techniques and serious “green” building strategies. Not to mention Pfeiffer’s ability to design a green yet functional house to accommodate a family of six. “It’s tough to do a “Not So Big” house when you’ve got a herd of kids to house,” he added. This one-of-a-kind, high end, custom residence is sited on a midsized central city lot to take advantage of the prevailing cooling breezes and good solar orientation in such a way as to maximize passive cooling in the summer and passive solar heat gain in the winter. The layout of the interior spaces reinforces these pragmatic comfort goals, while also being unique to the way a contemporary family lives. An open central stair tower helps cool the home, while flooding its center with glare free daylight and creating a fun backdrop for the family piano. An ample sized casual living, dining, kitchen area that opens onto a screened porch allows for kids supervision and for four-season relaxation. The master suite represents a sanctuary in the trees and includes a European style bathroom/dressing room set-up.

Actual utility bills are tracked using an extensive computer based modeling performed during design. The utility bills for this home are roughly equivalent to homes 1/3 the size — approximately $200 total for average monthly electricity and gas costs for a five bedroom, I2 full-time occupant home. Rainwater collection for irrigation, gray water recovery, ventilated radiant barrier roof system, rigid foam wall and attic insulation, carefully sized roof overhangs, sealed attics, hydronic heating, and a water based air-conditioning system that uses the swimming pool as a heat sink are among some of the strategies included. More strategies include:

- Open plan featuring much use of indirect day lighting, and florescent lighting,
- Stair tower that brings daylight to the home’s core, and provides a thermal siphon for enhanced natural ventilation of the entire structure,
- Recycled content steel roof with integrated heat, thwarting radiant barrier and novel lathing system to promote ventilation and condensation control,
- Detached garage (for better IAQ), water based cooling tower, rainwater collection system, and
- South facing façade collects prevailing breezes yet provides shade; rot resistant composite and locally obtained natural building materials; the pool serves as an A/C system heat sink.

Besides following ASHRAE guideline for materials in hot, humid climates, in his design Pfeiffer implied (according to his own narrative) some conventional building materials, new products and some passive methods:

- HOUSE ORIENTATION: House sited with long axis running east-west with the majority of the windows facing north and south. This critically important “green building” strategy is great for receiving the prevailing SE breezes, so the house and screened porch remain cool even on the hottest of August days.

- WINDOWS & OVERHANGS: Wood framed windows with doubled pane "Low E" Argon gas-filled glass. Windows were sized and placed with proper solar orientation and the prevailing breezes in mind. All overhangs above the doors and windows were accurately sized and designed for both optimum solar shading (using a sun-angle calculator) and daylight reflectance (to brighten up the interior without direct sunlight and glare).
- RADIANT BARRIER ROOF/ THERMAL BREAK CEILING SYSTEM: Since the bulk of energy costs in central Texas are spent on cooling the home, a major focus of the energy reduction strategies is to reduce unwanted solar heat gain. The light colored metal roof contains a self-venting radiant barrier system, which consists of dual venting paths, keeping attic temperatures 40 to 50 degrees cooler than a typical attic in our area. Other attics in the home are sealed to control humidity and heat gain. Insulation board (no HCFCs) installed under the vaulted ceilings keeps the upstairs more comfortable in the summer months by providing a thermal break between the finished ceiling and the roof structure.
- LIGHT COLORED EXTERIOR & LOCALLY QUARRIED STONE: The light exterior color scheme reduces the "urban heat island" effect, enhancing personal comfort. Exterior stone is locally quarried, reducing the "embodied energy" content of this home. Or simply saying that less energy had to be expended to produce and transport the product.
- INFILTRATION & PASSIVE HUMIDITY CONTROL: The exterior wall sheathing is thoroughly wrapped in TYVEK COMMERCIAL WRAP and 30# ASTM building paper - also utilizes a self-adhering rubber membrane flashing in such a way as to keep moisture out of the walls. This protects the house from mold and wood decay, while reducing the work the air conditioner has to do in the summer to de-humidify the home. This also makes for a healthier, bug free, indoor living environment.
- SPRAY FOAM INSULATION & SEALED ATTICS: Wall cavities are filled with a 1" thick spray of air-sealing, high-density spray foam, and then bulk filled

with borate-laced cellulose. Attic ceilings are sealed with 6” of low-density foam to create a vented roof and a sealed attic. This also contributes to remarkably low indoor humidity levels and consequential mold control within the structure.

- SCREENED PORCH: The screened porch is strategically placed to capture breezes that naturally rise up from the greenbelt below, yet remain comfortable during the winter months.
- ENHANCED NATURAL VENTILATION: Windows are placed and arranged to provide “enhanced” natural ventilation. This means good cross ventilation coupled with high windows that exhaust hot air out by way of “thermal siphons” and natural low pressure zones. The operable windows high up in the sitting room above the stairs are not just architectural features; they provide for ample natural ventilation and balance out the natural day lighting of this home. As the hot air exits out of the home through these windows, cooler air is drawn in through the ground floor windows.
- WHOLE HOUSE FAN: A very large fan sitting above the main stair that mechanically draws cool nighttime air through the house during the spring and fall evenings. This “charges” the interior with cool temperatures. Yet, unlike the typical “attic fan” arrangement, this fan has a unique cover box that prevents air, heat, and humidity leakage when not in use.
- OPTIMUM VALUE ENGINEERING & RE-CONSTITUTED FRAMING PRODUCTS: Engineered floor and roof trusses are large structural spans accomplished without the use of long or old growth lumber. *Microllam* plywood beams and *Paralam* structural beams (made from waste strands of timber); Finger-jointed 2x4 studs (made from recycled wood); Timber Strand door and window headers (made from oriented strands of wood); Smart Guard exterior structural OSB sheathing (manufactured with B orates for decay and insect control from oriented strands of wood).
- HEAT RECOVERY FAN SYSTEM: A thermostatically controlled, variable speed re-circulation duct system pulls warm air from the upper reaches of

the home down to the main level, providing for more comfort and energy savings.

- LIGHTING AND NATURAL DAYLIGHTING: The central stair shaft brings natural daylight into the core of the house, much like in vernacular central Texas architecture, reducing reliance on electric lighting and enhancing the interior ambiance. A skylight above the back porch brings reflected light, but not solar heat, into the Family Room and Screened Porch. Light colored galvalume metal eaves surround the house to reflect glare-free daylight into the home. Much use of electronic ballasted high resolution fluorescent lighting, both indirect and direct, for soft artificial lighting that saves electricity and helps keep the home cool & comfortable.
- AIR CONDITIONING COOLING TOWER, SWIMMING POOL INTERFACE & COMPUTER BASED ANALYSIS: The 17 Seer water-cooled AC system is linked to the swimming pool to provide free pool heat during the fall and spring. A Cooling Tower (miniature version of what is commonly found on commercial buildings) employs evaporative cooling to greatly improve the A/C cooling efficiency. It is manufactured locally and quite reliable. Careful A/C system sizing was accomplished utilizing a computer based energy analysis program that allows for an average of 1 ton of cooling capacity per 750 square feet of living space — significantly better than the industry standard of 1/ 500.
- HYDRONIC HEATING: Water based heating is employed to take advantage of the 94% efficient Polaris water heater, which re-circulates its hot water to a hydronic-heating coil in each air handler. This system allows for three less gas fired appliances in the home, further enhancing the indoor air quality by eliminating the negative effects of surrounding an air handler with outside combustion air, and eliminating the chance for flue gas interior air pollution.
- HIGH PERFORMANCE DUCTING SYSTEM: The very carefully planned and installed duct system is constructed of sealed unlined sheet metal,

maximizing even air flow throughout the house to diminish the chance of some rooms being warmer, or cooler, than others. This attention to detail also reduces the chance for dirt or molds to accumulate inside the ducts, and reduces duct leakage to below 10% (independently “duct blaster” tested). Duct leakage is a major source of energy waste in most homes. Tight ducting contributes to lower energy bills and a better indoor air quality. Minimal use of ‘flex” ducting makes for a more permanent and better-sealed duct system also. Pressure relief ducts between bedrooms and common areas assure proper temperature and pressure balancing within each zone.

- DIGITAL PROGRAMMABLE ENVIRONMENTAL CONTROLS: Three separate air-conditioning systems allow for independent zoning of the major areas of the home, and are controlled by digital programmable thermostats with multi-speed dehumidification capabilities. This makes for greater comfort, less energy consumption, and greater flexibility as the living needs change over time. Relative humidity levels within this home run between 35% and 45%, compared to the norm in this area of between 50% and 65%.
- AIR FILTERING & INDOOR AIR QUALITY: Each air-handler contains high intensity ultra-violet lamps and a SPACE GUARD pleated filter medium for super clean air. Clean air is further assured by the controlled importation of fresh air directly to each air handler. This provides a slight positive pressurization of each zone, further reducing the chance for the infiltration of overly humid outside air in the summer, annoying cold drafts in the winter, and reducing the immigration of molds and pollens from the outside.
- APPLIANCES — WATER USE & HUMIDITY: Energy efficient *Asko* dishwasher and front loading Frigidaire clothes washer were installed in the home. The horizontal axis sealed washing compartment saves water, energy, and eliminates the second major internal cause of humidity within a home, while enhancing comfort, health, and indoor air quality.

- APPLIANCES — HEALTH: A whole house central vacuum system reduces household dust by exhausting directly to the outside. The outside venting is located far from the home’s fresh air intakes.
- HEALTHFUL WIRING: House electrical distribution is done so to minimize occupant exposure to electro-magnetic forces. Breaker panels were located away from frequently occupied spaces and wiring was minimized along the bed walls in the bedrooms.
- FUTURE PHOTO-VOLTAICS (PV): South facing roof is designed to accommodate future PV panel installation. Electrical conduits are in-place and electrical panel access is provided to facilitate the required wiring.
- PLUMBING — WATER HEATER: One 94% efficient 50 gallon natural gas fired *Polaris* water heater was plumbed and placed in such a way to deliver almost immediate hot water without the use of a mechanical re-circulating loop. Features include stainless steel tank, electronic ignition, re-use of hot flue gasses, and sealed combustion chamber.
- PLUMBING SYSTEM - GREYWATER RECOVERY: Beneficial use is made of laundry washing machine waste water (called “Greywater”) by diverting the water to a separate tank in the front yard for use in landscaping needs.
- RAINWATER COLLECTION SYSTEM: Majority of the roof rainwater was collected in a cistern behind the garage to reduce dependence on the City for landscape watering and cooling tower operation. Simple “roof washer” system diverts initial wash of dirty water from the collection tank.
- XERISCAPING & DRIP IRRIGATION: The landscaping consists of an impressive variety of native and low water use vegetation. Sod is drought tolerant *Zoysia* (Palisades variety). All planting areas, other than sod, are drip irrigated.

3.3.4 Conclusions

The different simulation studies reviewed through this section revealed different methodologies on parametric studies for the improvement of houses in warm humid conditions. Most of the studies are related to the performance of free-running houses, even if most of the authors agreed with the increasing demand for air-conditioning systems; the limits of passive solar design approach in providing comfort and the existent incompatibility of free-running and conditioned modes for maximum thermal comfort and energy use. PVRES Florida, the study which considered the conditioned mode, developed an extensive experiment on the use of PV and energy efficiency but did not consider the possibility of free-running mode, due to the extensive use of NC for houses in the USA.

For these studies, the parametric changes were mostly concerned with the effects of mass, insulation, ventilation regime, and sun control. The effects of parametric changes on the comfort inside demonstrated in summary that:

- Thermal mass and insulation (especially if located externally) for both free-running and conditioned buildings improved the performance, in sequence, roof/ceiling, walls and floors,
- Provision of window shading for both modes is essential for the whole year. Window distribution for conditioned mode should be kept to provide minimum levels of daylighting.
- Ceiling and roof insulation is a critical point for the thermal performance of both modes, in which radiant barriers should always be present,
- Light external colors improved thermal performance,
- Roof space ventilation demonstrated a great potential for minimizing heat gains, and
- The use of pre-cooling mode on the PVRES project have minimized the energy requirements and shifted the peak load demands.

3.4 Passive Solar Principles

In this age of energy crisis, practicing passive solar fundamentals in building design is on the rise not only in the European countries but also all over the world. In his book 'The solar house: passive heating and cooling', Chiras has completely mentioned that only the holistic way is the key to use passive principles as well as a energy-efficient design. He used the term 'Integrated Design'. Integrated design is nothing but designing the building as a whole or in my words treating the building-design task as a design of air conditioning unit itself. A home or a building is itself is a package of building components which comes with design features and in every elements of a building there is scope to think something about efficiency.

Now when it comes to passive solar techniques in building, the question of why arise. Here is few reasons according to me which can be claimed as benefits of using passive solar principles than normal mechanical air conditioning.

- It will lower energy bills for some amount. After all, we all are in result oriented society and money matters here. Therefore, lowering energy bills is directly linked with monetary factor.
- Liberty of design. Architects will have liberty to design bigger window, bigger outside view which leads to an attractive living standard. For residential use, the users can have sunny interiors; less artificial lights which all together leads to a psychological healthy atmosphere.
- Although the Comfort level will be optimized here than a typical case of mechanical air conditioned space but it will give more adaptability to nature. It might improve the immunity as well.
- Eventually the house or building will give high level of owner satisfaction which in the end will lead to high real estate value.
- If designed properly, a very little maintenance can be done than regular mechanically ventilated house. Therefore, maintenance could be a valid positive for passive solar houses.

- Concern about environmental issues. Passive houses use not only less energy but less environmental pollution and less carbon footprint also. Passive Solar House will definitely be environment friendly solution.

In his book he also declared the F*ourteen principles of Passive solar (*Chiras, Daniel D.; The solar house: passive heating and cooling, 2002, p. 218-223)

1. Ensure site has good solar exposure
2. Orient the east-west (long) axis of the home within 10 degrees of true south
3. Concentrate windows on the south side of the house
4. Minimize east and west glazing
5. Provide overhangs and shade to regulate solar gain
6. Provide well-positioned thermal mass for heating cooling
7. Insulate ceiling, walls, floors, and foundations
8. Protect insulation from moisture
9. Design house so that rooms are heated directly and for optimal natural heat distribution
10. Create sun-free zones for computer work and television watching
11. Seal leaks and cracks to reduce air infiltration but ensure adequate ventilation for fresh air
12. Provide efficient, properly sized, environmentally responsible backup heating and cooling systems
13. Protect homes from winter winds by landscaping, earth sheltering, and other measures
14. Design interior space to correspond with solar gain and living patterns.

In this business of Passive solar principles, singing with the tune of an African proverb: “Turn your face towards the sun and leave the shadows behind!” In my design, the approach is to design the affordable home to use this huge passive and active solar power to gain the maximum efficiency and comfort spending less money. Recent days,
Practicable Passive Techniques are –

- Solar chimney in architecture
- Wind catcher
- Natural ventilation
- Stack effect
- Hybrid Ventilation System
- Passive solar
- Trombe wall
- Earth cooling tubes
- Stand alone green power (Hydrogen based electrolysis in site)

3.5 Passive Cooling of the Building

In her thesis on the wind catchers of Yazd in Iran, Susan Roaf (1988) describes the daily thermal routine of the local adapted population occupying traditional mud brick houses, with their wind catchers set in the one- to three-storied buildings over deep cellars:

> *In contrast to the Western approach to comfort and design in which the individual chooses the climate for a room, the Yazdi living in a traditional house selects a room for its climate. Such choice and movement around a house during a day constitutes a behavioral adjustment that has been an essential adaptive strategy evolved by the people of such hot desert regions, enabling them to inhabit a seemingly hostile environment with some degree of comfort. In the heat of the Yazdi summer, starting out from sleeping on the roof, they will migrate to the courtyard, which provides shade and relative cool in the morning and, thence, to the cellar to rest through the hottest hours of the day. Towards evening they will come out into the relative heat of the courtyard, which may initially be cooled a little by water thrown on to the hot surfaces, and will then grow cooler as night draws near. In late autumn, a different migration occurs, horizontally from the shaded north-facing summer wing, to the south-facing winter rooms of the courtyard, deliberately warmed by the sun. The consequence of this daily movement is that by recording climate in one or two spaces, one does not cover the diurnal range in climate experienced by the occupants of the houses. In Yazd, it has been necessary to follow the occupants around the house, climatically, in order to record and, in turn, understand, the nature of the 'occupied' summer climate in the houses of Yazd.*

In a different context Fergus Nicol (1974) quotes a description by M. R. Sharma of the daily routine in laboratories and offices in the Central Building Research Institute (CBRI) in Roorkee, India:

> *The room is full of warm air in the mornings. The windows are opened and the fans* ***run*** *at full speed to churn cool air into the room. Within half or three quarters of an hour the air is cool enough for work to begin. Conditions remain comfortable with fans running throughout the forenoon.*

Two different stories from different occupants in different geographical location but with almost same climate are telling one basic truth. It's "adaptive" cooling and in both cases occupants are using their building as a cooler. They are not using a mechanical unit to cool their building down. There are plenty of building in India done by CBRI is not mechanically air conditioned at all and they are having the adaptive/optimum comfort inside the built environment.

The purpose of the design of buildings should ensure means to reject (block, or reduce) the heat build-up in the interior of the building (by any means of cooling: natural, mechanical, or hybrid). The provision of ventilation naturally or mechanically is a possibility of controlling the indoor air quality and to achieve thermal comfort in a passive way. Appropriate air velocities can provide thermal comfort by physiological cooling, produced by air movement, even when the temperature and humidity are not the most appropriate. This is the basic principle for a design-case in hot-humid climates. Also, the renewal of the air by ventilation is a powerful means to exhaust air pollutants, generated indoors.

Heat transfer by convective effects occurs due to the presence of a difference between the indoor and outdoor air temperature. In naturally ventilated buildings, most heat exchange will take place through convection. Nevertheless, most authors, e.g. Givoni (1994), Bittencourt (1993), agree that even if the outdoor temperature is above the comfort limit, ventilation would reduce the degree of overheating.

According to Koenigsberger *et al* (1974), ventilation has three different functions, which are the supply of fresh air, convective cooling and physiological cooling. Ventilation for convective cooling, as well as for the removal of contaminants and fresh air supply require a relatively small air volume flow rate. Physiological cooling requires significant velocities, which would result in a much larger airflow. In this case, velocity is the critical factor. It is the most important principle for warm-humid climates, as it enables the extension of the upper limits of the comfort zone, considering the acceptable indoor air speeds.

The ASHRAE Handbook of Fundamentals (1985) permits an extension of the upper comfort limits by 1 K for an increase of 0.275 m/s, (up to 2K) up to 28°C with air speed of 0.8 m/s. This is the highest indoor air speed permitted by ASHRAE. Based on studies by Humphreys (1978) and Auliciems (1981,1989), the levels of acclimatization and expectations of people living in hot areas were higher for upper limits. Givoni (1994), suggested that the indoor air speed acceptable for naturally ventilated buildings, in regions which do not exceed 28/32°C (daily swings of less than 10K) should be 1 .5-2m/s. Auliciems and Szokolay (1997) presented an approximation, which would exemplify this cooling effect, and the extension of comfort zone limits:

$$dT = 6* (v-O.25) - (v-O.25)$$

Where dT is the apparent cooling effect of air movement

Greenland and Szokolay (1985) suggested that controlled ventilation could be achieved through three different ways:

- Stack effect
- Forced ventilation by fans
- Using the local winds

The stack effect is a result of difference in air temperature within spaces, and therefore can provide cooling air to the building. However, the low air speeds achieved by stack effect would suggest (Greenland & Szokolay 1985) that to be noticeable, a minimum of two-storey height is necessary. If the indoor air speeds are insufficient to provide thermal comfort another possibility is the use of mechanical devices, such as fans. The small energy input with great physiological cooling effects are an encouragement for the use of these devices as stated by Givoni (1969, 1994) and Santamouris (1996). Lastly, the use of local winds relies on the different pressures generated around and through buildings. Appropriate design could optimize this effect and provide physiological cooling, increasing the convective heat loss and accelerating evaporation from the skin.

In terms of window size, different effects could be achieved depending on whether the room is or is not cross ventilated and if the wind is perpendicular to the wall. Without cross ventilation, the size of the window will have a minimal effect on the internal airflow. However, if the wind is oblique to the wall, reasonable ventilation could be achieved depending on the size of the window and if wing walls could be provided. Different pressure zones would generate an indoor airflow. In case of cross-ventilation, when inlet and outlet are of equal size, the highest flow rate and average velocity is produced. If the outlet is larger and the inlet is smaller, the maximum indoor speed is higher but concentrated. This is desirable when it is necessary to direct the airflow, such as bedrooms. In this case, wingwalls or horizontal centre pivot windows or casements could be used for directing wind to the occupants. For living rooms, larger inlets are best solutions as there is more necessity for the distribution of airflow.

The provision of air movement can be disturbed by the necessity of the exclusion of insects, especially in the tropics. Oakley (1961) suggests that other means of avoiding insects should .be applied, such as yellow lights, vegetation which are effective mosquito deterrent, or controlling by neighborhood or regional level (clearing rivers, draining of swamps, etc).

However, these are quite often not completely effective and fly screens are one reality in warm-humid regions such as Darwin. Results of experiments with wind tunnels made by Givoni (1969) demonstrated that when placing the screens on balconies or verandas, which could optimize the wind catching from bigger inlet areas, so greater ventilation effect would be achieved. In hot humid regions another important consideration is when wind and solar orientation conflict with each other. Givoni (1994) claims that if this happens, ventilation should be the primary factor, as the issues of solar control can be solved with shading devices and the color of the envelope. Szokolay (1987) argues that solar orientation should be the primary factor, as the wind can be captured by different types of openings and wing walls whilst the sun always follows the same path.

Passive cooling strategies, which consist of the rejection of heat from the interior of the building to heat sinks such as water, the upper atmosphere, the ambient air and the earth are features capable of providing thermal comfort and effectively reducing indoor temperatures, unlike the natural ventilation process. The first measure (natural ventilation) aims to provide relief from the heat gains and the high air temperature while the second attempts to lower the interior air temperature.

Passive cooling systems might be classified in terms of the available sinks (“cooling sources”), the mode of heat transfer and fluid flow, and the materials in which the “coolness” may be stored from the period of its availability to the time of its demand (Szokolay 1980b). In terms of heat transfer, it is possible to have passive cooling systems based on radiative, evaporative and conductive heat transfer mechanisms.

Radiative cooling is based on the fundamental principle that any warm body emits thermal energy in the form of electromagnetic radiation to the facing colder ones. It is known however that radiative cooling is much stronger in clear night skies due to the reduced presence of particles, such as water vapor, carbon dioxide and dust in the atmosphere. These particles absorb and emit back long-wave radiation; thus the net outgoing radiation heat flux from any object on the earth is equal to the radiation emitted from it towards the sky dome minus that re-emitted from the atmosphere. This difference in radiation rates determines the maximum potential of radiative cooling. This is why in warm-humid regions, radiative cooling is not an effective passive cooling strategy as the moisture content of the air is quite high and there is a predominance of partially cloudy skies. The potential of radiant cooling has best prospect in arid regions and if used in warm-humid climates it will only be effective under clear sky conditions. According to Szokolay (1982), a maximum of 1.5 K of depression can be expected below air temperature from night radiant roof cooling systems.

Evaporation is the phase change of water from liquid to vapor. Cooling of buildings by water evaporation is possible through direct or indirect ways, through mechanical systems or building elements. The performance of each technique depends upon the climatic conditions of the region. The main difference is that with the first strategy the moisture content of the supply air is increased whereas this does not happen with indirect evaporative cooling.

Although solar induced evaporative cooling has been found to be successful even in some warm-humid regions, as observed by Saini & Szokolay (1975), the constant high relative humidity of the air does not provide a large scope for its use as a cooling strategy for the building structure. Nevertheless, some cooling may be achieved in the afternoons when the relative humidity of the air is not so high (around 60% on hot days) and a decrease of 2-3K in air temperature may be highly appreciated.

As evaporative cooling systems add moisture to the air and increase humidity while lowering the dry bulb temperature, these are more appropriate for hot arid regions. Givoni (1994) presented a number of case studies with extremely good results in improving thermal comfort and reducing temperature for those regions. However, even for warm-humid locations such as Darwin, Szokolay (1976) demonstrated the possibilities of using fan-driven evaporative coolers, obtaining comfort during six months of the year (dry season) when humidity levels were up to 60%.

An alternative to the direct process of evaporative cooling is the indirect system, which can be either obtained by mechanical means (two stage indirect mechanical evaporative cooling) or through building elements, such as roof ponds or sprays. In the indirect mechanical systems evaporation takes place separate from the supply air, i.e. the latter is cooled indirectly, through a heat exchanger. Through this process, the air that comes in contact with the cool surface is subsequently cooled without increasing its moisture content. The efficiency of the evaporation process depends on the temperature of the air and of the wet surface, the moisture content of the air and the velocity of the air flowing over the wet surface, as demonstrated by Szokolay (1

980b). If roof ponds are considered, these can be located over roofs, under or near buildings. When located over the roofs, maximum waterproofing should be provided, and as in warm humid climates there is no need for insulation, Givoni (1994) recommends that this should be eliminated for increasing the thermal conductance between the pond and the space below. Mainly, the pond gains heat from the room air by convection. Some heat also is gained by conduction from the indoor space and by long-wave radiation from the shade elements. The balance between the heat gain and loss results, in an average water temperature a little higher than the average ambient wet bulb temperature.

For warm-humid regions, the applicability of roof ponds is directly related to the limits on WBT, which should not be over 24°C. Its use is limited to single storey buildings and the need to have flat roofs, which would support a load of about 300 kg/m^2 (Givoni, 1994), and the impact that fixed or floating insulation could cause in the architectural design.

Another cooling strategy is earth cooling. Conductive heat exchanges have been used to provide an effective heat sink through earth coupling, but the cooling potential is only great in areas of large annual temperature swings, which is not an attribute of the regions, as agreed by many authors, e.g. Bittencourt (1993). The soil conductivity depends on its composition and particularly on its moisture content, which in warm-humid locations is normally high. In these types of climates, also the soil temperature in summer is usually too high for it to serve as a heat sink. The use of underground pipes to cool the air before introducing it indoors has been attempted but also presented problems in warm-humid regions, as shown by some experiments of Givoni, (1994). These provide conditions for insects breeding and mould growth inside the tubes contaminating the incoming air with unpleasant smells. Other negative points of earth coupling notably with earth covered or underground buildings for tropical regions are the lack of contact (by natural daylighting and natural ventilation) with the external environment. In the tropics, this is psychologically important, even when there is no physiological thermal comfort increase (Szokolay, 1984, 1990).

As demonstrated, the operation and efficiency of passive cooling techniques is quite dependent on climatic conditions but it is also dependant on the building type and the occupancy patterns. The choice of appropriate cooling techniques depends upon the balance among these elements. If however, all cooling techniques are much limited, the use of other means of cooling should be considered, such as mechanical air conditioning (NC). Szokolay (1987) and Carruthers (1991) recommend that the option of relying on a conditioned mode, should be taken early in the design stage, as the two approaches should lead to different design solutions and different building construction. A building designed for passive cooling should ensure maximum natural ventilation and therefore would be unsuitable for air conditioning. Instead, if air-conditioning is considered, the approach would rely on a sealed and insulated envelope, completely inappropriate for natural cooling.

3.6 Active Solar Cooling Design

Mechanical cooling for comfort began early in the twentieth century, and the research & developments in this area have been rapid. Nowadays, a wide range of air conditioning equipments are available in the market, matching the needs for the many different building applications. In terms of housing, the small 'packaged' type units are most common due to their ease of installation and this is the item analyzed here.

Cooling energy is the sum of the sensible and latent energy components that are required to maintain comfort conditions inside the cooled zones, for specific time periods. The sensible cooling energy is the energy required to reduce the temperature of the air without changing its moisture content; and the latent cooling energy is the energy required to condense water vapor in the air during the cooling process, (Willard, 1998). It is possible to have mechanical cooling by several means: vapor compression systems, gas compression systems and thermoelectric systems (Threlkeld, 1970). The most common one is the vapor compression system, which is used in houses as single package units. These are available as window units, which have the lowest purchase price. All wall units, which are mounted externally to reduce indoor noise and as portable units, are mobile. These systems can also be 'cooling only' or reverse cycle, for provision of heating during the winter period. For the purpose of this study, ‘reverse cycle’ is not used considering the very little under heating that occurs during the “winter” of the warm-humid tropics.

Small packaged air conditioning units produce their cooling effect by the direct expansion of refrigerant, actually within the cooling coil tubes. Cooling is accomplished by evaporation of the working fluid (the liquid refrigerant) under reduced pressure and temperature, in the evaporator, resulting in heat transfer from a high-temperature space. It is then that the refrigerant enters the compressor as a slightly superheated vapor at a low pressure, leaves the compressor and enters the condenser as vapor at some elevated pressure. It is condensed as a result of heat rejection to ordinary cooling water or atmospheric air. The heat extracted from the hot refrigerant gas in the condenser coil is transferred to the condenser’s discharge air. The condensed refrigerant flows back as a liquid to the ‘indoor’ unit coil through a check valve thus completing the thermodynamic cycle (Parlour, 1998).

The rising concern for energy efficiency in buildings has prompted research into ways of minimizing the use of active environmental control systems such as refrigerated air conditioning and artificial lighting in buildings. It is also widely recognized that improvements in energy efficiency could play a large part in addressing the problems of rising energy demand. For the purpose of this research improvements to the building envelope are considered which would result in significant NC load reductions. According to Parker & Dunlop (1994) for conditioned buildings, these changes include in general wall and ceiling insulation, white exterior walls, reflective roof, reflective windows, and landscape shading of walls and windows and minimization of internal heat gains. In terms of housing, Szokolay, (1987) suggested that a passive design for hot-dry climates would also be good for NC, as the building should be basically highly insulated, should prevent infiltration or escape of air and prevent the direct transmission of solar radiation, but this is not so for warm- humid climates.

Generally heat is produced within a building by lights, people and equipment. Solar radiation, when entering through a window adds heat to the interior. Conduction through the envelope causes either heat gain or loss depending on the outside temperature. In hot-humid weather, there is a need for cooling to remove both the internally generated heat and the heat conducted through the envelope. The main variables of importance in the conditioned envelope design are the proportion, shape and shading of windows (normally small openings); color and insulating value of the envelope design; and the mass of the construction.

Windows in buildings play a number of roles from aesthetics, weather protection and acoustics to energy optimization. In order to design effectively for energy efficiency, it is important to optimize their solar, thermal, acoustic and optical properties. As stated by Smith (1989), the problems of air infiltration would suggest that ‘non-operable’ windows have advantages, however, cleaning should be considered as it would have to be done from the outside and the occupants would be unable to control the windows.

The insulating value of windows, even multiple-glazed windows, is less than that of a well-insulated wall. However, advanced glazing materials are now becoming available with properties equivalent to those of an insulated wall. Prasad (1993) claims that the manipulation of absorbing, emitting, reflecting and transmitting properties and the convective and radiative behavior within systems has changed glazing design. The technologies being perfected such as evacuated systems, smart glazing such as electro-chromic, photochromic and thermochromic glasses together with infill media such as aerogels, transparent insulation and novel gases and frame technology should further enhance design flexibility.

Thomas (1998) claims that electrochromic (EC) is the most flexible and widely studied form of high-tech switchable glazing. Its properties are altered by the application of an electrical charge. Since their solar optical properties can be switched at will, it is possible to darken the glazing when solar heat rejection is required, and keep it clear when solar gain is required. The added cost of the EC process has been estimated in the range of US$100-lOGO per square meter of window area. The prices are still prohibitive but the technology is being developed for further commercialization. Window frames are another important factor for energy efficiency for windows. Wood, fiberglass, and vinyl frames are better insulators than metal, such as aluminum or steel when there are no thermal breaks as stated by DOE (1999), and therefore should be preferably used in conditioned spaces.

The main recommendations for windows for conditioned spaces in warm humid climates, are low U-value, low Solar Heat Gain Coefficient (SHGC) but sufficient visible transmittance to maximize daylight and view. Air leakage should also be low enough to avoid infiltration and raise the interior humidity levels. In terms of insulation and color, it is common sense that the dominant factor that affects the thermal performance of houses in tropical climates is ceiling insulation. This is followed by wall type and insulation and floor type. Under-floor insulation for a slab-on-ground floor and carpets can reduce performance. (Willrath, 1998). Dark external colors degrade thermal performance as agreed by many authors e.g. Givoni (1994). In terms of mass of the construction, high mass houses perform better than houses of lower thermal mass, and this is true for both conditioned and free-running buildings as demonstrated by Szokolay (1996), Walsh et al (1982), Willrath (1998). Together, if properly designed, all these strategies can help to reduce both the plant size and the energy consumption for cooling purposes.

In 1990 about 4.1 EJ of primary energy was used to air condition buildings in the U.S.A, which is about the same as the total energy use of Australia. This energy end use is on the rise and is expected to increase as the population shifts to the warmer southern states. (Pesaran, 1992). This phenomenon of increased use of air conditioning systems appears all over the world (Santamouris, 1996; Parlour, 1998). This presents the air conditioning industry with several challenges. Among these are demands for increased energy efficiency and improved indoor air quality, growing concern for improved comfort and environmental control, increased ventilation requirements, phase-out of chlorofluorocarbons (CFCs) and rising peak demand charges. Apart from the possibility of optimizing the building envelope by passive means, new approaches to air conditioning are also being evaluated to resolve these economic, environmental and regulatory issues.

For reasons of both the finite quantity of fossil fuels and environmental damage consciousness (Lodhi, 1997), there has been a worldwide increase in the application of solar technologies in buildings since the 1970’s. Following the oil crisis in 1973 solar cooling has considered necessary to reduce peak demand of electricity for air conditioning as much as possible so that new construction of power plants could be avoided. The idea of using heat from solar energy for cooling purposes has attracted public attention. Since then the technology of solar absorption cooling systems has been developed quite successfully to realize practical applications with government subsidies. In the 1990’s, the number of new solar cooling installations has been decreased primarily due to the reducing cost of conventional energy, the increasing complexity of such systems and their lower COP (coefficient of performance).

Szokolay (1975a, 1993), Carruthers (1991) and other authors have extensively worked with solar cooling devices, and agree that cooling using solar energy offers the major advantage that it is the only application where the maximum energy demand coincides with the maximum energy availability.

Szokolay (1977) states that the most common types of solar cooling devices are - the compression type, the absorption type, and the open cycle desiccant cooling type. In the compression type refrigeration cycle solar energy is used to produce mechanical work to drive the compressor. In the absorption type the solar heat is directly used to drive an absorption refrigerator. In this case, the working fluid for the system is a solution of refrigerant and absorbent. The absorption refrigeration machine operates with changes of vacuum in the absorber, regenerator, evaporator and condenser, while the open cycle system is open to the atmosphere so that the water can be evaporated by solar energy from the diluted liquid desiccant to be concentrated. Then the concentrated liquid desiccant may be capable of absorbing water vapor from the space to be dehumidified. Lithium chloride, calcium chloride or ethylene glycol solutions may be used as liquid desiccants.

Essentially this may be called a solar dehumidification system and it is necessary to have a sensible cooling process for the regenerated desiccant of high temperature for the dehumidified air to be supplied to the interior space.

Most researchers have withdrawn from working on solar absorption chillers, as these systems have been developed up to technical maturity in reliability and performance and further cost reduction is unlikely. The same is not true for the desiccant cooling systems. In Australia James Cook University, Monash University and CSIRO have done significant work in this area. In the USA, since 1995, it is being researched by the National Renewable Energy Laboratories — USN Advanced Desiccant cooling & dehumidification program (NREL) in conjunction with the Oak Ridge National laboratory (ORNL). Throughout this program, the technology has improved the performance, reliability and cost-effectiveness of desiccant equipment. It is successfully used in supermarkets, where it is used to controls the moisture levels in freezer display cases. If an “anti-sweat” heater were used, it would consume considerable energy.

The desiccant systems have helped many commercial buildings in saving energy by controlling humidity independent of temperature. This is the great contribution of desiccant systems (Pesaran, 1992). Residences can also benefit from desiccant dehumidification by providing drier indoor conditions, reducing mould and mildew growth. Conventional vapor-compression cooling systems are not designed to handle temperature and humidity loads separately. Consequently, oversized compressors are installed to dehumidify the incoming air. However, further cost reduction and improvements are needed before desiccant systems can compete successfully in the broader residential and commercial market.

There is a growing consensus that solar photovoltaic air conditioning for residential buildings is a promising technology, e.g. Kimura (1993), Szokolay (1993). Photovoltaics, as stated by Wilson & Young (1996) applied to buildings may be a realistic option in climates with higher levels of solar radiation. It is truly a means of producing electricity on site, directly from the sun, without concern for energy supply or environmental harm. These solid state devices simply make electricity out of sunlight silently with no maintenance, no pollution and no depletion of materials. Interest in the building integration of photovoltaics, where the PV elements actually become an integral part of the building, often serving as the exterior weathering skin, is growing worldwide (Roaf, 1997).

3.7 Climatic Variables and Human Comfort

Thermal comfort is defined as that condition of mind, which expresses satisfaction with the thermal environment (ASHRAE 1985). Dissatisfaction may be caused by warm or cool discomfort for the body as a whole, but thermal dissatisfaction may also be caused by unwanted heating or cooling of one particular part of the body (local discomfort).

The human body may be considered a thermodynamic system. Heat is a by-product of body movement. Food and oxygen are inputs into the body. This system requires, in healthy conditions, to maintain a constant internal temperature around 37 ± 0.5°C, otherwise the functionality of important organs may be severely damaged. In order to maintain constant internal body temperature, the rate of heat generation of the body must be equal to the rate of heat loss from it. The job of the body’s thermoregulatory system is to maintain the heat balance which is a fundamental condition for survival and necessary for comfort.

Because humans are “homeotherms” (mammals of constant body temperature) heat balance of our bodies, as expressed by the equation below, must be maintained over any significant period of time (Gagge, 1936 as quoted by Auliciems, 1981).

$$M - E \pm C \pm R \pm S = 0 \qquad \text{...eq.1)}$$

Where	M	is metabolic rate less any external work done;
	E	is evaporative heat loss
	C	is the rate of heat exchange by convection and conduction
	R	is the rate of heat exchange by radiation
	S	is the storage rate within the body

The body’s thermoregulatory system ensures that S is 0 (zero) with slight fluctuations. When S is less than 0 (zero), the body releases more energy than it is produces, and its temperature tends to decrease. The first action of the thermoregulatory systems involves thermal resistance on the skin that is increased by means of a vasoconstriction mechanism (the blood vessels under the surface of the skin constrict). Vasoconstriction leads to a reduction of the blood flow and, consequently, to a reduction in the body surface temperature and in the rate of heat loss. On the other hand, for tropical conditions the opposite happens most of the time. When S is greater than O (zero) heat losses are not balancing heat production. The first action of the systems is to replace with perform vasodilatation; blood vessels expand, skin temperature increases and, with it, the heat loss rate. The overall effect is that of reducing the thermal resistance of the skin. If the first action is not enough, sweating starts, involving larger and larger fractions of the body's surface area according to the extent of the inequality in the energy balance. Sweating improves evaporative heat losses.

The complexity and dynamism of our perception of comfort is enormous. Comfort parameters vary spatially in a building and also vary in time; it tends to influence the occupants' perception in accord with seasonal and diurnal changes. Behavioral adaptation (clothing, postures, activity, etc.) on the other hand, can influence perception of certain elements of comfort.

The variables, having some impact on the sensation of comfort, appear in two groups (Goulding et al, 1992). In the first group, there are variables which are related to the physical environment itself and which characterize the range of comfort conditions (Szokolay, 1987).

i. Air temperature
ii. Mean radiant temperature
iii. Atmospheric humidity
iv. Air velocity
v. Light
vi. Sound

There are also other elements of climate, which influence human comfort. While usually described as independent climatic factors, they are more the resultants of impact that variables listed above bring about in combinations with each other. These would include (Szokolay and Sale 1979):

i. Precipitation
ii. Cloud cover (sky conditions)
iii. Air purity

In the second group, the variables represent affected individuals — subjects of the comfort investigation. They point to the way people in buildings respond to certain stimuli, and show how occupant behavior may affect the perception of the building's performance (Koenigsberger *et al* 1974):

i. Thermal insulation of clothing
ii. Activity level
iii. Acclimatization
iv. Body constitution (shape and subcutaneous fat)
v. Age and sex
vi. State of health fitness
vii. Food and drink

The question of what constitutes a 'comfortable' thermal environment has established the implications of the way we design and operate buildings; the amount of energy required to cool and the resulting impact on the quality of both the natural and built environments.

Owing to individual differences it is almost impossible to specify a thermal environment that would satisfy everybody. However, a number of different comfort indices had been devised to attempt to express the satisfaction of certain percentages of the occupants.

Much discussion had been undertaken especially concerning the constancy and adaptive models of thermal comfort. The standard ISO 7730 (1994) is based on the early work of Gagge et al (1971) and Fanger (1970). This static model, which is based on extensive and rigorous laboratory experiments have demonstrated that thermal preferences of humans are the same regardless of geographical location or climate.

However, researchers have questioned the simplistic cause-and-effect approach embodied in these laboratory-derived models to describe real-world thermal perception. A field-studies approach (Adaptive model, Humphreys 1975, Auliciems 1981, de Bear *et al* 1997) has led to a demonstration that when people are engaged in daily tasks in real built environments, their thermal preference has a geographic component. In the adaptive approach to modeling thermal comfort, thermal perception is affected by circumstances beyond the physics of the body's heat-balance, such as climatic setting, social conditioning, economic considerations and other contextual factors. This hypothesis demonstrates that one's satisfaction with an indoor climate is achieved by matching the actual thermal environmental conditions prevailing at that point in time and space, with one's thermal expectations of what the indoor climate should be like.

These important expectations result from a confluence of current and past thermal experiences and cultural and technical practices (Auliciems, 1989). People adapt by changing the physical parameters (environment), their physiology or activity level, their clothing, and their expectations.

The re-analysis by Auliciems of Humphreys data has resulted in the following relationship (combined for both free-running and conditioned buildings):

$T_n = 17.8 + 0.31\ T_m$
Where T_n = neutrality temperature
T_m= average temperature of the month

Numerous studies (Auliciems 1981), (Karynono, 1996), Nicol and Roaf (1996) have also compared comfort measurements with prediction by the constancy and adaptive models. It was found that people living in tropical conditions prefer higher temperatures than those recommended by ISO and ASHRAE standards. De Dear *et al* (1997), Brager *et al* (1998) have also demonstrated through field evidence that there is a wide distinction between thermal comfort responses in air-conditioned and naturally ventilated buildings.

Results from these comfort studies have revealed reasonably close agreement with the static model predictions for people normally in climate- controlled buildings in hot climates. The correlation equation for conditioned spaces found:

$T = 22.6 + 0.04\ ET^*$

Comfort zone = T -2 to T + 2°C (i.e. 4K wide) for 80% acceptability

= T - 1.2 to T + 1.2°C (i.e. 2 wide) for 90% acceptability ET- Effective temperature

For free-running buildings in hot climates, the results demonstrated wide discrepancies with the PMV static model. The adaptive model allows lower and higher comfort temperature with limits of the comfort band for 80 percent and 90 percent acceptability. For free-running buildings the equation found was:

$T = 189 + 0255\ ET^*$

Comfort zone = T - 2.5 to T + 2.5°C (i.e. 5K wide) for 90 % acceptability

= T - 3.5 to T + 3.5°C (i.e. 7K wide) for 80% acceptability

Note that Humphreys and Auliciems used DBT (Dry Bulb Temperature), whilst the last two equations by De Dear *et al*, employ ET*.

The adaptive model recognizes that in the tropics the comfort limits are higher. This is essential in an environment where extreme conditions are leading to the extensive use of air-conditioning even in the housing sector as earlier stated. Extensions of the comfort limits can be provided by the use of ventilation, natural or mechanical (fans). The minimum values of O.25m/s and maximum 2m/s are suggested. This would permit a maximum extension of the comfort zone up to 7K. From this point and above, air-conditioning should be switched on, as the heat stress is too high.

Auliciems and de Dear (1986) have discussed the disadvantages of home air- conditioning and the local demand for these systems. Results from field studies in Darwin had demonstrated that there was overwhelming rejection of home air-conditioning even for the stressful monsoonal build-up period. Perceived disadvantages were high running costs followed by the sensation of having no fresh air, odors and stuffy environment. The perceived advantages were mostly related to the improvement of comfort and the sensation of coolness. Noise, privacy or dust-free environment was minor perceived advantages. Szokolay (1975) had also observed the attitudes towards air-conditioning use in Darwin. From that survey, it was found that running costs was the largest disadvantage of these systems. Whenever the government would provide the installation and maintenance, the users would highly approve and install the equipment. The systems would be preferably installed in the Master bedroom (MB) only or MB and living areas.

The use of air-conditioning certainly reduces acclimatization but in extreme climatic conditions is desired for some periods of the year. Running costs is the main concern related to homeowners, as observed in the field works discussed.

The reduction of energy consumption levels by optimization of the building envelope is a key issue. Other factors include minimum use of NC equipment via combined fans and natural ventilation. These alternatives may be utilized to provide thermal comfort.

3.8 Natural Ventilation

Proper design of energy-conscious buildings requires a balance between two things:

i. the thermal performance of the building envelope and the appropriate selection of techniques for heating, cooling and daylighting;
ii. an acceptable quality of the indoor climate in terms of thermal comfort, ventilation effectiveness or indoor air quality

(Santamouris,, 1998)

These criteria are the basis of guiding principles of standards which demonstrate the evolution of social and technical trends.

Twenty five years ago, we notice a strong evolution of these requirements. In all western countries and more specifically in Europe, until 1973, there was no real policy for the rational use of energy in building design. Energy was cheap and available and building thermal performance and quality were mainly the result of good practice.

After the oil crisis of 1973, we can observe the enhancement of energy policies in all western countries as they became conscious of the limit of energy availability. The main result of this crisis in term of building activity was therefore to reduce significantly global energy consumption, mainly used for heating and air conditioning, while neglecting its impact on the comfort and health of building occupants. The main concepts of the new national regulations, developed in parallel by various countries at this period, were focused on a strong reduction of the energy needs for building heating and air conditioning. The solution proposed was to increase significantly the envelope insulation level and to reduce air infiltration by sealing the building envelope in order to reduce the building energy losses. This period also saw the real development of building research in western countries. The main consequence of the new regulations was a significant reduction of energy consumption in the building sector. However, this was accompanied by an increasing number of disorders, mainly due to humidity condensation and the growth of mould, which affected the health of the occupants, to overheating in summer or in intermediate seasons, which affected the thermal comfort of the occupants, and finally poor indoor air quality due to low air-change rates, which impacted the productivity and performance of the occupants of buildings.

3.9 Double Walled Wind Catcher

There are five main ventilation modes:

i. outdoor air curtain, when the air comes from the outside and is immediately taken in to the outside and returned to the outside – a normal flow;
ii. indoor air circulation, where the air circulates from the inside and stays in to the inside of building;
iii. air supply, where fresh air is supplied into the building through the external skin which might be mechanical and forced ventilation;
iv. air exhaust, where the air comes from the inside of the room and is exhausted from the building facade; and
v. buffer zone, where the facade is made airtight; the cavity comprises a buffer zone between the internal and external skin.

In cavity wall wind catcher, the first one direct airflow from outside is been used. Wind catcher is nothing but a wind catching tower which was used vastly in ancient times in Mediterranean countries. Ventilation towers, in the form of stacks or chimneys, are currently getting popular in modern low-energy ventilation designs. Ventilation towers work by amplifying natural driving forces and serve to extend the depth of space over which a cross-ventilation regime can be applied. There are two main types, wind and thermal chimneys, but several variants exist as classified by NiRiain and Kolokotroni (2000).

The concept of the thermal chimneys utilizes the buoyancy forces generated by the vertical density of temperature differences in a space and across the building envelope in order to drive a vertical circulation across the envelope. Temperature differences are caused by heat gains generated within the spaces themselves from occupants, and electrical and heating equipment and also from the external environment like ground reflectance and the height of the building. The general purpose of thermal stacks is to remove warm stale air at a high level. A variation of this is the solar chimney, which is usually positioned at the south façade of the building and acts as a concentrator of substantial solar heat gains. This further enhances thermal buoyancy. Solar stacks are designed to increase ventilation during the summer months. Constant airflow may reduce indoor temperature up to 5 degrees Fahrenheit.

In 1994, Bansal *et al*. experienced with solar chimney and wind catcher with his style of geometry and the mathematical results shows a significant amount of ventilation raise inside the built environment.

> *The concept of a solar chimney coupled with a wind tower to induce natural ventilation has been studied analytically in this paper. It is estimated that the effect of a solar chimney is relatively much higher on lower wind speeds. For ambient wind speed of 1.0 m/s for example, the wind tower alone creates a mass flow rate of 0.75 kg/s only. while the solar chimney assisted system is able to create an airflow up to 1.4 kg/s at 700 W/m^2- incident solar radiation.*

The double skin wind catcher also advocates cavity ventilation. The ventilation refers to the source of air collection and the destination of the air circulating through the ventilated cavity. The ventilation mode is independent of the type of ventilation applied; such as any suction by some passive solar principles i.e. solar chimney. Not all of the facades are capable of adopting all of the ventilation modes depending on their design and structure. According to Maria Kolokotrorti and Mat Santamouris's book *Advances in Passive Cooling*, at a given moment, a facade is characterized by only a single ventilation mode. However, a facade can adopt several ventilation modes at different moments, depending upon whether or not certain components integrated within the facade permit it (e.g. operable openings).

3.10 Solar Chimney

Historically, the residential use of solar chimneys date back to sixteenth century Italy. These houses were usually referred to as “Scirocco rooms”, where the solar chimneys were used in conjunction with underground corridors and water features to provide ventilation and cooling (Di Cristofalo *et al*, 1989). Due to the invention of mechanical ventilation, these primitive techniques became obsolete. Barozzi *et al*, (1992) developed a solar chimney based ventilation system for dwelling unit and derived from mathematical equation that solar can be used to improve the ventilation. Although their paper suggested design alteration for better results, it could be said as a conclusion that in early twentieth century the research and development has started for the better ventilation condition with solar chimney.

Bansal, Mathur *et al*, 1994 developed a steady state, mathematical model of a solar chimney system which consists of a solar air heater connected to a conventional solar chimney. The thesis concluded that solar chimney promotes ample amount natural ventilation inside the building during low outside air flow. In 2000, Khedari took the field measurements of performance of roof solar collector and compared it to the wall, which directly implies a significant result that passive solar ventilation plays a great role to warm up a building. It indicates that the roof solar collector could be formed below a heated roof to collect the air from the inside of a building. Eventually, the study goes further in 2003. Alfonso (2000) compared a solar chimney model with a conventional brick chimney and found a significant result. He figured out that the heat transfer is not one dimensional along the flow but it was towards the brick wall. There was a performance investigation of south faced solar chimney which was integrated with a one-story building through CFD simulation and an analytical model done by Miyazi *et al,* 2005. He researched for typical Japanese climate (Tokyo, Japan) but the result can be adopted world-wide that the solar chimney is a very important to incorporate natural ventilation inside a building.

> *“The effect of the air gap width was examined by the CFD simulation. The findings are summarized as follows:*

- *The air gap width of the solar chimney hardly affected the mass flow rate induced by buoyancy when the air gap width was more than 0.2 m. The inlet and outlet pressure losses would be dominant rather than the wall friction loss.*
- *The analytical model showed a good agreement with the CFD simulation concerning the prediction of the mass flow rate and outlet air temperature.*
- *Due to the natural ventilation induced by the solar chimney, the daily fan shaft requirement was reduced by 90% in January and in February with the solar chimney width of 1 m. The reduction throughout the year was about 50%.*
- *From a standpoint of the removal of room air contamination, the chimney width of 2 m was sufficient.*
- *In the natural ventilation mode, larger chimney area was required to reduce the cooling load of the building by passive cooling. With the chimney width of 4 m, the cooling load was less than that of the no solar chimney design between 10 a.m. and 12 p.m. on an average day in May.*
- *The solar chimney width of 1 m resulted in the reduction of the heating load. The enlargement of the chimney width more than 1 m caused the increase in the heating load because the surplus of the outdoor air supply resulted in the excess ventilation heat loss.*
- *By the improvement of an insulation level of the inner wall of the solar chimney, the induced mass flow rate was increased. The higher insulation caused, however, the rise of the cooling load and the reduction of the heating load due to the increased thermal resistance.*
- *From the comparison between the case of no solar chimney with 25 mm wall insulation and the case of 1 m solar chimney with 100 mm wall insulation, it was found that the solar chimney was effective to reduce the heating load by about 20% during the heating season. In contrast, the cooling load was increased by about 11%. The overall thermal load mitigation throughout the year was estimated as 12%.*

> *The results showed the advantage of the solar chimney as a passive heating device. It is a common issue for a passive heating design to mitigate the excess heat gain in summer. The authors' future work will be investigations of measures to contract the cooling load in the natural ventilation and the thermal insulation modes* (Miyazi *et al,* 2005)."

From all of these literatures, it clearly implies that Solar Chimney is one of the most important building components to articulate the natural ventilation in a building. Although the proper design of solar chimney is very important, in his thesis Agung Nugroho proved that a solar chimney in Indonesian climate can improve indoor air velocity up to 30% when compared to the standard field study model (Nugroho, 2009).

3.11 Micro Climate and Urban Heat Island Effect

Successful design of a free-running building requires a good understanding of airflow patterns around it and the effect of the neighboring buildings as well as the already mentioned design strategies to improve ventilation. The objective is to maximize the entry of wind flow into the indoor spaces. The main factors, which would affect comfort ventilation using the local winds, are the geometrical configuration, the location and area of openings, the window size, opening details, and the use of fly screens and vegetation. The most critical point is that both inlet and outlet openings should be provided, to produce "cross ventilation".

In hot humid conditions, the more elongated and spread out the building the better the possibilities for natural ventilation. The different pressure zones would increase the potential for catching the prevailing winds. Considering the orientation of buildings it is known (Givoni, 1994) that buildings exposed to oblique winds, angles of 300 to 60° away from the normal, have better chances of providing thermal comfort through ventilation than normal incidences. When considering the location of openings, the height should also be considered, as the height of the inlet opening would determine the level of indoor airflow. Openings close to the ceiling would provide poor ventilation. Opening details to direct airflow downward would be required.

4. METHODOLOGY

4.1 Introduction

These were the steps shown in the figure 4a. that were followed in this study. First, the analysis of weather, determining pros and cons of the site-climate, play with form and geometry based on the derived suggestions from the climate analysis, play with specific passive solar techniques, determining the characteristics of the basecase house, which included: the size of the house, layout, occupancy, envelope, lighting, and equipment, were determined followed by ASHRAE standards. In the second step, these characteristics were incorporated into the Architectural design model of the house. The third step involved an analysis from an architect's intuition.

In all these steps, previous studies were reviewed to determine the characteristics of the climate which lead towards a discovery of array of passive technologies to be used in the basecase house; to investigate better comfort measures in non A/C environment, conditions for their optimal performance. The following sections describe these steps in detail (Figure 4b.).

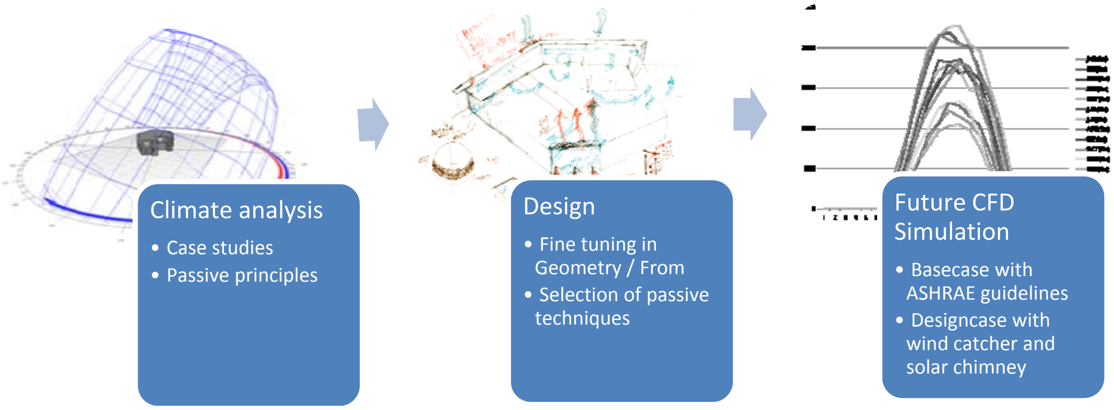


Figure 4a. Methodology – three steps of design philosophy

Here is the diagram of the basic three-step methodology of this study. After climate analysis, the selected passive techniques have been included in the design. These three steps are a normal way to scientifically approach to design. It's the scientific design philosophy. The detailed methodology has been portrayed in the tabular form below. The process of literature review and the climate analysis goes simultaneously. The goal of this research is to find a solution which is affordable and real energy efficient without sacrificing comfort level. In this research study, a residence has been designed.

Determining design guidelines for the Austin Climate

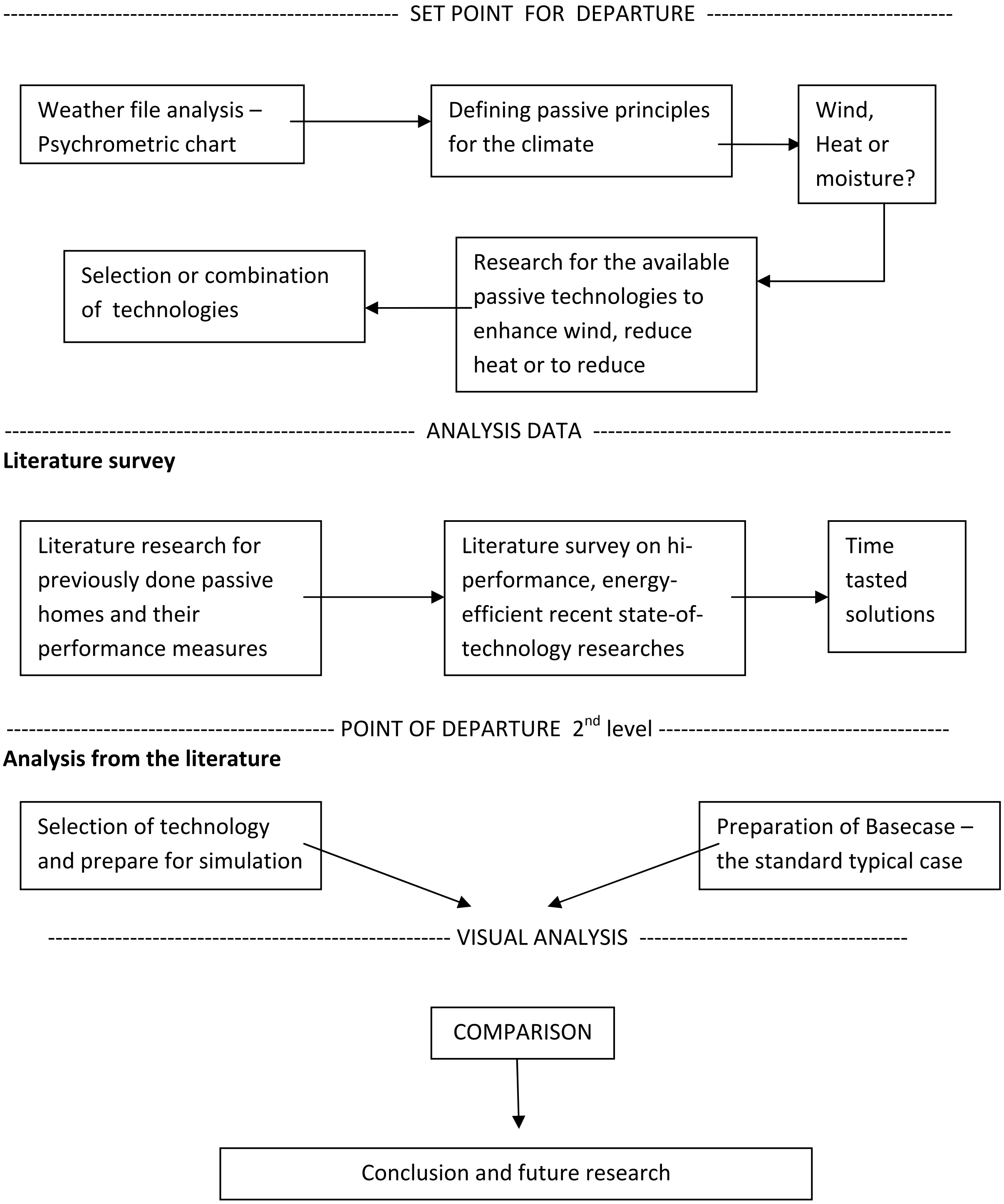


Figure 4b. Detail structure of thesis

4.2 Analysis of Hot Humid Climate of Austin, TX

According to the Climate Consultant 4.0 weather analysis tool, the climate of Austin has the under described properties – The climate file is based on the location 32^{o}29 N and 97^{o}74 W. Therefore, it's not a micro-climate analysis.

From the psychometric chart of Austin's climate, there is only 3.4% of the total time of the year in human comfort zone. 11% of the time can be cooled by natural ventilation and 11.7% of the time can be cooled by fan forced ventilation. 25.1% of time can be taken inside the comfort temperature zone by sun shading.

In the software, Climate Consultant 4.0 there were few recommendations for the passive technologies which could be used in the house-

i. Window overhangs (designed for this latitude) or operable sunshades (extend in summer, retract in winter) can reduce or eliminate air conditioning
ii. In this climate air conditioning will always be required, but can be greatly reduced if building design minimizes overheating
iii. On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees Fahrenheit (2.8^{o}C) thus less air conditioning is needed
iv. Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
v. Raising the indoor comfort temperature limit will reduce air conditioning energy consumption (raise thermostat cooling set point)
vi. Keeping the building small (right-sized) because excessive floor area wastes heating and cooling energy
vii. Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
viii. Use plant materials (ivy, bushes, trees) especially on the west to shade the structure (if summer rains support native plant growth)

ix. Locate garages or storage areas on the side of the building facing the coldest wind to help insulate
x. Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain
xi. High Efficiency air conditioner (at least Energy Star) should prove cost effective
xii. Locate door and window openings on opposite sides of building to facilitate cross ventilation, with larger areas facing up-wind if possible
xiii. Traditional homes in hot humid climates used light weight construction with open-able walls and shaded outdoor porches, raised above ground
xiv. Trees (neither conifer nor deciduous) should not be planted in front of passive solar windows, but rather beyond 45 degrees from each corner
xv. Traditional homes in warm humid climates used high ceilings and high operable (French) windows protected by deep overhangs and porches
xvi. Screened porches and patios can provide comfort cooling by ventilation and prevent insect problems
xvii. For passive solar heating face most of the glass area south to maximize winter sun exposured, but design overhangs to fully shade in summer
xviii. A whole-house fan or natural ventilation can store nighttime 'coolth' in high mass interior surfaces, thus reducing or eliminating air conditioning
xix. Extra insulation (super insulation) might prove cost effective, and will increase occupant comfort by keeping indoor temperatures more uniform
xx. Heat gain from equipment, lights, and occupants will greatly reduce heating needs so keep home tight, well insulated (use ventilation in summer)

From these suggestions, it has been clear that summer heating is one of the vital problems in this climatic condition; southern sun during the winter is vitally needed; and most importantly the #xviii natural ventilation might eliminate air conditioning.

Therefore, my main focus in this design research was to reduce summer heat by improving airflow inside the building which can reduce up to 5 degrees Fahrenheit (2.8^{o}C) in temperature.

4.3 Passive Building Components

For this research, I deliberately picked up a wind catcher and a solar chimney. The selection was not arbitrarily chosen out of the various available passive technologies. In 1994, Bansal *et al* did the first research on wind catchers and solar chimneys together and through his mathematical derivation he proved that to reduce indoor temperature by enhancing airflow, these technologies worked perfectly. There is limited further research on this topic during the decade. There are research papers on each of the techniques either solar chimney or wind catcher. There are papers about the sizes, efficiency and perfectibility of the solar chimney and wind catcher.

These are factors, I considered deeply for my design. The bold items have been taken into consideration in my design and therefore it could be justified through the future CFD simulation.

a. Geometry to reduce summer heat gain
b. Special treatment in design to get enhanced the natural ventilation – solar chimney and wind catcher
c. Building material and insulating material according to ASHRAE standards

4.4 Wind Flow Diagram

The wind flow pattern has been analyzed from the software program, which clearly derives that major wind flows from the south-eastern corner. If we consider summer months then, it’s the direction from where we can fetch a big amount of wind to flow inside the house (figure 4c.). Also, the winter wind flow pattern has been analyzed. Most cold wind flow comes from the north-western direction (figure 4d.). All of these graphic analyses conclude to the form – which is designer intuition. I have put my initial sketches (figure 4e.) of the form-generation which is a part of brainstorming in the design process.

The detail wind analysis has been included in the appendix section.

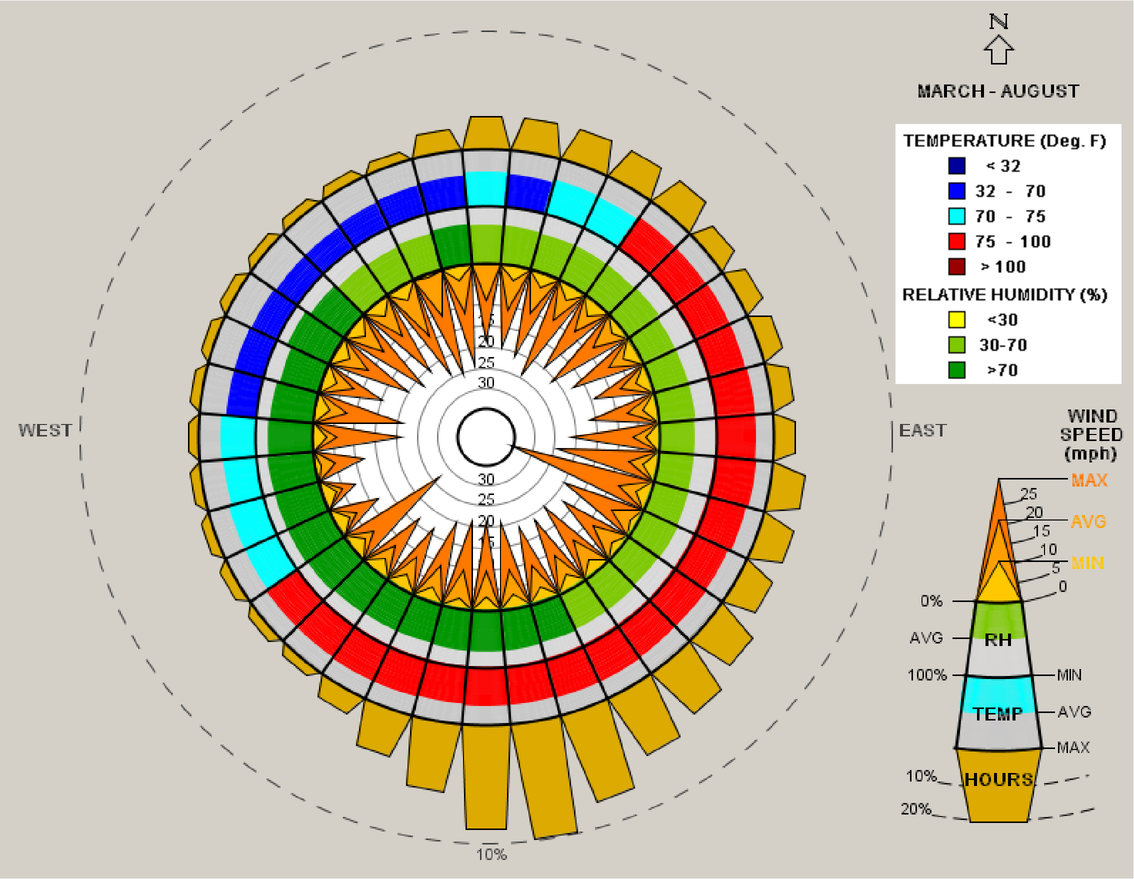


Figure 4c. Summer (extended) wind wheel (*Climate Consultant 4.0*)

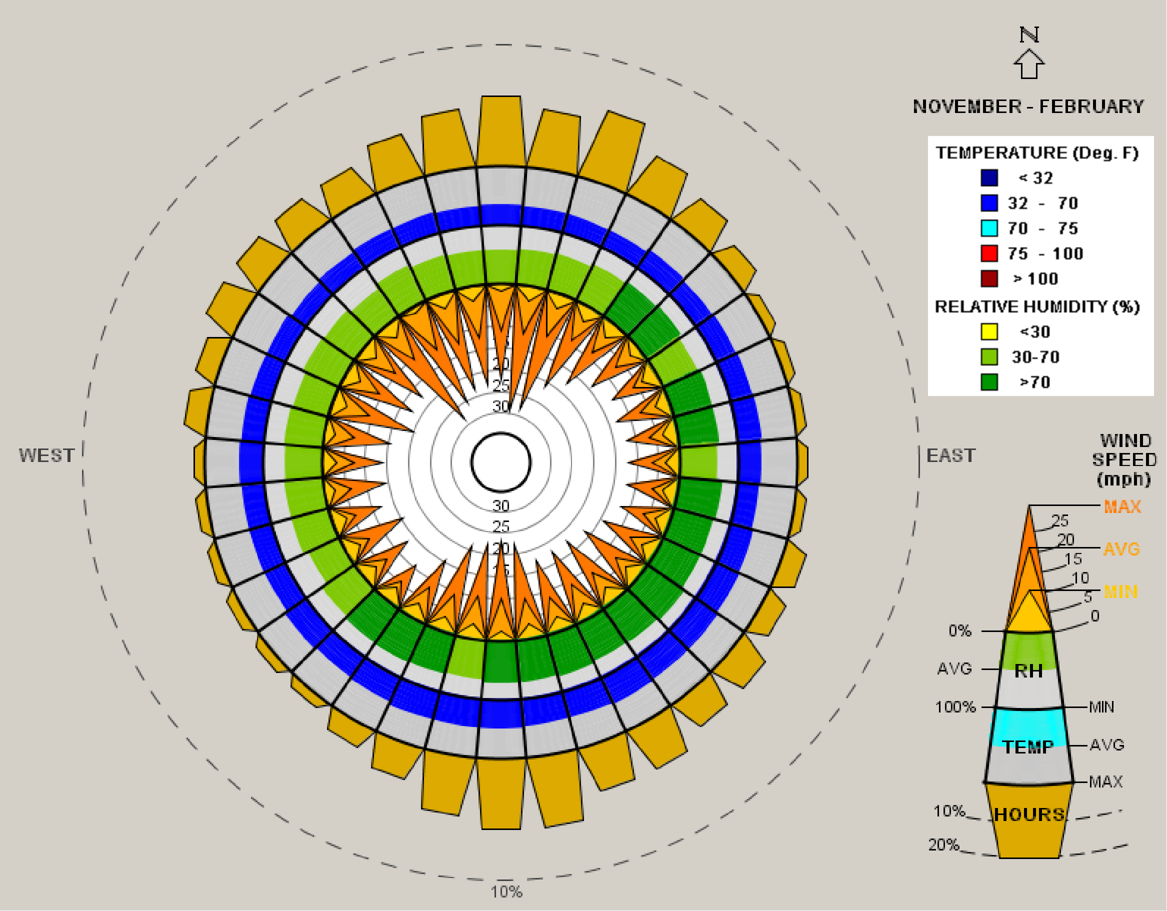


Figure 4d. Winter (extended) wind wheel (*Climate Consultant 4.0*)

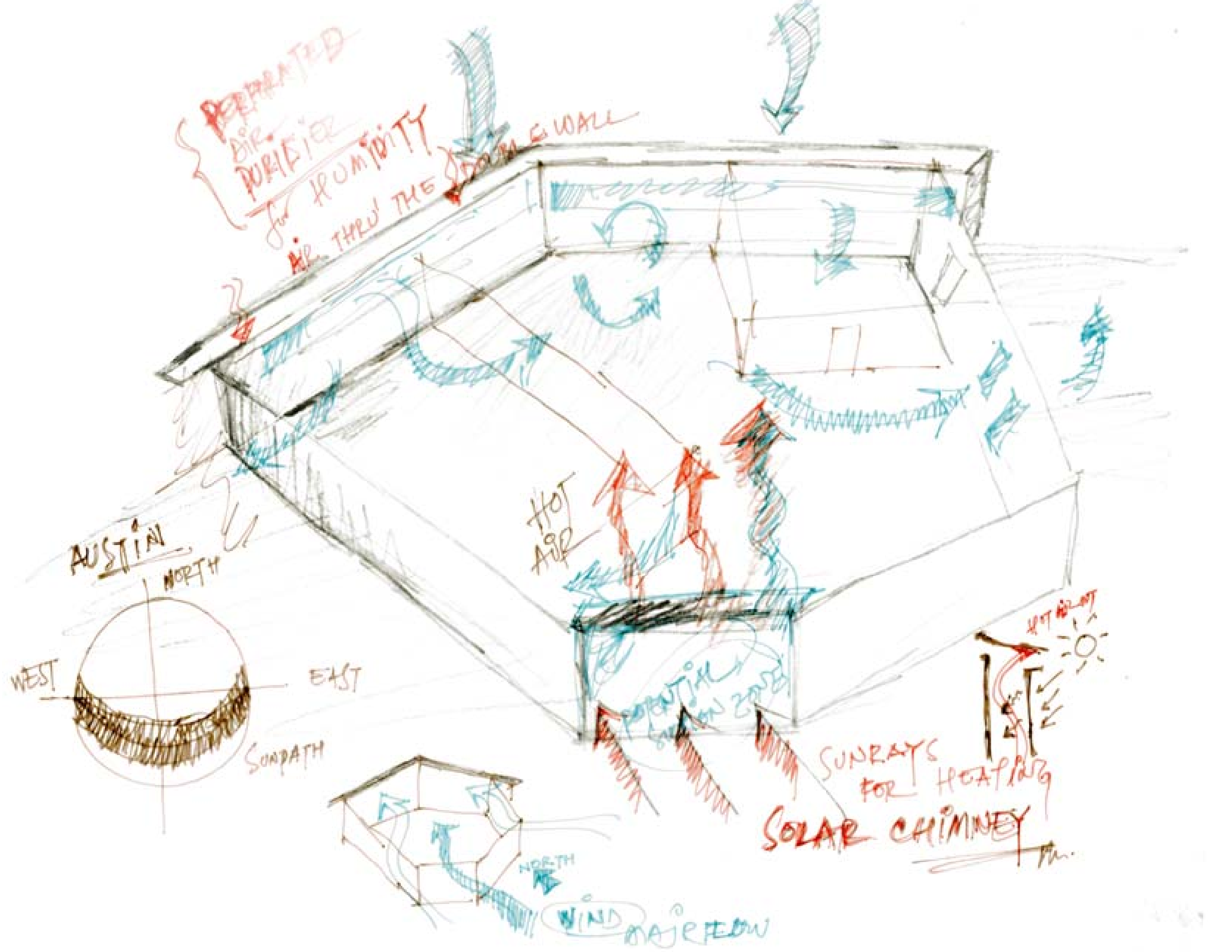


Figure 4e. Initial sketches

4.5 Development of Passive Solar Home

Based on a few studies, this passive solar home is developed. NiRian & Kolokotroni, in the year 2000, did experiments with the solar chimney application in residences. There are few approaches done by researchers in University of California, Los Angeles and Arizona State University in early nineties. There was primitive use of wind catcher in the architecture of Mediterranean countries.

Why?

Although the Solar chimney and wind catcher have been quantified for energy saving measures, there are very less complete built (or designed) residential projects where these techniques were used together.

What?

A Residence design with Double Wall and Solar chimney – the Passive Solar Home.

4.5.1 Plan, Elevation, Orientation

Here are the series of the diagrams to express the evolution of the design process. The sun path diagram has been analyzed which leads to a proper glazing orientation of the building. The images are self explanatory itself.

At the first image there is nothing but the annual sun path. The southern travel path of the sun leads to place the most heat gain-able part of the house at the southern corner. Here goes the solar chimney.

Then there is the wind flow diagram throughout the year for the site. Clearly by analyzing the summer wind flow direction pattern and the winter pattern, the form of the wind catcher comes naturally. The principle is to get more wind during the summer period and to get rid of chilly wind during the winter period. By this simple analysis the form of wind catcher derives.

The house itself is designed to facilitate cross natural ventilation throughout all the windows located on east and west side of the house. Self explanatory diagrams are here (figure 4s.). In these snapshots (figure 4g, 4h, 4i, 4j, 4k) from the simulation program Autodest Ecotect, the sunpath diagram and wind wheel has been put together to visualize the climatic factor of the site. These are the factors which involves the shape-form revolution. The orientation of the building has been calculated for its best (to reduce solar gain) which is 24^{0} off the north line (figure 4f.) and it has been assumed that there are only few trees which barely create shadow over the building.

North Offset: -24.0°

Altitude: 0.0

Figure 4f. Site plan of the house

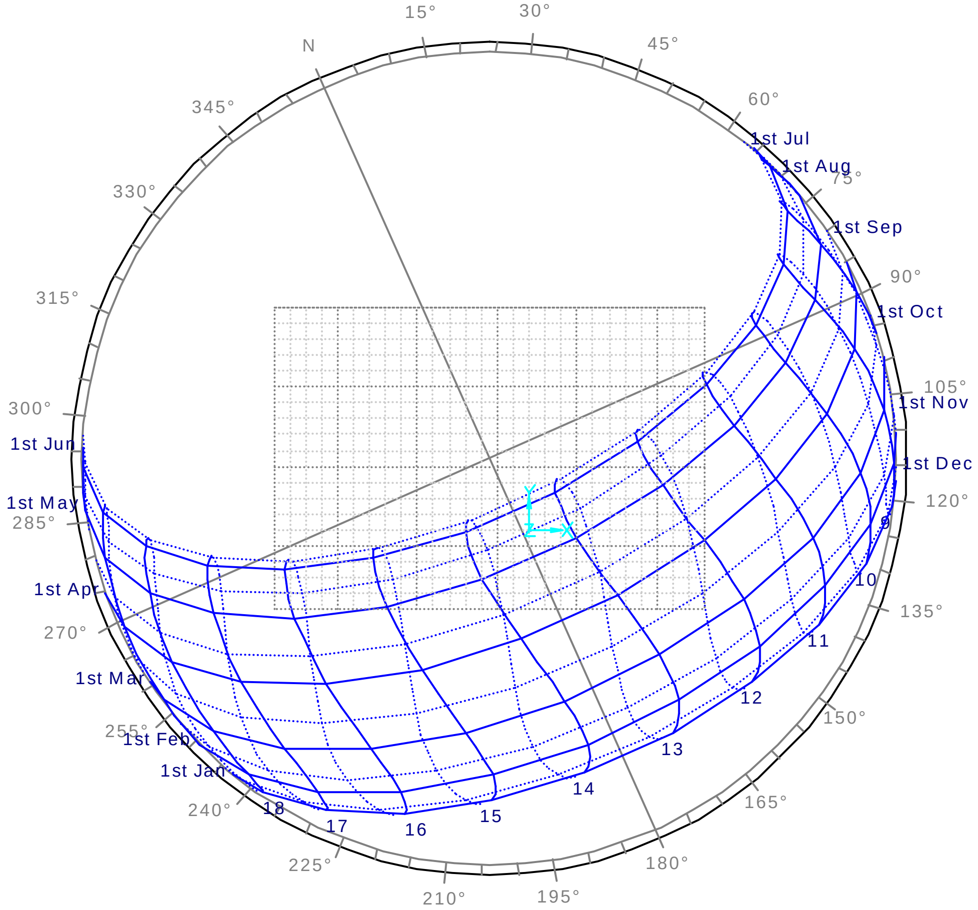


Figure 4g. Annual sunpath diagram over the site

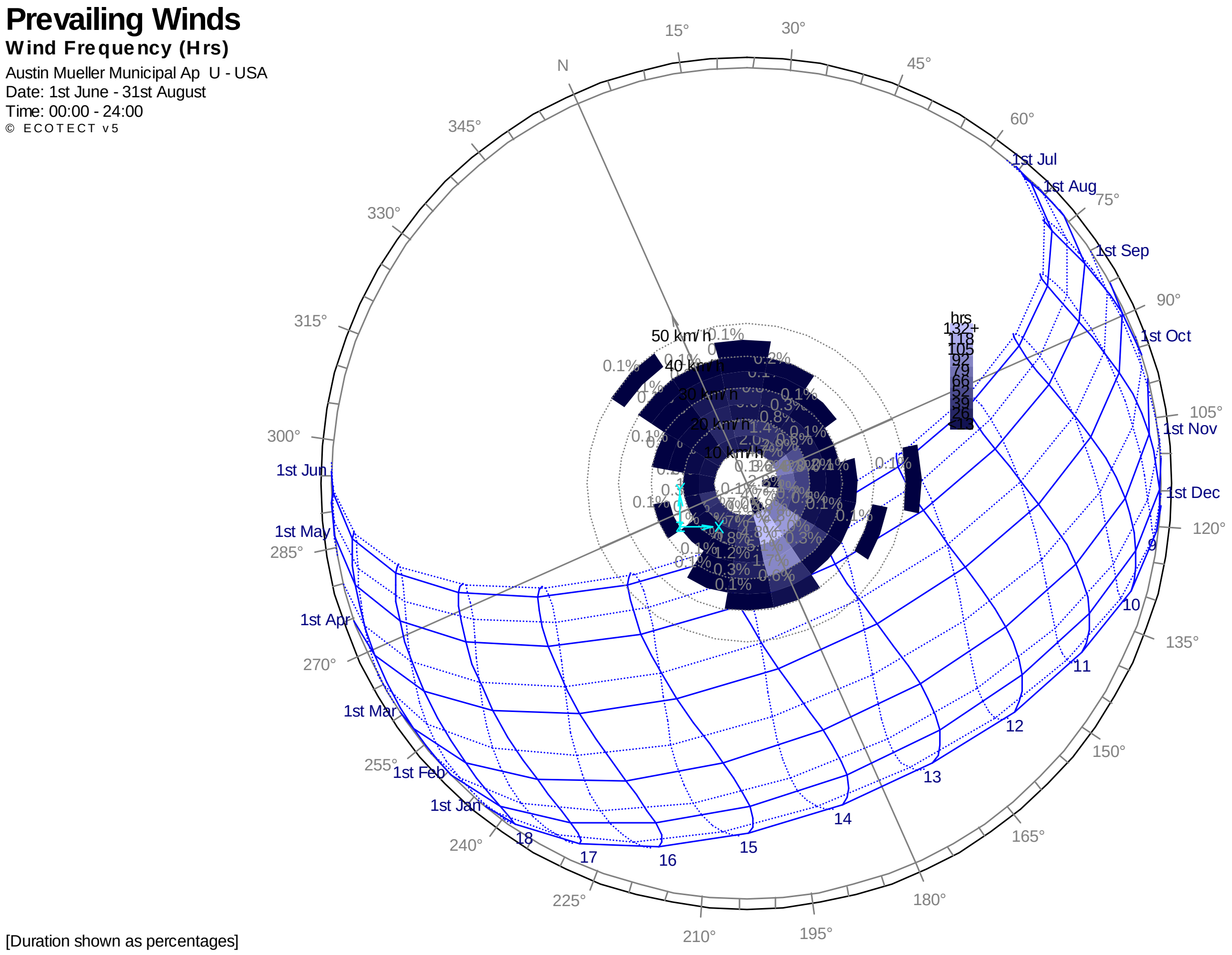


Figure 4h. Prevailing Summer wind over the site

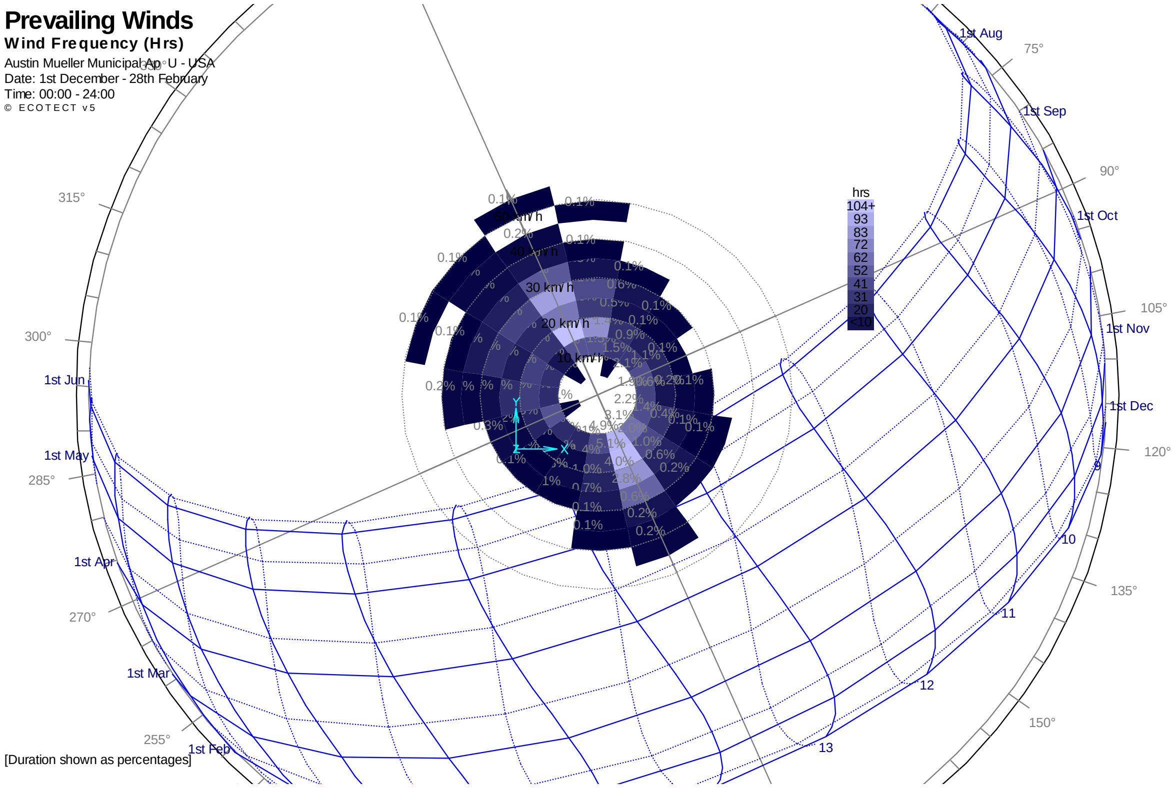


Figure 4i. Prevailing wind in the site

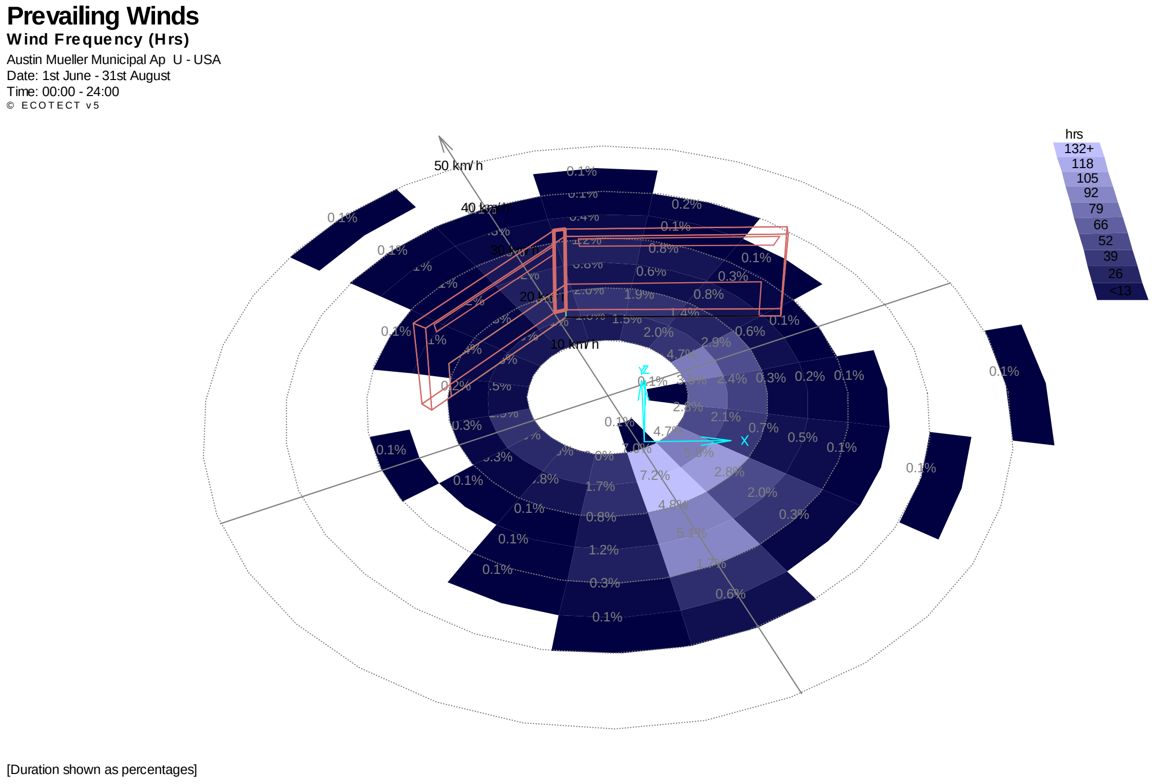


Figure 4j. Origin of the form - wind catcher

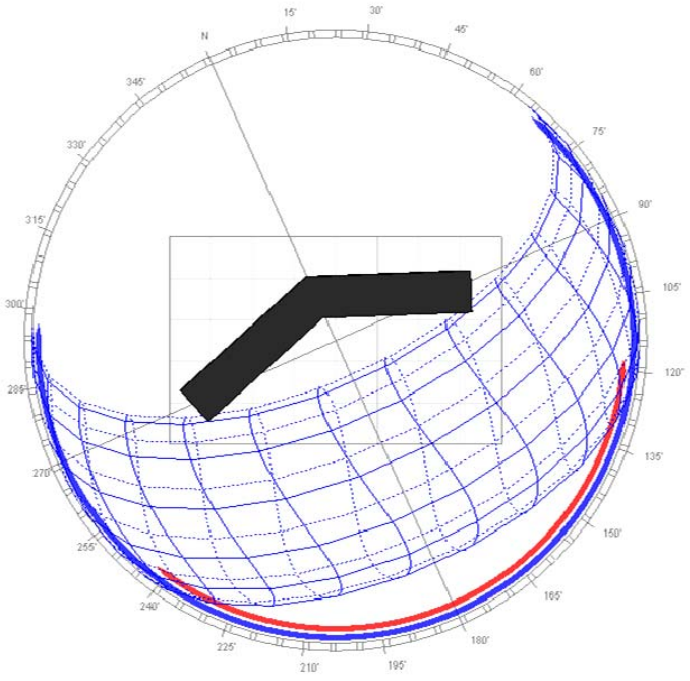
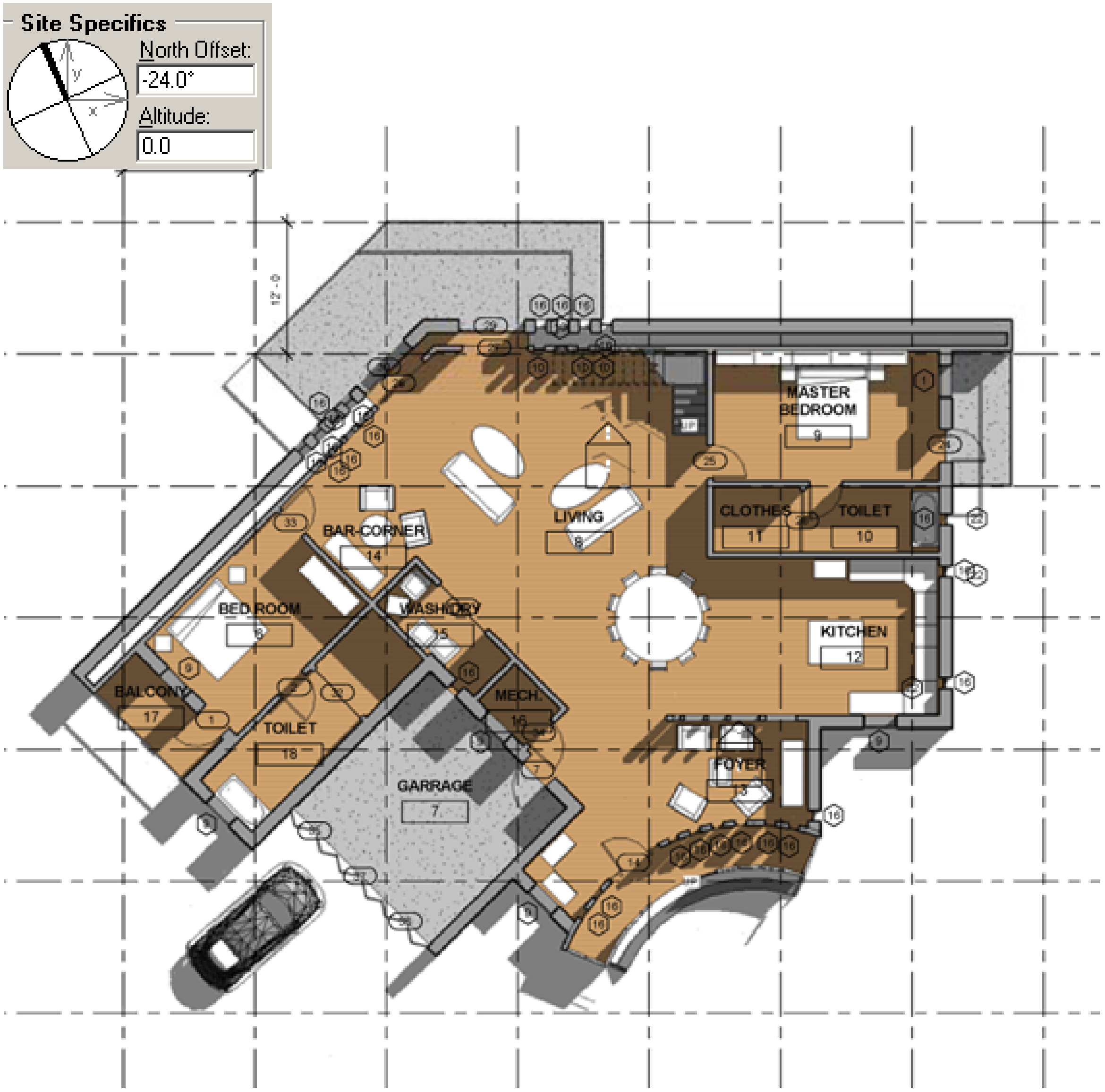


Figure 4k. Position of the solar chimney according to the annual sun path

Plan, Elevation, pathways to natural ventilation airflow and sectional detail (figure 4 l,m,n,o,p,q,r,s,t,u) has been shown in this section of the report. The building consists of two stories. At the ground floor, there in garage at the south-west west corner to give the house a buffer zone which will eventually creates a thermal barrier. Windows are positioned for the optimum cross ventilation. The roof geometry of the house is considered as flat which is against the surrounding neighborhood architecture. The construction materials for the building has chosen from the IECC 2003 manual. Almost all windows in this building are daylight windows which has calculated sun shade. The length is optimum for blocking the sun in summer. A favorable micro climate should be created when the landscaping around the building. Four elevation has been provided here. There are perspectives of the building. From these drawings, the idea of the building and conceptual mind sketch has been produced.

The Basecase has been created exactly the same way of Designcase. The planning of zones. Rooms will be the same but in the Designcase there is these passive features.

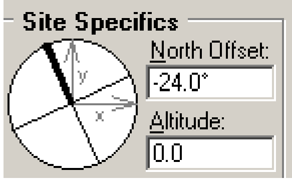


Site Specifics

North Offset: -24.0°

Altitude: 0.0

Figure 4l. Ground floor plan



Site Specifics

North Offset: -24.0°

Altitude: 0.0

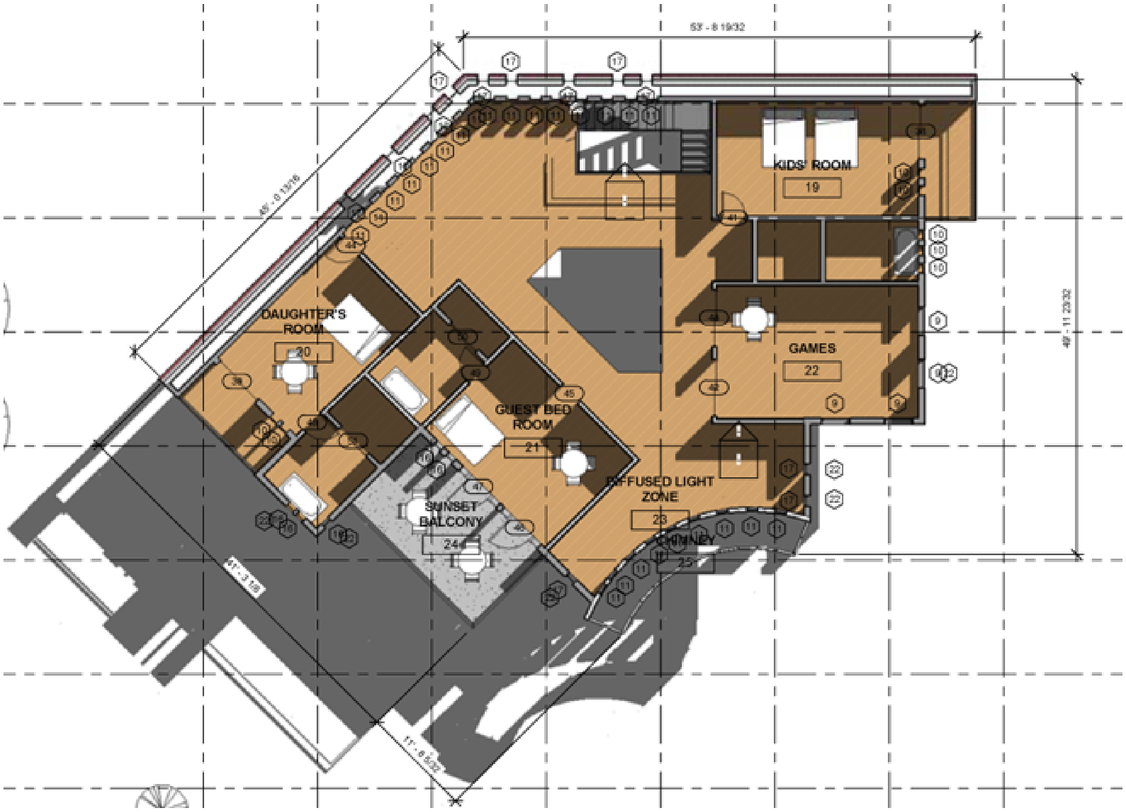


Figure 4m. Plan of first floor

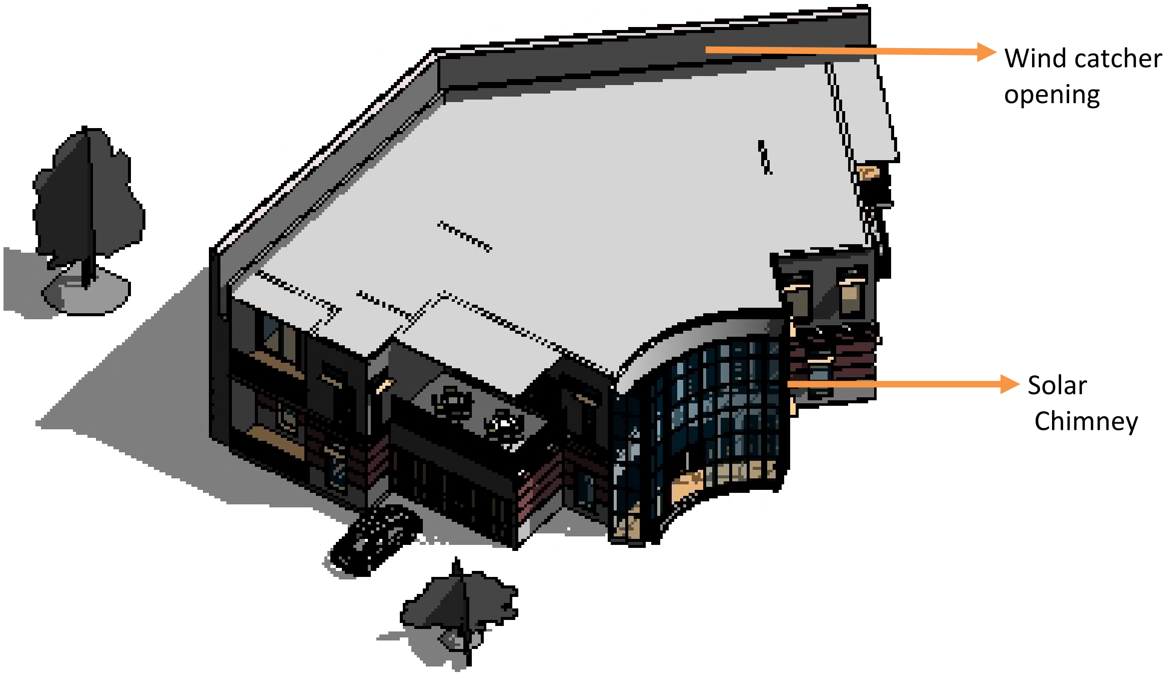


Figure 4n. Passive components in the residence

Figure 4o. West elevation

Figure 4p. East elevation

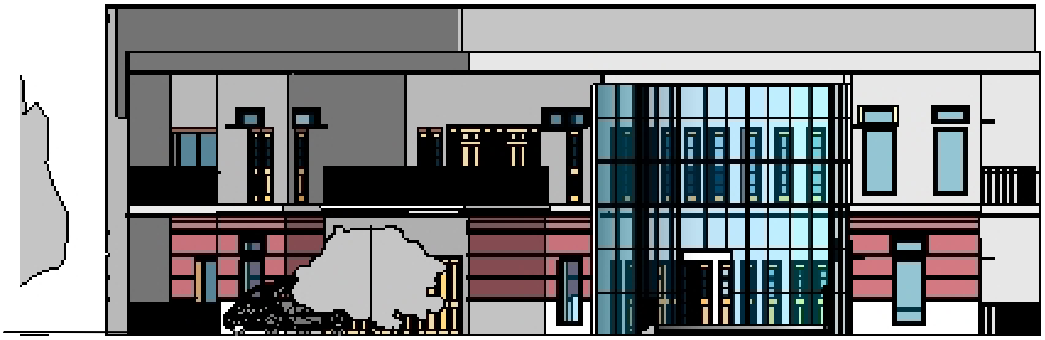


Figure 4q. Front elevation

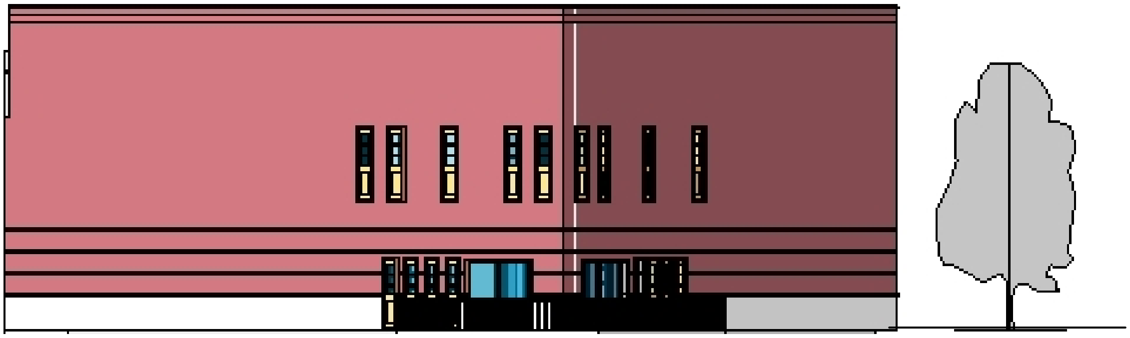


Figure 4r. Back elevation

Figure 4s. Cross ventilation through the openable windows

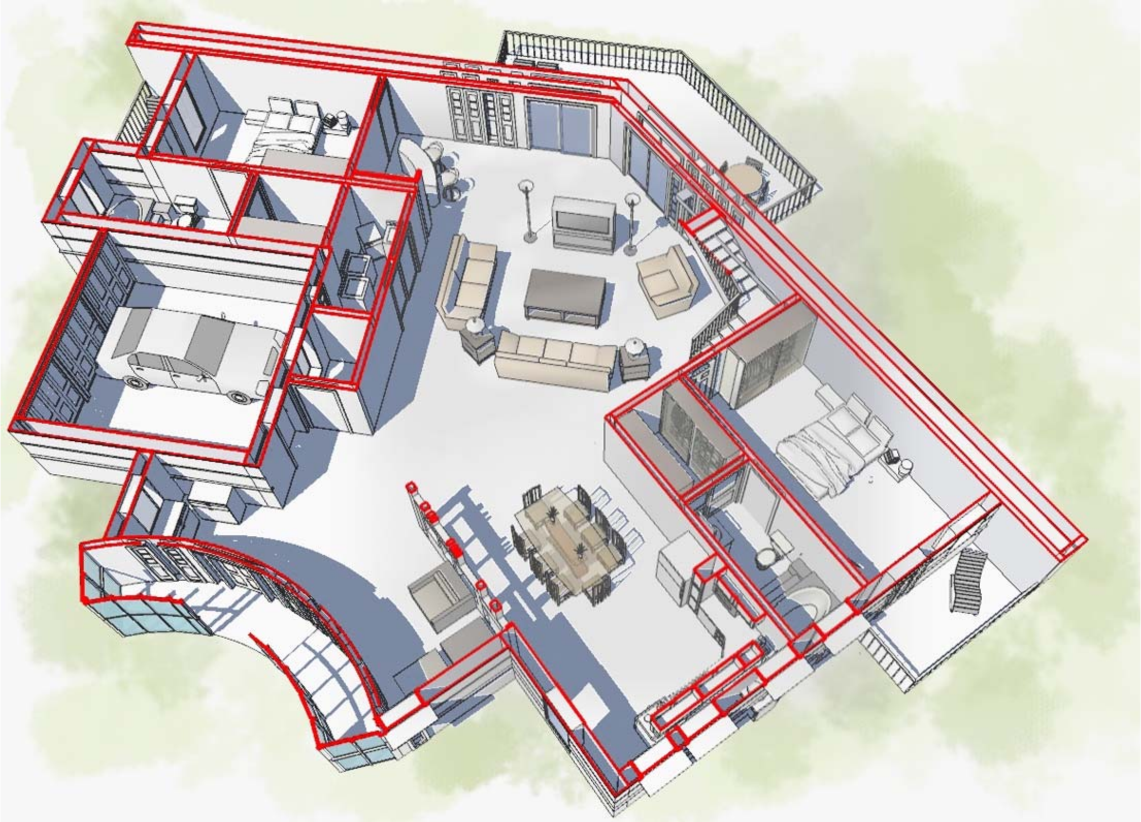


Figure 4t. Sectional view of ground floor

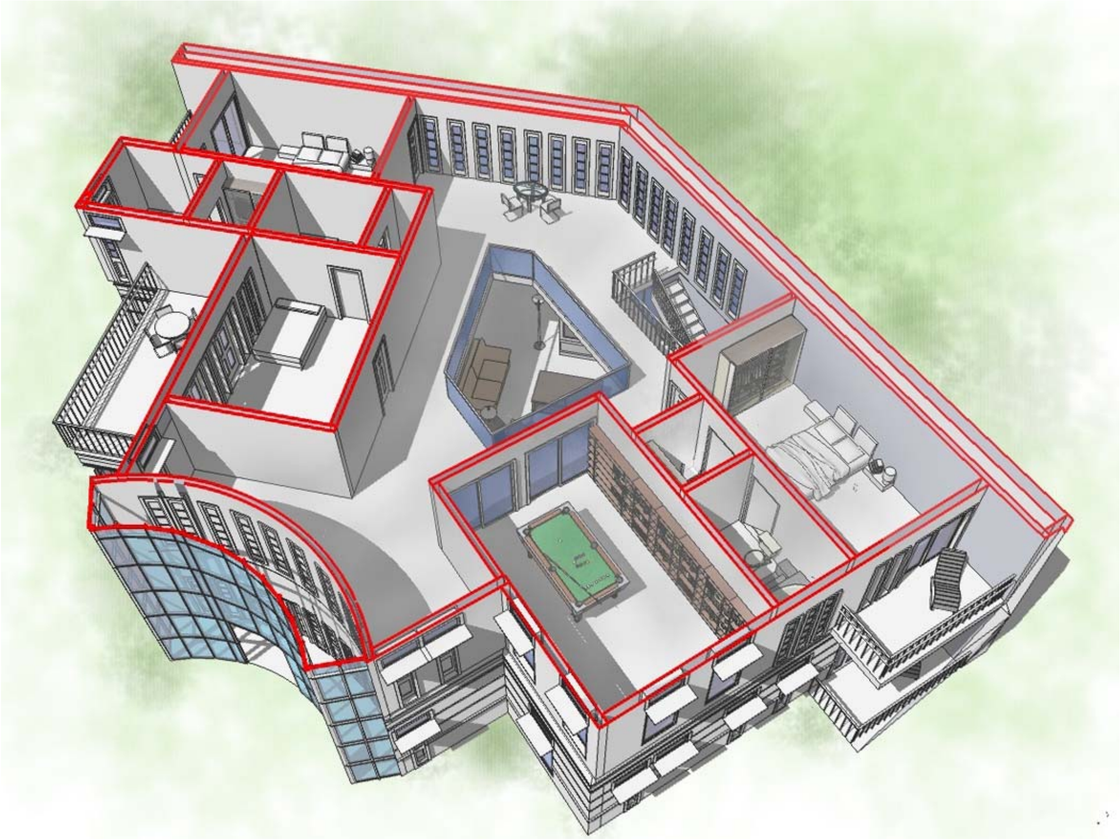


Figure 4u. Sectional view of first floor

4.5.2 Characteristics

For the future CFD simulation the house is a standard house located in Austin, designed in accordance with the Chapter 4 of the 2003 IECC. The house is assumed to be a single family two story house having 2,530 ft2 in each floor, with the front of the house facing south. The floor to ceiling height of the building is 10 ft. The house is assumed to have four bedrooms and altogether six rooms which is the found more in numbers (USCB 2007), and occupied by a family of four people that includes a working father, a housewife, a high school graduate student, and one school-age children.

Building Envelope -The characteristics of the building envelope were determined from Chapter 4 of the 2003 IECC, for a standard design located in Austin that has 1,737 heating degree days.

Equipments and Systems -For the sake of simulation the building has been run as non-air conditioned building. There will not be any kind of mechanical air conditioning or heating equipments present inside the house.

4.5.3 Occupancy

The heat gain from the living elements inside the house is very important factor. Human comfort level is dependent upon the occupancy of the house. The regular activities of the occupants of the house for weekdays and weekends were assumed to represent that of a typical family of four. This assumed a working father, a housewife, one college going daughter and one school going son. The daily routine was assumed to start at 5:30 AM on weekdays and at 8:00 AM on weekends. The children and the father leave the house at 8 AM and return at 3 PM and 6 PM on weekdays, respectively. On weekdays, the mother leaves for shopping from 11 PM to 1 PM. On Weekends, the family goes out from 9AM to 12PM and again from 3 PM to 6 PM for extracurricular activities. The household cleaning and laundry was assumed to be done on Saturdays and Sundays. The major cooking was assumed to be done twice a day, except on Sundays.

4.5.4 Construction Type

According to International Energy Conservation Code 2006 suggestion Austin, which has 1737 Heating Degree Days, falls under zone 4. For that Exterior of single family detached residential building mass wall assembly R value will be 8.9 to 10.8.

In the Ecotect energy model, the material has selected according to this standard.

The ceiling or the roof has been classified as cold-framed steel roof. For the Ecotect model, I have used R-38 assembly.

By the law of IECC 2006, here are the properties of the construction materials.

Fenestration *U* factor – 0.4

Skylight *U* factor – 0.60

Glazed fenestration SHGC – NR

Ceiling *R* value – 38

Wood frame *R* value – 13

Mass wall *R* value – 5

Floor *R* value –19

Slab *R* value and depth – 10, 2 ft.

4.5.5 Fenestration Properties

Apart from abiding by all the standard measures from IECC 2006, the windows used here are all light-self window. All of the windows have projected sun shade and daylight opening above the sun shade (Figure 4v). These windows are standard features from Autodesk Revit, the drafting software I've used for this research.

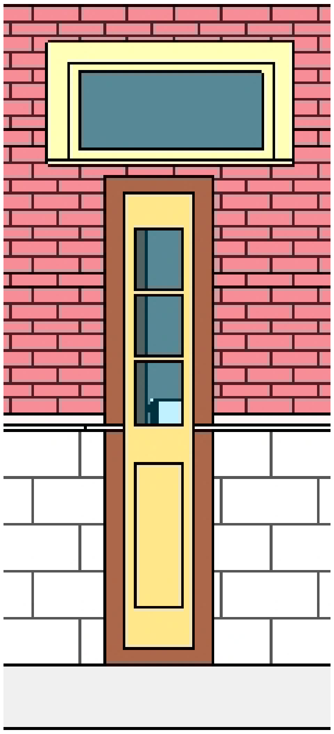


Figure 4v. Typical sidelight window with daylighting and sun shade

4.5.6 Summary

The wind catcher has been placed at the north-western corner, at the edge of the building facing south. The optimum wind flow direction has been calculated and the orientation has been determined.

Solar Chimney is on the most southern part of the building. It is supposed to gain the maximum solar radiation that way the artificial suction pressure will be created inside the house which will lead buoyancy driven air flow.

There will be controllable louvers inside the wind catcher to regulate the airflow. Though the maximum cold wind blows from the opposite direction (*Climate Consultant 4.0;* Austin weather file analysis), there will be arrangement of the operable louvers. The flow controlling louvers could stop the heat loss during the winter time by preventing cool wind catching. It will act like an air buffer which will be great insulating substance.

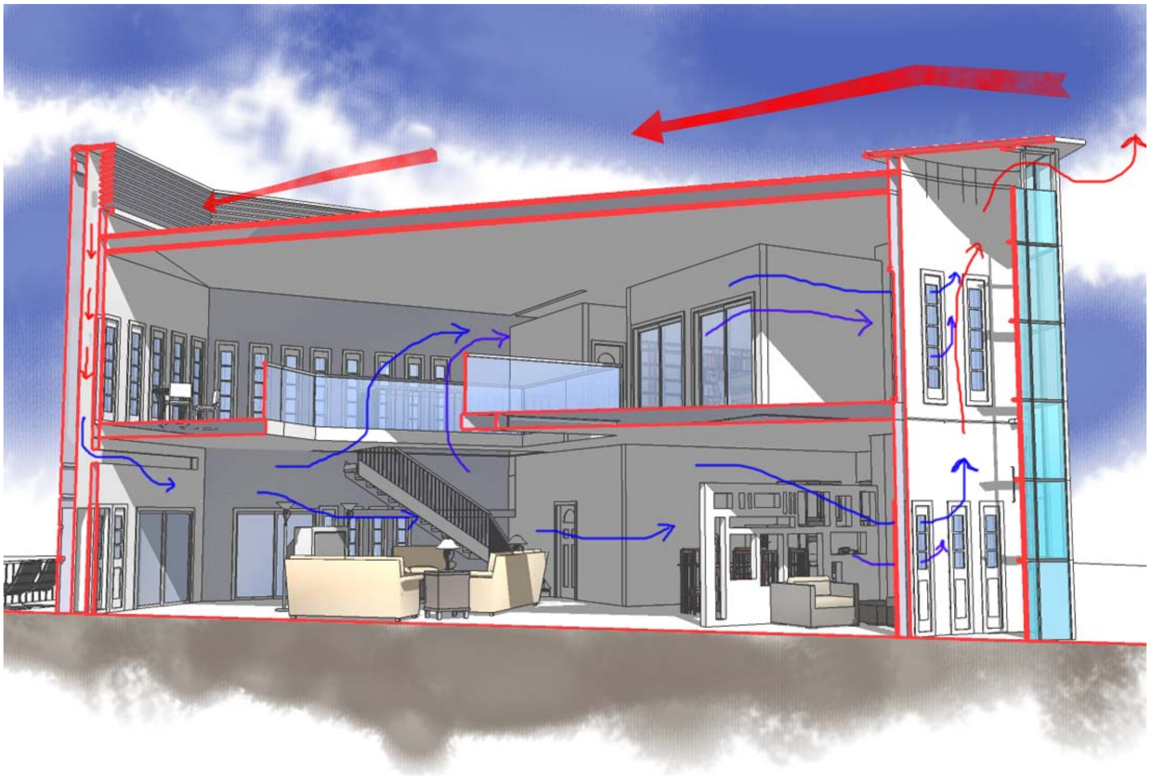


Figure 4w. Section showing the wind flow through the building

4.5.7 Designcase and Basecase

Basecase: Characteristics and specifications

For the visual comparison, a basecase is generated. The Basecase model is nothing but the Designecase except the solar chimney and the double wall wind catcher. All building materials are same. Window area remained same in the north facing wall of the Basecase. Every design feature has been tried to remain same like the Designcase. Here are the pictures of the models of the design case and the basecase (Figure 4x., 4y).

Model of Designed home

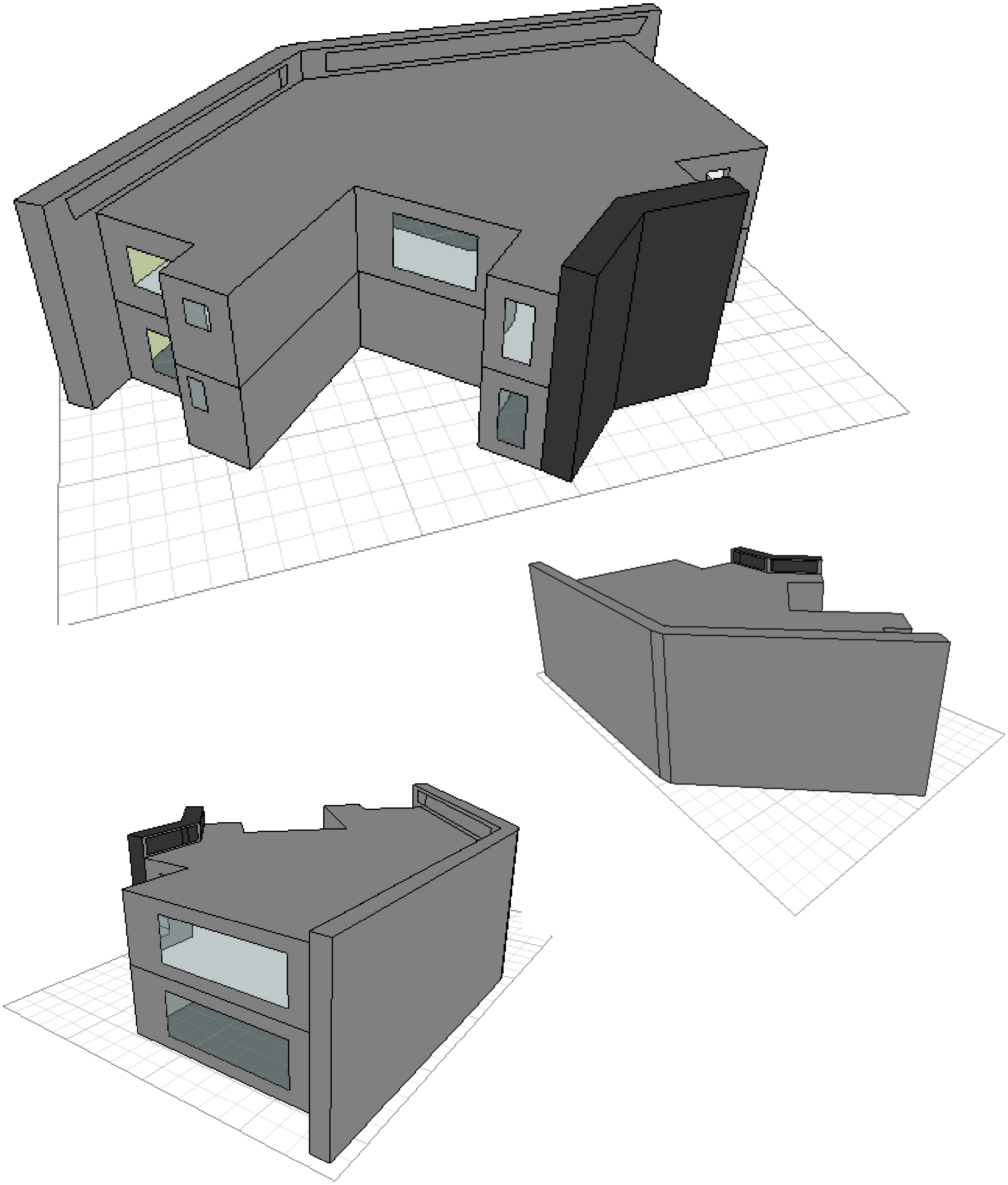


Figure 4x. Various images of the model

Model of Basecase

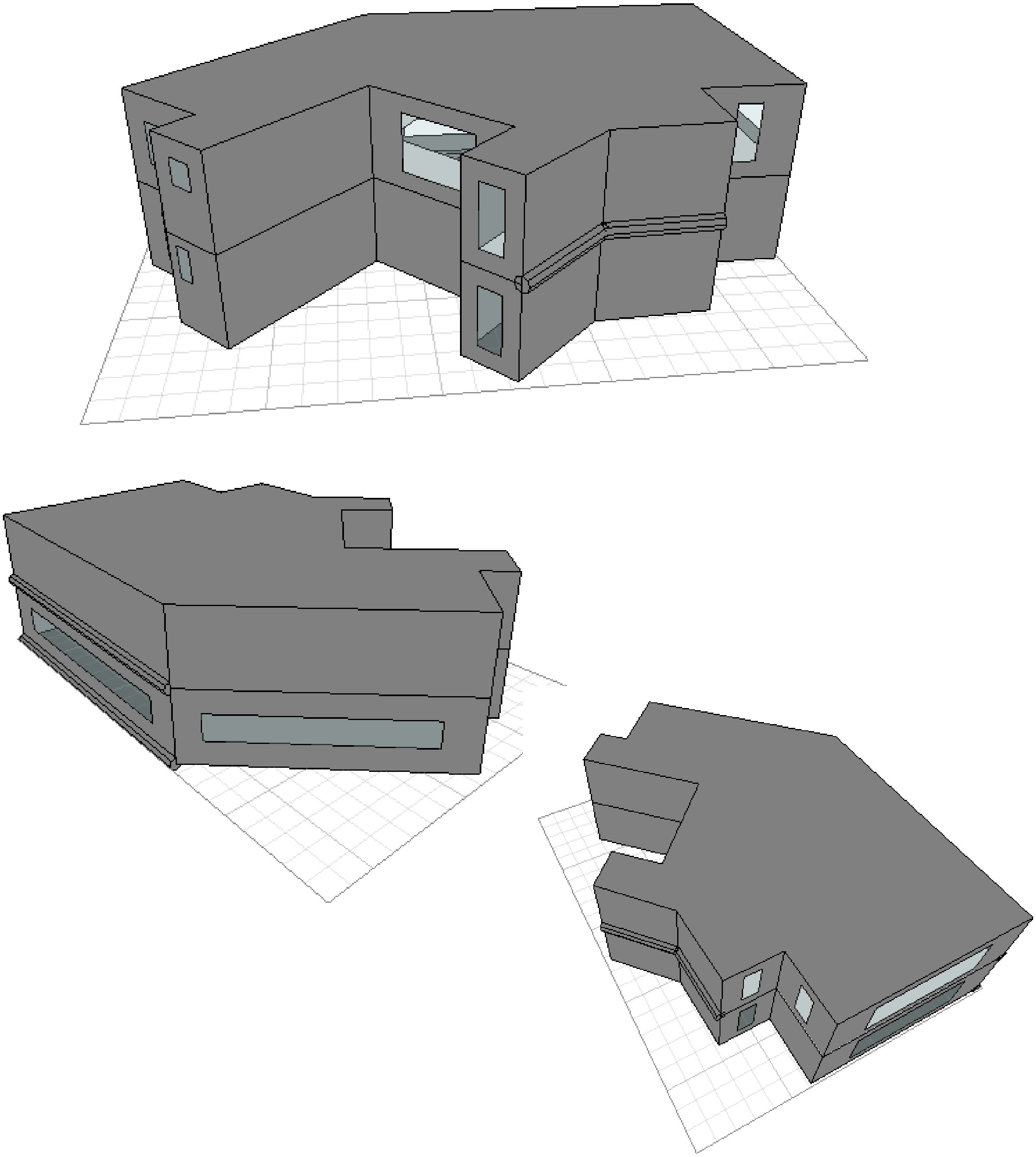


Figure 4y. Various views of the Basecase

5. CONCLUSION

5.1 Suggestions for Future Research

There is no proven conclusion but from the architectural sense it can be concluded that in the house there will be increased airflow which might trim down discomfort hours during the summer as well as in winter. By the passive design, we might be able to get less discomfort hours in hot humid climate like Austin, TX.

This intuitive conclusion from the thesis explores that the solar chimney with wind catcher might bring more thermal comfort (less dissatisfaction level) in indoor climate which can eventually save energy. The intent of the design during the summer is to rid the building of warm air while circulating a cool breeze, which will reduce the number of indoor discomfort hours.

This thesis did not included the analysis of many other energy-saving measures such as, high-tech home appliances, hi-performance equipments for mechanical air conditioning, daylighting, solar thermal and photovoltaic, rain water harvesting, landscaping etc. These measures can be analyzed using other future CFD simulation programs in conjunction with the Ecotect, to fully realize the potential of renewable energy sources available on the site and maximize savings.

In the future CFD simulation, there should be simulation for different building geometry like high-pitch roof, vented attic and ducts inside the vented attic, which are typical characteristics of residences in the hot and humid climate of the United States.

To perform a more accurate analysis, a detailed energy modeling program should be used which is perfect determining boundary condition in CFD algorithm.

However, 2006 IECC does not include any specification for orientation and slope of the roof. In future, more detail analysis of the protocol which has wind catcher and solar chimney together can be researched in more detail – about the sizes, length and height.

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APPENDIX A

The Basic Approach to the Design

Primary source*:* Bansal et al. *, Passive Building Design*, Elsevier Science B.V.

Going through all these building types I came up with few conclusions. To have optimum thermal comfort without using air conditioning systems, we need to play with humidity and mostly natural ventilation. Technical solutions for natural ventilation in residential buildings depend on the building type, size, and form, as well on the climate of the site. Two basic types of dwelling are the most common: the one-or two-storey single-family unit, either a single house or a unit in a terraced building or multi story apartment building. But I am here to concentrate upon the single unit detached or one terraced unit.

Through a proper study of local weather and climate we need to decide the insulation factors for the building skin. Effective use of solar can optimize the direct heat gain and the passive solar can be used for natural ventilation.

For typical Hot Humid climate in Austin, Cooling is very important.
Here is some state of technology passive techniques for cooling.

- Reduction of solar and convective heat import
    1. Orientation
    2. Shading of neighborhood building
    3. Shading by vegetation
    4. Shading by overhangs, louvers and textured facades
    5. Reflecting surface
    6. Shelter against hot winds
- Reduction of heat transmission into building
- Increase of heat loss from the building radiation

- Increase of heat loss from the building by convection
    1. Outdoor wind management
    2. Indoor natural management (Solar Chimney, Stack effect, Courtyard effect, air vent)
    3. Indoor forced ventilation
    4. Air cooling by tunnels
- Indoor forced ventilation
- Evaporation
    1. Outdoor air cooling
    2. Indoor air cooling
    3. Building surface cooling
- Thermal storage
    1. Building elements
    2. Earth cooling
    3. Water cooling

Wind-driven cross ventilation through windows placed on opposite external walls is relatively easy in single-family residential units, if a careful interior design and a proper location of the windows allow for optimal use of the differential pressure generated across the building.
When wall cross ventilation is not effective owing to low air speed caused by the low level of opening, shielding or meteorological conditions, roof ventilation can be added. This is based on Bernoullli-Venturi effect that includes air to be sucked out of a roof opening at the ridge, as mentioned above in relation to wind escapes and air vents. The sucking effect is stronger if a Venturi tube is used as a roof ventilator. Based on this principle, wind-driven cross ventilation can be enhanced in both one-storey and two-storey residential units, providing ground and upper floors are connected by an open stairwell.
Even when wind is absent, roof ventilation can increase the airflow rate as a result of the stack effect. Special Roof opening can be employed in order to optimize the combination of wind and stack ventilation. A double-shaft roof ridge opening with mono-directional flaps against the wind functions only as a suction device combining the Bernoulli and stack effect.

(Bansal *et al.*, *Passive Building Design*, Elsevier Science B.V.)

One of the difficulties in designing natural ventilation systems is the estimation of internal temperature distribution. Especially in summer conditions, the temperature of each space will depend on the ventilation rate, which will itself depend on the temperature distribution, particularly when using buoyancy driven strategies.

In principle this difficulty can be overcome by combining a ventilation model/ Envelope flow or Computational Fluid Dynamics with a thermal model. Ideally the two models would be completely integrated such that the governing equations are solved simultaneously. A simpler strategy is to solve the two models separately, with some form of link between their solutions.

There is a class relatively simple model that combines an envelope flow model with the internal flow associated with buoyant plumes, leading to simultaneous prediction of ventilation rate and temperature stratification within the space. Although capable of giving good quantitative agreement with simple physical models, the assumptions made about the internal air motion and heat transfer mean that this type of model is not at present suitable for quantative design.

Apart from all these technology used in these available ready-made homes there are few fundamental physics that can be used as passive design techniques. Application of Solar Chimney, Stack effect, and Geo-thermal energy (According to NREL south Texas has few geo-thermal potential zone.) are the most recent trends in designing building. Though lots of research has been done on passive solar architecture from early seventies but it’s still on business.

APPENDIX B

The Climate Analysis

With the help of the tool called *Weather Tool* (Centre for Research in the Built Environment, Cardiff University, UK) and with ASHRAE weather file, the psychometric data of the Austin climate has been analyzed. The average 20 years of climatic data are stored in the ASHRAE climate file. Therefore, after analysis of the data, an optimum orientation has been defined for a two story residence. The orientation has been calculated to catch the less summer wind and maximum hot winter wind. According to the orientation, a wind catcher has been designed.

Here are few snapshots from the *Weather Tool* with *USA_ TX_Austin_TMY2.epw* (weather file from DOE website).

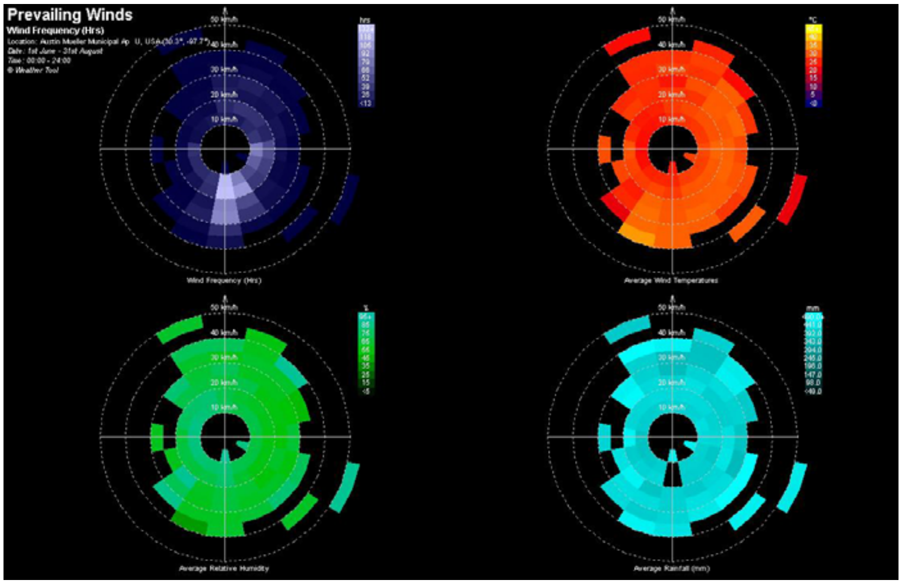


Figure 5a. Austin summer prevailing wind flow, temperature, rainfall, relative humidity direction

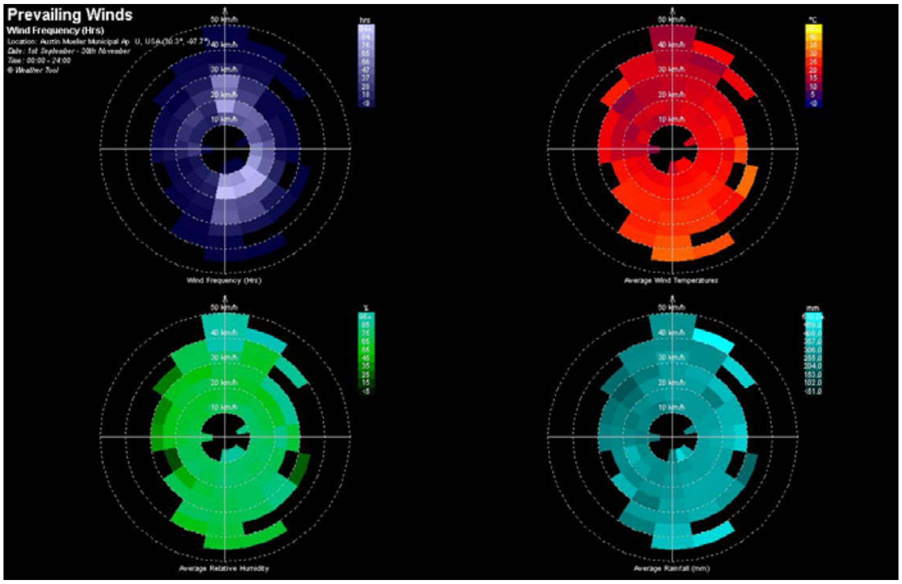


Figure 5b. Austin fall prevailing wind flow, temperature, rainfall, relative humidity direction

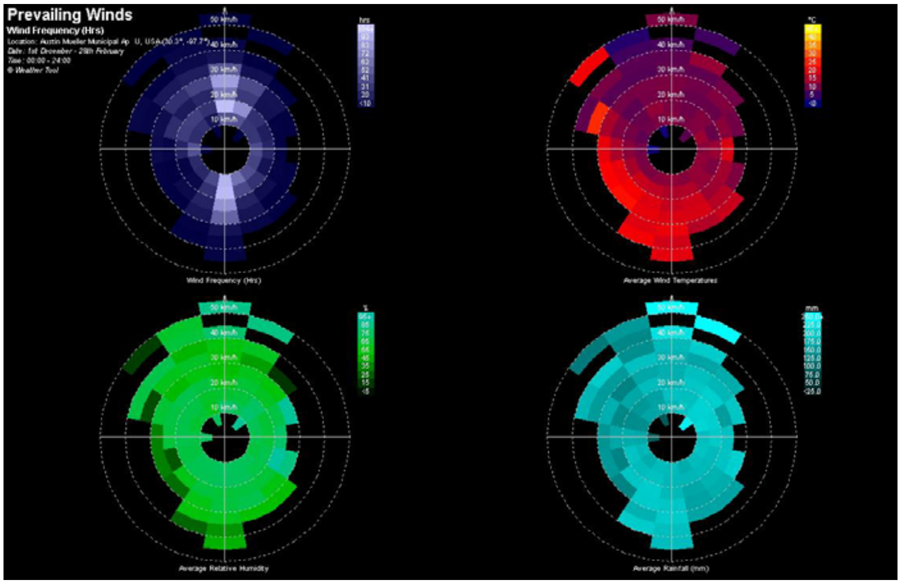


Figure 5c Austin winter prevailing wind flow, temperature, rainfall, relative humidity direction

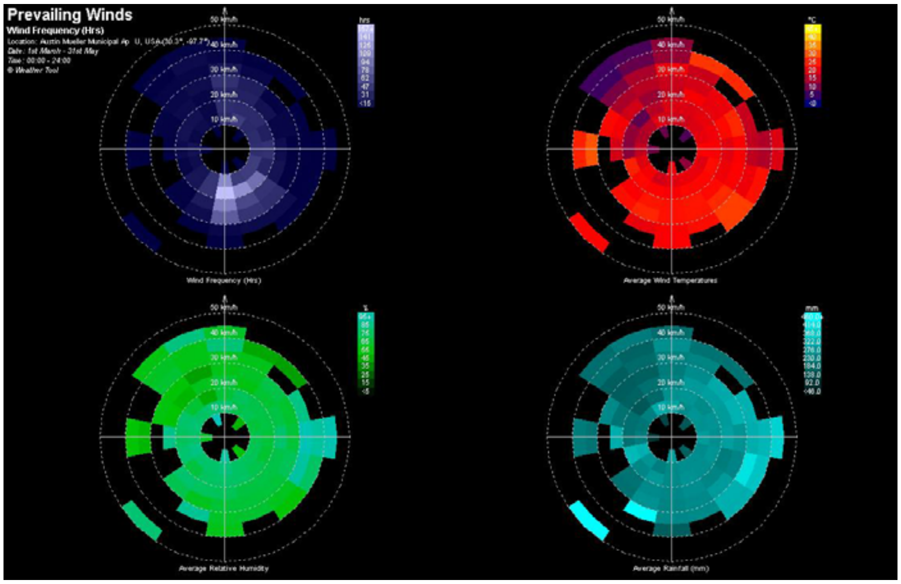
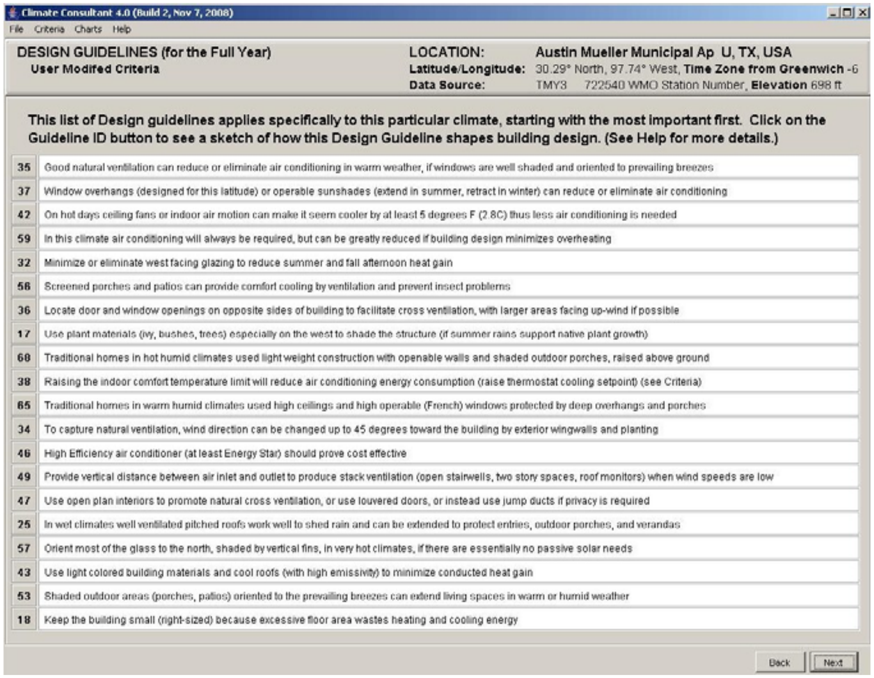


Figure 5d. Austin spring prevailing wind flow, temperature, rainfall, relative humidity direction

There is another program called *Climate Consultant 4.0 (Robin Liggett & Murray Milne, Energy Design Tool Group, UCLA.)* has been used for the climate analysis of Austin. The same weather file has been used here. There are snaps in the methodology section.



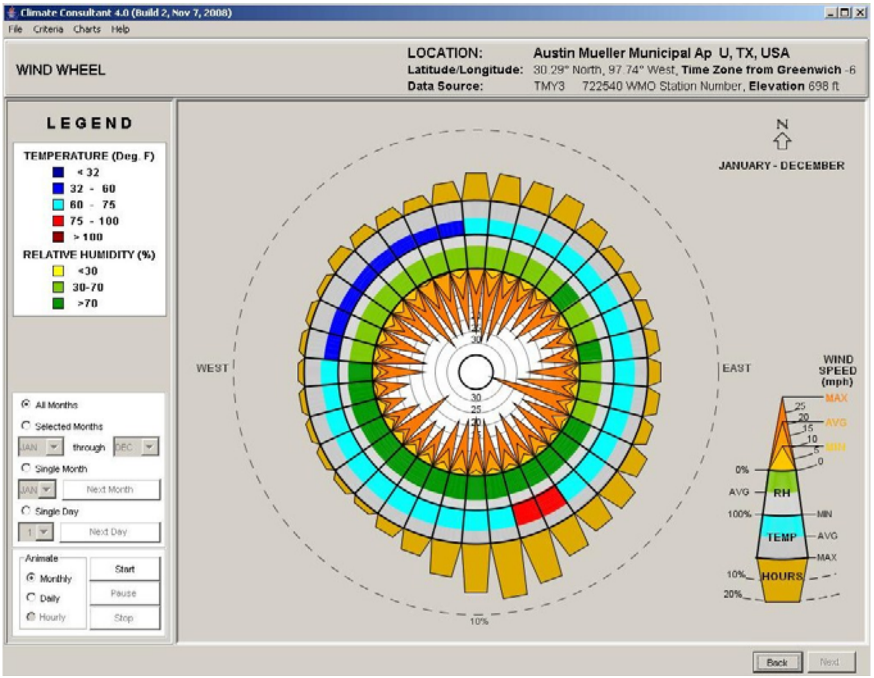
DESIGN GUIDELINES (for the Full Year)
User Modifed Criteria

LOCATION: **Austin Mueller Municipal Ap U, TX, USA**
Latitude/Longitude: 30.29° North, 97.74° West, **Time Zone from Greenwich** -6
Data Source: TMY3 722540 WMO Station Number, **Elevation** 698 ft

This list of Design guidelines applies specifically to this particular climate, starting with the most important first. Click on the Guideline ID button to see a sketch of how this Design Guideline shapes building design. (See Help for more details.)

35	Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes
37	Window overhangs (designed for this latitude) or operable sunshades (extend in summer, retract in winter) can reduce or eliminate air conditioning
42	On hot days ceiling fans or indoor air motion can make it seem cooler by at least 5 degrees F (2.8C) thus less air conditioning is needed
59	In this climate air conditioning will always be required, but can be greatly reduced if building design minimizes overheating
32	Minimize or eliminate west facing glazing to reduce summer and fall afternoon heat gain
56	Screened porches and patios can provide comfort cooling by ventilation and prevent insect problems
36	Locate door and window openings on opposite sides of building to facilitate cross ventilation, with larger areas facing up-wind if possible
17	Use plant materials (ivy, bushes, trees) especially on the west to shade the structure (if summer rains support native plant growth)
60	Traditional homes in hot humid climates used light weight construction with openable walls and shaded outdoor porches, raised above ground
38	Raising the indoor comfort temperature limit will reduce air conditioning energy consumption (raise thermostat cooling setpoint) (see Criteria)
65	Traditional homes in warm humid climates used high ceilings and high operable (French) windows protected by deep overhangs and porches
34	To capture natural ventilation, wind direction can be changed up to 45 degrees toward the building by exterior wingwalls and planting
46	High Efficiency air conditioner (at least Energy Star) should prove cost effective
49	Provide vertical distance between air inlet and outlet to produce stack ventilation (open stairwells, two story spaces, roof monitors) when wind speeds are low
47	Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required
25	In wet climates well ventilated pitched roofs work well to shed rain and can be extended to protect entries, outdoor porches, and verandas
57	Orient most of the glass to the north, shaded by vertical fins, in very hot climates, if there are essentially no passive solar needs
43	Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain
53	Shaded outdoor areas (porches, patios) oriented to the prevailing breezes can extend living spaces in warm or humid weather
18	Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy

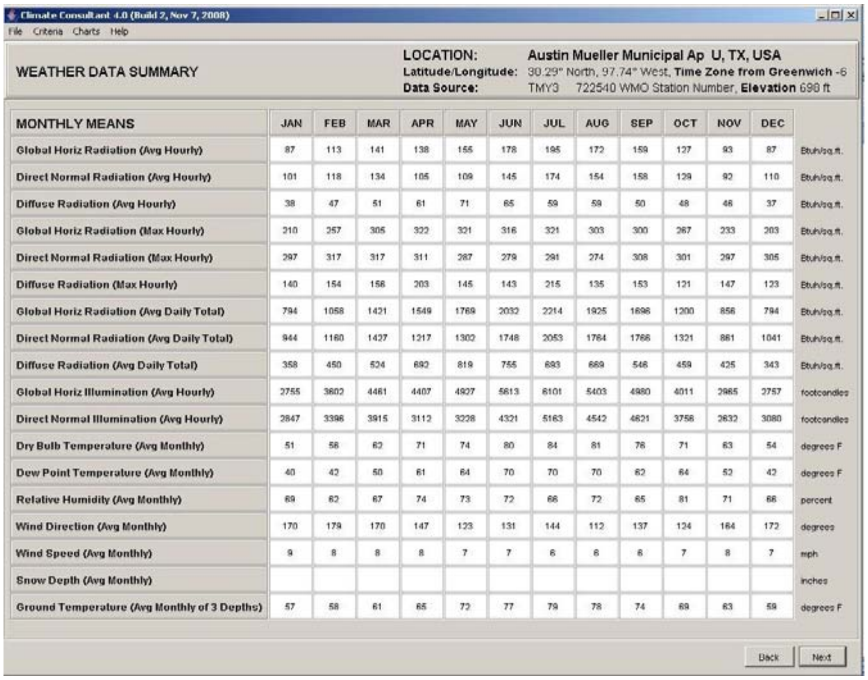
Figure 5e. Austin weather: design guidelines from *Climate Consultant 4.0*



WIND WHEEL

LOCATION: **Austin Mueller Municipal Ap U, TX, USA**
Latitude/Longitude: 30.29° North, 97.74° West, **Time Zone from Greenwich** -6
Data Source: TMY3 722540 WMO Station Number, **Elevation** 698 ft

Figure 5f. Austin weather: wind wheel

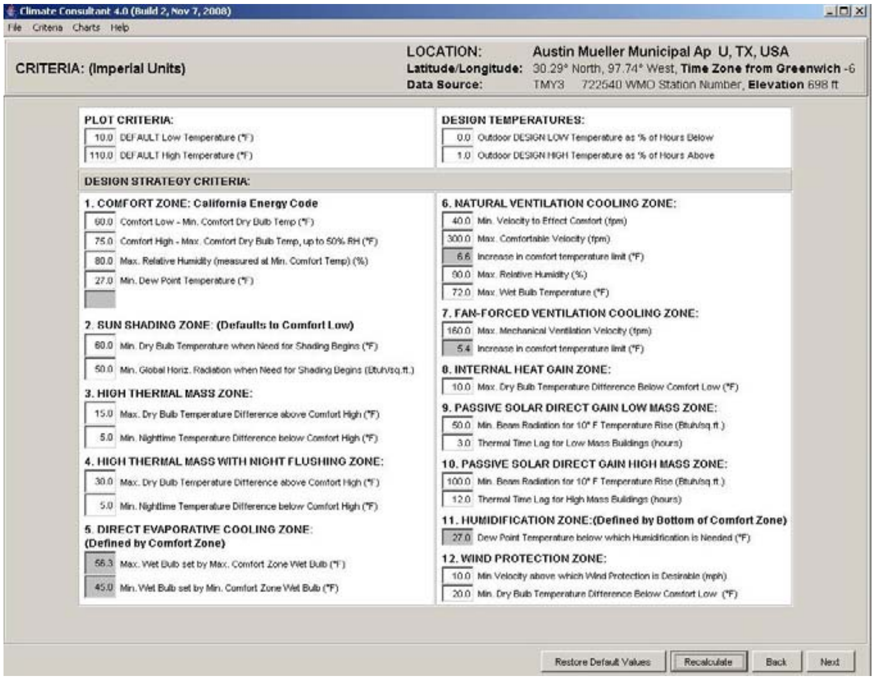


WEATHER DATA SUMMARY

LOCATION: Austin Mueller Municipal Ap U, TX, USA
Latitude/Longitude: 30.29° North, 97.74° West, **Time Zone from Greenwich** -6
Data Source: TMY3 722540 WMO Station Number, **Elevation** 698 ft

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	87	113	141	138	155	178	195	172	159	127	93	87	Btuh/sq.ft.
Direct Normal Radiation (Avg Hourly)	101	118	134	105	109	145	174	154	158	129	92	110	Btuh/sq.ft.
Diffuse Radiation (Avg Hourly)	38	47	51	61	71	65	59	59	50	48	46	37	Btuh/sq.ft.
Global Horiz Radiation (Max Hourly)	210	257	305	322	321	316	321	303	300	267	233	203	Btuh/sq.ft.
Direct Normal Radiation (Max Hourly)	297	317	317	311	287	279	291	274	308	301	297	305	Btuh/sq.ft.
Diffuse Radiation (Max Hourly)	140	154	158	203	145	143	215	135	153	121	147	123	Btuh/sq.ft.
Global Horiz Radiation (Avg Daily Total)	794	1058	1421	1549	1769	2032	2214	1925	1698	1200	856	794	Btuh/sq.ft.
Direct Normal Radiation (Avg Daily Total)	944	1160	1427	1217	1302	1748	2053	1764	1766	1321	881	1041	Btuh/sq.ft.
Diffuse Radiation (Avg Daily Total)	358	450	524	692	819	755	693	669	546	459	425	343	Btuh/sq.ft.
Global Horiz Illumination (Avg Hourly)	2755	3602	4461	4407	4927	5613	6101	5403	4980	4011	2965	2757	footcandles
Direct Normal Illumination (Avg Hourly)	2847	3396	3915	3112	3228	4321	5163	4542	4621	3758	2632	3080	footcandles
Dry Bulb Temperature (Avg Monthly)	51	58	62	71	74	80	84	81	78	71	63	54	degrees F
Dew Point Temperature (Avg Monthly)	40	42	50	61	64	70	70	70	62	64	52	42	degrees F
Relative Humidity (Avg Monthly)	69	62	67	74	73	72	66	72	65	81	71	66	percent
Wind Direction (Avg Monthly)	170	179	170	147	123	131	144	112	137	124	164	172	degrees
Wind Speed (Avg Monthly)	9	8	8	8	7	7	6	6	6	7	8	7	mph
Snow Depth (Avg Monthly)													inches
Ground Temperature (Avg Monthly of 3 Depths)	57	58	61	65	72	77	79	78	74	69	63	59	degrees F

Figure 5g. Austin weather: summary



CRITERIA: (Imperial Units)

LOCATION: Austin Mueller Municipal Ap U, TX, USA
Latitude/Longitude: 30.29° North, 97.74° West, **Time Zone from Greenwich** -6
Data Source: TMY3 722540 WMO Station Number, **Elevation** 698 ft

PLOT CRITERIA:
10.0 DEFAULT Low Temperature (°F)
110.0 DEFAULT High Temperature (°F)

DESIGN TEMPERATURES:
0.0 Outdoor DESIGN LOW Temperature as % of Hours Below
1.0 Outdoor DESIGN HIGH Temperature as % of Hours Above

DESIGN STRATEGY CRITERIA:

1. COMFORT ZONE: California Energy Code
60.0 Comfort Low - Min. Comfort Dry Bulb Temp (°F)
75.0 Comfort High - Max. Comfort Dry Bulb Temp, up to 50% RH (°F)
80.0 Max. Relative Humidity (measured at Min. Comfort Temp) (%)
27.0 Min. Dew Point Temperature (°F)

2. SUN SHADING ZONE: (Defaults to Comfort Low)
60.0 Min. Dry Bulb Temperature when Need for Shading Begins (°F)
50.0 Min. Global Horiz. Radiation when Need for Shading Begins (Btuh/sq.ft.)

3. HIGH THERMAL MASS ZONE:
15.0 Max. Dry Bulb Temperature Difference above Comfort High (°F)
5.0 Min. Nighttime Temperature Difference below Comfort High (°F)

4. HIGH THERMAL MASS WITH NIGHT FLUSHING ZONE:
30.0 Max. Dry Bulb Temperature Difference above Comfort High (°F)
5.0 Min. Nighttime Temperature Difference below Comfort High (°F)

5. DIRECT EVAPORATIVE COOLING ZONE: (Defined by Comfort Zone)
56.3 Max. Wet Bulb set by Max. Comfort Zone Wet Bulb (°F)
45.0 Min. Wet Bulb set by Min. Comfort Zone Wet Bulb (°F)

6. NATURAL VENTILATION COOLING ZONE:
40.0 Min. Velocity to Effect Comfort (fpm)
300.0 Max. Comfortable Velocity (fpm)
6.6 Increase in comfort temperature limit (°F)
90.0 Max. Relative Humidity (%)
72.0 Max. Wet Bulb Temperature (°F)

7. FAN-FORCED VENTILATION COOLING ZONE:
160.0 Max. Mechanical Ventilation Velocity (fpm)
5.4 Increase in comfort temperature limit (°F)

8. INTERNAL HEAT GAIN ZONE:
10.0 Max. Dry Bulb Temperature Difference Below Comfort Low (°F)

9. PASSIVE SOLAR DIRECT GAIN LOW MASS ZONE:
50.0 Min. Beam Radiation for 10° F Temperature Rise (Btuh/sq.ft.)
3.0 Thermal Time Lag for Low Mass Buildings (hours)

10. PASSIVE SOLAR DIRECT GAIN HIGH MASS ZONE:
100.0 Min. Beam Radiation for 10° F Temperature Rise (Btuh/sq.ft.)
12.0 Thermal Time Lag for High Mass Buildings (hours)

11. HUMIDIFICATION ZONE:(Defined by Bottom of Comfort Zone)
27.0 Dew Point Temperature below which Humidification is Needed (°F)

12. WIND PROTECTION ZONE:
10.0 Min Velocity above which Wind Protection is Desirable (mph)
20.0 Min. Dry Bulb Temperature Difference Below Comfort Low (°F)

Figure 5h. Austin weather: design consideration, thermal comfort temperature range etc.

APPENDIX C

Research on Building Components

Research summary on building components effecting in building energy usage

Primary Source: Malhotra, Mini. 2007, An analysis of maximum energy-efficiency in hot humid climates. MS Thesis, TAMU.

Table 2a. Research summary on building components effecting in building energy usage

Source	**Context**	**Substance**	**Remarks**
Akbari and Konopaki 1998	Roof reflectivity and emissivity	Impact of roof reflectivity and emissivity on building cooling and heating energy use for several residential and commercial prototypical buildings	• Reflective roofs provided greater opportunities for energy savings in warmer climates than in cooler climates. • White coating roofs reduced cooling energy use between 10-50% depending on the roof insulation. • Low emissivity roofs resulted in heating energy savings in very cold climates, and a cooling energy penalty in hot climates. • Decreasing roof emissivity from 0.9 to 0.25 resulted in net 10% increase in annual energy use in hot climates, no savings in cold climates, and up to 3% heating energy savings in very cold climates.

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
ASHRAE 2001a	Building envelope	Fundamentals of heat transfer through the building envelope; and thermal and optical properties of insulation and fenestration materials	• Recommended having a reasonably tight building envelope, and a properly designed and operated mechanically ventilated system for residences; to avoid possible difficulties of lack of control of ventilation rates, poor humidity control, air moisture infiltration, and lack of opportunity to recover the energy used to condition the ventilation air. • Recommended using daylighting, passive solar heat gain, glazing with special transmission properties, and insulated glazing with low air leakage to optimize the energy impacts of fenestration. • Recommended using single or multiple (insulating) glazing, interior and exterior shading, and spectrally-selective coatings and tinted glass to control the heat flow through fenestration.

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
Berdahl and Bretz 1997	Roof reflectivity	Provided solar reflectance for different materials; discussed effects of material composition, roughness, purity, infrared (IR) emittance and convection on solar reflectance	• High solar reflectance, thermal emittance, and convection coefficient were recommended for keeping surfaces cool; since materials with low emittance showed higher temperature rise due to their reduced ability to radiate heat by IR radiation. • Roughness or corrugation on the surface lowered reflectance. • Temperature measurements in sunlight illustrated a strong correlation between solar absorptance and roof temperature for materials with IR emittance of about 0.9.
Conway 1994	Lighting	Reported lighting energy savings from various energy-efficient lighting measures	• Motion detectors can save lighting electricity by 40% in bathrooms, 30% in bedrooms and kitchens, and 20% in living rooms and kitchen/dining areas. • An average of 26% annual operating cost savings were found from replacement with more efficient lamps, 45% from typical manual on/off controls with dimmers, timers, or sensors, 57% from an integrated system of efficient lamps,

Table 2a. Continued

Source	Context	Substance	Remarks
			efficient luminaries and appropriate controls.
DOE 1996	Lighting	Energy end use data for lighting in residences	• Lighting energy consumption was only 9.4% of all electricity consumption in the residential sector in 1993. • Replacement of incandescent lights with CFL had one of the highest (35%) energy-saving potentials.
DOE 2000	Advanced wall framing	Design considerations, construction specifications, details, and benefits of advanced framing techniques	• Reduced thermal bridging in advanced wall framing results in improved whole-wall R-value, and elimination of cold spots that are susceptible to condensation and mold growth. • Material and cost savings of about \$500 or \$1000 (for a 1200 and 2400 ft2 house), labor cost savings of between 3 to 5%, and annual heating and cooling cost savings of up to 5% can be achieved.
DOE 2001a	Appliances	Provided energy end use data for different home appliance, discussed factors affecting appliance energy use, and	• Water saving models of washing machines can cut water and energy usage by more than 40%. • Gas dryer costs 15-25 cents/load, compared to 31-40 cents in an electric one. Energy-

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
		provided energy savings estimates from efficient appliances	efficient measures for clothes dryers include using cool down cycles, locating them in a heated space, and cleaning and proper maintenance. Also, simple timers, advanced temperature sensors, and sophisticated moisture sensors in clothes dryers will reduce dryer energy use by 10% to 15%. • Electric ranges containing ceramic, halogen, or induction range elements are more efficient than the type containing electric coils. Electric ranges with solid disk elements are the most energy consuming.
DOE 2001b	Domestic hot water	Performance evaluation of the GFX in a typical residential application in Tennessee	GFX saved about 40% of the total energy needed for the shower. • Actual savings in water heating energy depended on the specific installation, hot water consumption patterns, and whether the GFX is piped as balanced or unbalanced flow, however, 30-50% savings was a reasonable estimate of energy savings from GFX.

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
DOE 2004	Building energy use data	Residential building primary energy consumption and end-use splits for 2002, and aggregate residential building component loads for space heating and cooling	• Primary energy consumption of 20.9 quads of residential energy use was electricity: 67%, NG: 24%, oil: 7% and renewable: 2%. • End-use split was space heating and cooling: 32% and 12%, water heating: 13%, lighting: 12%, refrigeration 9%, electronics, cooking and wet clean: 5% each, computers 1%, other end uses 4%. • Heat loss through roofs, walls, infiltration, and conduction through window were 12%, 19%, 28% and 26% of the total space heating, and 14%, 10% 16% and 1% of the total cooling load. Also, foundation caused 15% of heat loss, and solar gain through windows and internal gains caused 32% and 27% of the total heat gain.
	Fenestration	Comparative analysis of effects of shading and glazing type on energy use and energy cost savings to optimize	• The results indicated 14% reduction in afternoon peak electricity demand and 12.4kWh (30%) reduction in daily total cooling load from combination of high performance shading and glazing in hot dry climates,

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
		the interaction of various methods to reduce solar heat gain	9.4kWh (22%) only from shading and 4.4kWh (11%) reduction from upgrading windows. • Spectrally selective glazing with shading performed the best for daily load of air conditioning electricity use. • Daily cooling energy savings were higher from architectural and site shading than from upgrading windows.
Friedman 2000	Building envelope	Guidelines for building layout and construction for achieving minimum energy requirements, and estimates for resultant energy savings	• Simple rectangular shapes for buildings were recommended that result in energy savings both directly and indirectly due to reduced wall and window area, reduced heat gain or loss, and reduced infiltration. • Simplifying floor plans from an L-shape to a rectangle showed up to 15% energy savings. Up to 21% and 43% savings resulted in a 1200 ft2 unit designed as a 14 ft. x36 ft. duplex and as a row house, respectively.
Givoni, 1998	Building envelope	Design guidelines for different climatic regions to improve comfort and energy	• Discussed the effects of architectural and structural design features including layout, window orientation, and

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
		conservation in that particular climate	shading and ventilation conditions on the indoor climate and energy use - A compact plan with a smaller exposed surface area of the walls and roof reduces the energy demand, whereas a spread out plan has potential for natural ventilation and natural illumination. - Shading devices that intercept only the direct solar radiation would be less effective in hot and humid regions, whereas the diffused radiation from the sky comprises a significant portion of the total solar heat gain due to partly cloudy sky.
ICFA 2004	Insulated concrete forms	Benefits, technology and application of insulated concrete forms	- ICF walls using polystyrene foam have insulating values of R-17 to R-26 compared to wood frame's R-9 to R-15. - ICF walls reduce conduction heat losses by 50%, are 50% more airtight, and have thermal mass that contributes about 6% of the needed energy to the house for free. - These result in heating and

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
			cooling energy savings of 30-40% compared to frame houses (with higher savings associated with bigger house), and allow the installation of smaller heating and cooling equipment. • Cooling savings are higher in hot climates, and heating savings are higher in heating climates.
Kosny et al. 2001	Thermal mass walls	Analyzed of the thermal performance of different massive wall configurations with insulation	• Thermal mass benefit depends on wall material configuration, climate, building size, and orientation. • The most beneficial application was Phoenix, AZ and Bakersfield, CA (8% of the whole building energy savings in Minneapolis and 18% in Bakersfield, for high R-value walls). • Most effective wall assembly is the wall with thermal mass in good contact with the interior. • Walls with insulation concentrated on the interior side performed much worse. • Wall with insulation on both sides of concrete wall core performed slightly better, but significantly worse than walls

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
			containing foam core and concrete shells on both sides. • For ten U.S. locations, average whole building energy savings potential of R-15 and 20 ICF walls was between 6 and 8%.
DOE 1997	Fenestration	Guidelines for selecting fenestration properties for different climate regions	• In heating dominated climates, multiple pane, low-e and gas filled window configurations, or super windows that combine all the above advanced features are cost-effective and advisable. • In hot climates, less expensive glazing with low-e coatings and gas fills with shading techniques are cost-effective and energy-saving option. • In hot sunny climates, spectrally selective glazing with SHGC of 0.4 or less and visible transmittance of 0.6 or greater are recommended for maximum energy-efficiency, good light transmittance, and visibility. • Among the available frame and spacer options, wood, fiberglass, and vinyl frames are better insulators than metal. Aluminum frames with thermal

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
			break perform better than those without thermal break. - Spacer thermal performance depends on its geometry and material composition. Well designed metal spacers insulate almost as well as foam.
Lechner 2001	Building envelope	Listed climatic design priorities; and design strategies for achieving them for schematic design of buildings in different climatic regions in the U.S.	- Natural ventilation is the highest priority measure for summer cooling and moisture removal in hot and humid climates, followed by that for protection from summer sun and exposure to winter sun. - For natural ventilation, orientation and planning the building for maximum contact to outdoors to capture the prevailing winds, open indoor plan, high ceiling, two storey spaces, open stairwell and elevated living spaces are recommended for maximized air flow and less humidity level indoors. - Compact designs, attached or clustered buildings and earth sheltering, are the common measures to protect from

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
			extreme hot and cold temperatures as well as undesired winds. • Orienting building along the east-west axis, maximizing exposure to the south, southeast and southwest sides, providing clear solar access and sunspaces on the south, buffer spaces along the north, and temperature zoning inside the building are additional measures to maximize solar gain and minimize heat loss in winter. • Building envelope shading could be added to these measures to minimize heat gain in the summer.
Mayfield 2000	Fenestration	Discussed different shading options and provided guidelines for their selection in different contexts	• Shading options for residences included: overhangs, decks and porches, awnings, low-e films and coatings, shade screens, solar screens and rolling shutters.
Miller et al. 2002	Roof emissivity	Introduces complex inorganic color pigments (CICPs) that could improve thermal	• For climates predominated by heating loads, surfaces with moderate reflectance and low IR emittance will save in comfort heating.

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
		performance of dark roof	• CICPs make dark-color roofs behave similar to white-color roofs in the near-infrared portion of the solar energy spectrum and reflect much of the near-IR heat. This could improve energy thermal performance, durability and life expectancy, and reduce replacement and disposal cost for asphalt shingle roofing that has lower thermal performance, but is preferred due to their appearance, cost, and durability.
Nayarat R. 2003	Daylighting	Analyzed the effectiveness of three daylighting strategies and their energy performance using a scale model and DOE-2 simulations	• Daylighting strategies included: 6 ft. overhangs with vertical fins, 6 ft. overhangs, and 18-inch combined light shelves. • Lighting electricity savings were 22%, 25%, and 18%, respectively. • Cooling energy savings were 10%, 8% and 6%, respectively. • Heating energy penalty were 4%, 4% and savings of 4%, respectively. • Annual electricity savings were 6%, 6% and 8%, respectively.
Olgyay	Building	Investigated the	• The optimum shape of a

Table 2a. Continued

Source	Context	Substance	Remarks
1963 Table 2a continued	envelope	thermal impacts for different building shapes in different climates, and recommended optimum building shapes for each climate	building in all climates was a form elongated somewhere along the east-west direction with the amount of elongation depending upon the climate. • For hot and humid climate of Miami, Florida, length to width ratio of 1:1.7 was found the optimum for a 1000 ft2 house with usual insulated frame construction (U=0.13) and 40% single pane glass on the south. • In all climates, attached units (such as row houses) with east and west common walls were most efficient.
SIPA 2004	Structural insulated panels (SIPs)	Benefits, technology and application of SIPs	• SIPs avoid thermal breaks or penetrations in the panels, thus, have higher insulating values and are 95% more airtight. • These allow reduced system size and save energy cost by 50%.
Turrell 2000	Fenestration: Storm windows	Benefits of storm windows, effect of wind speed on heat loss and air leakage for window assemblies	• Benefits included: protection from storm damage, reduced conductive heat loss, and air infiltration. • Adding storm windows was an energy-saving retrofit in older buildings especially with single

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
			glazed windows. - Research results conducted in ORNL indicated higher reduction in heat loss and air leakage due to storm windows at higher wind speeds.
Vieira and Shienkopf 1992	Building design, envelope, doors and windows, systems and appliances	Recommendations for building energy-efficient residences in Florida, and energy savings and first cost estimates for all the strategies	Estimated energy savings of up to: - 50% for cooling and 70% for heating from building design, - 25% for heating and cooling each from foundations and floor, - 15% for cooling and 20% for heating from efficient walls, - 30% for heating and cooling each from efficient doors and windows, - 65% for heating and 60% for cooling from efficient space conditioning equipment, and - 30% energy cost savings from efficient appliances. In Florida Combined energy savings can be calculated as: Total % savings = [100 - (100 - savings A) * (100 - savings B)]
Watson and	Building envelope	Control strategies for promoting or	The strategies included: - Wind breaks to minimize winter

Table 2a. Continued

Source	**Context**	**Substance**	**Remarks**
Labs 1983		estricting heat gain or loss	wind exposure, • Plants and water for shading and evaporative cooling, • Indoor/outdoor rooms for summer cooling and winter heating benefits, Earth sheltering for insulation, winter wind protection and summer cooling, • Solar walls and windows for winter heating, • Thermal envelope isolating the interior space from the cold winter climate, and • Sun shading for overheated summer period and natural ventilation for summer cooling.

APPENDIX D

Energy Efficient Residences

This section of the appendix is about all the residence I have looked into as my literature survey. First few remarks have been included elaborately in the literature review section. There is another table for high performance homes which are more technologically advanced but barely on that house, passive solar techniques have used. I still included them in my study because of the knowledge base and to have evolution in my thinking process.

Primary Source: Malhotra, Mini. 2007, An analysis of maximum energy-efficiency in hot humid climates. MS Thesis, TAMU.

Table 2b. Energy-Efficient residences

Source	Context	Features	Remarks
Kootin-Sanwu 2004	A low income housing in hot-humid climates of the U.S	Investigated energy saving potential and cost-effectiveness of envelope, systems and landscape improvements	• Potential energy-efficient upgrades included: improved windows, CFL replacement, improved attic and wall insulation, efficient HVAC systems, equipment without pilots lights, and white roof. • The most economically favorable measures were: CFL replacement, equipment without pilot lights, and air-conditioner with a more efficient stainless system. • Improved insulation showed small annual

Table 2b. Continued

Source	Context	Features	Remarks
			electricity savings; however, a significant cooling energy savings in the summer.
Rasisuttha and Haberl 2004	A case study house in Bangkok, Thailand	Analyzed individual and combined effect of energy-efficient strategies for building components, systems and renewable energy systems	• Maximum total energy savings of 9.08% from light-weight concrete block walls with insulation on the inside compared to 4 inch brick walls. • 20% savings from combining this strategy with improved ceiling insulation, replacement of single-pane clear glass with double-pane low-e glazing, exterior shading, and efficient systems, lighting and refrigerator. • 72.58% savings from further addition of solar thermal and photovoltaic (PV) systems to the above combination.
Chulsukon 2002	A typical house in Bangkok, Thailand	Analyzed strategies to reduce lifetime building energy use of the house	• Strategies included: insulated walls and roof, improved glass type, light-colored exterior surfaces, increased ground reflectance and variation in thermostat setting. • Maximum annual energy savings of up to 13% from improved glass type and from thermostat setting, followed by 3-4% savings from wall insulation, roof insulation and light-colored exterior wall surfaces, and 1-2% savings from increased ground reflectance and light-colored roof • Up to 30% annual energy savings from

Table 2b. Continued

Source	Context	Features	Remarks
			combining all these strategies.
Gamble et al. 2004	Achieving zero-energy in homes	Assessed opportunities to integrate energy-efficient and passive solar features with on-site generation	• Energy-efficiency packages included: upgraded building design, envelope, systems, lighting and appliances, and behavioral modifications • Demonstrated up to 75% energy savings in hot climates. • Demonstrated a net-zero energy use by coupling such upgrade packages with PV systems, with net overall costs close to that of standard code built homes.

Here is another table for the high performance homes. Most advanced technological instruments have used in these house in innovative way. Most of these homes are the evidence of great research in heating, cooling and air conditioning in building. There are researches on almost every process and elements of HVAC units have done in those researches.

Table 2c. High performance homes

Source	Context	Features	Remarks
Building America 2004	Production homes in different climatic regions of	Provided characteristics of the houses, key energy-efficient	• Common energy-efficient features included: advanced framing, detailed air sealing and insulation, double-pane low-e vinyl-framed windows, unvented attic, and efficient systems.

Table 2c. Continued

Source	Context	Features	Remarks
	the U.S.	features, cost of efficiency upgrades, and energy performance summary	• These features allowed downsizing air conditioner and a simplified duct layout, which reduced the added cost of incorporating these features. • REM/Design computer simulation program was used to evaluate energy cost and consumption, design loads and Energy Star scores.
Casebolt 1993	An off-grid solar house in Arizona.	Explained characteristics of the house, energy and water conserving practices, and average daily energy use and energy cost savings	• Energy-efficient features included: passive solar design, a PV system, efficient lighting, systems and appliances, and energy and water conserving features. • These features accompanied with energy and water conserving practices allowed the installation of a smaller, less expensive PV system. • The energy use was 855 kWh/year (2.34 kWh/day) as compared to 9,300 kWh/year in nearby homes.
Christian 2005	First ORNL zero energy home in Tennessee	Described energy efficient features of the house and measured energy savings	• 35% heating and cooling energy savings from ducts in the conditioned space, • 10% less energy use from structural insulated panels, • 60% savings in DHW use (64kW/yr) from heat pump water heater, • 5% DHW savings from the heat recovery shower, and

Table 2c. Continued

Source	Context	Features	Remarks
			• 65% energy cost savings and 40% reductions in summer PM peaks from a grid-connected 2 kW PV system.
Kent 2003	A high efficiency house in Pennsylvania.	Described design, construction and monitoring of the test house to research, evaluate and test new systems, methods and practices	• Used standard construction practices to save time and construction cost. • Energy-efficient features included: improved building envelope, improved floor framing and duct design, efficient lighting, systems and appliances, and energy recovery ventilators (ERVs). • 5% increase in the construction cost due to energy-efficient upgrades. • 55% reduction in the energy use compared to 1993 MEC benchmark (HERS score: 91.4).
Smith 2001	A passive solar house in Colorado	Described building features, computer modeling and monitoring details	• Energy-efficient features included: air-tight concrete construction, natural ventilation with thermal mass, shading, solar heating, and efficient windows. • 56% energy savings as compared to the MEC base-case house. • The analysis indicated a potential energy savings of 70.4% with increased insulation.

VITA

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