CHAPTER 1
INTRODUCTION

Buildings are large energy consumers in many countries, and energy demand is growing every day. The global contribution from buildings towards energy consumption, both residential and commercial, has steadily increased and has exceeded the other major sectors: industries and transportation. Growth in population, increasing demand for building services and comfort levels, together with the rise in time spent inside buildings, assure the upward trend in energy demand will continue in the future. For this reason, energy efficiency in buildings is today, a prime objective for energy policy at regional, national and international levels (Luis Perez-Lombard et al 2008). Among building services, the growth in heating, ventilating, and air conditioning (HVAC) systems energy use is particularly significant. Adoption of energy efficiency practices and cutting edge technologies can help to shift towards a low-carbon economy (Ramesh & Emran Khan 2013). Climate responsive or passive building design can play a significant role in reducing the energy demand of buildings without compromising modern living standards. India is currently the second fastest growing economy in the World. Energy is one of the major drivers of a growing economy like India and is an essential building block of economic development. Economic growth in India has largely been associated with increased energy consumption. Though Per capita energy consumption of India remains much lower than that of industrialized countries; India’s total energy consumption is expected to increase significantly, arising due to population explosion and urbanization (Susanne Bodach et al 2014). Buildings already consume 30% of India’s energy. India is yet to build nearly two-third of its 2030 building
Without a concerted effort to reduce energy intensity in buildings, the additional demand for electricity will worsen the chronic power shortage situation in India (Ramesh & Emran Khan 2013). Growth in building sector will lead to more Greenhouse Gas (GHG) emissions with serious impacts on the global environment. Adoption of energy efficiency programmes in existing and new buildings will be a major step in mitigating environmental degradation.

1.1 BUILDINGS AND ENERGY CRISIS

India, the seventh largest country in the world, is one of the leading economies and home to over one billion people living in various climatic zones. The country’s economy has been growing at a faster pace, ever since the process of economic reforms started in 1991. Construction plays a very important role in its economy, contributing on an average 6.5% of the GDP (Abdus Salam Azad & Jamshed Ahmed Usmani 2013). Commercial and residential sectors continue to be a major market for the construction industry. The sectors consume a lot of energy throughout the life cycle of buildings, thus becoming a major contributor to Green House Gas emissions. India faces a formidable challenge to meet its energy needs and to provide adequate energy of desired quality in various forms to the users in a sustainable manner at reasonable costs. Given the spiraling urban growth, the number of buildings, energy consumption and the resultant carbon emissions are on a rise in the country. Seventy percent of the buildings that will exist in India by 2030 are yet to be built (Center for science and development, New Delhi, India, 2013). This means that India has a singular opportunity to realize tremendous savings by incorporating various energy efficient measures during the design and construction stages. There is over 50% saving potential in the building sector to meet the challenges of global energy and climate change. Prioritizing energy-smart building construction across India will deliver dramatic savings, according to expert studies.
The Energy Statistics 2013 of India’s National Statistical Organization (NSO) shows electricity accounted for more than 57% of the total energy consumption during 2011-12 in India, and building sector is already consuming close to 40% of the electricity (Center for science and development, New Delhi, India, 2013). This is expected to increase to 76% by 2040. A large quantity of incremental electricity demand will come from the residential sector in India. Building’s heating and cooling are the most energy-intensive activities, followed by electricity use for lighting and appliances (Harvey 2009). India, being in a temperate climate, demands intensive cooling than heating. However, the energy consumption can be reduced significantly by employing passive environmental solutions instead of mechanical ones (Torwong Chenvidyakarn 2007). Passive design allows buildings to adapt more appropriately to their local climate and take better advantage of natural energy resources, such as wind and thermal buoyancy, to help condition their interior environments.

1.2 RESIDENTIAL BUILDINGS AND ENERGY USE

In most countries, residential buildings are responsible for a major part of the energy consumption in the building sector (UNEP, 2007). In India, the building sector consumes about 40% of electricity out of which commercial sector consumes 8% whereas residential sector accounts for 32% (Manoj Kumar Singh et al 2010). The energy use intensity of the residential buildings is expected to grow because of the increase in air-conditioned areas, more access to electricity, and the increase in ownership and usage of appliances by the tenants. Till date, India’s policymakers have focused on reducing energy consumption in new commercial buildings, but it is notable that achieving a higher target would depend on the inclusion of the residential buildings sector in the target area. Residential buildings make up 75% of India’s construction market, and until now has not been a priority for energy efficiency policy. The potential for expanding and adapting existing
energy-efficiency policies to the residential segment is tremendous (The Economist Intelligence Unit, 2013). Until today, energy efficiency in buildings – in particular in the residential sector – has received limited attention in India. This has been due to the relatively low electricity tariffs, a fledgling market for energy-efficient materials, the lack of efficiency standards for building materials, and energy performance of buildings. Now, energy prices are high in India. Incorporating energy efficiency measures in new and existing buildings will help India achieve a reliable energy future and save money while addressing the threat of climate change (The Energy and Resources Institute, India, 2009).

The design of residential buildings has a significant impact on everyday lives of people. As energy consumption from residential buildings is predicted to rise by more than eight times by 2050, it is of vital importance for India to develop energy efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand (Global Buildings Performance (GBP) Network & Centre for Environmental Planning and Technology’ (CEPT) University 2014). The study specifically focuses on assessing the role of the building envelope, particularly roofs, in relation to comfortable air conditioning systems and appliances, in achieving energy efficiency in dwellings in the Indian residential sector.

1.3 IMPORTANCE OF BUILDING ENVELOPES AND ITS THERMAL PERFORMANCE

Energy required in buildings is mostly towards providing thermal comfort. Energy savings in a building can be achieved by appropriate energy efficient design of building envelopes (Hatice Sozer 2010). These building envelopes act as the interface between the interior of the building and the outdoor environment, including the walls, roof, and foundation; serves as a thermal barrier and plays an important role in determining the amount of
energy necessary to maintain a comfortable indoor environment relative to the outside environment (Akeel Noori 2015). It is the key factor that determines the quality and controls the indoor conditions irrespective of transient outdoor conditions. Building envelope comprises a configuration of building materials, the thermo physical properties of which, determine the climatic response of the envelope. To reduce the energy consumption in buildings, it is necessary to understand the thermal performance of the building envelope on the indoor environment. A building’s climatic response is determined by the prevalent exposure conditions (micro-climate) and the ability of the building envelope to regulate thermal transmittance (building physics). This ability to passively thermo-regulate the indoor thermal comfort is determined by the materials configuring the envelope geometry (Balaji et al 2013).

The thermal performance of a building refers to the process of modeling the energy transfer between a building and its surroundings. For a conditioned building, it estimates the heating and cooling load and hence, the sizing and selection of HVAC equipment can be correctly made. For a non-conditioned building, it calculates the temperature variation inside the building over a specified time and helps one to estimate the duration of uncomfortable periods (Mathew Joseph et al 2015). These quantifications enable one to determine the effectiveness of the design of a building and help in evolving improved designs for realizing energy efficient buildings with comfortable indoor conditions. The present research tries to develop a scientific ranking system for various roofs which will be a user friendly manual so that users can avoid tedious calculations and use any of the listed roof systems readily.
1.4 SIGNIFICANCE OF ROOFS IN THERMAL PERFORMANCE OF BUILDINGS

The occurrence of hot discomfort during the daytime is a serious problem for the citizens living in tropical regions. This drives the citizens to look intently on thermal comfort conditions. In tropical regions, the most prominent component that affects thermal comfort is the roof architecture as roofs are exposed to direct solar radiation and the angle of incidence is close to the normal during the hotter parts of the day (Chitrarekha Kabre 2010). Roofs contribute tremendously to building heat gain compared to vertical surfaces such as walls, mainly because the roofs are exposed to the sun throughout the daytime (Jayasinghe et al 2003). Roofs can represent 50%–70% of the total enclosure loads for a building. The roof typically receives significant amounts of solar radiation and consequently represents both a concern for energy consumption as well as an opportunity for environmental expression. The roof is where the building meets the sky and therefore the design of the roofing system should consider not only the materials and construction characteristics but also the possibilities for environmental integration (Hall 2010). India, being a tropical country, where daytime temperature is as high as 38°C on an average and diurnal temperature variation is medium to high, it is essential to look into the thermal performance of any roofing system before it is adopted (Koenigsberger et al 1975). This research presents issues and design strategies for the roof being an active participant in environmentally responsive architecture. Residential buildings in India, especially the low rise buildings are found to undergo high intensity heat transmission from the building envelope, whereby the roof represents around 70% of heat gain. This research presents a framework that will provide an intelligent artifact which will determine the optimum roof architecture according to the thermal comfort conditions in residential buildings.
1.5 PASSIVE BUILDING DESIGN AND STUDY RELEVANCE

Heating, Ventilation and Air Conditioning systems (HVAC) are the most energy consuming amongst the buildings services. Higher living standards lead to active climatization of buildings such as offices and hotels, and also residences. One of the sustainable approaches to cooling buildings by natural means is the passive cooling strategy (Kamal 2012). Passive design responds to local climate and site conditions in order to maximize the comfort and health of users while minimizing energy use. The key to designing a passive building is to take the best advantage of the local climate. Passive cooling refers to any technologies or design features adopted to reduce the temperature of buildings without the need for power consumption (Hanan M Taleb 2014). ‘Passive Architecture’ has a great advantage in that it requires no external energy source and therefore has neither a running cost nor does it contribute to environmental pollution (Szupinger & Csojob 2011). Recent years have seen a renewed interest in environmental-friendly passive building energy efficiency strategies. They are being envisioned as a viable solution to the problems of energy crisis and environmental pollution. The basic idea of passive design is to let in daylight, heat and airflow only when they are most beneficial, and to exclude them when they are not. In addition, the building envelope, itself, should be used to speed the transfer of excess heat into the outdoor environment. It is an alternative to mechanical air-conditioning systems and as such is an essential part of a sustainable building.

Generally, the countries with tropical climate have a high population density. Most of these countries still remain as developing countries. With the economic development, the energy consumption for thermal comfort is also rising. Therefore, it is an essential fact that, when designing dwellings, the designer should give due consideration to comply with nature to achieve thermal comfort by maximizing the natural sources (Perera and Modasia 2004). India has different climatic conditions, ranging
from extremely hot conditions to severely cold conditions. Energy availability is scarce and people have to protect themselves from these extremities of the climate in a natural way (Anupama Sharma 2003). Ancient architecture had many passive features, which helped, in creating comfortable thermal environment in the buildings. In traditional Indian architecture, this harmony with nature was an important design element by itself. During the course of development, somewhere, harmony was subdued for artificial control, resulting in buildings without context. History shows the importance of relationship between human activity and nature. Human lives remained much dictated by solar and seasonal cycles, instead of trying to homogenize living conditions throughout the year. The future is in living and working with nature rather than against it. Exploring these approaches in detail allows us to rethink how to effectively adapt these techniques to overcome the build-up of heat in modern houses in warm humid climate of India. The potential of these techniques vary from region to region, their application in the tropics should be examined.

1.5.1 Energy Savings Potential from the Implementation of Passive Roof Design

Passive cooling involves designing buildings and selecting construction materials in a way that reduces heat absorption and conduction through the roof and walls. Agrawal (1989) has postulated that by using proper passive design concepts, at least 2.35% of the world energy consumption could be avoided. A technical review was done by Sadineni et al. to discuss the energy savings of applying passive technologies on the various building envelope components, such as the wall, roof, window and door (Sadineni et al 2011). Among these envelope components, the roof is most exposed to the overhead solar radiation. An intelligent choice of material selection for roof construction can help in achieving passive cooling of our
built environment. Several passive cooling studies have been conducted over the years, with a focus on roofs. Mohammad A. Hamdan et al (2012) has conducted a study to evaluate the potential of passive cooling roof design in Jordan. Various experimental studies proved that the heat gain through the roof can be reduced by white paint, layers of wetted gunny bags, a water pond with movable insulation, and water spreading equipment (Nahar et al 1999, Runsheng & Etzion 2004, Dilip 2006). Several studies compared various passive cooling strategies (Amer 2006; Kumar 1994; Nahar Sharma & Purohit 1999; Nahar Sharma & Purohit 2003; Tiwari Upadhyay & Rai 1994) which ranged from painting roofs with white ceramic paint, installing thermal insulation above and underneath roofs, installing shallow water ponds, and incorporating air cavities in walls. Nahar et al (1999) fabricated five identical test structures for studying passive techniques for better comfort conditioning in arid areas. They found that the fall in roof and ambient temperatures inside the test structures were in increasing order for roofs treated with thermal insulation, painted with white paint, shallow pond with movable thermal insulation and evaporative cooling. Alvarado et al (2009) investigated the thermal effects of newly designed passive cooling systems on concrete roofs in existing buildings. Each tested passive cooling system consisted of a combination of materials that reduced net heat load in buildings.

Mesut B Ozdeniz & Polat Hancer (2005) conducted an experimental study to evaluate suitable roof construction for warm climates in Cyprus. Fourteen different roof constructions were selected and tested on a test house. These constructions included the types, which are widely used in Cyprus and also the new ones. This research was designed to study the roof constructions in terms of thermal comfort of the users. Chitrarekha Kabre (2010) has tried to find a scientific rating scheme for roof system for the warm humid tropics of India and Australia. She has identified a set of variables, which influence the performance of roof. Sodha et al (1986)
presented the thermal models of various passive cooling methods. Thermal modeling of passive cooling is important to study the design and operating parameters. Simulation model is a valuable tool for the prediction of performance of the passive cooling. The periodic analysis for hourly variation of passive cooling of roof is presented for bare roof, insulation beneath the roof, evaporative cooling above the roof and roof pond with movable insulation system. The simulated results have been validated with the published experimental values of Nahar et al (1999).

All these researchers support the potential of the roofs in improving the thermal performance of buildings through experiments conducted with various parameters. This study is an attempt to detect, document, analyze the design principles and to explore the present trends in house building technology and identify the problem of designing roof for thermal comfort in warm humid zone. This study has been conducted in Madurai, Tamilnadu, India, since Madurai has a rich blend of traditional and modern residential architecture. The study is aimed to evaluate the traditional roof construction techniques and the modern construction techniques and to provide better living environments that are affordable by all classes of people.

1.6 STATEMENT OF THE PROBLEM

Buildings are responsible for at least 40% of energy use in most countries. The absolute figure is rising fast, as construction booms, especially in countries such as China and India (UNEP 2007). It is essential to act now, because buildings can make a major contribution in tackling climate change and energy use. Progress can begin immediately because knowledge and technology exist today to slash the energy that buildings use, while at the same time improving levels of comfort. Of the 1.2 billion poor in the world, over a third live in India, who comprise 40% of the country’s population (UNEP 2009). Raising the living standards of almost half a billion people to
thermal comfort levels, let alone to those enjoyed by middle income families, remains a daunting challenge. Indian housing industry is facing a huge challenge to provide environmentally sustainable housing developments (Kalpana Gopalan & Madalasa Venkataraman 2015). The main issue concentrates on thermal performance of building envelopes to improve thermal comfort and energy savings.

Over 40% of India’s population lacks electricity access and use kerosene for lighting. Another 30% does not get it when it wants. Only 10% households have monthly electricity bills more than Rs 300. Access to electricity is still very uneven. Saving energy through energy efficiency improvements in buildings can cost less than generating, and transmitting energy from power plants and provide multiple economic and environmental benefits (Dilip Ahuja & Marika Tatsutani 2009). As energy consumption from residential buildings is predicted to rise by more than eight times by 2040, it is of vital importance for India to develop energy efficient strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand. The concept of housing requires a new understanding to effectively and synergistically address the pressing issues of climate change. No longer regarded as simply a roof over one’s head, housing today plays a crucial role in achieving sustainable development.

Passive design is based upon climatic considerations, attempts to control heating and cooling without consuming energy; it uses the form of building (plan, section) to control air flow and uses materials to control heat. It maximizes the use of free solar energy for heating and lighting; and maximizes the use of free ventilation for cooling; finally, it uses shade (natural or architectural) to control heat gain. Passive design is achieved when a building is created that simply works "on its own" (Samuel et al 2012).
Green buildings are envisioned as possibilities to create harmless, energy efficient and environmentally friendly buildings. Although the advantages of green building are impressive, there are still some restrictions. The type of architecture is new and unfamiliar for most architects which require more technical knowledge. There is uncertainty about the performance and life cycle of new emerging technologies. Green construction materials do cost more than the conventional building materials and indigenous building materials. Most of the recent residential buildings in warm humid regions in India are built with Reinforced Cement Concrete (RCC) slabs as roofing systems and clay tile roofs for a smaller percentage. Moreover, most of these buildings have no insulation material installed. As a result, these buildings act like a sauna, where most of the building facades are exposed to excessive solar radiations that absorb heat throughout the day. The heat is then conducted to the inner spaces, thereby creating thermal discomfort for the building occupants.

In India, there is a millennia-old reservoir of knowledge that can help reduce energy consumption in buildings today. India has rich traditions and history in holistic strategies for buildings and construction. India has a strong tradition of vernacular architecture, i.e. design suites to climate conditions that make use of local materials. Despite this, the sustainable buildings currently receive limited attention in India. Indian culture has always stressed living in harmony with the environment (UN chronicle 2007). The natural order is left intact. Modern culture, by contrast, seems more inclined to exploit nature and to disrupt the natural order. In India, traditional values as well as the timeless way of building compact residential environments are now threatened by new and foreign influences. These influences are incompatible with the climate of the country and the traditional culture of its people (Schoenauer NWW Norton 2000). Learning from the traditional wisdom of previous generations through the lessons of traditional
buildings can be a very powerful tool for (improvising) the buildings of the future. However, in traditional construction, the construction process is more involved and can require hiring higher-skilled designers and builders. Madurai, the selected study area, has a rich precedence of traditional and heritage architecture, which makes it appropriate for a case study for contemporary design and as a template for not only practices that are environmentally friendly, but also the processes of sustainable thought.

Successful buildings of the future will increasingly rely on the critical examination of, and learning from, the buildings of the past (Vale & Vale 1991, Hyde 2000). There is so much we can learn from such studies, it gives a good reason as to why passive design principles have been traditionally been preferred to (and are now once again chosen over) active systems. We can get solutions for buildings that can do more with less technology. The optimization of the building layout and detailing of the envelope system are essential for an integrated approach to the design of low-energy consuming buildings and cities (Hausladen et al 2005). Just optimizing buildings through the application of passive design principles can deliver energy savings up to 80% (Hausladen et al 2005). This research strives to make an exhaustive technical review of the building envelope components and respective improvements from an energy efficiency perspective and their effectiveness in offering passive climatic control to residential buildings under naturally ventilated conditions.

1.7 SIGNIFICANCE OF RESEARCH

The demand for energy in developing countries is alarming, whereas the means of electricity production remains limited. Due to climatic change, high temperature and humidity, there is a significant increase in the use of air conditioners to attain better thermal comfort. Depletion of fossil fuels and increase in fuel cost lead to an electricity shortage. And, the energy
crisis made an effort in reducing the overall energy consumption in building sector. The residential sector in India consumes 37% of the total energy generated, thus reflecting the importance of the sector in the national energy scenario. Electricity consumption is mainly influenced by seasonal variation in residential building. Most of the energy consumed for cooling, electrical appliances and water heating, mainly depend on the ambient temperature. Many cities in India experienced rapid urban growth without any references to the evolving urban environment. This puts a pressure on the energy demand in the country.

The demand for comfort conditions in buildings are significantly increased as a result of exposure to uncomfortable outdoor temperature (Ahmed 2003). Today India is an emerging country with 1.3 billion population (Ministry of Housing Aaffairs (MHA) 2011) and a rapidly growing economy. Most of Indian families and individuals still live in traditional rural houses or in buildings that are older by thirty years. Yet, the economic boom since 2001, a growing middle class in Indian cities and the migration of people from rural areas to urban areas has accelerated a tremendous construction and investment boom in rapid sprawling metropolitan areas. In India, private developers primarily target upper-middle housing segment and provide them with more luxury and high end climate controlled buildings which are not compatible with the natural environment.

On the other hand, the housing for the poor and Economically Weaker Sections (EWS) is provided by the government, where the main concern is only on the cost and not on the comfort of the users. There exists a huge dearth in the supply of thermally comfortable houses primarily demanded by this income group in India. Thermal comfort influences both physical and mental health of the inhabitants of the houses. Larsen (1998) stated that body comfort is the criterion, which governs building design in the
tropics and elsewhere. This research is mainly concentrated in developing architectural design strategies for the class of people who cannot afford for the sophisticated air conditioning systems to achieve comfort.

India is a country with highly variable climate at macro-scale (from region to region and at micro scale (within a region). Many thermal comfort researches have been stimulated with the current drive to achieve energy efficiency (Jaggs 2000; Kolokotsa et al 2009; Griego et al 2012). But, the literature on field studies on thermal comfort and energy efficiency (especially residential buildings) in India is still not very profound. Only a handful of studies are available on thermal comfort (Indraganti 2010; Rajasekar et al 2010; Singhet al 2012) and energy efficiency (Bhatia et al 2011; Dhaka et al) in India. With this growing awareness for a need to reduce the building energy use and to improve the indoor thermal environment, it becomes increasingly important to seek ways to assess the indoor thermal environment.

According to the report of Global Construction Perspective Ltd., (2011) between 2013 and 2020 India will become, behind China and the US, the third biggest construction market in the world with an annual growth rate of 8 %. It is more than evident that India, with its high demand of construction material and energy consumption moves straight to a critical resource shortage and carbon emission collapse, if the government and the society do not counteract with sustainable strategies and action plans for energy efficient building design and energy saving technologies. With about 40 % of the total national energy consumption, the construction and building area is the major energy consumer (de la Rue du Can 2009). India has a tremendous, not-to-be-missed opportunity to lock in energy savings for the next few decades, right now. The current trend of construction of houses in India is not very energy efficient. The ideas behind energy efficient housing
are simple, but applying them effectively does require information and attention to the details of design and construction. Some of these techniques are modest and very low cost, and require only small changes in a designer's standard practice.

In India, the bulk of electrical energy in residential buildings is used by mechanical systems to achieve thermal comfort. The high energy consumption is mostly related to poor thermal performance of building envelope (Indraganti 2013). This study is beneficial to those who design residential buildings as well as those people who try to design their house on their own who are less competent in the field of architecture and building energy efficiency. The study will provide general requirements on the proper thermal characteristics of the exterior building envelope, especially roofs of residential buildings that are necessary to achieve thermal comfort at low energy consumption. Demonstrating the profitability of energy efficiency measures is one key to driving change anywhere in the world.

1.8 AIM OF THESIS

The purpose of this study is to reduce heat load from the roof by identifying suitable passive techniques for cooling of building where major heat load in the buildings is only from roof. The objective is to reduce overdependence on electricity demand and energy use in residential buildings. The overall aim of the research is,

- To find out the useful passive design techniques for roofs that can be successfully incorporated into existing modern residential buildings in warm humid climatic region.

- To identify and assess practical approaches in roof design and roof treatments to provide thermally comfortable and sustainable building environments
1.9 OBJECTIVES OF PRESENT INVESTIGATION

Based on the past research, this research is aimed to investigate the effectiveness of various roof treatments, and their potential to achieve passive climatic control for residential buildings in warm-humid regions by reducing the indoor air temperature. This research also aimed to find a scientific rating scheme for residential roof system for the warm humid tropics. The above aim is achieved with the following tasks.

1. Study area delineation with the justification.
2. Analysis of climatic conditions of the study area and design strategies.
3. Categorization of the roofing typologies amongst the widely used roofing systems and materials used in residential developments in study area. Categorization of roofing typologies were based on the type of materials used for construction and the age of construction materials.
4. Testing of indoor thermal performance of various roofing systems (Traditional, conventional and alternative) by conducting experimental investigation.
5. Analysis of obtained data with the various thermal comfort standards / models to find out effective thermal comfort level.
6. Performance of numerical calculations to test the thermal properties of the existing as well as other passive roofs for warm humid climates inferred from literature.
7. Simulation studies by software to analyze the annual comfort ranges provided by each type of roof. Such tools provide insight to the dynamic behavior of the whole building and enable building designers to estimate and optimize envelope thermal performance, occupant thermal comfort and, ultimately, the energy performance of the finished building. In this research, attempt has been made to
evaluate the thermal performance and comfort levels provided by a range of roof constructions (existing as well as new roofs) that suit Madurai’s condition. Optimum combinations of roof and walls are also arrived. Using such simulation software helps to predict indoor comfort levels and optimizing the thermal characteristics of residential buildings at the conceptual level before the buildings are actually built.

8. Development of scientific rating system to rank the roofing system (experimented and examples from literature) with a set of variables, which influence the performance of roof.

This study also demonstrates the importance of choosing appropriate roofing systems and materials for better thermal comfort through the understanding on the effect of roofing systems on indoor thermal comfort. The recommended roofing systems and configurations will become useful guidelines for developers, architects, and house owners to improve thermal comfort of residential buildings in India. Therefore, this study will contribute in promoting energy and cost savings in Indian housing industry, as well as the whole country’s development.

1.10 RESEARCH METHODOLOGY

To frame the knowledge base, previous thermal condition researches, relevant to climatic condition of the study area have been analyzed. Six residences with six types of roofing systems have been selected for the study. These are the available roof types in Madurai. At each spot, air temperature, relative humidity and surface temperature were recorded at three different positions (at outdoor, roof surface and indoor space) using Indoor Weather Station and Infrared Thermometer during six days of April 2013. These days were characterized by clear skies, high solar altitude angle, high solar intensity and high duration of sun-shine. The study was primarily based
on field data measurement, observations, and discussions with inhabitants, comparison and analysis of data. The air temperature difference between the exterior (roof surface) and interior spaces was considered as significant indicator of the performance of the roof. Within the limited period of time for the study, residential areas of similar physical features were chosen, to minimize the impact of surroundings on the temperature variations. In addition, the simulation was also carried by using the software (Ecotect and PRO E) to analyze the thermal performance of existing roofs as well as roofing inferred from literature suited to warm humid conditions but does not exist in study area. Simulation study with software was also done to arrive at optimum envelope combinations. The detailed research methodology is described below.
1.11 STRUCTURE OF THE THESIS

This research aims to find the suitable roof constructions for warm humid climate. The proposed research will achieve this objective by adopting a multi-dimensional research approach that will develop a scientific rating.
system to rank the roofing system (experimented and examples from literature) with a set of variables, which influences the performance of the roofs. To conclude, the study intends to arrive at optimum combinations of walls and roofs that have high thermal comfort levels for residential buildings without using any air conditioning systems. For this study Madurai (9° 58' North Latitude 78° 00' East Longitude), Tamilnadu, India is chosen. To frame the knowledge base, previous thermal condition researches, relevant to climatic condition of the study area have been analyzed.

The different types of roofing systems have been selected for the study and have been assessed quantitatively. The quantitative approach begins with a preliminary observation survey on the common roofing systems and materials used in housing developments in Madurai. The roofs were classified under three different categories such as traditional, conventional and alternative roof typologies. Residential areas of similar physical features were chosen, to minimize the impact of surroundings on the temperature variations. In the detailed quantitative study the analysis of Thermal Transmittance value (U-value) of various roofs and the amount of heat transfer per unit area have been calculated numerically which are the most widely-used parameters for wall/roof thermal evaluation and compared with standards specified by National Building Code (NBC 2005) of India.

In tropical climates steady-state property, the overall air-to-air thermal transmittance, alone cannot provide a satisfactory performance criterion for rating roofs since the thermal performance of a roof is a function of outdoor and indoor climatic factors and orientation. A performance criterion based on thermal comfort and actual thermal performance of a roof section would be appropriate. Therefore an experimental investigation of continuous measurements of air temperature, relative humidity and air velocity in summer is done at outdoor and indoor environments of residential
buildings with various roof types. Sample houses under three different categories such as traditional, conventional and alternative roof typologies were selected for the thermal performance analysis. Residential areas of similar physical features were chosen, to minimize the impact of the surroundings on the temperature variations. The days when the recording was done were characterized by clear skies, high solar altitude angle, high solar intensity, and high duration of sunshine. The study was primarily based on field data measurements, observations, and discussions with inhabitants, comparison and analysis of data. The air temperature difference between the exterior (roof surface) and the interior spaces was considered as a significant indicator of the performance of the roof. The percentage of annual comfort hours of all the experimental houses were calculated using Ecotect5.1 software.

Various thermal performance indices like Time Lag, Decrement Factor, Thermal damping and Thermal performance index were calculated based on the surface temperature differences (roof and ceiling) calculated for various roofs and were compared with the standards. The surface temperatures were obtained by software (CREO 2.0) simulation for which the inputs were the thermal properties of materials used in various roof sections and the climate data of Madurai. The simulations of surface temperatures were validated by random measurements of surface temperatures of roof and ceiling in certain residential buildings of Madurai by infra-red thermal imaging camera. The software simulations for thermal performance analysis were done for the roof types that existed in the experimental region as well as for the roofs that have been inferred from the literatures of similar climatic region. In this research attempt has also been made to find the optimum roof and wall combination for the climatic conditions of the experimental study area.
In conclusion, this study demonstrates the importance of choosing the appropriate roofing systems and materials for better thermal comfort through the understanding on the effect of roofing systems on Indoor Air Temperature. The thermal performances of roofs have been monitored by observing the passive cooling capacity of various roof types. Guidelines have been developed to improve the thermal performance of widely used existing roofing typologies of residential buildings in the experimented region. The recommended roofing systems and configurations will become useful guidelines for the developers, the architects, and the house owners to improve thermal comfort of residential buildings in India. Therefore, this study will contribute in promoting energy and cost savings in Indian housing industry, as well as to the whole country’s development.

This thesis is divided into seven chapters. The first section is about literature review that discusses the significance and background for this research. This section is subdivided into three chapters. Chapter 1 deals with an introduction, background of the research problem, introduction of roof thermal performance, thermal comfort and significance of passive architecture, aim and objectives and thesis structure. Chapter 2 focuses on the complete comprehensive literature review. Chapter 3 describes about the climatic conditions of warm humid regions in Tamil Nadu with a critical analysis of climate of the study area and discusses the analysis of the roof typology of residential buildings in Madurai region. The second section of the thesis encompasses an in-depth research study of thermal properties and thermal performances of different roofs. This section is divided into three chapters. Chapter 4 describes the experimental investigation set up and experimental methodology that was carried out in different typology of roofs of houses in Madurai and also comprises of synthesis of data and analysis of results and discussions. Calculations made for the Thermal Transmittance value of various roof are presented and they are compared with the
acceptability limits. Chapter 5 describes the numerical calculations to assess the heat flow per unit area for various roofs which were experimented as well as inferred from previous researches in similar climatic conditions. The surface temperature differences between roof and ceiling for various roofs calculated by software simulation are presented. To test the thermal properties and comfort levels of various roofs. Results of simulation studies to test thermal performance of various wall and roof combinations to arrive at optimum combination are also presented. Chapter 6 comprises of synthesis of data and analysis of results and discussions. Chapter 7 concludes the research by arriving at a scientific ranking system for various roofs.