AN EXPERIMENTAL AND ANALYTICAL STUDY FOR USING GREEN MATERIALS TO REDUCING HEAT TRANSFER IN A BUILDING

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Abstract
One of the most important goals in building design is to provide thermal comfort to the occupants, while improving energy efficiency by minimizing the heat infiltration through the roof and walls of a building. The objective of the present study is to identify and prepare cost effective insulation materials prepared with locally available discarded materials. The experimental study was supplemented by an analytical model and the efficacy of the model vis a vis to the experimental findings is presented.

The experimental setup to analyses heat infiltration through roof structure consists of four identical prototype rooms established with similar orientation and specification at the roof of the Mechanical Engineering Department building at St. Xavier's Catholic College of Engineering, Nagercoil, India (8.1700° N, 77.4300° E). The three sides of the walls were covered with 0.229 m thick conventional burnt clay brick while the fourth side wall was made with an openable wooden door. The roof structures were covered with reinforced cementconcrete (RCC) of 150 mm thickness. Different configurations of over deck insulation were laid over each RCC roof structure to reduce the heat flux into theroom. The roof-1 (R1) was kept bare without any insulation as a reference, whileroof-2 (R2) was covered with a mixture of broken burnt bricks and lime mortar in the ratio of 3:1 (Conventional Indian practice) to a thickness of 50 mm. The roof-3 was over decked with an internationally renowned insulating material, extruded polystyrene (XPS), supplied by M/s. Owens Corning, USA of 50 mm thickness. The roof-4 was covered with a material developed for this work in collaboration with M/s Japeva Engineering Pvt. Ltd., Chennai, India, where discarded waste rice husk was mixed with aerogel and slag cement to prepare rice husk brick (RHB) with 50 mm thickness. Except the reference roof, the other three roof structures were finally laid with 25mm burnt clay tile over theinsulation.

Keywords: Heat transfer, insulation, conduction, convection, radiation, green mat

INTRODUCTION

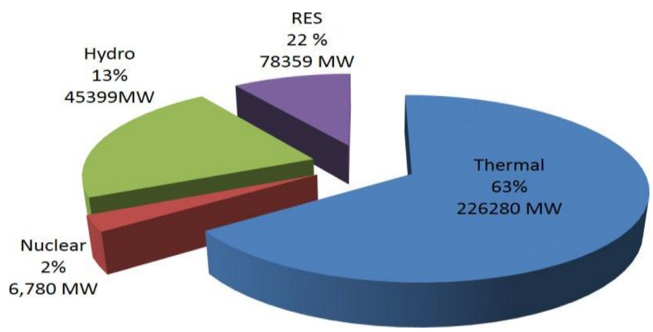
1.1 BUILDING-AN OVERVIEW

Building consumes resources such as energy and material and, in the process, generates waste, which can be potentially harmful to the atmosphere. Since the economy and population continue to expand, designers and builders face challenges to meet the demands of the new generation in new buildings as well as in their renovation. The main demands are security, health and productivity without adversely impacting the environment. This challenge can be achieved through an integrated synergistic approach that considers all the phases in the life cycle of a building. Sustainable approach supports an increased commitment to environmental stewardship and conservation. This results in an optimal balance of cost, along with environmental, societal and human benefits. The main objective of sustainable building designing is to avoid depletion of energy, water and raw materials in order to prevent environmental degradation throughout its life cycle and to create an environment that is liveable, comfortable, safe, and productive (Wu *et al.* 2016 & Liu *et al.* 2015).

1.2 ENERGY SCENARIO IN INDIA

India is the second largest commercial energy consumer in non- OECD East Asia, consuming 19 percent of the region's total primary energy. Economic growth of India has been largely associated with increased energy consumption. 78% of the total energy needs in India are met by conventional energy sources and the remaining 22% are met through renewable energy sources (Luthra *et al.* 2015). Over the past few years, climate change has become one of the main concerns driving energy policy.

Figure 1.1 All India installed power capacity as on 31-05-2019, IEA report (2019)



1.2.1 Power Capacity in India

The installed power capacity of India as on 31.05.2019 was 3,56,818 MW comprising of 2,26,278 MW thermal, 6,780 MW Nuclear, 45,784 MW hydro and 78,349 MW renewable (Figure 1.1). The country has significant potential for power generation from renewable energy sources, where efforts are being taken by the Government of India to harness it. An action plan has been formulated by the Government of India to achieve a total installed capacity of 175,000 MW from renewable energy sources by March, 2022.

1.2.2 Energy Consumption Pattern in India

The sector wise energy consumption in India is depicted in Figure

1.2. The industry sector accounts for the largest share (46%), followed by domestic (22%), agriculture (18%) and commercial sectors (9%) and others (5%). Energy consumption in India was about 849 kWh/capita in 2018, one among the lowest in the world. In comparison, China has a per capita consumption of 4,000 kWh and the average per capita consumption of the developed nations are around 15,000 kWh (Franco *et al.* 2017). Although India has considerably improved

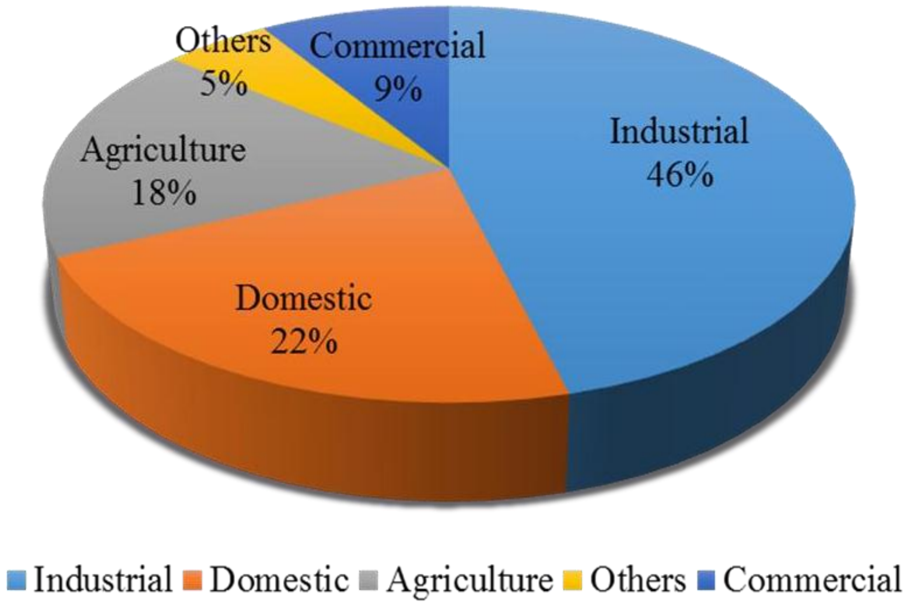


Figure 1.2 Sector wise energy consumption, IEA annual report (2018)

Its generating capacity, it still has difficulty in meeting the energy demand, which is a constraint for India's economic growth. Industrialization and commercialization have increased the use of electrical appliances, which has increased the demand for electricity. Moreover, approximately 30% of India's generated power is being lost in transmission. Furthermore, lack of transmission and distribution of power to thinly populated areas, which are located far away from the power generating stations is the major reason for not being able to achieve 100 percent electrification India (Amutha & Rajini 2016). India suffers shortages of electricity, particularly during peak hours and often experiences shut-downs lasting several hours a day in certain areas. The two possible solutions to mitigate this problem are either by increasing the power generation or by reducing the power consumption. Increase in power generation will lead to increase in carbon emissions, depleting natural resources, environmental degradation, health issues, and additional stress on the supporting infrastructure such as transport and manpower (Khan *et al.* 2013).

LITERATURE REVIEW

2.1 INTRODUCTION

The history of thermal comfort dates back to the beginning of humanexistence. Once they lived in caves and then slowly moved to houses built withmud, stone and woods. Then they started to build structures with manmade materials such as clay bricks to protect themselves from the harsh heat and the chilling cold. The testimony to this can be seen in the buildings such as the ancient pyramids of Egypt, which are made from stones and mud to protect residents from the desert heat during the day time and also to keep them warm at nights (Attia *et al.*2012)

2.2 IMPACT OF ENERGY AND ENVIRONMENT ONBUILDINGS

Buildings have an enormous and continuously increasing impact on the environment as they use around 40% of natural resources in an industrialized country. It consumes nearly 70% of electricity and 12% of portable water in developed countries (Lee & Chong 2016). The main challenge for

2.2.1 Worldwide Energy Consumption and Green House Emission inBuildings

The building sector has attracted increasing attention worldwide because it consumes 40% of the total energy in developed countries and emit around 40% of total Green House Gas (GHG) emissions according to an Intergovernmental Panel on Climate Change (IPCC) report (Cellura *et al.* 2018). The IPCC stated that GHG emissions from the building sector have doubled between 1970 and 2010, reaching a value around (10GtCO_2eq/y) nowadays. Most of the GHG emissions (6.02 GtCO_2eq/y in 2010) are indirect emissions, and they are increasing at a much higher rate when compared to direct emissions (Chen & Ng 2016). Due to the high contribution of indirect GHG emissions from the building sector, the environmental impact of buildings vary according to emission factors of the energy production processes.

2.2.2 Energy Consumption and Emission in Indian Building Sector

In spite of the rapid urbanization in recent years, most of the Indian population still lives in rural areas. Significant differences between rural and urban energy consumption profile exists in India. The urban population relies heavily on LPG and electricity for cooking, but the rural population still uses traditional biomasses. In terms of the consumption pattern in Indian buildings, a US Department of Energy study found that in rural areas, 93.8% of the energyconsumption is for cooking, 4.2% for lighting and 1.8% for appliances (Das *et al.* 2013). Minimal energy consumption was recorded for air conditioning in rural buildings. However, urban buildings have shown a different trend in energy consumption as active cooling systems are gaining much attention in recent years. Rapid urbanization is creating a high growth rate in demand for cooling and appliance services. The Indian building energy consumption pattern is closely following a typical developed country pattern (Kalbar *et al.* 2018). Due to this trend, the International Energy Outlook predicts that India's increasein residential energy consumption resembles that of China at 3.7% per year, andIndia's commercial sector energy consumption increases at an average rate of 5.4% per year, which is similar to that of developed countries.

2.3 ROOF INSULATION TECHNIQUES

Generally, people living in hot regions want to make the confined atmosphere cool, whereas the people living in cold regions want to keep themselves warm. Naturally, heat transfer takes place from the hotter region to the colder region and these phenomena affect both the above situations. To minimize this loss or gain of heat in buildings, thermal insulations are providedto reduce the heat transfer through the building.

2.4 MATHEMATICAL MODELS FOR ROOF APPLICATIONS

Providing thermal insulation by innovative building materials has increased significantly in recent years for both hot and cold climatic regions. The demand for thermal comfort in residential, commercial and governmental building has increased because it increases productivity. The thermal design of buildings depends on the requirement of indoor conditions, prevailing outside climatic conditions, and the choice of building construction materials andinsulation (Eben

Saleh 1990). Accurate method of analysis to predict the thermal performance of a whole building is needed for such design. A whole building thermal analysis is quite involved since all mechanisms of heat transfer are present and the building components are composite and consist of many layers of different materials. The analysis has to be dynamic, since the outside ambient temperature, wind speed and solar radiation vary with time. The heat gains due to occupants, equipment, lighting, and solar radiation, transmission through fenestration, besides the ventilation and infiltration have to be accounted in the analysis (Jensen 1995). Ozisik (Ozisik 1993) described various analytical methods for solution of one-dimensional problems with temperature-independent properties.

2.5 SCOPE AND OBJECTIVES

The literature review guides one to focus investigation on the cost- effective passive cooling system for buildings in India. Implementation of such passive design throws lot of challenges for new buildings, as well as retrofitting for the existing buildings due to economic and technological barriers. Modifying the traditional methods more scientifically for sustainable and reliable building structures needs lots of ingenuity. In the present work the following objectives were formulated:

- To develop the over deck roof insulation from discarded novel waste material to mitigate heat infiltration.
- To develop an analytical model from fundamental equations for various roof configurations to estimate cooling load in new buildings or in buildings with retrofit roof structure.
- To estimate the overall reduction in heat load in the top floor of a building to save energy, if air conditioned, or to provide comfortable living conditions for non-air conditioned buildings.
- To develop cost effective wall insulation materials for mortar and brick from discarded waste materials, since high rise buildings are the most important city dwellings.

METHODOLOGY

3.1 HEAT MITIGATION STUDY IN ROOF STRUCTURE

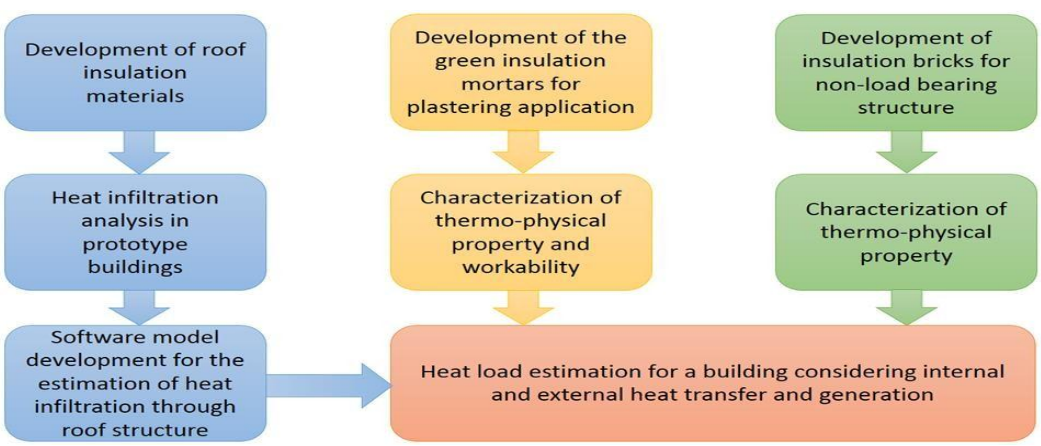


Figure 3.1 Flow chart of the present research work

"Prevention is better than cure" is a proverb, which in this context implies, it is better to stop the infiltration of heat into the building in the first place rather than removing it afterwards at the expense of energy and cost.

3.1.1 Climatology of the Region under Study

The prototype rooms built for the study are located at the roof top ofthe Mechanical Engineering block in St. Xavier's Catholic College of Engineering, Nagercoil, Kanyakumari district, Tamilnadu, India having the geographical coordinates as 8.1700° N, 77.4300° E. The general description forthe climatic conditions of this place would be warm and humid as per the energyconservation codes and guidelines developed for buildings. The weather stationattached with the experimental site reports the climatic conditions. The normal average day time temperature range is 30-35° C, relative humidity in the range of 70-90 %. The average annual rainfall is about 1000 mm and the wind velocity is around 5 m/s. The half-an-hour average weather data are recorded using logger and are compared for reliability with the data published in Energy Conservation Building Codes hand book for the nearby regions.

3.1.2 Prototype Construction

Four identical prototype rooms were constructed at the top of a building in Nagercoil, India as shown in Figure 3.2a. The size of each room was1 m×1 m×1.5 m and the three sides of the wall were constructed with 0.229 m thick conventional burnt clay bricks. The roof of the rooms was covered with 150 mm RCC structure to resemble a typical Indian style building system. The fourth side of the room was covered with a wooden door for accessibility. Proper ventilation was provided to ensure normal in-door conditions, similar to that ofa conventional house.

3.1.3 Roof Configuration and its Thermo-Physical Properties

The roof of the room1, R1, was kept bare as a reference structure, without any insulation over the RCC structure (Figure 3.2b), whereas R2, R3 and R4 were modified with over deck insulations. R2 was laid over with 50 mm thick typical Indian weathering coarse (WC), which is a mixture of coarse brick and lime in the ratio of 3:1. (Figure 3.2c,d).

Table 3.1 Layer configuration of different roof structures and itsthermo-physical properties

Roof Type	Layer Configuration	Layer Material	Layer thickness (mm)	Density kg/m^3	Specific Heat Capacity (J/kg K)	Thermal Conductivity (W/mK)
R1	Single layer	RCC	150	2300	1130	1.63
R2	Top layer	CT	25	1500	700	0.25
	Middle layer	WC	50	1300	800	0.23
	Bottom layer	RCC	150	2300	1130	1.63
R3	Top layer	CT	25	1500	700	0.25
	Middle layer	XPS	50	32	820	0.026
	Bottom layer	RCC	150	2300	1130	1.63

R4	Top layer	CT	25	1500	700	0.25
	Middle layer	RHB	50	1100	900	0.18
	Bottom layer	RCC	150	2300	1130	1.63

RESULTS AND DISCCUSION

4.1 INTRODUCTION

The first part of this chapter reports the results of the experimental studies conducted to find out the feasibility of mitigating heat infiltration in different roof configurations through design and fabrication of structures using discarded green insulation materials. The next part presents analytical models that were developed for each roof configuration by using weather station data and thermo-physical properties of insulative materials with finite difference technique, using MATLAB software. The simulation model enables one to predict the temperature profile and to estimate heat load in a building. Also, three green cement mortars were prepared for plastering application using discarded waste materials.

4.2 HEAT MITIGATION STUDY OF VARIOUS ROOFCONFIGURATION

The details of roof configurations are provided in section 3.1.3. Strategically placed temperature sensors in the roof structure provide real time temperature data. This data was further processed during analysis. Thermal performance analysis of a building uses parameters such as temperature distribution, heat flux to calculate the net heat flux infiltration per day. The effectiveness of every innovative thermal insulation configuration in the roof structure was evaluated for various building applications.

4.2.1 Roof Bottom Surface Temperature Analysis

The roof bottom surface temperature has direct influence on the amountof heat infiltration into the room through the roof structure. The average bottomsurface temperature distribution for the four roof

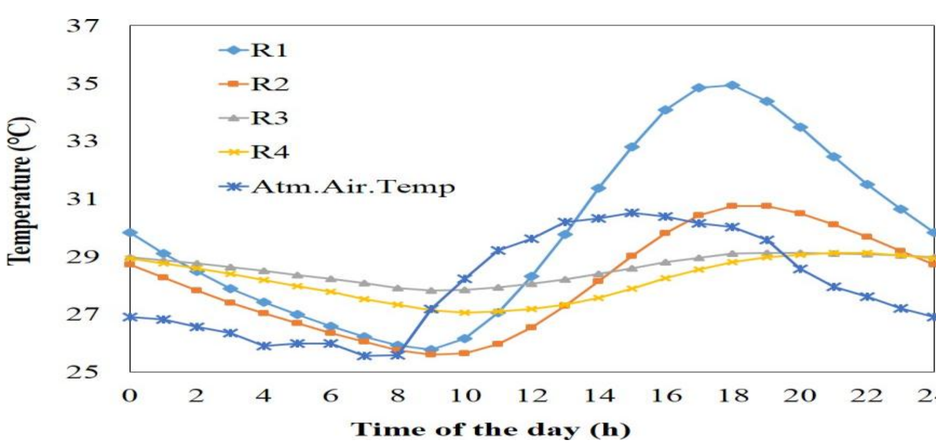


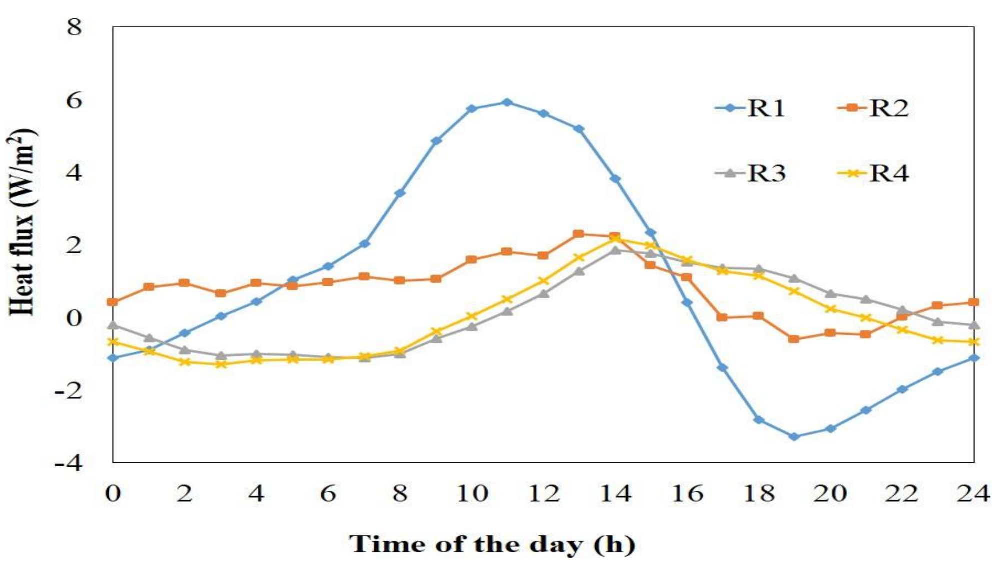
Figure 4.1 Roof bottom temperatures of various roofconfigurations along with atmospheric airtemperature

structures during the study periodis shown in Figure 4.1 along with the atmospheric air temperature Obviously, the maximum bottom surface temperature was recorded for the reference roof structure (R1), which was without any thermal protection.The temperature raises from 25°C to around 36°C during afternoons due to theheat of solar radiation, but the atmospheric air temperature remained less than 30°C. Since RCC is having higher thermal conductivity and higher thermal diffusivity, the temperature inside the room shoots above the atmospheric air temperature. Moreover, the time lag to infiltrate heat from the outer surface to the inner surface is significantly less compared with other roof structures. During the same period, the maximum roof bottom surface temperature for R2 was only 30.76°C, which is 14.5% lower than that of the reference roof R1.

4.2.2 Analysis of Heat Flux Infiltration

The main purpose of solar passive cooling is to reduce the net heat infiltration into the building, which has to be analysed to understand theeffectiveness of the insulative material. The heat flux exchange through the roofstructure was computed by assuming a constant convective heat transfer coefficient of 10 W/m^2K between the bottom roof surface and room air in everyroof configuration. The hourly heat flux infiltration into the room was plotted against the time of the day and is shown in Figure 4.2.

Figure 4.2 Hourly heat flux variation with respect to time of a day



CONCLUSION

Implementation of cost-effective innovative passive cooling strategies for Indian building is challenging and rewarding. Successful adoptionof traditional methods by incorporating discarded solid waste materials for reliable, sustainable and comfortable build structures provide satisfaction in research. The five-point agenda of the present work to develop innovative over-deck insulation, analytical model development for heat load estimation and design, development of non-load bearing insulation brick and insulation mortarfrom discarded waste material and the analysis of heat load benefits in buildingwere done successfully.

Around 59.20% reduction in external heat load for top floor area wasmade possible by the deployment of innovative over-deck insulation to roof andwall structures of a building. They together provide comfortable living conditions for tropical countries like India and will significantly reduce the cooling load for an air-conditioned building. Since the share of energy consumption in the building sector is ever increasing, innovative insulation to building envelop will contribute to solving energy crisis and to mitigate the rateof environmental degradation. The following are the salient contributions fromthis research.

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