COMPARATIVE STUDY OF DIFFERENT TYPES OF ROOF AND INDOOR TEMPERATURES IN TROPICAL CLIMATE

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Abstract - A roof provides protection to be safe from direct sunlight. From the shelter, shadow alone is not expected. Durability, sustainability, less life cycle cost, and low maintenance cost are expected from a selected roof. The world has a thirst to have a best roof. No roof will fulfil the requirement of humanity since the climatic conditions are different. Hence the roof should be selected according to the prevailing climate. And the roof selection depends on the need, taste and the spending capability of the house owner. Thatched shed, tiles covered roof, light roofs either using galvanized sheets or asbestos sheets, painted or unpainted metal sheets, RCC, Green roof, Roof pond, insulated roof, reflective roof, and cool roof are the roofs so far brought into use. Whatever be the roof, it should provide thermal comfort. Thermal comfort is felt through the thermal experience of the occupants. Thermal experience depends on the indoor temperature. Energy efficiency of a building is highly based on the indoor ambient temperature. Energy efficiency in buildings is compelling, cost effective, saves money and useful to compromise resource energy shortage. A light roof named as Single Decker (SID) and an insulated double roof using hybrid technique named as (DOD) are taken for this study. Among the selected roofs the DOD provides a better thermal performance and thermal comfort. The study has been carried out for the summer peak period in April 2014. Thermal performance and indoor temperature of the DOD is compared with other roof studies.

Key Words: Thermal comfort, Thermal experience, Energy efficiency, Single Decker, Double Decker

I. INTRODUCTION

More than 40% CO_2 emissions in developed countries come from heating, cooling and powering buildings. Globally, buildings are responsible for approximately 40% of the entire world's annual energy consumption. The increasing demand for residential and commercial building spaces in developing countries will further push up energy consumption. It has been predicted that CO_2 emissions from buildings (including the use of electricity) could increase from 8.6 billion tonnes in 2004 to 15.6 billion tonnes in 2030 under a high growth scenario [1]. The shortage of conventional energy and escalating energy costs have caused to reassess the general design practice. The increasing level of damage to the environment has created greater awareness at the global level, which has resulted in the innovation of new types of roofs such as Green roof, Reflective roof, Roof pond, Insulated roofs, and Phase Change Material doped roof, apart from RCC roof.

The tropical zone is defined as the area of land and water between the Tropic of Cancer (latitude 23.5˚N) and the Tropic of Capricorn (latitude 23.5˚ S). Occupying approximately forty per cent of the land surface of the earth, the tropics are the home to almost half of the world's population. There are variations in climate within the tropic. However ninety per cent of the tropical zones embody hot and humid climatic regions, whether permanent or seasonal. The remaining ten per cent is desert like, and characterized as hot and dry climate [2]. Local conditions may also differ substantially from the prevailing climate of a region, depending on the *topography*, the altitude and the surroundings, which may be either natural or built by human. Local climate can strongly be influenced by cold air pools, local wind, water bodies, urbanization, ground surface and altitude [3].

Over the past decade, environmentally oriented innovations in technology and services have emerged in all areas of the economy, driven by governmental policies, professional experts, market opportunities and social movements. In the residential buildings, indoor thermal discomfort has been highly challenging and it depends on, one or more of the materials used either as ceiling or wall or making doors or roofing support or combination of all. One of the special concerns of the trained builders is to design a building that is thermally tolerable and conducive to the occupants of the building. The ceiling materials are made with different thermal conductivity, thermal absorptivity, thermal diffusivity and thermal resistivity to bring out a good indoor thermal condition. Economically favoured people usually go for the costly ceiling materials without considering the efficiency of thermal insulation. Heat propagated into interior space is mostly through ceiling and ceiling panels and partly through walls by the process of conduction, convection and radiation. Cooling is the transfer of energy from a space or from the air to a space, in order to achieve a lower temperature than that of the natural surroundings. In recent years, air conditioning systems are used to dissipate heat, and to keep better moisture content within a space, in order to achieve the desired effects of the occupants. For cooling no energy should be supplied other than renewable energy, which would be desirable.

Thermal performance of a building refers to the process of modelling the energy transfer between a building and its surroundings. India is in energy transition. The energy consumption in Indian residential buildings is the highest among all the Asia Pacific Partnership (APP) countries [4] and is increasing at a phenomenal rate.

Passive design strategies seek to improve thermal performance of the building by paying attention to utilization of natural ventilation through orientation, insulation, window placement and designs [5]. Passive design approach makes use of natural energy in the environment which is available to the building through the use of the microclimate, the building form and fabric. Higher standards of living are being demanded today worldwide. A comfortable environment is where there is freedom from annoyance and distraction, so that working or pleasure tasks can be carried out unhindered physically or mentally [6].

Indian concrete roofs, with 150mm of concrete and 75-100mm of weathering course transfers 50-70% of heat in to the occupant zone. High reflective coatings can reduce 20-70% heat transfer [7].The heat incoming into the occupant zone through roof is the main cause of discomfort. The heat transferred into the occupant zone is true for single storey and top floor of the multi-storeyed buildings [3].

Green roofs are complex technological systems, adopting vegetation as integral part of the building shell and are considered as one of the green retrofit strategies. These not only alter the micro climate of the building roof, and the roof insulation but also provide cooling through transpiration of water to reduce roof temperature and thus the summer solar gains, without worsening the winter energy performance. During the summer period a green roof provides various benefits 1) the high thermal capacity, due to the soil layer and 2) free cooling of indoor spaces, induced by evaporation of water possessed by grass 3) improvement of acoustic insulation and filtering of dust. [8], [9].

“Lack of promotion from the government and social communities among the public and private sectors”, “Lack of incentive from the government toward the owners of the existing buildings”, “Increase of maintenance cost” and “Technical difficulty during the design and construction process” were the major barriers during the stage of planning and designing. It is suggested that the government should play the leading role in the stage of planning and designing for implementation of extensive green roof systems. During the stage of construction and operation as well as management stages, barriers including “Increase of maintenance cost” and “Technical difficulty during the design and construction process” were more essential [10].

The initial cost associated for making the green roof is higher and it is difficult to maintain properly. It also requires stronger roof beam to support the various roof layers of the green roof. Also in the roof with roof coating, the detritions of roof coating over the time are a Major setback. The settlement of dust over the roof coating may completely spoil the performance of the roof coating [7].

Among numerous methods available, passive cooling using roof pond system has been considered appropriate for those who cannot afford vapour compression air conditioning. Experimental investigations of passive cooling methods have been undertaken in some previous studies. Various roof pond techniques are possible, e.g. sky thermo, energy roof, sky bird, cool pool, water-retaining roof, trickle roof, and intermittent water spraying. Water spraying method is simple, inexpensive, and suitable for the tropical climate. Typically water is sprayed on the roof for 40 seconds every 5 minutes to reduce heat absorption due to solar radiation. Trickle roof is operated by water flowing above corrugated roof. Then, water is circulated through wall and roof to carry heat away. Water evaporation during its operation does not disturb indoor humidity, so that the trickle roof is suitable for house under hot and humid climate [12].

An experimental house equipped with the roof pond system was tested for seven days. The roof pond was a combination of trickle roof and intermittent water spraying. This system was consisted of three-layer plastic shading devices, one 0.5 hp pump, and one 200-L storage tank. The roof pond requires simple operation, without special monitoring and maintenance. However, awareness should be paid on aesthetic and wind damage. In brief, the roof pond system is a potential candidate to achieve better comfort conditioning of house in hot and humid area. It was experimentally demonstrated that it is possible to maintain the indoor temperature 2-4^{o}C lower than the outdoor temperature using this roof pond system in a tropical climate [13].

Architects traditionally have recognized that reflective building colours can reduce building thermal loads. Several studies have been carried out regarding the cooling potential of the application of reflective coatings on buildings. Unventilated small buildings in Israel that had white coloured walls were approximately 3^o C cooler in summer than when the same buildings were painted grey [14]. Increasing the roof reflectance of commercial buildings in California from about 20% to 60% dropped the roof temperature on hot summer afternoon by 45˚F [15]. The installation of the thermal control coating on a single storey building with identified high roof temperature reduced the peak roof temperature by 33˚ C [16].

The effect of the colour of roofs study at the Technion in Haifa, revealed that light weight roofs made of a type of concrete called Ytong, which is 7, 12 and 20cm thick and painted grey, showed a maximum external air temperature of approximately 31 ˚ C, generated an average maximum external surface temperature of about 69˚C. The maximum ceiling temperatures are likewise significantly affected by the thickness of the roof: 45˚C, 39 ˚ C, and 33˚ C, respectively. Conversely, when the roof was painted white and investigated with maximum air temperature about 27 ˚C, the average external maximum surface temperature was about 27.5 ˚ C. The maximum temperature of the ceiling was about 25.5 ˚C for all roofs [17].

The major importance of good insulation of the roof in tropical climate is thickness and colour of insulation. In general, 5cm insulation is being used for red and blue tiled roofs, which is inadequate. Therefore, insulation thickness needs to be at least 8cm (the value for medium colours) and to use polystyrene as insulation rather than mineral wool. Mineral wool is fairly cheap but not very well adapted to tropical climates: it loses its thermal properties when it absorbs ambient humidity. In another experiment more than 3˚C have been observed between a dwelling with a well- insulated roof and with no insulation [18].

Indian thermal comfort standards specify too narrow temperature ranges. Energy consumption in Indian homes is the highest among the Asia Pacific Partnership countries. Literature features little thermal comfort field research from Indian residences. The author conducted a field study in NV apartments in Hyderabad, in summer and monsoon, involving over 100 occupants in 2008. The analysis returned a comfort temperature of 29.23 °C and the comfort band (26 - 32.5°C); way above the Indian standard limits (23- 26 °C). Fanger's PMV grossly overestimated the actual sensation [19].

Keeping all these problems in mind, a new type of roof has been constructed to achieve an energy efficient building. The present work proposes and analyses a new type roof which uses a hybrid technique to bring out energy efficient building.

II. RESEARCH DESCRIPTION

While previous research efforts have investigated the thermal behaviour of various light roofing systems, this particular study represents, the first time an attempt made to quantify the roofing influence on cooling performance on identical unvented, unoccupied, two side by side modules. This study consisted of two modules located in Chidambaram, Tamilnadu. The focus of the study is to investigate how the two roofing systems impact the indoor temperature in hot and humid climate in summer. The two modules have the same plan and identical in construction and exposure. The sites are given a three letter code to describe each roofing system.

* Single Decker (SID)
* Double Decker (DOD)

Monitoring collected 2 hours data on comparative performance of the two modules in summer 2014 under unoccupied and carefully controlled conditions for a month. The two modules have same floor plan, wall area and orientation. The size of the module is 3m x 3m x 3m. The galvanized sheets are used in the modules which have the same thickness of 0.35mm. The walls have a thickness of 230 mm made up of brick. Two angles are used as purlins. It is a low sloped roof of 2˚. Walls of the modules are white washed and the flooring is done with cement mortar. The experimental module is Double Decker (DOD) in which wooden insulators and mineral wool is used between two galvanized sheet roofs. The Single Decker (SID) is the control module. Relevant construction details are summarised in Table.1

Table I. Construction data of the Experimental Modules

Sl. No	Description	Dimensions in m^2
1	Floor Area	9.29
2	Net Wall Area	35.26
3	Ceiling	11.12
4	Doors	1.76
5	Overhang	1.82

A. Control Module (SID)

In Single Decker, (Fig.1) Galvanized sheets are used as roof element, where the walls are made by brick and cement mortar. The galvanized sheets are good heat conductors. As the solar radiation falls on the roof, the sheets are terribly heated even by early morning due to conduction and it extends for the whole day. During the peak hour the amount of heat propagated into the building is too high. It is used because of its rapid installation, larger clear spans, light weight and design flexibility and the major advantages are tightness, safety, recyclability, durability and the lowest life cycle cost. About fifty years ago, an optimum blend of zinc-aluminium alloy coating for steel was developed and commercialized about forty years ago which was invented by Luigi Galvani. This product has established itself as the unquestionable leader for steel roofing applications around the world, for residential roofing and commercial projects, both in steep - slope and low -slope applications.

B. Experimental Module (DOD)

Experimental module is a newly designed roof. The design is carried out in four steps. In the first step, first roof is made using galvanised sheets. In the second step wooden reapers of size 3000 mm X 50 mm X 25 mm were arranged over the roof. The spacing between the reapers is 200 mm. In the third step, 50 mm thick packed mineral wool roll was spread Fig.2. In the fourth step galvanized sheets were set over it as second roof. The two roofs are separated by 100 mm to 122 mm. Since light roofing system have two light roofs enclosing the wooden reaper and mineral wool, it is named as Double Decker Fig.3. Between the wooden reaper and the bottom roof sheets hemi cylindrical air spaces are created. In the same manner hemi cylindrical air gaps are created between the upper roof sheets and the mineral wool bed. The hemi cylindrical vents helps to drain away the hot air above and below the mineral wool bed. The roof cooling is done by convection of air. The mineral wool insulation prevents the heat entering the roof. Instead of a single technique the roof uses a hybrid technique.

Fig.1 SID Module

Fig.2 construction of DOD

Fig.3 DOD Module

III. EXPERIMENTAL SET UP

The experiments were carried out in Chidambaram, Tamil Nadu, 11˚24´N latitude and longitude 79˚44´E.The location is characterized by hot and humid weather and it is in the tropical region. The modules, used in this study are exactly identical in terms of their geometry, orientation, area and climate conditions.

The two modules are fully instrumented. To measure the Indoor Ambient Temperature and Relative Humidity Single channel data logger is used. In two hours interval the roof, wall and floor temperatures were measured by means of Infra-Red Thermometer. Roof, wall, floor and indoor ambient temperature and relative humidity field data have been catalogued for the summer season of 2014. Although the performance of the SID and DOD was evaluated continuously, for clarity, only five peak performance days in summer are shown.

IV. RESULTS OVER THE MONITORING PERIOD

The data are plotted for the time period between 24^{th} to 28^{th} April. 2014. Based on the temperature data April. 24^{th} and 25^{th} were the hottest days of the summer during the monitoring period. As shown in figure.1, the peak hour roof temperature of the control module was 44.3 ˚C and in the experimental module 33.8 ˚C. There is a notable roof temperature difference of 10.5˚C between the experimental module and the control module has been observed. Roof Temperature of the experimental module and control module in Fig.4.

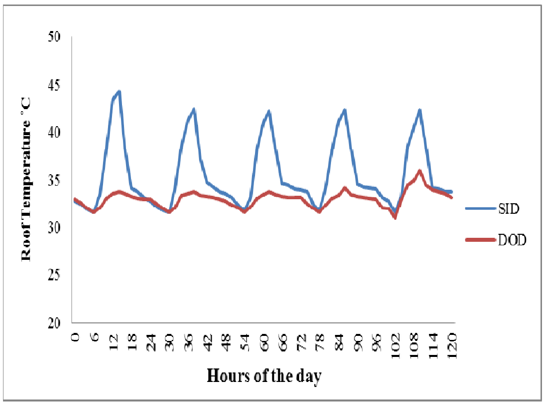

Fig.4. shows the variation of roof temperatures of the experimental module and the control module with hours of the day

As shown in fig.5, the peak hour floor temperature of the control module was 34.4˚C and in the experimental module 32.6 ˚C. There is a notable floor temperature difference of 1.8˚C between the experimental module and the control module has been observed.

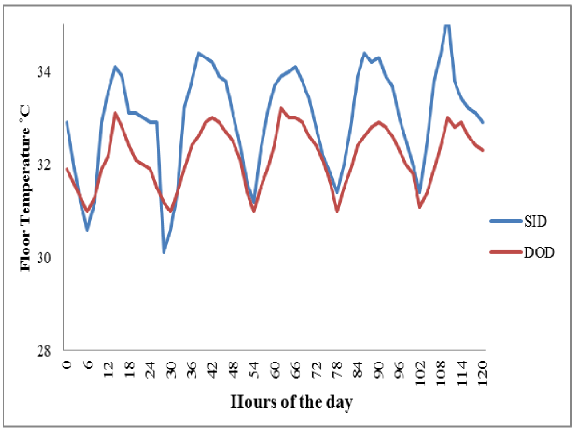

Fig.5 shows the floor temperature of the experimental module and control module with hours of the day

As shown in fig.6, the peak hour wall temperature of the control module was 38.4 ˚C and in the control module 34.6 ˚C. There is a notable wall temperature difference of 3.8˚C between the experimental module and the control module has been observed.

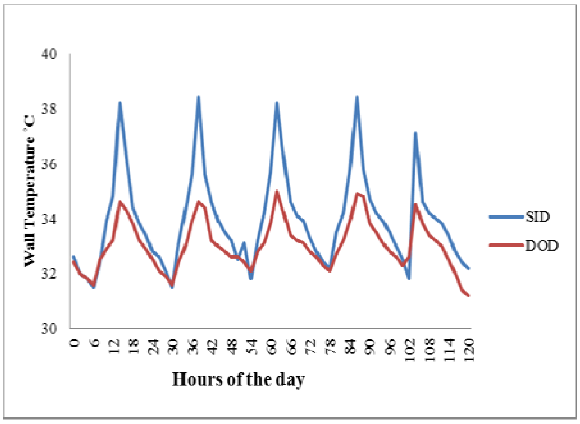

Fig.6 shows the mean temperature of walls of the experimental module DOD and control module SID with hours of the day.

As shown in fig.7, the peak hour indoor ambient temperature of the control module was 38.2˚C and in the experimental module 33˚C. There is a notable roof temperature difference of 5.2˚C between the experimental module and the control module has been observed.

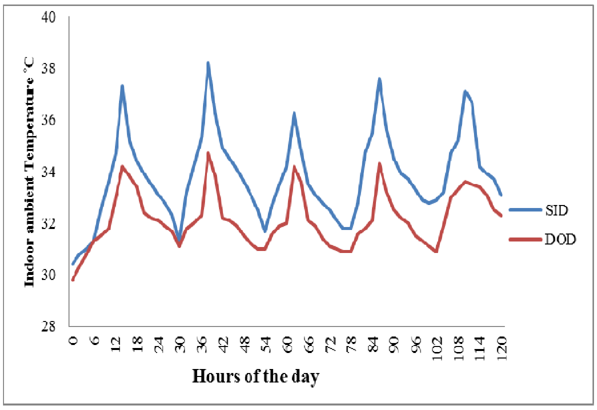

Fig .7 shows the Indoor Ambient Temperature of the experimental and control module with hours of the day.

As shown in fig.8, the peak hour relative humidity of the control module was 59% and in the experimental module 68%. There is a notable roof temperature difference of 9% between the experimental module and the control module has been observed.

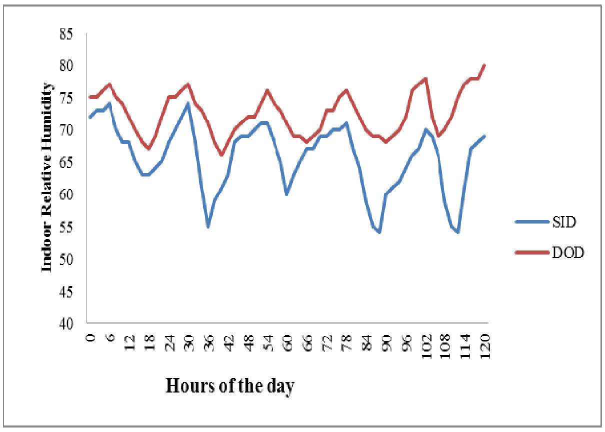

Fig .8 shows the Relative Humidity of the experimental and control module with hours of the day.

A. *Comparison with the Other Roof Studies:*

1) *Green Roofs:* The daily maximum temperature on the vegetated rooftops was reduced and dampens diurnal temperature fluctuations Fig.9. Researches in US indicated that vegetated rooftops decreased the peak temperature from 0.5 K to 3.5 K; along with dropping of temperature, the albedo increased from 0.05 up to 0.61 [20].

2) *Roof pond:* By using a roof pond it was experimentally demonstrated that it is possible to maintain the indoor temperature 2 - 4˚ C lower than the outdoor temperature (Fig.10) using this roof pond system in a tropical climate [13].

3) *Reflective roofs:* Reflective roofs Fig.11 lose its reflectivity, owing to the accumulation of dirt and weathering conditions, particularly in large cities. The use of reflective roofs is an effective strategy during hot months, but not during cold months. Moreover, highly reflective roofs result in visual discomfort and glare, and as such, its use is not advisable for areas near flight paths. Thus, the site topography and building regulations limit its application in some cases. It was demonstrated that the use of reflective coatings can reduce a white concrete tile's surface temperature under hot summer conditions by 4˚C and during the night by 2˚C. It can be warmer, than the ambient air by only 2˚C during the day and cooler than the ambient air by 5.9 ˚C during the night. "Cool" coatings present superior thermal performance even compared to other "cool" materials. This study can assist in choosing more appropriate coatings for building envelopes and other surfaces of the urban environment, and thus contribute to the mitigation of the heat island effect as well as the reduction of cooling loads and electricity consumption of buildings [21].

4) *Double Decker:* The experimental module Fig. (2 & 3) used for this study provides an indoor temperature of 7 to 9 ˚C less than the outdoor temperature. The roof is an insulated roof with mineral wool of thickness 50mm. Additional insulation is provided by wooden reapers and the enclosed air. The mineral wool is available in the form of one side shielding. Lengthy polyethylene sheets are used to cover and shield the other side of the mineral wool. This tight packing avoids the mineral wool bed from absorbing the air moisture. During rainy season if there be any leak on the roof that will be drained easily by the cover sheet over the mineral wool.

Fig.9 Green Roof Chicago's City Hall building in U.S

Fig.10 Roof pond Chiang Mai University located in Chiang Mai province (700 km North of Bangkok-2006)

Fig.11 Reflective white roof (Cool Roof Hawaii, 2013)

V. CONCLUSION

This study investigated the technical and economic feasibility of Double Decker. Thermal performance of roofs exercises a powerful effect on indoor ambient temperature. This study tested two side by side modules in Chidambaram, Tamil Nadu with identical floor plans and orientations using different materials for roofs. The techniques of construction evaluated for DOD is commonly used normal techniques and low cost than others. Further the same roof material strongly reduces the house peak cooling demand. The data showed that solar heating had a large effect on the SID roof and on wall and consequently on floor. Light roofs are easily excited by solar radiation during the day time hours causing a high temperature of the occupant zone. The impact of ceiling and wall heat transfer by DOD is very less. The experimental module DOD provides a best presentation to periods with high solar irradiance. The DOD provides a lower indoor ambient temperature of 5-6˚C than the control module SID. Regarding the DOD module, the variation between the Indoor Ambient Temperature and Outdoor Ambient Temperature is 7 - 9˚C in the peak summer. Comparing with other roofs, this light roof provides a better indoor ambient temperature.

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