COMPARATIVE STUDY OF THERMAL PERFORMANCE OF INSULATED LIGHT ROOFS IN TROPICAL CLIMATE

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Abstract: Thermal performance of a building depends on many factors. It is associated with solar insolation, the type of roof, type of wall, orientation, colour of paint given to the walls, and the motion of Earth around the sun. The building elements, roof and wall play an important role in the thermal reception from the solar insolation. Residential buildings consume more energy for heating and cooling. A residential building should not be a mere shadow maker. It should be a less energy consumer. It should provide a good thermal experience. To reach this aim the indoor environment should be feasible. The indoor environment depends on the indoor temperature and the indoor relative humidity. If the indoor temperature increases then the relative humidity will be decreased. Now the occupants feel thermal discomfort. So control over the indoor temperature is a must. The quantity of heat entering the inside the building can be modified through Roof and wall insulation. In this study, to get a better thermal performance roof insulation is alone considered. Two side by side modules of the same size and orientation were constructed with different insulated roofs. The construction of walls and floor are having the same dimension. Polyurethane readymade panels are used as roof material in one of the modules and named as PUD module. The polyurethane panel is an industrial product. The other module is provided with a newly designed roof called Double Decker (DOD). Both the roofs are having intermediate insulation. Thermal performance of the newly designed roof is better than the industrial product in the summer peak hours. The cost of the DOD is relatively less. The study has been carried out from September 2013 to August 2014, in the tropical climate.

Key words: DOD, Indoor temperature, PUD, Relative humidity, Thermal comfort, Thermal performance.

I. INTRODUCTION

Energy consumption in buildings is also increasing at an unprecedented rate, as more and more buildings are designed in lightweight materials like Galvanized sheets, Asbestos sheets, glass and aluminium giving little importance to the passive methods of heat control and human adaptation to comfort. It is well known now that buildings with poor adaptive opportunities often produce intolerable indoor conditions within, and consume high energy.

In the residential buildings, indoor thermal discomfort has been very 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. The ceiling materials are made by different materials with different thermal conductivity, thermal absorptivity, thermal diffusivity and thermal resistivity. Heat propagated into indoor space is partly through ceiling and partly through walls by the process of conduction, convection and radiation. Shortage of conventional energy source and enhancing energy cost has caused the re-examination of the general design practice Hence, the major focus of researchers, policy makers, environmentalists and building architects has been on the conservation of energy in buildings. Energy efficiency in buildings can be achieved through a multipronged approach involving adoption of bioclimatic architectural principles responsive to the climate. Use of materials with low embodied energy and effective utilization of renewable energy sources should be carried out to power the building. Studies of various countries have shown that buildings with wooden structures require less energy and emit less CO_2 during their life cycle than buildings with other type of structures.

The energy efficient roofs so far designed costs too high, and they do not reach the common. Most of the heat developed by the solar radiation in the roof and wall is transferred into the occupant zone. The sun is the primary source of thermal energy. Roof receives the solar radiation directly from the sun light and it becomes a secondary source of heat. The east wall receives heat directly up to the noon and the west wall receives heat directly after the noon. The two walls also becomes the secondary source of heat. The floor of a building does not heated directly by the sun light in most of the buildings. The roof and walls become secondary heat sources. As soon as the roof and walls emit heat radiations into the building, the heat is transferred to the indoor air. Regarding light roofs the indoor temperature of a building closely follows the outdoor temperature.

II. BACK GROUND OF THE STUDY

The Tropics is regarded as a region where the human evolved and comfort has been often taken for granted, built environments are increasingly becoming issues of public concern. The tropical outdoor environment has been regarded as important as indoors in the life of the populace. This tendency has put increased demand on the comfort requirements in the design of buildings. Comfortable outdoor spaces have a significant bearing on the comfort perception of the indoor ambience. The demand for comfort conditions in buildings are significantly increased as a result of exposure to uncomfortable outdoors [1]. Generally the tropical zone is defined as the area of land and water between the Tropic of Cancer (latitude 23.5^{o} N) and the Tropic of Capricorn (latitude 23.5^{o}S).Occupying approximately 40% 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 90% of the tropical zones embody hot and humid climatic regions, whether permanent or seasonal. The remaining 10% is desert like, and characterized as hot and dry climate [2].

The higher thermal resistance systems containing bulk insulation within the timber frame, the measured result for a typical installation was as low as 50% of the thermal resistance determined considering two dimensional thermal bridging using the parallel path method. This result was attributed to three dimensional heat flow and insulation installation defects, resulting from the design and construction method used. Translating these results to a typical house with a 200 m2 floor area, the overall thermal resistance of the roof was at least 23% lower than the overall calculated thermal resistance including two dimensional thermal bridging [3]. Providing insulation for walls and roof in a building increases their thermal resistance and limits conductive heat flow through the building envelope. The building envelope insulation is a main component because it plays a major function in the energy consumption. The building‘s roof, windows, walls and floors lead the flow of energy between the indoor and the outdoor of the building. The envelope insulation is very important, and it is the best solution in order to have an efficient and less consuming energy building. [4].

Thermal insulation has a dual nature. It decreases daytime the extra heat that come to a building, but prevents the building from cooling down at night. Based on their study, this dual nature makes insulation inappropriate for buildings with natural climate control. Perhaps the solution is to first define the cooling load at the design phase and then making decision whether this cooling load would be decreased by applying thermal insulation in the building or by using passive means of control [5]. Many studies have also quantified the energy savings from improved insulation. Retrofitting exterior masonry wall insulation from R-3 to R-13, energy consumption reduces by 9 -15% in Arizona [6].

Requirements for energy efficiency in a building envelope surrounding the heated and cooled parts of the building is generally set based on resistance or contribution to heat transparency through a unit of the construction, respectively R-value or U-value. [7]. A study of a typical un-insulated masonry house in the hot and humid climate of Bangkok, Thailand indicated 3-4% annual energy savings from light-weight walls with R-11 batt insulation and from cement tile roof with R-11 batt insulation [8]. A study of a house in Bangkok showed 8% of total energy reduction from light-weight concrete block walls with R-10 exterior insulation, and 9% reduction from similar wall construction with R-10 interior insulation [9]. Wall insulation does not significantly affect reducing heating and cooling load in buildings. He stated that adding 50 mm of polystyrene as wall insulation only causes in 1.7 % 33 [10]. Structural control of a modern building are its main parts such as walls, roof, floors and glazed materials (glass) in openings. The ability of a building enclosing elements to conduct heat from one side of the wall to the other is the thermal transmittance denoted as U value for the element [11].

Mineral wool, also known as rock wool, is an insulation material produced from steel slag. The slag, a by-product of steel manufacturing containing of dirt and limestone, is combined with other chemicals, heated and turned into a fibrous material that is a good insulator. It defined as a permanent insulation because it does not rot; burn or melt, and it does not absorb moisture, and does not maintain mould or mildew. It is available in batts or as a loose-fill product that can be blown into walls and ceilings. It can also be installed between wall studs by using a mesh screen across one side of the studs, letting floor to ceiling filling with a technique virtually the same as with blown-in cellulose. Because of its greater density and water resistant properties, mineral wool performs as a vapour barrier and, unlike fiberglass, does not need an additional vapour barrier to be effective (ORNL 2002) [12].

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 [13].

III. RESEARCH DESCRIPTION

The earlier research efforts have investigated the thermal performance of various roofing systems. In this study an attempt has been made to quantify the influence of insulation on indoor ambient temperature. The two modules have same floor, wall area and orientation. The size of the module is 3mx 3m x 3m. The galvanized sheets used in the modules have the same thickness of 0.21 mm. The walls have a thickness of 230 mm made up of brick and cement mortar. Two angles are used as purlins. It is a low sloped roof and is maintained to be 2˚. Walls of the modules are white washed and the flooring is done with cement mortar.

First Module (PUD):

The first module was constructed with Polyurethane panels of length 3660 mm and breadth 1000 mm is used as roof, which is an industrial product. The thickness of the Poly Urethane Decker is 35 mm and the thickness of the sheets is 0.35 mm. The white painted panels reflects the solar radiation on one hand and on the other hand polyurethane prevents heat entering the inside of the building.

Second Module (DOD):

The roof of the second module was newly designed. The design was carried out in four steps. In the first step, first roof was 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 packed mineral wool roll was spread. Thickness of the mineral wool is 50 mm. 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 was named as Double Decker. Since the sheets are trapezoidal, air gap of 11 mm above and below the mineral wool pack and wooden reapers is formed. The air vents created are the passage for the air and takes away the heat produced between the galvanized sheet and the mineral wool bed. Likewise the air vents created between the lower roof sheet, the wooden reaper and the mineral wool bed is also drains away the heat produced by convection. The mineral wool, wooden reapers and the air enclosed in the gaps are serving as insulators. This assembly possesses three insulators wooden reapers, mineral wool and air gap. Mineral wool has a low thermal conductivity among the building materials used (K= 0.04 W/m K).

Fig.1 Mineral Wool

Fig.2 Double Decker

Fig.3 Polyurethane Decker

IV. EXPERIMENTAL PROCEDURE

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. The modules, used in this study are exactly identical in terms of their geometry, orientation, area and climate conditions. DOD and PUD are reflective roof material. All the modules are fully instrumented. To measure the Indoor Ambient Temperature and Relative Humidity Single channel data logger is used. In six hours interval (6, 12, 18hr) the roof, wall and floor temperatures are measured by means of Infra-Red Thermometer. Roof, wall, floor and indoor and outdoor ambient temperature and relative humidity field data have been catalogued for eleven months for two different insulated roofing systems exposed to weathering on an indoor and outdoor test facility. The data are plotted for the time period between September 2013 and August.2014.

V. RESULT AND ANALYSIS

Fig.4 shows the Mean Monthly indoor ambient temperature by 6 hours for the observation period. This figure shows that the indoor ambient temperature of the DOD module is higher than the PUD module from September to March 2014. After March to July the indoor ambient temperature of DOD module is lesser than the PUD module. But the variation of indoor temperature between the two modules during the months of September to March is 0.44.the variation during the months between March to July is 0.2 to 0.4˚C. The indoor temperature decreases from September to December.2014 and then increases to a maximum during the summer months of June and July.2014.

Fig.5 shows the Mean Monthly indoor ambient temperature by 12 hours for the observation period. This figure shows that the indoor ambient temperature of the DOD module is lesser than the PUD module from September to July 2014. But the variation of indoor temperature between the two modules during the months of September to July is from 0.4 to 1˚C.

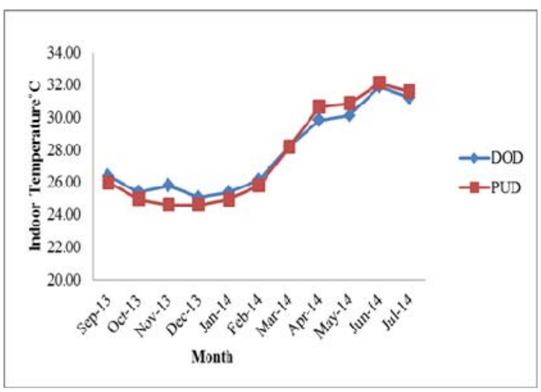

Fig.4 Mean Monthly indoor ambient temperature by 6 hours

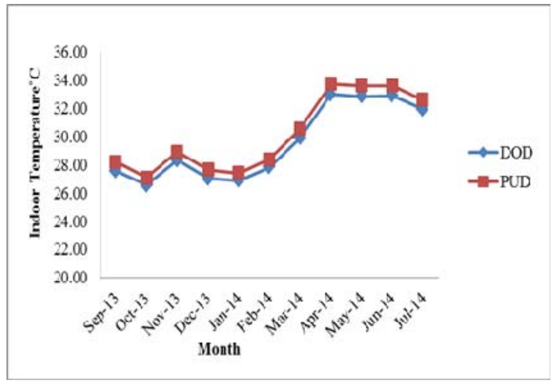

Fig.5 Mean Monthly indoor ambient temperature by 12 hours

Fig.6. shows the indoor ambient temperature of the modules by 18 hours. The variation of the temperature is alike as the 6 hours temperature performance.

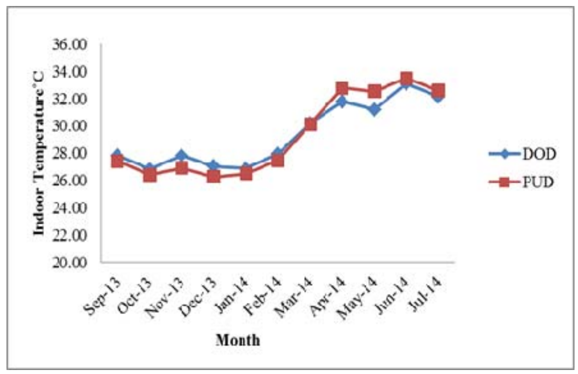

Fig.6. Mean Monthly indoor ambient temperature by18 hours

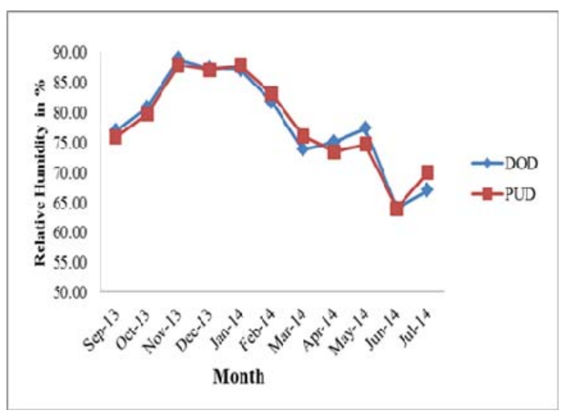

Fig.7 Indoor Relative humidity of the two modules by 6 hours

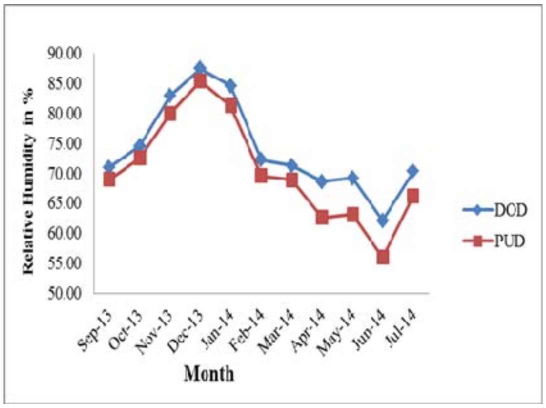

Fig.8 Indoor Relative humidity of the two modules by 12 hours

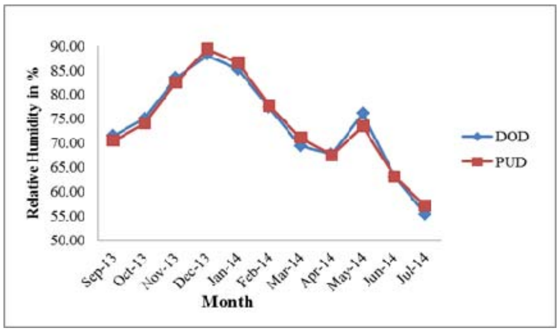

Fig.9. Indoor Relative humidity of the two modules by 18 hours

Fig.7 & 9 shows the Indoor Relative humidity of the two modules by 6 hour and 18 hour during the monitoring period. Relative humidity during these periods is showing a little difference. Measurement during 12 hours Fig.8 shows an obvious difference. The relative humidity increases from September and reaches a maximum in December and then deceases up to June. From June to July there is an increase. During the winter months DOD module attains a maximum of 87.5% and the PUD module attains a maximum of 85.5%. During the summer months the PUD module reaches minimum of 56% and the DOD reaches a minimum of 62%. The variation in the relative humidity is appreciable.

VI. CONCLUSION

In this Study two insulated roofs have been engaged. Insulated roofs are highly effective in reducing the indoor temperature. The PUD and DOD module performs well. The DOD performs in a better way than the PUD module during the summer months. The indoor temperature of DOD is 7 - 9 ˚C lesser than the outdoor temperature. The indoor relative humidity is appreciable during the summer months in the insulated roofs. The DOD has a higher relative humidity of 6% than PUD during summer. The cost of PUD roof per square meter is Rs.1500/- Whereas the cost of DOD roof per square meter is Rs. 1000/- Hence the newly designed roof is comparatively less cost. Regarding the thermal performance and cost effectiveness the DOD roof is superior to the other one.

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