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Evaluation of the Thermal Performance of Light Roofing Systems

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***ABSTRACT*:** *Thermal performance of roofs exerts a powerful influence on indoor ambienttemperature. Thermal gain by single storey houses covered by light roofs is enormous during the peak hours of the day, which offers thermal shock to the occupants and necessitates high cooling energy demand. This paper presents a new design for light roofing structure in order to improve the indoor environment. Industrial buildings, ware houses, workshops and Lower economic group people use the light roof sheets as a roof material. Light roofs are in the form of Galvanized sheets, Asbestos sheets, and Cool roofs. Higher indoor ambient temperature of industries leads to fatigue of workers which causes a lower labour productivity. To enhance the labour productivity, improved indoor environment should be provided. Five different modules are constructed with identical floor plan and orientation but with different materials for walls and roofs. Single Decker (SID), Overall Galvanised Sheet (OGS), Overall Asbestos sheet (OAS), Double Decker (DOD), and Poly Urethane Decker (PUD) are the modules used for this study. The modules utilize no energy for cooling. Effort has been engaged to fetch a best indoor environment by the roof among the selected modules.*

***KEYWORDS*:** *Thermal performance, Indoor ambient temperature, Indoor relative humidity, Double Decker.*

I. INTRODUCTION

Energy crisis and Environmental impact is serious, with the development of the world economy. The fossil fuel is depleting. More than 30% of primary energy is consumed by non-industrial buildings, including houses, offices, schools, hospitals, and so on [1]. Energy consumed in the production of building materials is 20% of the world fuel consumption. It demands immediate action to develop energy efficient buildings.

The total electrical energy consumed by Indian buildings is 33%. If the Energy Conservation code is enforced for the construction work, it will yield annual savings approximately 1.7 KWH. Estimates based on computer simulation models can use 40 – 60% less energy than conventional buildings. The efficiency of a building strongly depends on the way it is built, managed and used and furthers the selection of roof according to the purpose apart from the wall and floor plans and the orientation of the building. [2], India has been divided into five major climatic zones, Cold and Sunny, Cold and Cloudy, Warm and Humid, Hot and Dry, Composite and Moderate. According to the classification, India is a quite challenging country to the planners, designers and architects. The human body continuously produces heat by its metabolic processes. This heat must be dissipated to the environment, or else the body temperature will increase. The body's thermal balance can be expressed as:

$$\Delta S = M \pm Rd \pm Cv \pm Cd - Ev \quad (1)$$

Where,

ΔS = Change in stored heat, M = metabolic heat production,Rd = net radiation exchange, C_d= conduction Cv=Convection including respiration,Ev = evaporation including respiration. At equilibrium condition, (ΔS) is zero, and such equilibrium is a precondition of thermal comfort at the 50% RH and less than 0.15m/ airflow speed. The comfort band of room temperature is 18˚C – 27˚C [3]. The comfort band of room temperature is 26˚C – 32.5 ˚C and the relative humidity ranges between 17% - 78% from a field study in Hyderabad, India[4].Roof is the element which directly receives the most of the solar radiation in different angles than the other elements of the building. Inadequate roof insulation results in heat transfer from the roof to indoor. Insulation can be applied between roof rafters or on the rafters. For concrete roofs, outer insulation over the concrete can be applied [5].

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 [6].The heat incoming into the occupant zone through roof is the main cause of discomfort [7]. The heat transferred into the occupant zone is true for single storey and top floor of the multi-storeyed buildings [8].Traditional architecture in hot climates has long recognised that the building colours can reduce cooling loads[9], [10]. A series of simulation and experimental studies have demonstrated that building reflectance can significantly impact cooling needs [11], [12], [13], [14].

The impact of reflective roofing's on the air conditioning use in Florida and California building field tests have shown that there is electrical energy savings [15]. Beyond roof reflectance other approaches such as tile roofs and unvented attics with insulation under the roof can produce cooler attics resulting in energy improvement, but of unknown comparative magnitude [16], [17]. The attic heat gain to the thermal distribution system can increase residential cooling loads by up to 30% during peak summer periods [18]. Further benefits arise from the reduction of attic air temperature and its impact on ceiling conductivity [19]. The selection of roof with high solar reflectance represents one of the most significant energy saving options in hot climates [20].The cooling energy savings due to the application of heat island mitigation strategies have calculated (application of cool materials and increase in vegetation cover) for 240 regions in the United States. It was found that for residential buildings the cooling energy savings vary between 12% and 25%, for office buildings between 5% and 18%, and for commercial (retail stores) buildings between 7% and 17%[21].

Even though, some advanced cool coloured materials have been available along with NIR reflective pigments to cool the roof estimated the effect of cool coating on thermal comfort and stated that increasing the roof solar reflectance reduces the cooling load by 18-93% and the indoor thermal comfort is improved by decreasing the hour of discomfort by 9-100%[22]. Light colour coating may help to reduce 30% total heat gain in the weather condition of Australia since the roofing may have much lower absorptivity[23]. Even though the above methods are more suitable in reducing the heat gain to the Room, the cost incurred for the making such a roof should be considered. 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 [1]. With all these information present work proposes and analyses a new type of roof DOD to reduce the indoor heat gain.

II. RESEARCH DESCRIPTION

Previous research efforts have investigated the thermal performance of various roofing systems. In this study an attempt has been made to quantify the roofing influence on cooling performance of the five modules and the living comfort of the occupants. All the 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 0.35 mm. The walls have a thickness of 230 mm made up of brick. Two angles are used as purlins. The slope of the roof is maintained to be 2˚. Walls of the modules are white washed and the flooring is done with cement mortar.

The first module is Single Decker (SID) in which galvanized sheets are used as roof material. The second module is overall galvanized sheet module (OGS), in which roof and walls use the galvanized sheets. The third module is overall Asbestos sheet module (OAS) in which asbestos sheets is used for the roof and the wall. The fourth module is double decker (DOD) in which wooden insulators and mineral wool is used between two galvanized sheet roofs. Brick walls are used for SID, DOD and PUD modules. The fifth module is poly urethane decker (PUD) module in which poly urethane panels are used as roof material.

The construction data of the modules used in this study are tabulated in Table I.

Sl. No	Description	Dimension
1	Floor Area	100 sq.ft
2	Net Wall Area	382 sq.ft
3	Ceiling	120 sq.ft
4	Doors	18 sq.ft
5	Overhang	20 sq.ft

Table I: Construction data of the Research Modules

2.1 First Module (SID)

In Single Decker, Galvanized sheets are used as roof element, where the walls are made by bricks. When the solar radiation falls on the roof, the sheets are very easily heated even by early morning due to conduction and it extends for the whole day. During the peak hour the amount of heat transmitted into the building is massive.

2.2 Second Module (OGS)

The roof and wall of the OGS module is constructed with Trapezoidal shape Galvanized sheets. This roofing is adopted by the industries, workshops, warehouses and is also followed by the Low economy Group community because of its light weight, easiness in construction and low cost. Being a conductor the sheets easily permit solar radiation into the occupant zone not only through the roof but also via walls.

2.3 Third Module (OAS)

The third module is constructed by using trapezoidal Asbestos sheets for the roof and wall. Though asbestos is banned by developed countries, but it is used still in India. This type of roof too allows the solar radiation into the occupant zone through the roof and walls.

2.4 Fourth Module (DOD)

Design of Double roof is carried out in three steps. In the first step, roof is made using galvanised sheets by setting the second roof over the first and named as Double Decker (DOD) as shown in (Fig1). In the double decker the sheets of first roof have contact with the second roof on longitudinal lines and hereafter called lines of contact. At this condition the shape of the double roof is similar to that of a Stationery wave. In a stationary wave there are nodes and antinodes. Nodes have zero displacement where antinodes have a maximum displacement of the particles of the medium. The nodes of a stationery wave are identical with the lines of contact of double roof. As the area of contact between the two roofs is decreased, the heat transmitted into the dwelling by conduction is also reduced to about 70%. Cylindrical air gap of 22 mm thickness is formed between the two lines of contact. In the second step, wooden reapers, of size 3000mm x50 mm x 25 mm are introduced between the two roofs (Fig2) in 200 mm spacing, consequently the two roofs are separated by 50 mm and separation of two roofs ranges from 50 mm to 72 mm. In the third step, mineral wool roll of thickness 50 mm is spread over the wooden reapers and the second roof is made (Fig 3). Now the two roofs are separated by a thickness of 100 mm to 122 mm. The wooden reapers and the mineral wool are the insulators where they prevent direct heat transmission by conduction and further the air flow between the gaps reduce heat by convection.

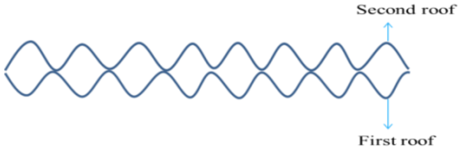

Figure 1: Diagram of the Double roof

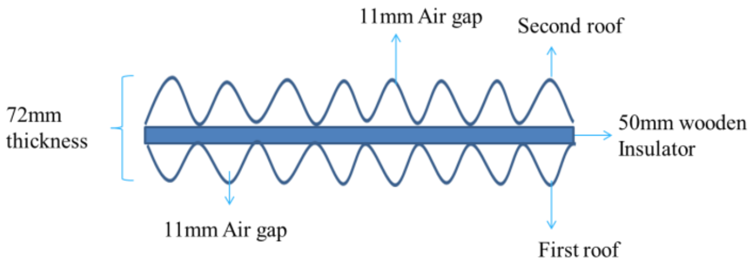

Figure 2: Diagram of the Double roof with wooden reaper

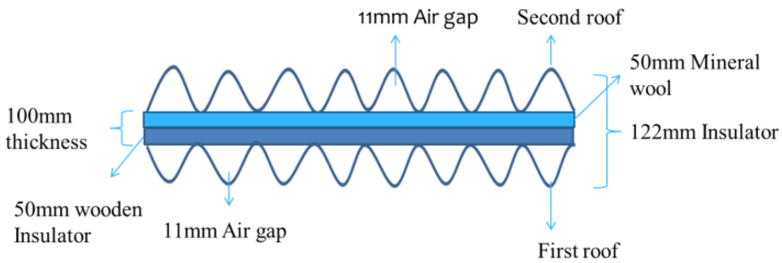

Figure 3: Diagram of double roof with wooden reaper and Mineral wool

2.5 **Fifth Module(PUD)**

Polyurethane panels of length 3660 mm and breadth 1000 mm used as roof for the fifth module, which is an industrial product. The half white painted reflective steel sheets of thickness 0.47 mm and the poly urethane thickness is 35 mm is used by the industry, to make the panels. One side of the surface shape is trapezoidal and the other side is plain.

III. 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. SID, OGS, DOD, PUD are reflective roof material but OAS is not a 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. The night time temperature does not increase in the hot and humid climates under normal conditions hence the temperature measurement for 24th hour is not included. Roof, wall, floor and indoor and outdoor ambient temperature and relative humidity field data have been catalogued for seven months for five different roofing systems exposed to weathering on an indoor and outdoor test facility. The data are plotted for the time period between September and March.

IV. RESULTS AND DISCUSSION

At peak hour, the Average Roof Temperatures of DOD, SID, OAS, OGS and PUD in winter were 26.50˚C, 33.77˚C, 39.20˚C, 44.21˚C and 27.40˚C and further in the early spring the values were 31.59˚C, 37.70˚C, 49.19, 57.33˚C and 34.03˚C are shown in Fig. 4. In winter the DOD is 7.27˚C cooler than SID, and 12.7˚C cooler than OAS, and 17.71˚C cooler than OGS and 0.9˚C cooler than PUD. In the early spring the DOD is 6.11˚C cooler than SID, and 17.6˚C cooler than OAS, and 25.74˚C cooler than OGS and 2.44˚C cooler than PUD. The Average Roof Surface Temperature profiles over the monitoring period are shown in Fig. 4. It is obvious that OGS module gains the highest temperature during both the seasons and the DOD module gains the lowest value and the PUD gains a moderate value.

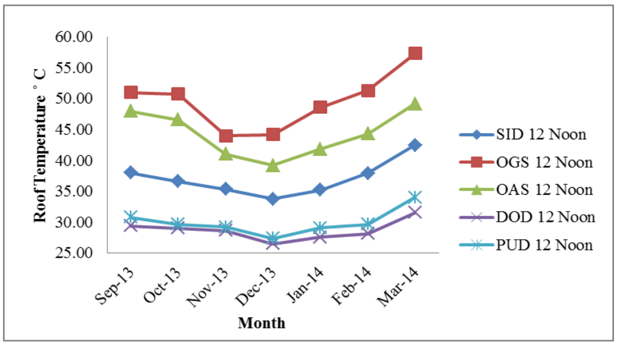

Figure 4: Average Roof temperature of 12 Noon

At peak hour, the Average Floor Temperatures of DOD, SID, OAS, OGS and PUD in winter were 25.31˚C, 26.16˚C, 31.76˚C, 31.97˚C and 25.83˚C and further in the early spring the values were 28.74˚C, 31.26˚C, 35.65˚C, 36.65˚C and 29.94˚C are shown in Fig. 5. In inter the DOD is 0.85˚C cooler than SID, and 6.45˚C cooler than OAS, and 6.66˚C cooler than OGS and 0.52˚C cooler than PUD. In the early spring the DOD is 2.52˚C cooler than SID, and 6.91˚C cooler than OAS, and 7.91˚C cooler than OGS and 1.20˚C cooler than PUD. The Average Floor Temperature profiles over the monitoring period are shown in Fig. 5. It is observed that OGS module has the highest floor temperature in both seasons, the DOD module has a lower value than others and the PUD module has a moderate value.

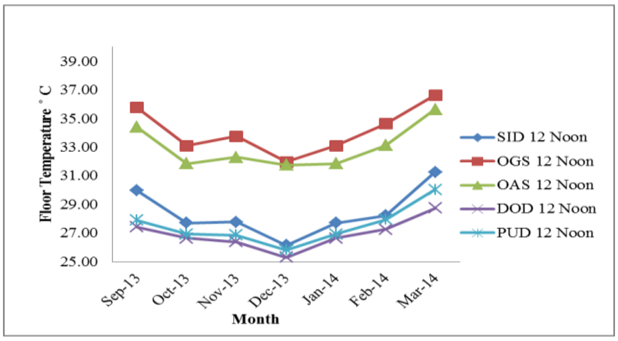

Figure 5: Average Floor temperature of 12 Noon

At peak hour, the Average Wall Temperatures of DOD, SID, OAS, OGS and PUD in winter were 25.58˚C, 26.69˚C, 35.40˚C, 38.23˚C and 26.17˚C and further in the early spring the values were 30.59˚C, 32.30˚C, 39.80, 42.95˚C and 31.04˚C are shown in Fig. 6. In winter the DOD is 1.11˚C cooler than SID, and 9.82˚C cooler than OAS, and 12.65˚C cooler than OGS and 0.59˚C cooler than PUD. In the early spring the DOD is 1.71˚C cooler than SID, and 9.21˚C cooler than OAS, and 12.36˚C cooler than OGS and 1.20˚C cooler than PUD. The Average Wall Temperature profiles over the monitoring period are shown in Fig. 6. The average wall temperature is high for OGS and low for DOD and moderate for PUD.

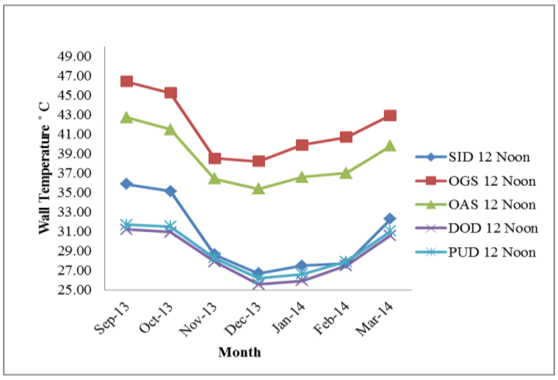

Figure 6: Average Wall Temperature of 12 Noon

At peak hour, the average Indoor Ambient Temperatures of DOD, SID, OAS, OGS and PUD in winter were 26.37˚C, 27.57˚C, 33.26˚C, 34.17˚C and 27.03˚C and further in the early spring the values were 29.90˚C, 32.61˚C, 35.43˚C, 37.82˚C are shown in Figure 7 and 30.42˚C. In winter the DOD is 0.8˚C cooler than SID, and 6.89˚C cooler than OAS, and 7.80˚C cooler than OGS and 0.66˚C cooler than PUD. In the early spring the DOD is 2.71˚C cooler than SID, and 5.53˚C cooler than OAS, and 7.92˚C cooler than OGS and 0.52˚C cooler than PUD. The Average Indoor Ambient Temperature profiles over the monitoring period are shown in Fig. 7.

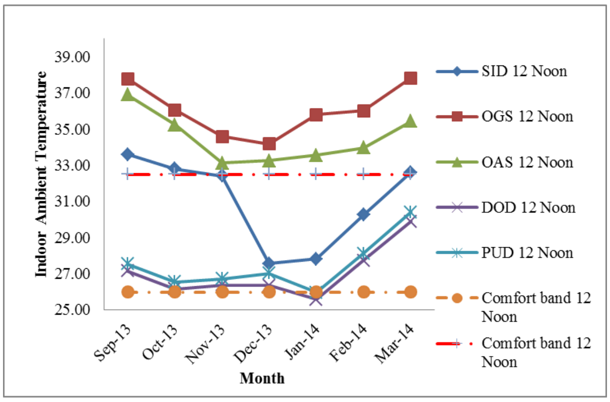

Figure 7: Average Indoor Ambient Temperature of 12 Noon

At peak hour, the average Indoor Relative Humidity of DOD, SID, OAS, OGS and PUD in winter were 87.03%, 84.90%, 65.77%, 63.39% and 88.04%. In the early spring the values were 69.45%, 60.58%, 47.90%, 42.13% and 70.73% are shown in Figure 8. In the winter the Indoor Relative Humidity of DOD is 2.13% higher than SID, 21.26% higher than OAS, 23.64% higher than OGS and 1.01% less than PUD. In the early spring the DOD is 8.87% higher than SID, 21.55% higher than OAS, 27.32% higher than OGS and 1.28% less than PUD. Average Indoor Relative Humidity profiles over the monitoring period are shown in Fig. 8. The DOD module provides a low ambient temperature within the comfort band but the OGS module provides a highest value which is not in the comfort band. The PUD module avails a moderate indoor ambient temperature with in the comfort band than the rest of the modules.

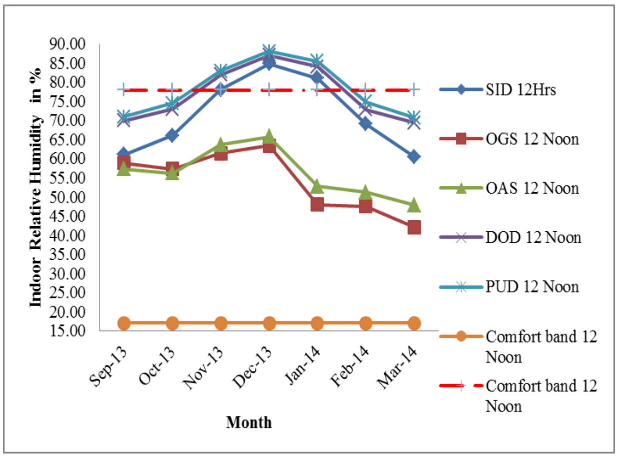

Figure 8: Average Indoor Relative Humidity of 12 Noon

The indoor relative humidity is high for the month of November. Relative humidity has a decreased value for the other months. The IRH value is very low for OGS for the month of March.The mean rise and fall temperatures of Roofs, Floors, Walls and IAT of all modules and IRH of all modules for 6, 12, 18 hours are given in Fig. 9,10,11,12,13,14,15,16for both seasons of winter and spring.

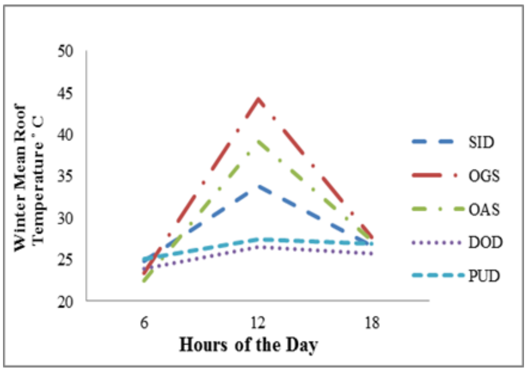

Figure 9: Winter mean temp. of roofs

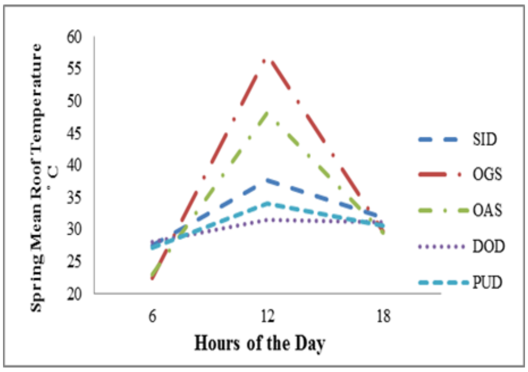

Figure 10: Spring mean temp. of roofs

The mean values of the roof temperature for all the modules for 6, 12, 18 hours are provided in Fig. 9 and 10 for the winter and spring seasons. It is clear that the peak hour temperature is very high for the OGS roof and is low for DOD and is moderate for PUD. The rise in temperature does not fall to the same level in all type of roofs. To some extent the temperature is retained by the roof due to the continuous reception of solar radiation.

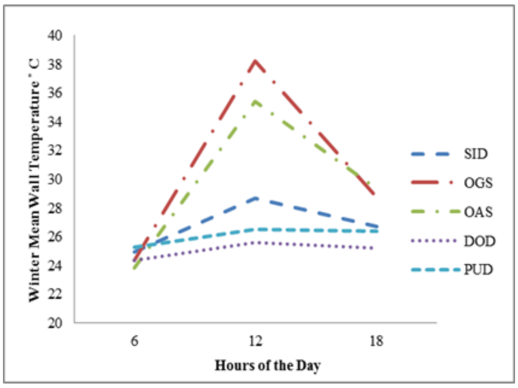

Figure 11: Winter mean temp. of walls

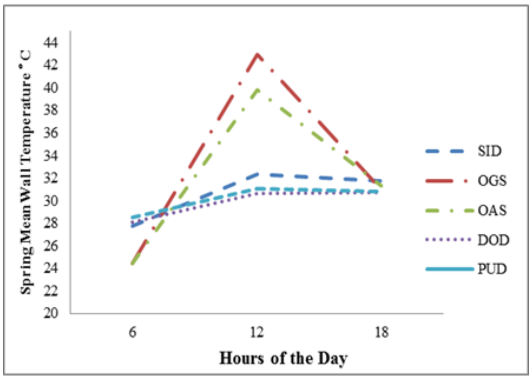

Figure 12: Spring mean temp. of walls

The mean values of the average wall temperature for all the modules for 6, 12, 18 hours are shown in Fig.11and 12 for both the seasons. The rise in wall temperature at peak hour does not fall to the same level by18th hour. The solar radiation reception is no way obstructed by the east facing modules from 12 to 18th hours. Hence it is obvious that the orientation is the main cause for the retention of heat.

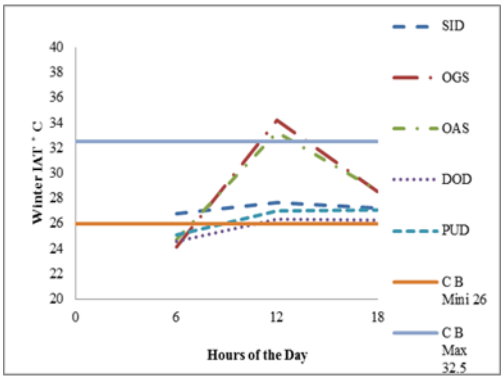

Figure 13: Winter Indoor ambient temp.

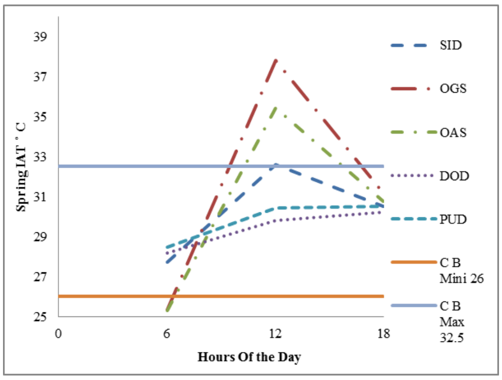

Figure 14: Spring Indoor ambient temp.

The Indoor Ambient Temperature mean values for 6, 12, 18 hours for all the modules for both the seasons are shown in the Fig.13 and 14. The indoor ambient temperatures for OGS, OAS and SID modules are high and are less for DOD and PUD. The figures display that the 6th hour IAT is less and the 18th hour value is high. The orientation of modules makes the roof and walls to receive the sun's radiation continuously resulting to the higher IAT in the 18th hour than in the 6th hour. It is observed that for both the seasons the indoor ambient temperature is within the comfort band.

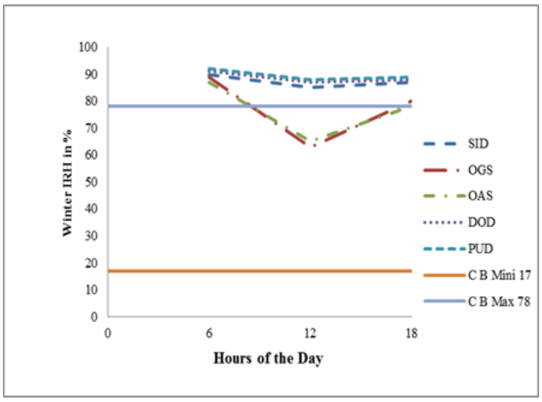

Figure 15: The winter IRH

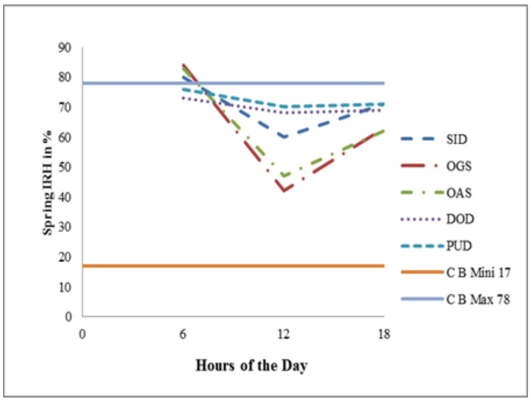

Figure 16: The Spring IRH

The mean values of IRH for both the seasons for 6, 12, 18 hours are depicted in the Fig.15 and 16. From the figure it is perceived that SID, PUD and DOD have a high IRH but the other two modules OGS and OAS have a lower IRH.

V. CONCLUSION

Thermal performance of roofs exerts a powerful influence on indoor ambient temperature. This study tested five side by side modules in Chidambaram, Tamil Nadu with identical floor plans and orientations using different materials for roofs and walls. The data showed that solar heating had a large effect not only on the roof but also on wall and floor. Light roofs are easily heated by solar radiation during the day time hours causing a high temperature of the occupant zone. The large influence on cooling demand is primarily due to the impact of ceiling and wall heat transfer. The orientations of the modules have a control on the indoor temperature gain. Each of the examined alternative roofing systems were found to be superior to overall galvanized sheet module both in providing lower indoor ambient temperature and higher indoor relative humidity. The DOD provides a best performance among the five roofing systems to periods with high solar irradiance. PUD roof provides a better indoor ambient temperature and relative humidity. In summary, the selection of double roof with mineral wool is superior in providing comfort level of indoor environment than PUD, SID, OAS and OGS in hot and humid climate. The DOD provides a lower indoor ambient temperature of 8-10˚C approximately than OGS. This research points to the need for double roofs packed with insulating materials for good energy performance. The modules DOD and PUD need no energy for cooling. The techniques of construction evaluated are commonly used customary techniques and low cost than others. Further the same roof material strongly reduces the house peak cooling demand during utility coincident peak hours - a highly desirable attribute.

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