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Numerical Analysis of Thermal Performance of RCC Roof

***Abstract*- The ever alarming cost of energy in buildings enforces a statuary demand of energy conservation passive design techniques in buildings. Modern buildings reveal inadequate thermal performance and require mechanical devices to bring thermal comfort. Hence, it is necessary to know the thermal performance of the RCC roof structure, which is quite commonly available. This paper concentrates on developing a numerical model of a Reinforced Concrete (RCC) roof for analyzing its thermal performance. Numerical Simulations have been performed for unsteady conditions with time-varying solar heat flux along with grid independence tests for accurate analysis.**

***Index Terms*—** RCC Roof, Thermal Performance, Numerical Simulation

I. INTRODUCTION

Climate change, caused by the release of greenhouse gases (mainly carbon dioxide) into the atmosphere, has been recognized as one of the greatest threats of the 21st century. The total amount of energy used by commercial buildings has risen significantly since the 1980s, reflecting a 50% growth in the total amount of office space available and a 33% increase in energy consumption per square foot of space [1]. With the convergence of urbanization, globalization and a rapidly changing and expanding economy, India is experiencing a rapid spurt in building construction across a range of city activities and socio-economic spectrum, increasing consumption of building materials such as glass, cement, metals and ceramics. Maximum consumption of these energy materials is a reason for environmental degradation. Buildings are the dominant energy consumers in modern cities accounting up to 40% energy consumption. There is over 50% saving potential in the building sector and thus it is considered as a potential sector to meet the challenges of global energy and climate change [1]. Roofs are a critical part of the building envelopes that are highly susceptible to solar radiation and other environmental changes, thereby, influencing the indoor comfort conditions for the occupants [2]. In developing countries, masonry houses with RCC roofs are popular owing to their pest resistance, natural calamities resistance, availability and cost effectiveness of concrete ingredients [3]. Depending on the weather, the thermal load enters into a building in three major ways such as penetration of direct beam sunlight, conduction of heat through roofs, infiltration of outside air [4].

II. DESCRIPTION OF RCC ROOF

Flat clay tile roof is selected for modeling and simulation. Horizontal slabs of steel reinforced concrete, typically between 100 and 500 millimeters thick, are most often used to construct floors and ceilings. A 10 cm thick layer of brick-bat concrete is laid, consisting of 3 parts of brick-bats, 1 part of gravel and sand, and 50 percent of lime mortar by volume is laid over the RC slab. The concrete is well rammed so that the thickness reduced, by wooden hand beaters. The surface is cured by sprinkling lime water. When the brick bat is set a course of flat tile is laid in lime mortar (1:1 ½). This type of roof is conventionally used in most of the residences in hot humid climates in Tamil Nadu, India hence it is taken as a reference roof for study. The roof section is schematically represented in Fig. 1. The thermo physical properties [5] of roof materials are shown in Table 1.

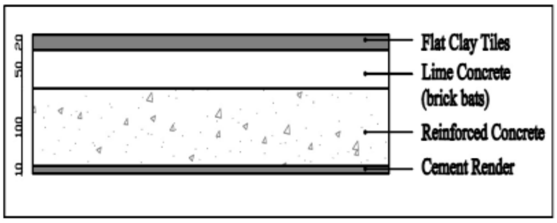

Fig. 1 RCC roof section

Table 1 Properties of materials

MATERIAL	DENSITY (kg /m^3)	SPECIFIC HEAT (J/kg-K)	THERMAL CONDUCTIVITY (W/mK)
CLAY	1845	1089	1.036
LIME	2320	810	2.15
CONCRETE	2300	1130	1.27
CEMENT	1900	1130	0.3024

III. GEOMETRIC MODELLING

The roof model is made in GAMBIT software. The model is made in the form of 2-dimensional structure of 180x100 mm. The leftmost portion of model is defined as “outside” of the roof. The rightmost portion of the model is defined as "inside" of the roof. All the four portions of the roof, of different materials, are defined as separate faces. Fig. 2 shows the meshed model.

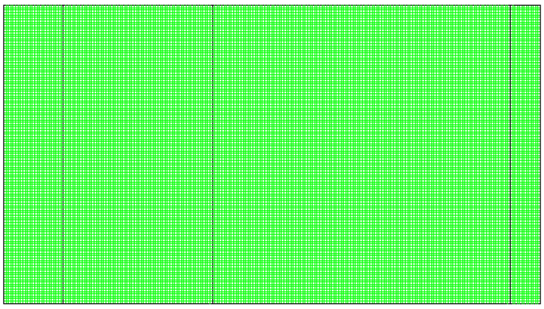

Fig. 2 Meshed Model of roof section

IV. GRID INDEPENDENCE TEST

The meshing was made with different interval sizes, ranging from 0.1 to 0.9. Each and every model was subjected to steady state conditions for the analysis using constant heat flux of 700W/m^2 defined on outside of the roof and convective heat transfer at inside portion of the roof. Fig. 3&4 show the temperature plots. From the Fig. 3&4, it can be concluded that, the curve seems to saturate around interval size of 0.8.The temperature difference matches closely for interval size of 0.7 and 0.8.The time taken for iteration is lesser for interval size 0.8 compared to 0.7. Thus 0.8 is chosen as optimum grid size.

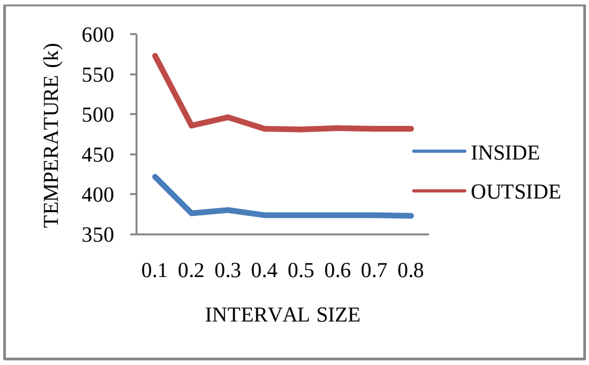

Fig. 3 Temperature Vs Interval Size plot

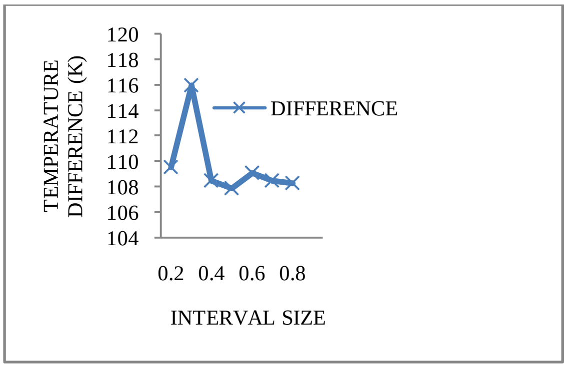

Fig. 4 Temperature Difference Vs Interval Size plot

IV. NUMERICAL SIMULATION OF RCC ROOF

In a normal day, the solar heat flux is never a constant quantity. It is estimated that average heat flux on a normal sunny day, increases in magnitude from morning to noon, reaches the peak value at afternoon and then decreases during evenings. It is observed that in a normal day, influence of solar heat prevails for 8 hours [6]. The residents feel comfort during the period of the measurement, in which the Mean Room Temperature ranged 27~32°C, the room air temperature 28~32°C [7]. Thus, the room air temperature is taken as 303K. Unsteady conditions have been taken into account. The convection effect is considered around the roof edges with heat transfer coefficient assumed as 10W/m^2 K. It is necessary to use time dependent input as boundary condition. Time varying heat flux input is obtained with the help of User Defined Function (UDF).Using [8] the UDF was developed according to the required condition. The iteration is performed for a period of 8 hours. The initial temperature of the roof is assumed as 300K. The convergence criterion is set as 1e-08. Fig. 5 shows the applied input heat flux, as a plot.

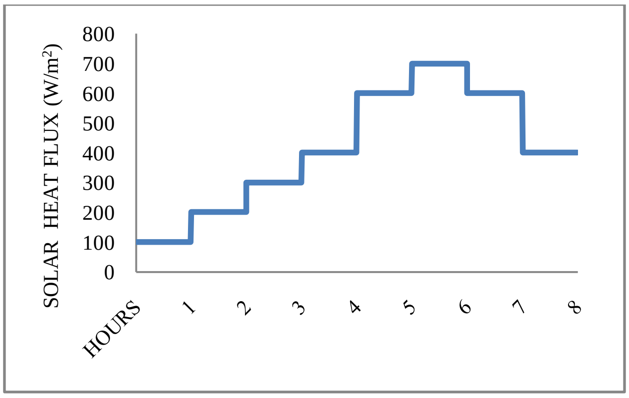

Fig. 5 Input Heat Flux plot

The obtained temperature contour is shown in Fig. 6. It is observed that, maximum temperature is 332K and minimum temperature is 306K after 8 hours. This drop occurs due to varying conductivities of the different materials in the roof section. During simulation, the average outside and inside roof temperature data are obtained and plotted in a graph as in Fig. 8.

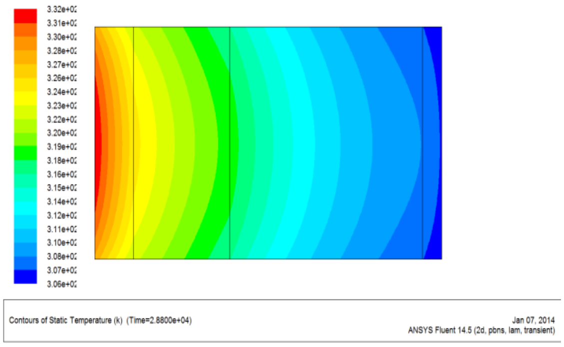

Fig. 6 Temperature Contours

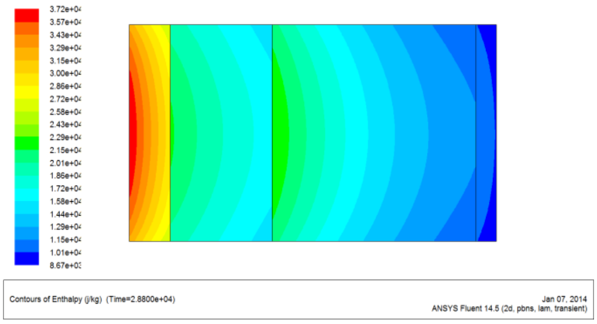

Fig. 7 Enthalpy Contours

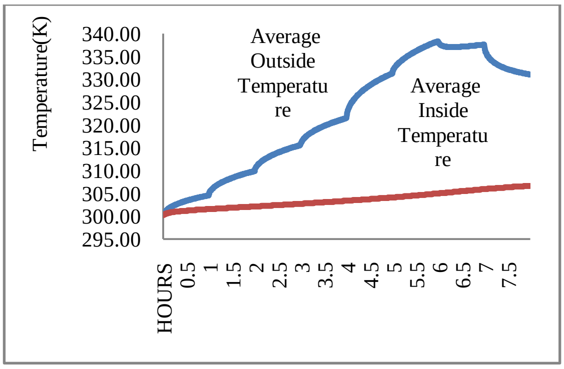

Fig. 8 Temperature Vs Hours plot

VI. VALIDATION

The actual conditions are determined using non-contact temperature measuring equipment (Infrared camera). The thermal image is captured in the afternoon, when the solar radiation is intense. The captured image is displayed above in Fig. 9. The outside temperature obtained from the simulation, is in agreement with the thermal image result and literature [9].

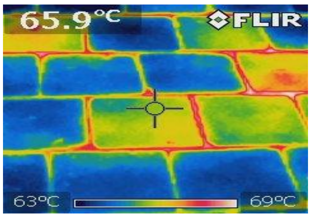

Fig. 9 Thermal Image of outside portion of the roof

V. RESULT AND DISSCUSSION

The temperature contours (Fig. 6) show the temperature distribution along the roof. It is observed that temperature drop of 31.6 K occurs along the roof at peak condition, when solar intensity is maximum. This means the input energy is stored in the roof. The enthalpy variations show that, enthalpy, as a function of internal energy, is dependent on the specific heat capacity of the material. Another significant observation made from the plot is that, flat clay tile has higher enthalpy compared to other materials. The cement layer has lower conductivity. It does not transfer energy from concrete quickly. From the Fig. 8, the inside temperature increases linearly with hours. The outside temperature varies in a non-uniform manner as it depends on solar heat flux .Further, it is found to increase till 6 hours and then decrease in accordance to heat flux.

VI. CONCLUSION

The thermal performance of the RCC roof section is numerically analyzed. The grid independence test was conducted and the optimum grid size has been determined. The temperature distribution across the roof has been obtained. This paper will prove useful for estimation of heat load of RCC structure. Currently, a lot of advancement techniques are springing up for the reduction of heat loads by varying the passive design. This paper can provide basic information for such ideas.

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