A CFD STUDY ON THE APPLICATION OF COOL ROOF TECHNOLOGY IN AN AIR-CONDITIONED ROOM

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Abstract –*There has been a radical increment in the utilization of air conditioning system for cooling the buildings all around the globe. Because of cooling load necessities of building, developing countries faces extreme energy crisis in the most recent two decades. The cool roof strategy, a passive cooling technique subsequently not required energy for cooling. It acts as solar heat barter in the roof. Utilization of this passive cooling with an active cooling technique, may diminish the cooling load in structures, in this way lessening the span of the air-conditioning equipment and the period for which it is for the most part required. This paper analyzes influences of solar reflective coating in an air-conditioned room using Computational Fluid Dynamics strategy.*

Key Words: Air-conditioner, Computational Fluid Dynamics, Cool roof, Solar radiation, cooling load and Mean radiant temperature.

1. INTRODUCTION

India is a tropical subcontinent extending in the vicinity 8°4' and 37°6' north latitude, with the cooling essential in the larger parts of its states. The altitude of air-conditioned residential floor area was noticeably increased by 2.21 times in India for the period of the year 2006 to 2011 [1]. The colonized building utilizes 40% of power for cooling purposes in the aggregate power usage. This high consumption of energy in the active cooling process can be diminished by utilizing a passive cooling method in the building. Cool roof technology is one of the most effective passive cooling methods for the Indian climate. The states like Gujarat, Rajasthan, north Maharashtra and west Madhya Pradesh gets more than 3000-3200 hours of intense sunlight annually and the global solar radiation got each year is more than 2000 kWh/m^2 in this states [2]. Because of this intense solar radiation, roofs of the building warmed up swiftly amid day-time and transfer heats to the building inside, constitute 70% of the total heat gain [3]. Cool roof reflects and emits back the solar radiation to the sky instead of transferring it to the buildings. It has high solar reflectance and thermal emittance property.

Due to the adverse climate condition in India, we cannot depend upon only one cooling technique. The passive cooling method can cool the building only one certain limit. Again active cooling method like air-conditioning devours an enormous measure of energy. So this paper emphasized on the application of solar heat barriers along with air-conditioner in the room to minimize of cooling load and size of the air-conditioner system.

2. MATHEMATICAL MODEL

The problem is solved using the following equations and models-

Conservation of Mass equation:

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \qquad (1)$$

Where u_i = mean velocity component in x_i direction.

Conservation of Momentum equation:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial(\rho u_i u_j)}{\partial x_j} = -\frac{\partial P}{\partial x_j} + \rho\beta(T_o - T)g_i + \frac{\partial}{\partial x_j}\left[\mu_{eff}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] \qquad (2)$$

Where ρ = Air density, u_j=Velocity component in x_j direction, P =Pressure, T_o=Temperature of a reference point, T= Temperature, β=Thermal expansion of air, μ_{eff} = Effective dynamic viscosity.

$$\mu_{eff} = \mu_t + \mu_l \qquad (3)$$

Where μ_t=Turbulent viscosity, μ_l=Laminar viscosity

Conservation of Energy equation:

$$\frac{\partial \rho T}{\partial t} + \frac{\partial(\rho u_j T)}{\partial x_j} = \frac{\partial P}{\partial x_j}[\left(\frac{k}{C_p} + \frac{\mu_t}{\sigma_t}\right)\frac{\partial T}{\partial x_j}] + S_T \qquad (4)$$

Where k=Thermal conductivity, C_p=Specific heat capacity of fluid, S_T=Source term allowing for the rate of thermal energy production.

Turbulence was modeled using k-ε model which consist of transport equation for turbulence kinetic energy 'k' and its dissipation rate 'ε'.

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho u_j k)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\epsilon-Y_M+S_k \qquad (5)$$

$$\frac{\partial(\rho \epsilon)}{\partial t}+\frac{\partial(\rho u_j \epsilon)}{\partial x_j}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right]+\frac{\epsilon}{k}C_{1\epsilon}C_{3\epsilon}G_b+\rho C_1 S_\epsilon-C_2\rho\frac{\epsilon^2}{k+\sqrt{\nu\epsilon}}+S_\epsilon \qquad (6)$$

C_2 and $C_{1\epsilon}$ are constants. σ_k and σ_ϵ are the turbulent Prandtl numbers for k and ϵ respectively. S_k and S_ϵ are source terms.

2.1 Solar Radiation Model

Solar load model is calculated using ANSYS FLUENT-14.5 software, providing global position (latitude, longitude, time zone) of the computational domain, date and time of calculation, solar irradiation method, grid orientation and sunshine factor. In the present study analysis was done for an office room situated at Bikaner, Rajasthan. Calculation was observed on 15th of May, 2016 at 12 noon for fair weather condition.

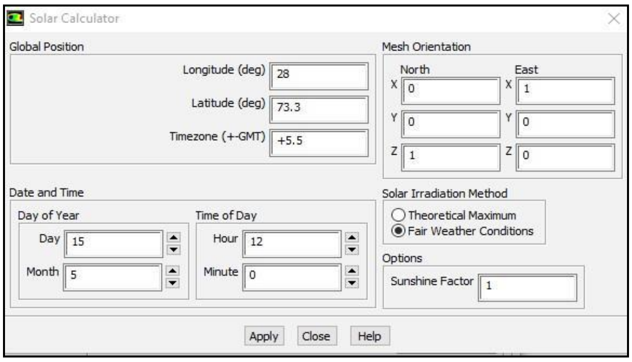

Fig -1: Solar radiation calculation

2.2 Sol-air Temperature

The Sol-air temperature is defined as the outside air temperature which, in the absence of solar radiation, would give the same temperature distribution and rate of heat transfer through a wall or roof as exists due to the combined effects of the actual outdoor temperature distribution plus the incident solar radiation [4].

A surface (roof or wall) exposed to sun, transfer heat through conduction and loss through convection and radiation.

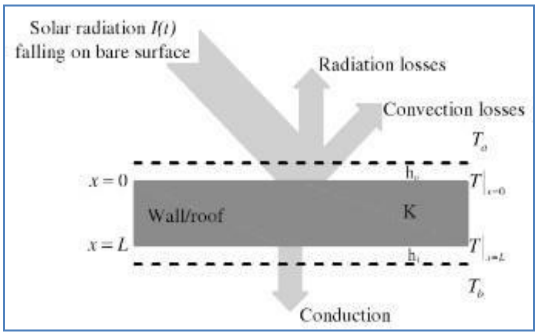

Fig -2: Surface exposed to solar radiation [4]

Heat transfer through conduction at X=0 is given by-

$$q^{\cdot}=h_o(T_{sa}-T_{X=0}) \qquad (7)$$

Where,

h_o = Overall heat transfer coefficient of the interface between the external surface and ambient air (W/m²K)

$T_{X=0}$ = Temperature of the surface at X=0 (K)

T_{sa} = Sol-air temperature for the surface (K)

$$T_{sa}=\frac{\alpha}{h_o}I(t)+T_a-\frac{\varepsilon\Delta R}{h_o} \qquad (8)$$

Where,

α = Fraction of solar radiation absorbed by the surface.

I(t) = Intensity of the solar radiation (W/m²)

T_a = Temperature of the ambient air (K)

ε = Emissivity of the exposed surface

ΔR = Intensity of the long-wave radiation emitted from the surface.

2.3 Mean Radiant Temperature (MRT)

Mean radiant temperature is defined as the uniform temperature of a surrounding surface giving off blackbody radiation which results in the same radiation energy gain on a human body as the prevailing radiation fluxes which are usually very varied under open space conditions. But in this study the absolute temperatures of objects are large compared to the temperature differences. So, the Mean radiant temperature (MRT) is simply the area weighted mean temperature of all the objects surrounding the body.

$$T_{MRT}=\frac{A_1T_{S1}+A_2T_{S2}+A_3T_{S3}+A_4T_4}{A_1+A_2+A_3+A_4} \qquad (9)$$

Where

T_{Si} = Surface Temperature of the walls

A_i = Surface Area of the walls

3. CFD MODEL

For the analysis, a room of size 6.08m x 3.8m x 3.14m is modeled using ANSYS ICEM. The roof of the room is consists of RCC of 12 cm thickness. The thickness of the walls are 20 cm each. In this room direct solar radiation takes place only through roof but not through the walls, window or ventilator. A split AC is installed on a wall at a height of 2.81 m as shown in fig 3.

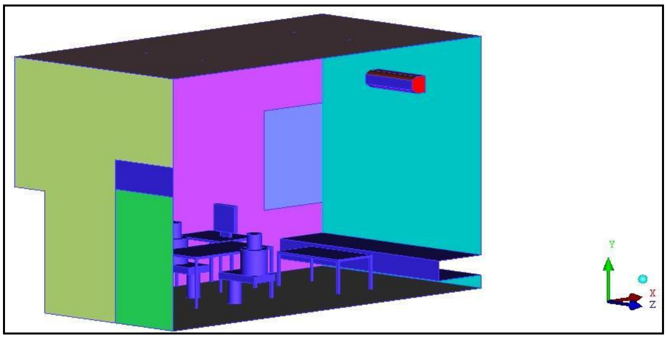

Fig -3: Computational domain

4. BOUNDARY CONDITION

For this examination constant reference air-conditioner supply air velocity (V_{in}) = 3 m/s, temperature (T_{in}) = 288 K is considered. Heat transfer coefficient and external emissivity for walls and uncoated roof are 22.7 W/m^{2}K, 0.88 [5] respectively. uncoated roof solar radiation absorptivity is 0.65[5].

TABLE-1: Properties of Cooling Roof Material [6]

Cooling roof material	Solar Reflectance	Infrared Emittance	SRI
White Cement Tile	0.73	0.90	90
PVC white sheet	0.83	0.92	104

In the present study two types of solar heat barrier namely White cement tiles and white PVC sheet is used (Table-1)

Table –1: Heat production rate of occupants [7],[8]

Occupants	Rate of heat production (W/m^2)
Computer	33
Tube light	33.5
Human (Sitting, Normal office work)	55

5. RESULT AND DISCUSSION

From the results of the simulations it is observed that maximum external heat is transferred to the room through the roof. Cool roof techniques can helps to minimize the heat transfer through the roof by mitigating the solar heat.

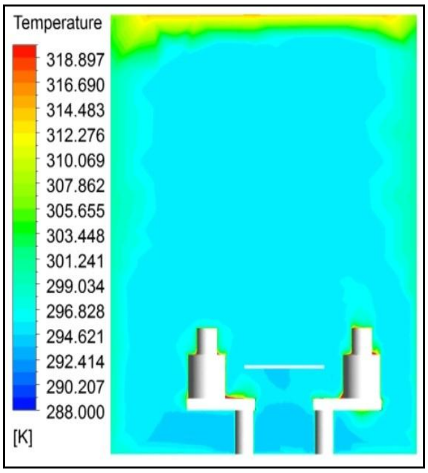

Fig-4: Temperature contures for uncoated roof

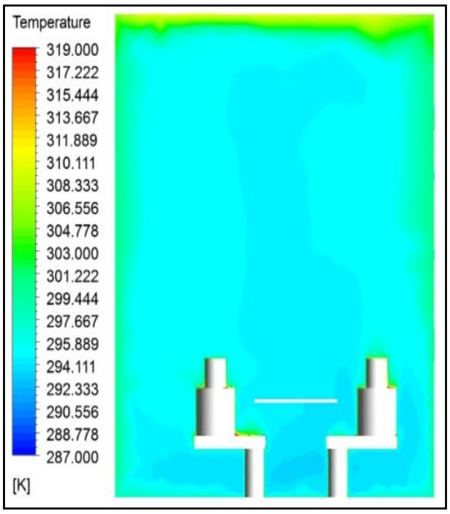

Fig-5: Temperature contures for white cement tile coated roof

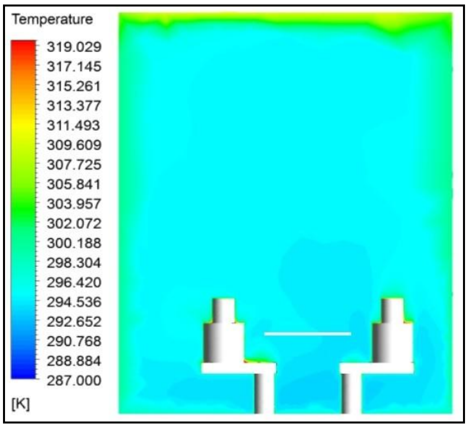

Fig-6: Temperature contures for PVC white coated roof

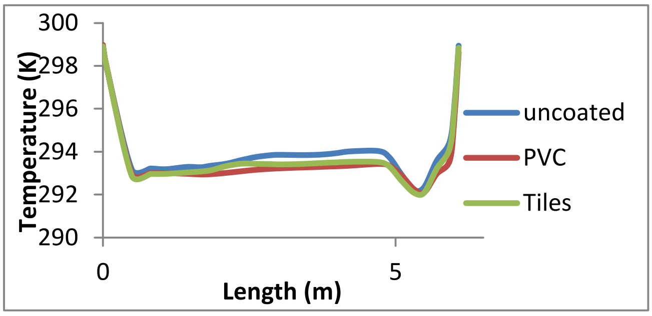

Fig-4: Temperature distributions along length of the room

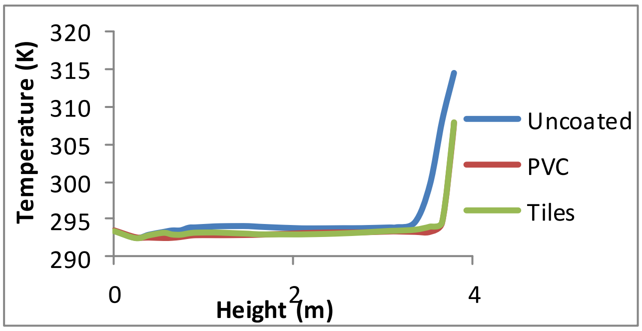

Fig-4: Temperature distributions along height of the room

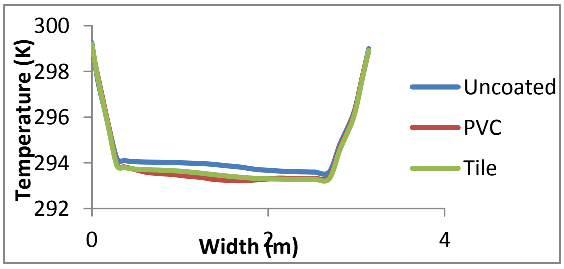

Fig-4: Temperature distributions along width of the room

TABLE-3: Roof Surface Temperature

Roof Type	Outer roof temp. (K)	Inner roof temp. (K)
Uncoated	335.55	312.05
White Cement Tile	319.53	307.937
White PVC sheet	314.47	307.925

From the above simulation, the temperature contours, comparison graph shows that using cool roof coating, both the inner roof surface temperature and outer surface temperature of the roof are significantly reduced. The decrease of roof surface and under surface temperatures is noted in Table-3.

After the utilization of cool roof materials in the outer surface of the roof, the Mean Radiant Temperature (MRT) is reduced. The value of MRT before using the cool roof materials is 300.921 K, which is reduced to 300.205 K and 300.203 K when White cement tiles and White PVC are coated respectively on the rooftop. When White PVC sheet is coated as solar heat barrier in the roof, the outer roof temperature reduces to 16.02 K and inner surface temperature is reduced to 4.113 K as compared to uncoated roof. Again the solar heat barrier White Cement Tiles reduces the outer roof surface temperature to 21.08 K and inner surface temperature is reduced to 4.125 K as compared to uncoated roof.

6. CONCLUSION

In the study, two different solar heat barrier materials are examined separately on the outer surface of the roof of an air-conditioned room. The CFD examination demonstrated that those materials are to a great degree viable. It contributes exceptionally to diminish the cooling load of the room. Subsequent to utilizing the cool roof materials, the Mean Radiant Temperature (MRT) is lessened altogether. So AC needs to do less work to cool the room.

However, in the winter season, solar heating through the roof is beneficial. It warmed up the room. So a year-round study for particular climates chooses the best possible cool roof materials. These are some areas for future review.

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