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Effect of Gypsum Board Ceiling on Temperature Reduction in a Room using Finite Element Method

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ABSTRACT: The present study describes the use of the finite element method to determine the effect of the gypsum board ceiling on room temperature. A simulation of air particles coming from air conditioners is carried out in a large room and the simulation is repeated after providing a gypsum board ceiling in the room, to identify its effect on room temperature. A three-dimensional computer-aided design (CAD) model of a large room with three air conditioners was made and the flow behaviour of air particles is analyzed using ANSYS fluent V15 software. The simulation process is done considering both possibilities, one is which room acts as an open system and the air is allowed to flow through the door of the room and the second as a closed system, in which air flows inside the room only. The analysis is also done with the same model after providing a gypsum board ceiling in the room. The difference generated in room temperature due to the gypsum board ceiling is determined. It is a challenging task to provide a ceiling in the CAD model with different thermal properties than the wall surface. It is necessary to understand the effect of these properties of gypsum on heat transfer in the room. The results suggest that by providing a gypsum board ceiling, a temperature reduction of 3-4 °C can be easily achieved. This reduction in temperature provides thermal comfort for the people living in the room. It also reduces the total cost required for air conditioning.

Keywords: Gypsum board, Finite element analysis, HVAC System, Air temperature

Abbreviations: HVAC, heating, ventilation and air conditioning system; CAD, Computer aided design; CFD, Computational fluid dynamics; STEP, standard for the exchange of product model data; CATIA, Computer-Aided Three-dimensional Interactive Application; AC, air conditioner.

I. INTRODUCTION

It is essential to maintain an adequate temperature in a room or any workplace to provide thermal comfort to its occupants. This thermal comfort is achieved by providing a heating, ventilation and air conditioning (HVAC) system. In most HVAC systems cooling of a building or room achieved by some mechanical means such as an air conditioner or fan etc. in which either the warm air is sucked by the system to the supply cold air or a cooling effect is created by flowing surrounding air. Converting the warm air into the cold is a much more effective method of cooling. This method of air conditioning is effective but very costly too. According to the climate map of India (ECBC 2009) [21], Most of its area comes mainly under three climates warm humid, hot dry and composite so it needed a cooling effect for almost 7-8 months in a year. Considering the time and the cost required for cooling. There is a growing need to find some effective design methods for HVAC systems. Now a particular design method of an HVAC system can be analyzed using the experimental method which gives results based on global parameters, but performing an experimental method for an HVAC system is very costly. It also needs an equivalent environmental condition i.e.; the outside temperature should be equal for all experiments performed. This approach is very time-consuming. The finite element method provides an alternative solution to study an HVAC Model. Which is an easier and cost-effective method than an experimental method. With enough boundary conditions can give near real-life solutions.

Several researchers have done a simulation study to make cooling more efficient and effective such as Prakash *et al.* [1] performed the simulation of airflow inside a room with two windows of equal size. The air is supplied from the outside atmosphere to the CAD model of a room. The position of the windows changed to determine the best-suited window position for the maximum possible thermal comfort. The study suggests that the windows positioned in the middle of the room increase the low-temperature zone by 50%.

M. Ismail *et al.* [2] studied the effect of the number of exhaust fans and the arrangement of these exhaust fans on the air temperature and its velocity inside a modular badminton court. A CAD model of the modular badminton court was analyzed in ANSYS fluent software. The indoor warm air was removed through the holes at different locations to find the best-suited position for exhaust fans where the lowest possible air temperature can be achieved.

Bamodu *et al.* [3] investigated the cooling effect in an office by a 4 – way cassette air conditioner. A comparison is also done between 4 – way cassette air – conditioner and mixing ventilation system based on ADPI simulations. The results suggest that the 4 – way cassette air conditioner achieve much larger air distribution as compared to the wall-mounted air conditioning system.

Aryal *et al.* [4] also utilized the CFD technique to determine the effect of the partition in a building on the air temperature and the quality of air. The study suggested that a significant change in thermal comfort occurred when the area with neutral sensation reduces significantly. If there is not an additional air conditioning unit then the installation of a partition in the desired location is not suggested.

Lee *et al.* [5] compared the CFD technique with the experimental method to identify the dispersion of air contaminants in an indoor workspace. A simulation for the dispersion of air is done in an enclosed CFD model at two different air flow rates and to demonstrate the simulation accuracy. The result suggests that with enough boundary conditions a CFD method can provide near to real-life solution.

Peng *et al.* [6] performed a similar simulation of the airflow in an office with a wall hanging air conditioner. The air is supplied at three different angles with three different velocities. Based on the velocity field and temperature field, thermal comfort is determined. The result suggests that air supplied at an angle of 75° downward with a velocity of 3.0m/s provides maximum thermal comfort.

Ogoli *et al.* [7] did a study for temperature detection in a building with high and low thermal mass at the equator. Four test chambers with different heat absorption capacity were investigated under different types of ceiling. A long-time lag time achieved with the materials of high thermal mass with an average temperature swing.

Baskaran *et al.* [8] done a simulation for the flow of air particles around a large building, the simulation is also repeated for the flow of air particles around two buildings. The study compared the pattern of flowing air particles with the single building, two-building condition with multiple building configurations.

Abir *et al.* [9] performed a computational analysis to see the effect on velocity and temperature distribution for the air inside the room, when the air conditioner positioned at different locations vertically. The air conditioner positioned at three different heights (1.5 m, 2 m & 2.6 m) analyzed. The result suggests that the maximum thermal comfort is achievable at a 2.6-meter height.

II. MATERIALS AND METHODS

In the finite element analysis method, a body is divided into several numbers of small elements. These elements are called finite elements.

The original body now considered as a group of finite elements, all connected with a finite number of nodes or nodal points. In finite element analysis, the various properties are determined in these nodes, each node presents a different value of a particular property. To obtain the resultant property for the entire body, the property on each node is combined. The finite element method, which is also called finite element analysis, according to Robert D. Cook is a computational procedure for analyzing structure and continua. Usually, the problem is addressed too complicated to solve by the classic analytical method [14]. This technique is used to solve various boundary value problems to find near to a real life solution. The three-dimensional computer-aided design (CAD) model of a large room with 3 air-conditioners is made using CATIA-V5R20 software and the file is saved in STEP format. The STEP file of the CAD model was imported into ANSYS 2015 software for simulation and analysis. The analysis process is also repeated with the same CAD model after providing a gypsum board ceiling in the room. The temperature drops in the room, then calculated and compared considering the cost of gypsum ceiling and reduction in the cost of cooling effect.

The temperature in a room due to natural convection is depended upon the size of the room and the size of opening doors and windows for ventilation. Buoyancy is the major driving force responsible for natural ventilation. The buoyancy in the room depends upon the difference in indoor and outdoor density. When it is the dominant force, the flow of air takes place in the upward direction. If the temperature difference between inside and outside of the room is negligible, then buoyancy force will be negligible.

Buoyancy effects in the room can be determined by Grashof number. It is a dimensionless number given as the ratio of buoyancy force to the fluid viscous force.

$$Grashof\ Number\ Gr = \frac{g l^3 \beta \Delta T}{v^2} \quad [15]$$

Where g is the acceleration due to gravity, l is the length, β is the coefficient of thermal expansion, v is the kinematic viscosity and ΔT is the temperature difference.

One more reason which is responsible for the flow of air inside the room is wind-driven flow. This type of flow occurs when there is a pressure difference exist in the room or buildings due to the wind flow. This pressure difference is mostly developed at the window or door side of the building.

III. MODELLING

A simple CAD model of a large room with an opening door was made in CATIAV5R20 software. The dimensions of the room taken at 12 meters in length, 6 meters in width and 5 meters in height. Three air-conditioners of approx. length of an original one is given in the room.

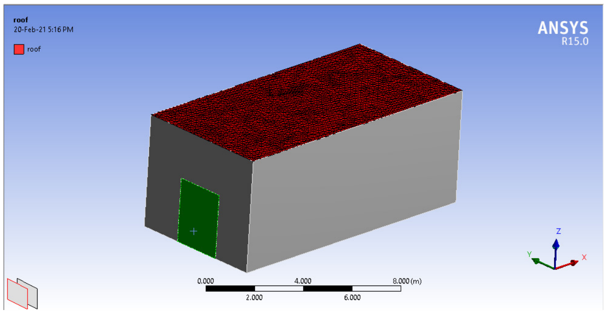

Fig. 1. 3-dimensional CAD model of a large room with a roof.

A large opening door in the front of the room provided with a dimension of 3 meters in height and 2 meters in width. The CAD model is saved in STEP format and imported into ANSYS fluent 2015 software for the simulation. All air-conditioners are named for the velocity inlet. Then the CAD model is messed with fine sizing. Tetrahedral element meshes were generated for better accuracy.

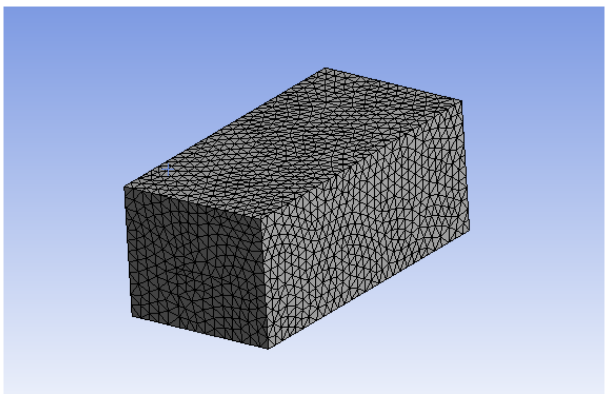

Fig. 2 Tetrahedral messing of the CAD model.

The CAD model of the room with air-conditioners was simulated in fluent fluid simulation software under ANSYS 2015. The K- ε turbulence model with realization is used to solve the simulation problem. In turbulent flow condition K- ε turbulence model is the most commonly used because it is a two-equation model which increases the efficiency in comparison to most simpler models. The material used for the room walls changed to masonry wall by changing their properties. The density of the wall is taken as 1900 kg/m^3, the specific heat at constant pressure is taken as 880 j/kg-k and thermal conductivity of the wall is taken as 0.711 W/m-k [16]. The air is taken as flowing fluid in the room at default values. The velocity taken for the flowing air from air condition is taken as 0.9 m/s considering the ASHRAE Standards for thermal comfort [17]. The pressure outside the door maintained at atmospheric value i.e., 101325 pascals [18].

The simulation is also repeated with the same CAD model after providing a gypsum ceiling. The thickness taken for the gypsum board is 12 mm. The thermal properties of the gypsum material are given in Table 1.

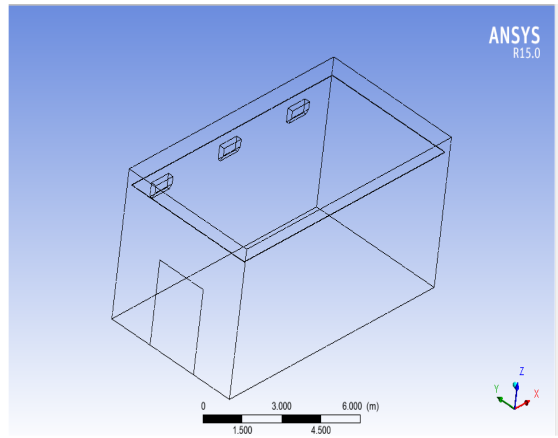

Fig. 3. 3-dimensional CAD model of the room with a gypsum.

Table 1: Physical parameters and thermal properties of the room and air conditioning system.

Serial number	Parameters	Values
1	Nodes	8322
2	Elements	43634
3	Roof temperature	313 K
4	Air conditioning temperature	290 K
5	The density of Gypsum board	724 kg/m^3
6	Thermal Conductivity of Gypsum	0.328 W/m-k
7	Specific heat at constant pressure	950 J/kg-K

IV. RESULTS AND DISCUSSION

The CAD model of the room with 3 air-conditioners are shown in Figs. 1-3 and the properties related to the room and gypsum ceiling is given in Table 1. The simulation of the air considers two different cases, one in which the room is considered as an open system and the cold air is allowed to flow through the door, and a second in which the room is considered as a closed system, and the flow of air is redistricted in the room only. The simulations are repeated after providing a gypsum ceiling in the room. The temperature of the roof maintained at 313 K, considering the outside temperature in summers and most of the roof comes in direct contact with sun rays. The air conditioners supplied the cold air at the velocity of 0.9 m/s. The air temperature supplied from the air conditioners was maintained at 290 K temperature. The outside pressure of the door maintained at atmospheric pressure and temperature at 313 K the same as the outside temperature. The velocity streamlines for the air particles are shown in Fig. 4.

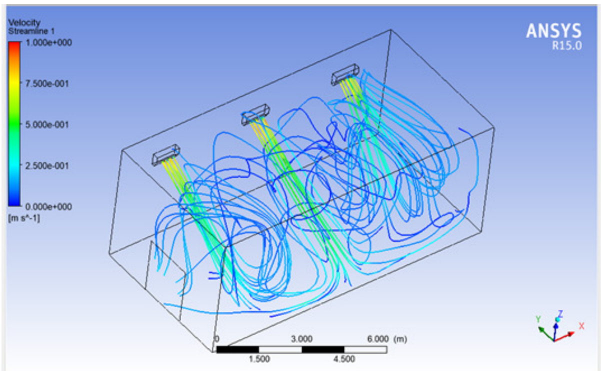

Fig. 4. Velocity streamlines for the air particles.

In figure 4, Velocity streamlines are given for the first case in which the air is allowed to flow through the door and temperature is calculated without considering the gypsum ceiling. Temperature isosurfaces are made to identify the air temperature at different locations in the room. The undeniable max temperature of 313 K can be seen on the roof. To identify the air temperature in the room area-weighted average method is used to calculate the temperature. The calculated value of the air achieved in the room is 294.15 K

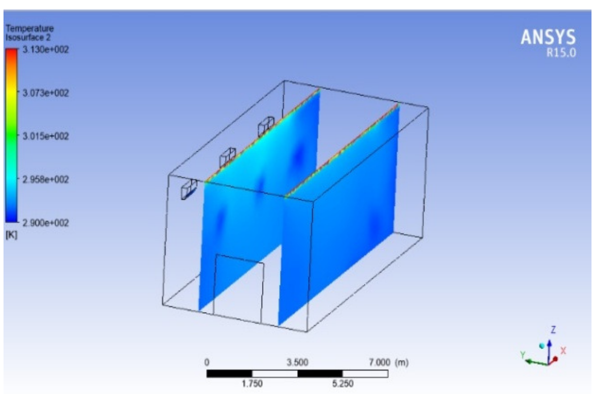

Fig. 5. Temperature isosurface without gypsum ceiling (Opening door).

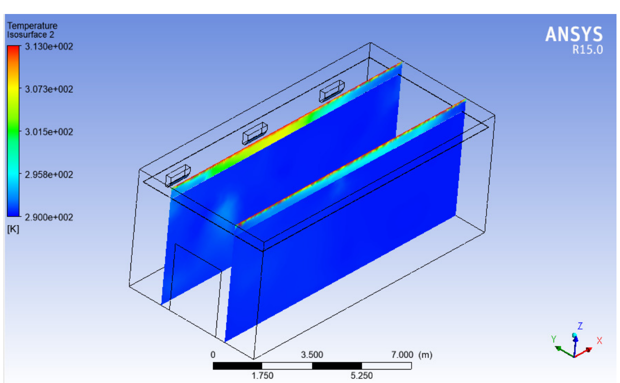

Fig. 6. Temperature isosurface with gypsum ceiling (opening door).

The simulation process, then repeated for the second case in which a gypsum board ceiling is provided in the room. The thickness taken for the ceiling is 12 mm. The temperature isosurface, in that case, is given in Fig. 6. The area-weighted method is used to calculate the room temperature, which is equal to 291.07 K. By using a gypsum board ceiling, a temperature difference of 3.08 ℃ achieved.

The effectiveness of the gypsum board ceiling is also identified considering the room as a closed system in which the flow of cold air is restricted in the room only. The cold air from the air - conditioners are supplied again at 290 K. The temperature isosurface for this case is shown in Fig. 7.

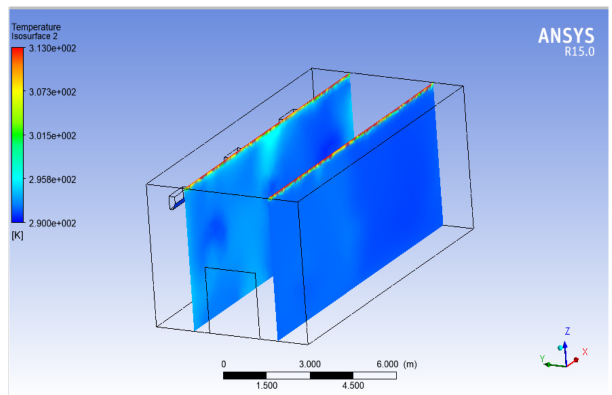

Fig. 7. Temperature isosurface without gypsum ceiling (closed door).

The area weighted average temperature achieved in that case is 292.74 K. Which is lesser than that in Case 1 where cold air is allowed to flow the through the door. The similar simulation is repeated after providing a gypsum ceiling in the room. The isosurface for this case is shown in Fig. 8. The area-weighted temperature achieved in this case is 290.08 K. Which is almost equal to the air conditioning temperature and the total drop in temperature achieved by using a gypsum ceiling is 2.66 ℃.

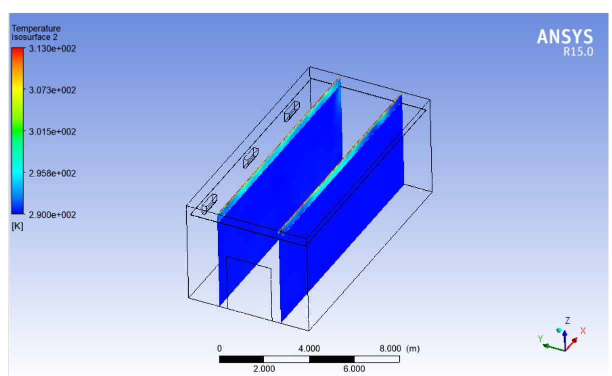

Fig. 8. Temperature isosurface with gypsum ceiling (closed door).

Table 2 given below gives the temperature achieved in every case. After comparing the temperature calculated via the area weighted average method in fluent software, we get a temperature drop of 3.08℃ in the open system and a temperature drop of 2.66℃ in the closed system. The results conclude that a temperature drop of up to 4℃ is achievable by using a gypsum board ceiling.

Table 2: Comparison of temperature achieved in all cases.

Room Temperature	Without Gypsum Ceiling	With Gypsum Ceiling	Temperature Difference
Open System	294.15 K	291.07 K	3.08 ℃
Closed System	292.74 K	290.08 K	2.66 ℃

This material also has some benefits other than the cooling effect. One of the major benefits is, it is a heat-resisting material. The gypsum is chemically combined with the water ($CaSO_4 \cdot 2H_2O$) in its core. Whenever a flame comes in contact with the gypsum board, it starts releasing water drops in the form of steam. Even after converting all water into steam, it continues to resist flame [24]. The gypsum ceiling also works as a sound-insulating material so if it used in a workshop where machines keep making noise, it can absorb excess sound and can improve communication [25]. Most importantly, this material has little to no environmental effects means it doesn't emit any harmful products in the atmosphere which is harmful to occupants or the environment. Hence, the gypsum board ceiling is not just cheap and an effective way of proving thermal comfort but also has many other advantages.

VI. CONCLUSIONS

In this study, the finite element method was used to analyze the effect of the gypsum board ceiling on temperature reduction inside a room. After comparing the results generated from the CFD analysis. We observed that by adding a gypsum ceiling in the room, a maximum reduction in the temperature of 3-5 ℃ can be achieved. On regular daytime, in summer a reduction in the temperature of 2-4 ℃ achieved using the gypsum board ceiling. Considering the low cost of gypsum board and little to no environmental effects. It can save the cost needed to provide thermal comfort in a room. Even if there is no air conditioning system in the room, a gypsum board ceiling is an effective way to reduce the room temperature.

VII. FUTURE SCOPE

There are several possibilities for further study. One can study to determine the effect on room temperature due to the change in locations of air – conditioners. One can also consider a heat-generating body inside a room to determine the effect on room temperature with a gypsum board ceiling. Several different materials other than gypsum can also be used as ceiling material.

It is well known in advance that the air is a bad conductor of heat. When a layer of gypsum board is provided in the ceiling, the air-filled between the ceiling and the layer of gypsum board restricts the flow of heat in the room. The air gap captures most of the heat and allows a minimal amount to flow in the room. which generates a temperature drop. The drop in temperature depends on many environmental conditions. Our study utilized the FEM analysis considering all important boundary conditions to get near to a real-life solution.

V. COST-SAVING AND BENEFITS

Various temperature plots and velocity streamlines for the different cases are given in this study. The result shows that the gypsum board ceiling is an effective way to reduce room temperature. The use of a gypsum board ceiling can reduce the energy required for the cooling in the room.

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