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Transient analysis and improvement of indoor thermal comfort for an air-conditioned room with thermal insulations

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Abstract Thermal insulations over the building envelop reduce the heat gain due to solar radiation and may enhance good and uniform indoor thermal comfort for the occupants. In this paper, the insulation layer-wood wool is laid over the roof and exposed wall of an air-conditioned room and its performance on indoor thermal comfort is studied by computational fluid dynamics (CFD) technique. From this study, 3% of indoor thermal comfort index-predicted mean vote (PMV) is improved by providing wood wool layer. In addition, the optimum supply air temperature of air-conditioning unit for good thermal comfort is predicted as in the range of 299–300 K (26–27 °C).

1. Introduction

In buildings, thermal comfort is a vital factor that decides the occupant's health and productivity. Since 90% of the people spend most of their time inside the building, they are interested to invest high cost to live in a comfort environment with air conditioners and air coolers. Also the buildings in cities consume a large proportion of electrical energy mainly for HVAC (heating, ventilation, and air-conditioning) systems [1]. Even though the air conditioning unit controls the indoor temperature and provides good indoor comfort, occupants are still suffering from many health related symptoms like nose irritation, stuffed nose, rainy nose, eye irritation, cough, tightness in chest, fatigue, headache, rash and many more [2]. Hence it is very imperative to operate the air conditioning unit for reduced health related problems under less consumption of energy without sacrificing the thermal comfort. This can be achieved by operating the air conditioning unit at sufficient temperature level of air supply. Also the indoor thermal comfort should be maintained with a same value for a complete 24 h irrespective to the variations in solar radiation.

Among the many sources that gain the heat into the building, solar radiation is identified as the major factor that raises the indoor temperature. The incoming solar energy is absorbed by the earth surface as 51% and gets reflected by 4%; atmosphere and clouds absorb 19% and reflect 26% respectively. Vijayakumar et al. [3] stated that the heat transmission across the building roof is about 50–70% of the total heat entry of the

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room. Chou et al. [4] also stated that the heat gain through the roof due to solar radiation incident on the roof reaches more than 1000 W/m^2 in clear sky condition. Hence a good thermal insulation is required for both roof and exposed wall of an air conditioned and non air conditioned building to reduce the heat gain of the indoor. The thermal insulations in roof and exposed walls also reduce the capacity of air-conditioning system and the annual energy cost for a building. Also, it extends the periods of thermal comfort without reliance on air-conditioning unit especially during inter-season periods. In this contest, much research work has been made to reduce the heat transmission across the roof by adding insulation layers like phase change material, reflective coating, green roofs and etc. [5]. Barrios et al. [6] studied the effect of mono layered and multi layered roof/wall configuration in an air conditioned room and identified that providing such a insulation layer on the exterior side of the roof/wall gives a better thermal performance than placing the insulation layer on the interior sided of the wall/roof [7–9]. The thermal conductance coefficients (U-factor) of the non-insulated roof ranges from 7.76 (250 mm concrete) to 18.18 W/m^2 K (100 mm concrete) [10]. Therefore, the heat transfer across non-insulated roofs is greater than roofs with insulation. Al-Sanea and Zedan [11] studied the effect of insulation layer location on the heat transfer characteristics of building walls under steady periodic conditions. Halwatura and Jayasinghe [12] studied the impact of insulation (polyethylene) thickness and concluded that adding a 2.5-cm thick polyethylene insulation on the scaled concrete roof reduces the peak roof soffit temperature from 42 to 33 °C in the tropical climate of Sri Lanka. Alvarado et al. [13] studied the thermal performance of concrete-based roof prototypes with different types of insulations and found that the combined application of aluminum reflector and polyurethane insulation offers a heat flux reduction of 88% in comparison with the un-insulated roof prototypes. Ashok kumar and Suman [14] experimentally evaluated the impact of insulation material for walls and roof on indoor thermal comfort under composite climate. Hence, this study also interested to reduce the heat gain due to solar radiation by providing insulation layer over roof and wall of an air conditioned room through the analysis of indoor air flow characteristics.

The indoor air flow characteristics are studied either by small-scale or full-scale models. Small-scale models are constrained by the need of scaling factors for heat transfer and air flow, while the full-scale environmental chambers for indoor evaluations are expensive and practical experiments are time consuming. Nevertheless, computational fluid dynamics (CFD) technique plays an important role in the design and evaluation of indoor air flow characteristics, thermal comfort conditions, smoke conditions or air quality in worldwide large space buildings such as Yoyogi National Stadium in Japan [15], Galatsi Arena in Greece [16], Kansai Airport in Japan [17], Great Hall of the People in China [18], etc. Thus, in this study the CFD tool is employed to analyze the indoor thermal comfort of an insulated air conditioned room under various operating conditions of air conditioning unit.

2. Room model and CFD methodology

An isolated room of size width = 5 m and height = 4 m is considered in this study. This traditional room is having a roof thick of 0.15 m of concrete, 0.02 m thickness of weathering tile and 0.2 m of wall thickness. Later the traditional room is modified by providing an additional insulation layer of wood wool over the roof and wall. The air conditioning unit is located on the east facing wall at the height of 3 m from the floor. The 2-dimensional model of the test case room is created in the Gambit software through Cartesian coordinates and shown in Fig. 1. The traditional room is improvised through three modifications as mentioned in Table 1.

The model created in the Gambit software is meshed with the quadrilateral grid of size 0.01 m and imported to the FLUENT software for solving the computational domain. This grid structure is independent of the result as it is verified by repeating the test with a greater number of cells. The material properties of the building construction materials are given in Table 2.

2.1. Assumptions

(i) The heat conduction in the composite roof is one dimensional and the end effects are neglected.
(ii) The thermal conductivity of roof materials is considered as constant and not varying with respect to temperature.
(iii) Interfacial resistance is neglected.
(iv) The doors and windows are closed and the air leakage is neglected.
(v) East facing wall is the exterior wall, other is the interior wall
(vi) Adjacent rooms have no air conditioning unit.
(vii) The parametric values of air supply from the air conditioning unit are constant.

2.2. Governing equations of fluid flow and heat transfer

The fundamental equations that govern the fluid flow are conservation of mass, momentum and energy.

Conservation of Mass

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho v_x)}{\partial x} + \frac{\partial(\rho v_y)}{\partial y} = 0 \tag{1}$$

Conservation of momentum

The momentum equation in the x direction is given in Eq. (2)

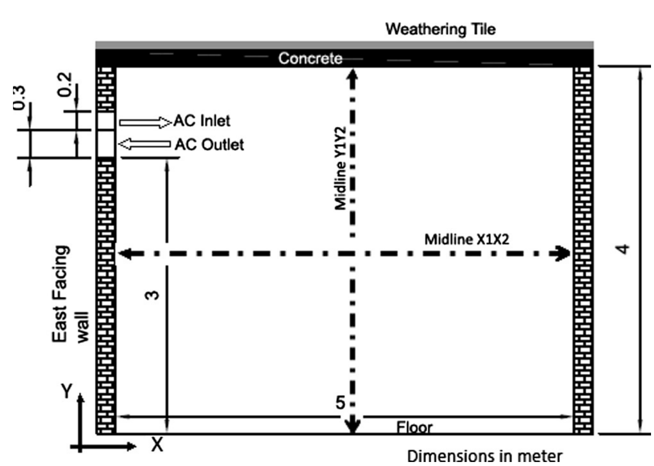

Figure 1 Computational model of test case room.