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Thermal Performance Analysis to Assess Inhabitant Comfort inside LIG houses in Chhattisgarh

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Abstract

In India about 73% of electricity is used in residential building for lighting and thermal comfort. Due to complexity and use of modern components/material in building, electricity consumption is increasing day by day. The present paper reports the thermal performance assessment of an LIG house under extreme climatic conditions as prevails during the month of May at Raipur, CG, (21.14ºN, 81.38ºE). Thermal comfort is an important parameter for design of any building and it has been observed that LIG houses constructed by CG Housing Board do not fulfil the comfort requirement under extreme weather conditions. For a non-conditioned building, thermal performance analysis measures the temperature distribution inside the building and the results of thermal analysis will help to estimate the deviation with standard thermal comfort. In this paper temperature distribution inside the houses has been estimated using CFD. The result presented in the study reports the temperature distribution inside the building and identifies and classifies different thermal zones to suggest solutions in the form of design modifications to moderate the thermal conditions naturally and cost effectively.

Keywords: Thermal comfort, Thermal performance, CFD, Room air temperature, LIG house

INTRODUCTION

Houses are built to provide the thermal comfort to its occupant, but due to modernization, using aesthetic things, the main aim of providing thermal comfort is deviating. The aspect of thermal comfort is very important to the designer, as poor thermal comfort makes more dependency on cooling equipment which leads to more energy consumption. In India, about 73% of electricity is used for lighting and cooling as reported by [4].Electricity consumption in Chhattisgarh increased by 14.24 % over a period of a year in 2014-15. Lower income group housing plans (LIG) are run by Government of India to provide residence to lower middle class family (Families with an annual income of Rs 1.2 lac or less). The design of these buildings are same irrespective of orientation and location. The National Building Code of India advocates the use of two indoor temperature ranges for summer (23–26 ^{O}C) and winter (21– 23 ^{O}C) for all region based on ASHRAE. Thermal comfort is an important parameter for design of any building and it has been observed that LIG houses constructed by CG Housing Board do not fulfil the comfort requirement under extreme weather conditions. The result will help to initiate building regulation aiming to provide thermal comfort. Literature review indicates that researchers have done thermal comfort analysis of habitats at specific locations of the country and pointed out the need of thermal comfort analysis for different regions to re-define the building design regulations so as to help in minimizing the electricity consumption of cooling in building.

Of these, based on adaptive approach of thermal analysis, temperature and humidity has been investigated by [5], for vernacular buildings in North-East India. And it is found that occupants have enhanced control over indoor environments in the vernacular houses. Questionnaire survey has been conducted by researcher [1], to predict the effect of temperature, humidity and air flow in Kerala traditional houses to analyse the thermal comfort. And it is concluded that in same atmospheric condition traditional residential houses are efficient to provide thermal comfort. [2] investigated thermal performance of a mud-house located at Solar Energy Park of IIT Delhi, India. Based on energy balance equations a thermal model of the mud house consisting of six interconnected rooms was developed and it is concluded that mud houses provide satisfactory thermal environment n all season.

Review indicates towards the non-availability of such a study for the region of Chhattisgarh. Being a region inflicted with extreme summer conditions, a study analyzing the thermal comfort of inhabitants belonging to these part of the Nation is, hence, the objective of the present study. Although various analyses to predict the thermal performance of a whole building has been reported by many researchers but very little work has been reported for India.

SIMULATION METHODOLOGY

The present paper reports the thermal performance assessment of an LIG house under extreme climatic conditions as prevails during the month of May at Raipur, CG, (21.14ºN, 81.38ºE). In this paper, whole building simulation model have been developed. The outdoor climate parameter wind speed, wind direction, humidity has been taken from meteorological department website. Indoor air temperature is depended on solar radiation, Material properties of building, heat transfer coefficient, internal heat gain and ventilation etc. Considering the heat transfer and fluid flow, analysis of closed space of LIG house is solved using an Energy balance equation in CFD:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \frac{\partial T}{\partial x} + \rho C_p v \frac{\partial T}{\partial y} + \rho C_p w \frac{\partial T}{\partial z} = \frac{\partial}{\partial x}\left[k \frac{\partial T}{\partial x}\right] + \frac{\partial}{\partial y}\left[k \frac{\partial T}{\partial y}\right] + \frac{\partial}{\partial z}\left[k \frac{\partial T}{\partial z}\right] + q_V \quad (1)$$

Heat transfer through the wall, windows and roof can be calculated from:

$$q = UA.(T_{sol} - T_r) \quad (2)$$

Heat transfer through the ventilation can be calculated from:

$$q_{ventilation} = \frac{\rho VCN(T_r - T_a)}{3600} \quad (3)$$

The overall heat transfer coefficient (U) of wall and roof can be calculated from:

$$U_{wall} = (\frac{1}{h_i} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{1}{h_o}) \quad (4)$$

Where L_1 and L_3 are thickness of outside and inside layer of plaster and L_2 is the thickness of intermediate brick. Solar radiation on wall/roof can be calculated using equations [3] given below:

Beam radiation (I_b) on horizontal surface can be calculated by given equation:

$$I_b = I_N \cos\theta_z \quad (5)$$

Diffuse radiation (I_d) on horizontal surface:

$$I_d = \left(\frac{1}{3}\right)[I_{ext} - I_N]\cos\theta_z \quad (6)$$

Total radiation (I_T) on an inclined surface is given by Liu and Jordan (1962):

$$I_T = I_b R_b + I_d R_d + \rho_r R_r \left(I_b + I_d\right) \quad (7)$$

Where I_N is the intensity of beam radiation. θ_z and θ_i are the angle of incidence on the horizontal and inclined surfaces. R_b, R_d and R_r are known as conversion factor for beam and diffuse and reflected components respectively, ρ_r is the surface reflectivity.

$$I_N = I_{ext} \exp\left[-\frac{T_R}{0.9 + 9.4\sin\propto}\right] \quad (8)$$

$$\propto = 90 - \theta_z \quad (9)$$

$$R_b = \frac{cos\theta_i}{cos\theta_z} \quad (10)$$

$$R_d = \frac{(1 + cos\beta)}{2} \quad (11)$$

$$R_r = \frac{(1 - cos\beta)}{2} \quad (12)$$

The intensity of extraterrestrial radiation (Iext) measured on a plane normal to the radiation on nth day of year is given as follows: (Duffie and backman 1991)

$$I_{ext} = 1367\left[1 + 0.033\, cos\left(\frac{360n}{365}\right)\right] \quad (13)$$

Sol air temperature of wall and roof can be calculated from following equation [2]:

$$\boldsymbol{T_{sol} = \frac{\alpha I}{h_o} + T_{amb} - \frac{\varepsilon \Delta R}{h_o}} \quad (14)$$

εΔR= 60 W/m2, for horizontal surface

εΔR= 0, for vertical surface

$\boldsymbol{\varepsilon \Delta R = \left(\frac{cos\beta}{sin\beta} X\ 60\right)\ W/m^2}$, for inclined surface

In this paper simulation work has been carried out for two different cases at same time when (i) doors and windows were open (ii) doors and windows were closed. LIG house plan and 3D model with boundary conditions is shown in fig 1 (a)-(b) respectively.

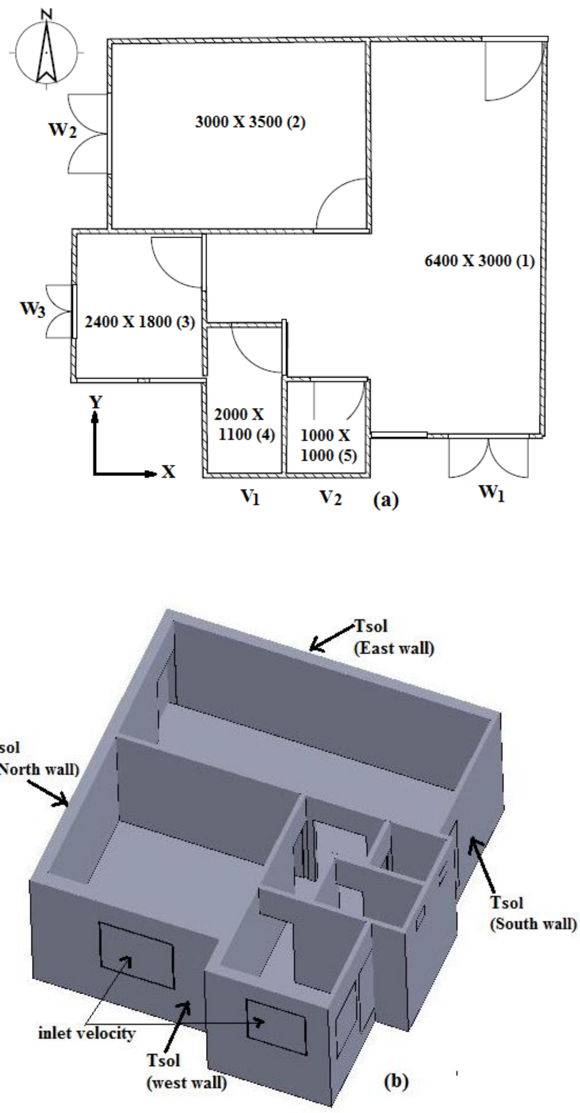


Fig 1: (a) The Layout of LIG house in C.G. prepared by housing board. (The dimensions are given by mm). 1. Living Room 2. Bed Room 3. Kitchen 4. Bathroom 5.Toilet (b) 3D model with boundary conditions.

RESULTS AND DISCUSSIONS

The thermal performance analysis of LIG house is carried out using CFD tool of SOLIDWORKS. The simulation is carried out on the meteorological data available for 13.00 hours, 21st May 2015 and the results are plotted in Fig. 2. During the month of May, climate at Raipur region is hot and dry and hence, humidity effects has not been incorporated in present work. Variation of ambient temperature on day time is shown in fig 4(b).The cut plot of temperature distribution plotted in Fig 2 (a-c) is at 0.5m, 2m and 3m altitudes of house with open doors and windows. The effect of air flow at different altitudes is evident from the plots. In Fig. 3 (a-c), similar cut plots of temperature distribution inside the LIG house is plotted with closed fenestrations. With the doors and windows closed, the air temperature in room 4 and 5 is lower as compared to other parts. In both cases, at high altitude inside the room, the temperature is more due to the effect of solar radiation from the roof.

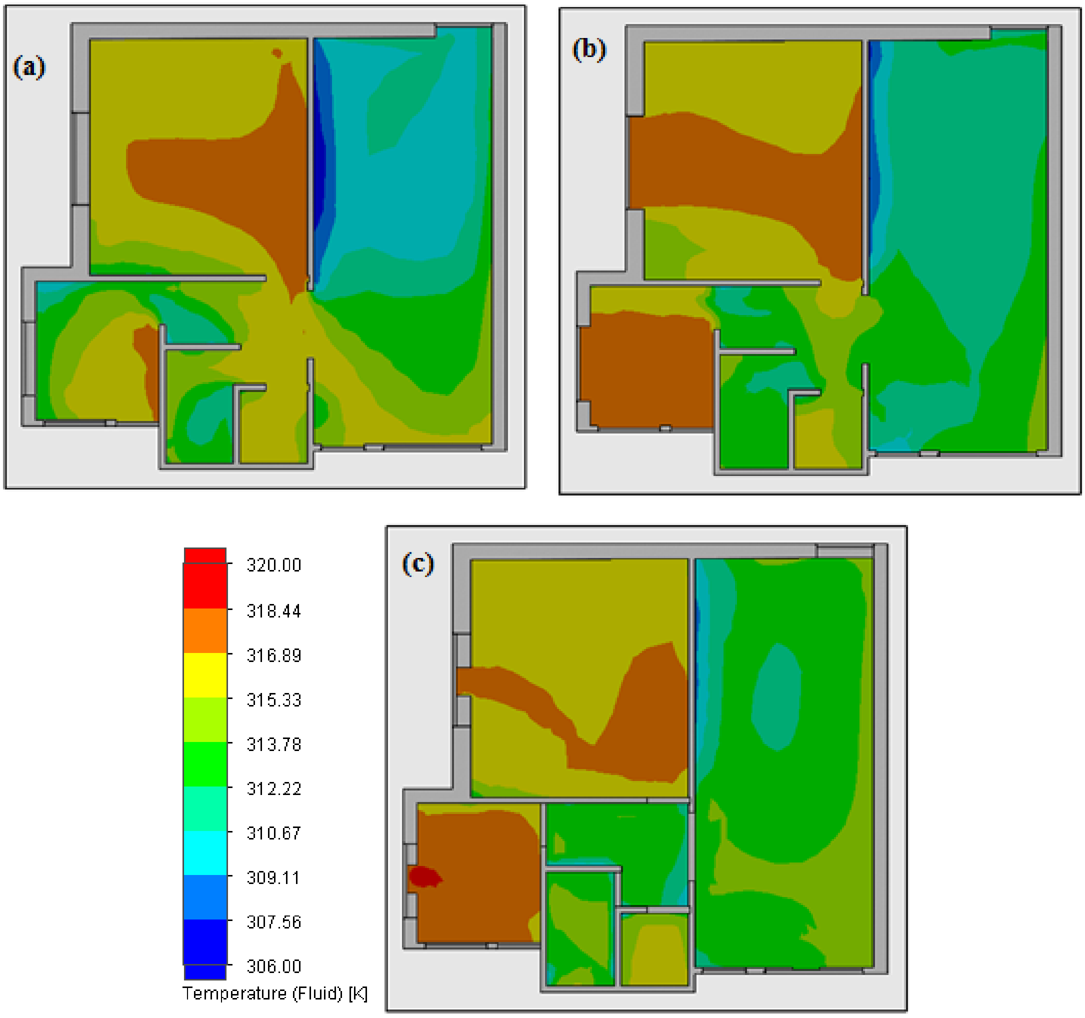


Fig 2. Effect of solar radiation and wind velocity on room air temperature with open windows (a) At 0.5 m height (b) At 2 m height (c) At 3 m height

It is evident from the results that in summer the room air temperature of LIG house in both cases more than the desired level to define human comfort condition. With open fenestrations, the room air temperature is higher as compared to that with closed room at every altitude. With closed fenestrations, near to southern area of house the temperature is low as compared to other area in houses throughout a day. During summer, hence, the southern portion of the house can be used intelligently for thermal comfort. Lengthwise room air temperature distribution of room 1 is shown in fig 4(a).

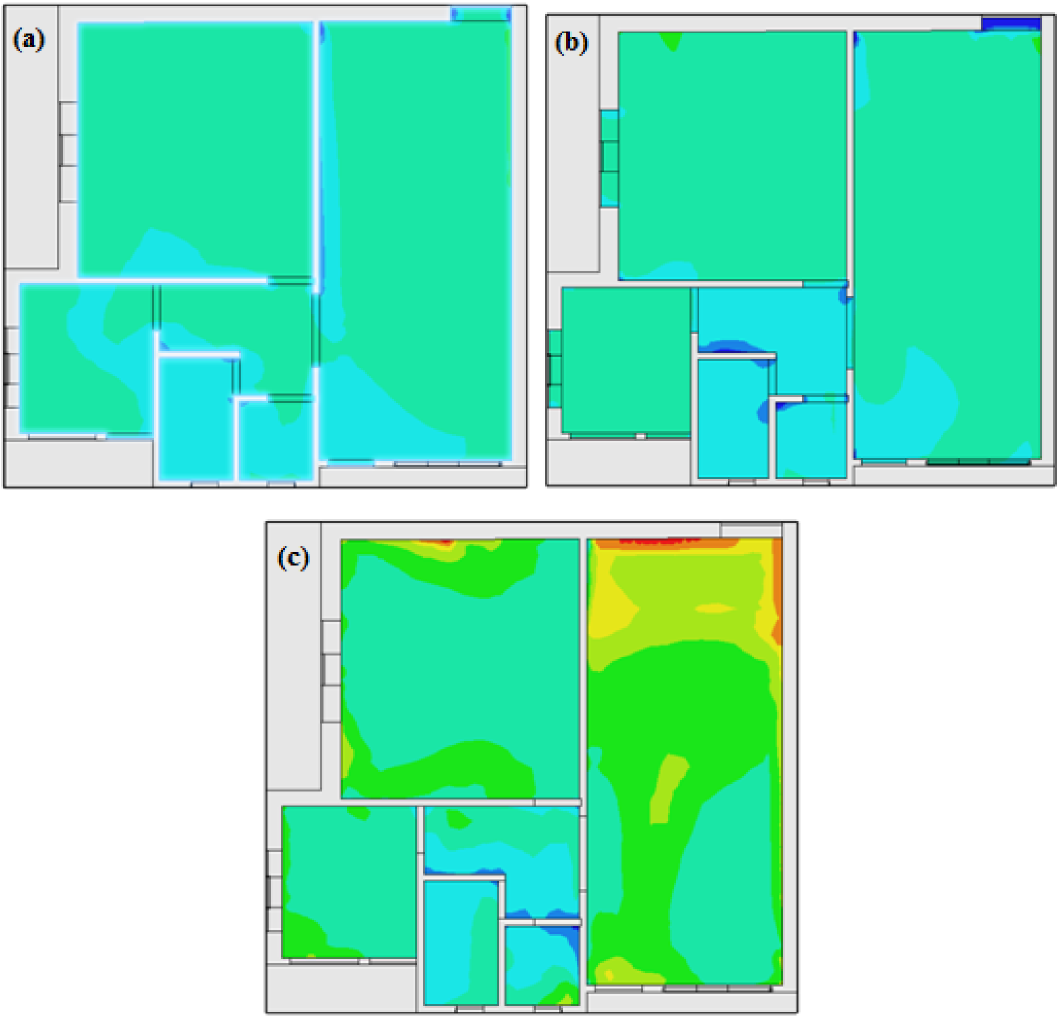
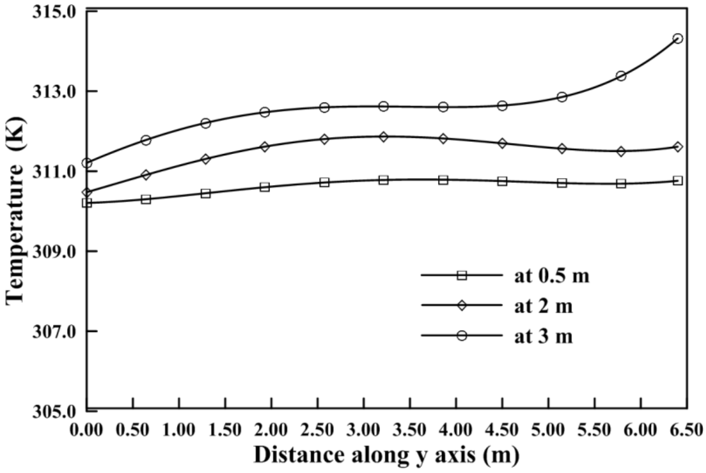
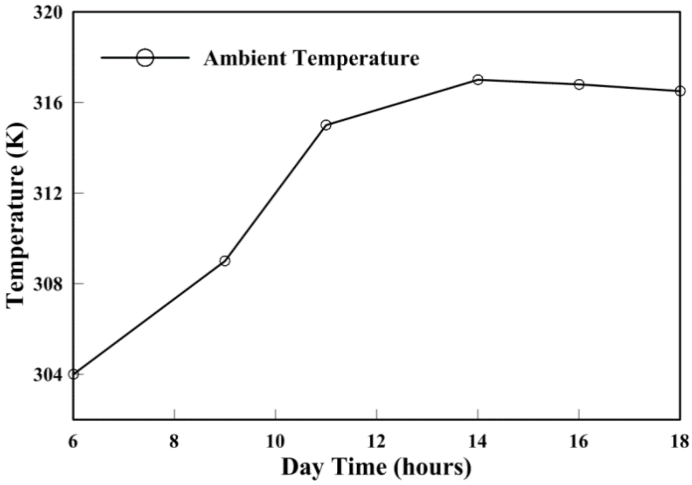


Fig 3. Effect of solar radiation and wind velocity on room air temperature with closed windows (a) At 0.5 m height (b) At 2 m height (c) At 3 m height



(a)



(b)

Fig 4. (a) Temperature distribution of room 1 at different altitudes (b) ambient temperature variation.

CONCLUSION

The effect of solar radiation and outdoor environmental conditions upon room air temperature is reported in the present work, and it is concluded that for Raipur region in Chhattisgarh, the building design of LIG housing overlooks the inhabitant comfort conditions. The study is carried out using CFD and the results plotted in the study report the temperature distribution inside the building and identifies and classifies different thermal zones to suggest solutions in the form of design modifications to moderate the thermal conditions naturally and cost effectively. Since the present design standards of LIG houses constructed by CG Housing Board do not fulfil the comfort requirement under extreme weather conditions, the present study aims at assessing the thermal performance of the existing houses so as to lay foundation for cost effective design modifications to enhance thermal comfort and conserve energy utilized under artificial cooling.

NOMENCLATURES:

T_r and T_{sol}	Room and Sol-air temperature
A	Area
U	Overall heat transfer coefficient
ρ	Density
L	Thickness of material layer
K	Thermal conductivity
h_i	Inside heat transfer coefficient
h_o	Outside heat transfer coefficient
β	Tilt angle
Cp	Constant pressure specific heat
q_V	Volumetric heat source
t	Time
T	Temperature
u,v,w	Velocity component in x,y and z directions
μ	Viscosity

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