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Evaluating building material based thermal comfort of a typical low-cost modular house in India☆

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Abstract

'Housing for All by 2022' is an ambitious initiative by the Government of India, to provide affordable and quality housing to the people of economically weaker sections (EWS) and the low-income group (LIG). Modular housing has become the de-facto in this context of low-cost and affordable housing. In this study, we evaluate the thermal comfort of a commercially available modular house with respect to different low-cost building wall materials and window glass panes. Dynamic energy simulations were carried out for Mumbai to analyse the thermal-comfort performance of such houses throughout the year. Results have shown that none of the low-cost building materials were competent enough to meet the ASHRAE-55 standards. However, a combination of glass fibre reinforced gypsum board and a blue tinted glass of a 6mm thickness, performed better in thermal comfort in comparison to other materials. This study showed the need for development of efficient low cost building materials in order to address the long-term sustainability of the low cost housing project.

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Keywords: Building materials; Mean radiant temperature; Operative temperature; Thermal comfort; Low-cost housing; Sustainability

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1. Introduction

The Ministry of Housing and Urban Poverty Alleviation (MHUPA), the Government of India (GoI) in their annual report for the FY- 2014-15, estimated that India suffers from housing shortages by 18.54 million units [1]. 96% of the housing shortage is in economically weaker sections (EWS) and the low-income group (LIG), who also suffers from lack of basic amenities like sanitation services, potable drinking water, electricity and effective solid waste disposal services [1], [2]. Attempts to mitigate this problem pertaining to the quality of life (QoL), the Ministry announced the National Urban Housing and Habitat Policy, 2007, which focusses on 'affordable housing for all with special emphasis on economically weaker sections of society such as SC, STs, OBCs, Minorities, women-headed households' [1].

In this purview, private corporations have flocked in to cater to this ambitious aim of the MHUPA, by providing modular low-cost houses, with an average floor area of 600 square meters [3]. However, the long-term sustainability of such modular houses is still unidentified, as different strata of the society has varied lifestyles with cultural and social needs. Moreover, current literature lacks building performance analysis in terms of thermal comfort of such modular houses, which can provide valuable insights pertaining to their long-term sustainability, and prepare designers, engineers and investors towards more sustainable low-cost housing design.

In India, where only 7% of the residential houses uses ACs during the summer months [4], [5], hence maintaining optimal thermal comfort levels becomes a critical sustainability clause, especially for EWS and LIG houses. Thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment" [6]. ASHRAE-55 standards suggest 26ºC as the desirable indoor temperature for prolonged thermal comfort [7]. Indian codes specify uniform comfort temperatures between 23 and 26ºC for all types of buildings as the required thermal comfort range [8]. The thermal temperature that our body experience in an indoor space is known as operative temperature (t_o). It is a combined effect of mean radiant temperature (t_r) and the air temperature (t_{db}). Mean radiant temperature (t_r), is defined as 'the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiant heat as in the actual non-uniform space' [9].

Here, we investigated the thermal comfort performance of a commercially available low-cost house with respect to different low-cost building material, with mean radiant temperature (t_r) and operative temperature (t_o) as the performance indicators.

Nomenclature

$F_{s\rightarrow i}$	angle factor between the i^{th} internal surface of the envelope and the subject
T_i	the absolute surface temperature of the surrounding surfaces
C_{dn}	day–night coefficient (equal to 1 in the daytime period and equal to 0 in the night period)
C_s	shading coefficient (equal to 1 when the subject is directly hit by the solar beam and equal to 0 in the other cases)
ε_s	emissivity of the human body
σ	the Stefan–Boltzmann constant (=5.67 X 10^{-8} Wm^{-2} K^{-4})
α_{irr}	the absorption coefficient
$I_{d_i,j}$	the diffused coefficient entering the room
$f_p I_b$	the projected human area factor in all the six directions
t_r	mean radiant temperature
t_o	operative temperature
t_{db}	outdoor temperature (dry-bulb temperature)

Fig 1. A typical commercially available low-cost modular house in India and its CAD model. [1]

2. Methodology

This study numerically evaluates the thermal performance of a modular low-cost house in India. Here, we simulate a typical low-cost modular house (see Fig 1) with different window glass and external wall materials, and calculate the annual indoor mean radiant temperature and the operative temperature using dynamic energy simulations. Such comparison of thermal performance will assess the 'comfort sustainability' of such houses that uses low cost building materials, and aims to fulfill the requirements of 'Housing for all by 2022' scheme. Thermal comfort analysis is crucial for low cost houses because if the indoor temperature becomes unbearable, then, the occupants will soon abandon them, and the whole concept of housing for all becomes ineffective.

2.1. Building Modelling

DesignBuilder v4.7 was used to perform building modelling and simulation using its natural ventilation module. It is a validated and widely used software for studying building performance dynamics and CFD analysis of building environment [10], [11]. It uses EnergyPlus as its core simulation engine, which performs climate based dynamic calculations for the prediction of energy simulation, load calculation, heat balance, and mass balance [10]. Here, we have incorporated EnergyPlus v8.3 for the thermal comfort calculations of the building as illustrated in Fig 1. Table 1 and Table 2 describes the properties of the studied house. Mumbai has a hot and humid climate with a mean average temperature of 27.2° C and average precipitation is 242.2 cm (95.35 inches). The mean maximum and minimum average temperatures is about 32 °C (90 °F) and 25 °C (77 °F), respectively in summer and in winter, while the average minimums are 30 °C (86 °F) and 20.5 °C (68.9 °F) in winter, respectively [12].

Table 1. Physical parameters of a typical modular house

Parameter	Dimensions
Length (m)	9.14
Breadth (m)	3.04
Height (m)	2.60
Overall Area (m^2)	30.65
Room (one room) (m^2)	6.09 X 3.04
Kitchen (one kitchen) (m^2)	3.04 X 1.21
Toilet (one toilet) (m^2)	3.04 X 1.82
Window to wall ratio	8%

Source: [13]

Table 2. Typical commercially available low-cost housing specification

Building Component	Specifications
Structural Steel	1.2 mm thick, 275 MPa Strength, C Sections
Foundation	Standard foundation of 600 mm
Wall Cladding	Cement Bonded Particle Board on both sides
Roofing Sheet	GC sheet
Roof type	Gable(Dual) slope
Fasteners	Standard fasteners (Galvanized), Self-Drilling Screws.
Insulation	High Density Wool Insulation in all walls to provide thermal comfort
Flooring	Standard Cemented flooring
Doors	Standard Steel Doors
Windows	Standard Steel-Net windows
External finish	Polymer coating on External boards, to give conventional look and feel
Internal finish	Wally Putty finishing on internal walls

Source: [13]

2.2. Simulations

Natural ventilation simulations were carried out using EnergyPlus v8.3 for the entire year using ISHRAE, 2013 weather data for Mumbai. The building materials were varied as per popular commercially available wall and glass materials available for low-cost housing (refer Table-3), followed by their thermal comfort calculations (t_o and t_r). The t_o and t_r are given as (see eq. 1 and 2) [14]:

$$t_o = \frac{(t_r + t_{db})}{2} \quad (1)$$

$$t_r = \sqrt[4]{\sum_{i=1}^{N} F_{s\to i} T_i^4 + \frac{C_{dn}}{s\sigma}\left(\alpha_{irr,d} \sum_{j=1}^{M} F_{S\to j} I_{d_i,j} + C_s \alpha_{irr,b} f_p I_b\right)} \quad (2)$$

Simulations were performed using three different low-cost window glass material and wall materials. The choice of the materials was such that each material could be replaced by the other material for the intended purpose, without changing the total cost of construction or compromising on the desired structural stability of the house. The Table 3 illustrates chosen materials and their properties. Infiltrations were considered in the thermal comfort calculations in the building in the form of minor cracks and gaps, such that the simulations can emulate the real life scenario. The windows are assumed to be kept open 50% of the time for a comfortable indoor temperature.

Table 3. Low-cost building material and their properties

Wall Material	Density (kg/m^3)	Specific Heat (J/kg-K)	Thermal Conductivity (W/m-K)
W1= Cement bonded particle board	1200	1500	0.23
W2= Glass fibre reinforced gypsum panel	1140	840	0.617
W3= Gypsum plaster board	950	820	0.160
Glass types	**U-Value (W/m^2-K)**	**Solar Heat Gain Coeff. (SHGC)**	**Visual light transmittance (VT)**
I1= Clear glass 3mm	6.257	0.850	90%
I2= Clear glass 6mm	6.121	0.810	88%
I3= Clear glass 6mm with blue tinted film	6.121	0.587	57%

Source: [13], [15], [16]

Table 4. List of simulation models based on different wall and glass material

M_{ij}	I1	I2	I3
W1	M11	M12	M13
W2	M21	M22	M23
W3	M31	M32	M33

Finally, nine models with varying glass and wall material were simulated as represented in Table 4, where M11 represents the simulation of the original building. For comparison purpose, we modelled the original house with standard brick and mortar wall (termed as M_Brick) with varying glass material, while keeping the other parameters constant. To understand that whether the material change produced significant difference in thermal comfort we performed 'one-way ANOVA' statistical test at 95% C.I. on the mean radiant and operative temperature.

3. Results

The simulated results have shown that building wall materials played a more significant role in enhancing thermal comfort than changing the window glass type. However, it has to be noted that only low-cost commercially available materials were chosen to evaluate the thermal comfort performance. Out of the nine models the wall material "Glass fibre reinforced gypsum panel (W2)" performed better than other two wall materials in providing relative thermal comfort. Very little variation was observed when the materials of the glass were varied. The 6mm glass with blue tinted film performed relatively better than the clear glass of a 3mm and a 6mm thickness, respectively (refer Fig. 2-7).

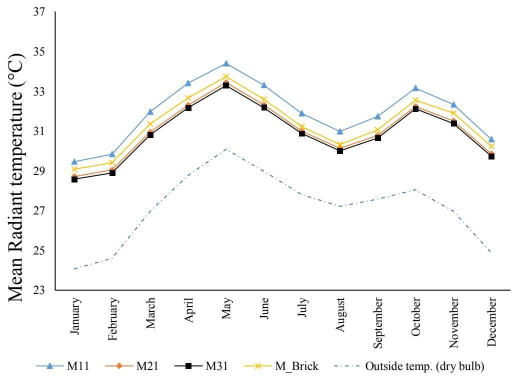

Fig 2. Differences in the mean radian temperature with respect to different wall materials and 3 mm clear window glass.

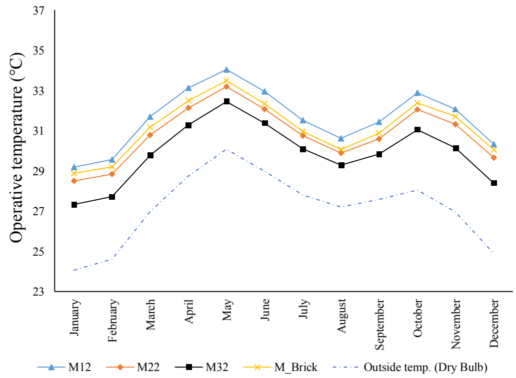

Fig 5. Differences in the operative temperature with respect to different wall materials and 6 mm clear window glass.

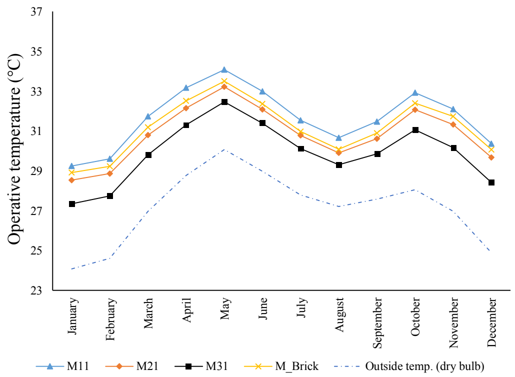

Fig 3. Differences in the operative temperature with different wall materials and 3mm clear glass in the windows.

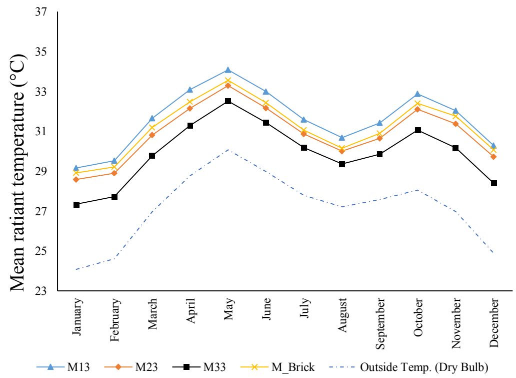

Fig 6. Differences in the mean radian temperature with respect to different wall materials and 6 mm clear window glass with blue tint.

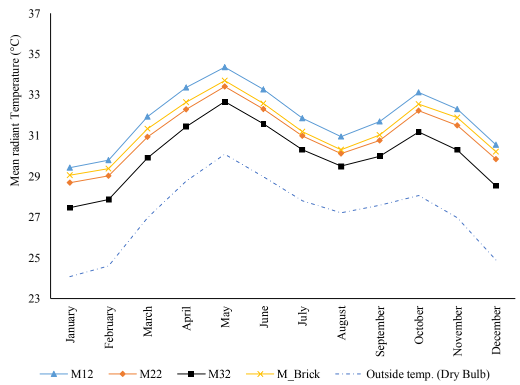

Fig 4. Differences in the mean radian temperature with respect to different wall materials and 6 mm clear window glass.

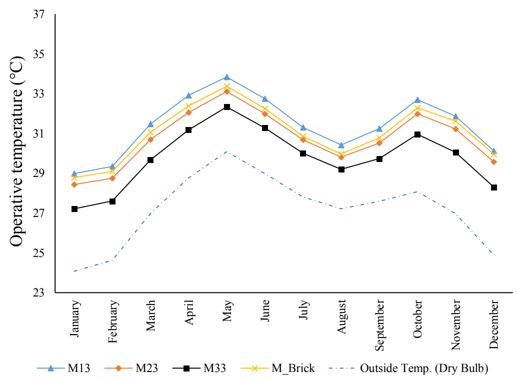

Fig 7. Differences in the operative temperature with respect to different wall materials and 6 mm clear window glass with blue tint.

Results from ANOVA revealed that significant variation was observed in operative temperature when the wall material was changed while keeping the glass material constant. In case of mean radiant temperature variation in thermal comfort performance of clear glass of 3mm was not significantly different at 95% C.I. Table 5 and Table 6 illustrates the results of ANOVA.

Table 5. Variation of operative temperature (t_o) for simulated wall materials with respect to glass materials

Glass material	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Clear Glass of 3mm width	18.25	2.00	9.13	4.14	0.02	3.28
Clear Glass of 6mm width	17.87	2.00	8.93	4.04	0.03	3.28
Clear glass 6mm with blue tinted film	15.81	2.00	7.90	3.58	0.04	3.28

Table 6. Variation of mean radiant temperature (t_r) for simulated wall materials with respect to glass materials

Glass material	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Clear Glass of 3mm width	7.55	2.00	3.78	1.79	0.18	3.28
Clear Glass of 6mm width	19.81	2.00	9.91	4.43	0.02	3.28
Clear glass 6mm with blue tinted film	17.26	2.00	8.63	3.86	0.03	3.28

4. Conclusion

In this study, we had evaluated the thermal performance of popular low-cost building materials in providing year-long thermal-comfort conditions in the houses constructed out of them. Low-cost housing is an important emerging sector, where both public and private institutions are keen on availing investment opportunities towards the ambitious 'Housing for All by 2022' scheme of GoI. Here, we found that the popular low cost building materials, are ineffective in maintaining indoor thermal comfort levels as per the ASHRAE-55 standards. This can drive the occupants either to shift to high priced conventional houses or resort to sprawling, hence defeating the whole purpose of the 'Housing for All' agenda. Future work lies in testing low-cost building materials that can provide structural, thermal and energy efficiency and arriving at indoor thermal comfort thresholds based on the occupant's preferences in local climatic conditions.

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Reference

[1] Ministry of Housing and Urban Poverty Alleviation, "Annual Report 2014-15," New Delhi, 2015.

[2] R. Bardhan, S. Sarkar, A. Jana, and N. R. Velaga, "Mumbai slums since independence: Evaluating the policy outcomes," *Habitat Int.*, vol. 50, pp. 1–11, 2015.

[3] KPMG India, "Affordable Housing – A key growth driver in the real estate sector?," *KMPG India*, pp. 1–20, 2010. Retreived: http://www.kpmg.com/IN/en/IssuesAndInsights/ThoughtLeadership/Affordable_Housing.pdf [accessed: 30-May-2016].

[4] Government of India, “The Final Report of the Expert Group on Low Carbon Strategies for Inclusive Growth,” 2014 Retreived: http://planningcommission.nic.in/reports/genrep/rep_carbon2005.pdf [Accessed: 30-May-2016].

[5] R. Bardhan and R. Debnath, “Towards daylight inclusive bye-law: Daylight as an energy saving route for affordable housing in India,” *Energy Sustain. Dev.*, vol. 34, no. October 2016, pp. 1–9, 2016. dx.doi.org/10.1016/j.esd.2016.06.005.

[6] ISO 7730:2005, “Moderate Thermal Environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort,” Zurich, 2015.

[7] R. J. De Dear and G.S. Brager, “Thermal comfort in naturally ventilated buildings: revision to ASHRAE standards 55,” *J. Energy Build.*, vol. 34, pp. 549–561, 2002.

[8] M. Indraganti, “Adaptive use of natural ventilation for thermal comfort in Indian apartments,” *Build. Environ.*, vol. 45, no. 6, pp. 1490–1507, 2010.

[9] R. de Dear, “Recent enhancements to the adaptive comfort standard in ASHRAE 55-2010,” *Proc. 45th Annu. Conf. Archit. Sci. Assoc.*, no. 1998, 2011.

[10] R. Debnath, R. Bardhan, and R. Banerjee, “Investigating the age of air in rural Indian kitchens for sustainable built-environment design,” *J. Build. Eng.*, vol. 7, pp. 320–333, 2016.

[11] Designbuilder, “DesignBuilder Simulation + CFD Training Guide,” pp. 1–224, 2011 [Accessed: 30-May-2016].

[12] Ministry of Earth Science, “Regional meterological Centre Mumbai,” 2016. [Online]. Available: http://www.imdmumbai.gov.in/. [Accessed: 30-May-2016].

[13] BMTPC, *Emerging Housing Technologies*. New Delhi: Ministry of Housing & Urban Poverty Alleviation, 2015. Retreived: http://www.bmtpc.org/ [Accessed: 22-May-2016]

[14] M. La Gennusa, A. Nucara, G. Rizzo, and G. Scaccianoce, “The calculation of the mean radiant temperature of a subject exposed to the solar radiation - A generalised algorithm,” *Build. Environ.*, vol. 40, no. 3, pp. 367–375, 2005.

[15] J. K. Nayak and J.Prajapati, “Handbook on Energy Conscious Buildings,” New Delhi, India, 2006.

[16] VDI Buch, *VDI Heat Atlas*. Berlin, Heidelberg: Springer Berlin Heidelberg, 2010.