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Enhancement of Indoor Thermal Comfort Using Alternative Building Materials and Construction Technology in Low Income Housing - A Case of Trivandrum, Kerala

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ABSTRACT

In India, rapid urbanisation followed by increased demand for housing has led to higher energy consumption in the building sector and a larger percentage of which is contributed by the housing sector. And the population using affordable housing is higher compared to other developed countries (MOUHA, 2013). The occupants tend to achieve the desired level of thermal comfort by personal adjustments and mechanical means. Using energy intensive methods for comfort is not feasible for a country, like India, with a low energy economy. This study analyses the indoor thermal comfort in low income housing with respect to the building materials and construction technology used. Two typologies of housing were studied which includes a row housing constructed using conventional materials, with hollow brick cement plastered walls and RCC roof slabs, and a vertical stacking multi dwelling constructed using Laurie Baker's alternative construction technology, with rat-trap bond brick walls and filler slabs. The study explored the current scenario of housing based on a thermal comfort field study using questionnaire survey and onsite measurements (following ASHRAE class II protocol) which was then simulated using Design Builder software changing the wall material used to understand the improvement in indoor thermal comfort. An adaptive thermal comfort model and neutral temperature was generated for both types of housing which was then compared with IMAC Model ranges. The adaptive comfort ranges obtained for both housing were too warm than the acceptable ranges and the PMV values in row housing are hot, while that in vertical stacking is slightly warm to warm. The neutral temperature obtained in vertical stacking housing (28 deg C) is within the acceptable range, whereas that of row housing (28.8 deg C) is greater than the upper limit range of neutral temperature under the IMAC model. The results showed that building material with good thermal performance can cause a significant reduction in indoor temperatures thus improving indoor thermal comfort. Thus indoor thermal comfort in low income housing can be improved by using alternative construction technology, without compromising cost-effectiveness and affordability, and thus contributing to energy efficiency.

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Introduction

Affordable Housing is the housing provided by housing associations to meet basic needs and improve the quality of life of urban poor. Housing can be 'affordable' semantically at any income level. Similar to the majority of other nations, India's government places a strong emphasis on providing affordable housing, with the private sector taking care of the middle class and upper class [1]. The thermal efficiency of the built environment and the occupants' preferred indoor quality are important factors in how much energy is used by buildings. The occupant's thermal preferences and expectations affect the indoor thermal environment. These are determined by the occupant's sensitivity to the current indoor environment. This factor influences how much control occupants need to feel comfortable in a designed setting [2]. In developing countries like India, the population using affordable housing is higher compared to other developed countries, so using energy intensive methods for comfort is not feasible for a country with a low energy economy [3]. The majority of residents in low-income housing settlements across the nation are dissatisfied with the thermal conditions and the levels of comfort attained, according to studies [4]. However, in light of climate change and anticipated temperature rises, future development, particularly in low-income neighbourhoods, must take into account thermal comfort, wellbeing, and energy efficiency [5].

Thermal comfort is defined as 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation' [6]. Investigating affordable housing's environmental performance in relation to human comfort is essential given the importance of affordable housing in the development of a sustainable built environment. The extent of the associated health implications makes thermal comfort a crucial environmental factor [7].

From the literature reviews referred to, in the Indian context the studies conducted related to thermal comfort in affordable housing were more to understand occupants' methods of environmental and behavioural adaptation and impediments in using controls to attain thermal comfort. The behavioural studies conducted on indoor thermal comfort, we can see that for attaining thermal comfort, occupants tend to depend on personal adjustments and mechanical means [4]. Using energy intensive methods for comfort is not feasible for our country [8]. This study will go with understanding how the use of alternative building materials and construction technology affect the indoor thermal comfort in low income housing.

Thus the main aim of this study is to study indoor thermal comfort in low income housing in Trivandrum, Kerala, India and analyse the effect of the building materials and construction technology used, on the indoor thermal comfort. The study explores to understand the role of building envelopes towards indoor thermal comfort and derive neutral temperature for the selected low income housing in Trivandrum. And assess the enhancement of indoor thermal comfort with respect to the alternative building materials and construction technology used.

Methodology

This study will undergo thermal comfort field study and software simulation. A thermal comfort field study was carried out to understand the current scenario by questionnaire survey and onsite measurements (following ASHRAE class II protocol) [9]. Questionnaire survey is the subjective judgments of the perceived thermal sensation with respect to the thermal environment condition of the dwelling users [4]. Onsite measurements of parameters including air temperature, globe temperature, relative humidity profiles, and air movement, inside of each house of all typology - plastered and unplastered, were noted. This collected data is simulated and validated by the DesignBuilder, then analysis to be carried out based on the inference of the study.

Survey and field measurements are taken in 100 households - 70 numbers of row housing and 30 numbers of vertical stacking. Longitudinal field study, conforming to ASHRAE Class II protocol, was conducted for a period of 7 days to understand thermal comfort conditions and preferences of the occupants. The data collection method included a thermal comfort questionnaire survey and concurrent monitoring and measurement of environmental parameters such as air temperature, relative humidity and air velocity [10]. The questionnaire was prepared in English and then translated into Malayalam. Each respondent was enquired thrice a day – during morning (8:00 am−12:00 noon), afternoon (12:00 noon −3:00 pm) and evening (3:00 pm–6:00 pm). These times were chosen based on the average temperature peaks of the city [11]. Measurements of parameters - air temperature, globe temperature, relative humidity and air velocity were taken, within each space - the common hall, bedroom and kitchen. Measurements of parameters and questionnaire survey were taken accordingly. Measurements of parameters were noted within 15 to 30 minutes [11]. This collected data is simulated and validated by design builder software, then analysis to be carried out. 55 the intention of thermal comfort simulation was to understand the existing condition of thermal comfort in houses and how it differs with changes in building materials and construction technology used.

Limitations

For assessing thermal comfort, out of the parameters affecting indoor thermal comfort only the effect of building materials is considered. The study will be limited to conditions of low income housing projects in Trivandrum.

Site Study

Site Overview

Chenkalchoola Housing Colony (Figure 1), now known as Rajaji Nagar, is a 12-acre slum redevelopment project located near Trivandrum's city centre, near Trivandrum Central Railway Station, and Thycaud. This slum was redeveloped in the 1970s to accommodate approximately 700 families. Later, in 2005, Ar. Laurie Baker added 9 more units for a total of 90 families. The project comes under Thiruvananthapuram Municipal Corporation, an initiation by Jnnurm. The built-up area is about 23000 sq m, accommodating more than 900 families, with each household unit area 25 - 35 sq m. The 90 percent of the men are employed, some are government employees and the rest engaged in taxi or auto driving, loading and unloading works, building construction works, market merchants, vendors, etc. this contributes to the main income of the colony. The rest of the daily income is from the working women as home maids, sweepers etc, also some working in higher income sectors. The population opted for surveying were homemaker women, elderly men and women, kids and men stayed at home due to health issues or other home related activities, also the one with small shops and service attached to their house.

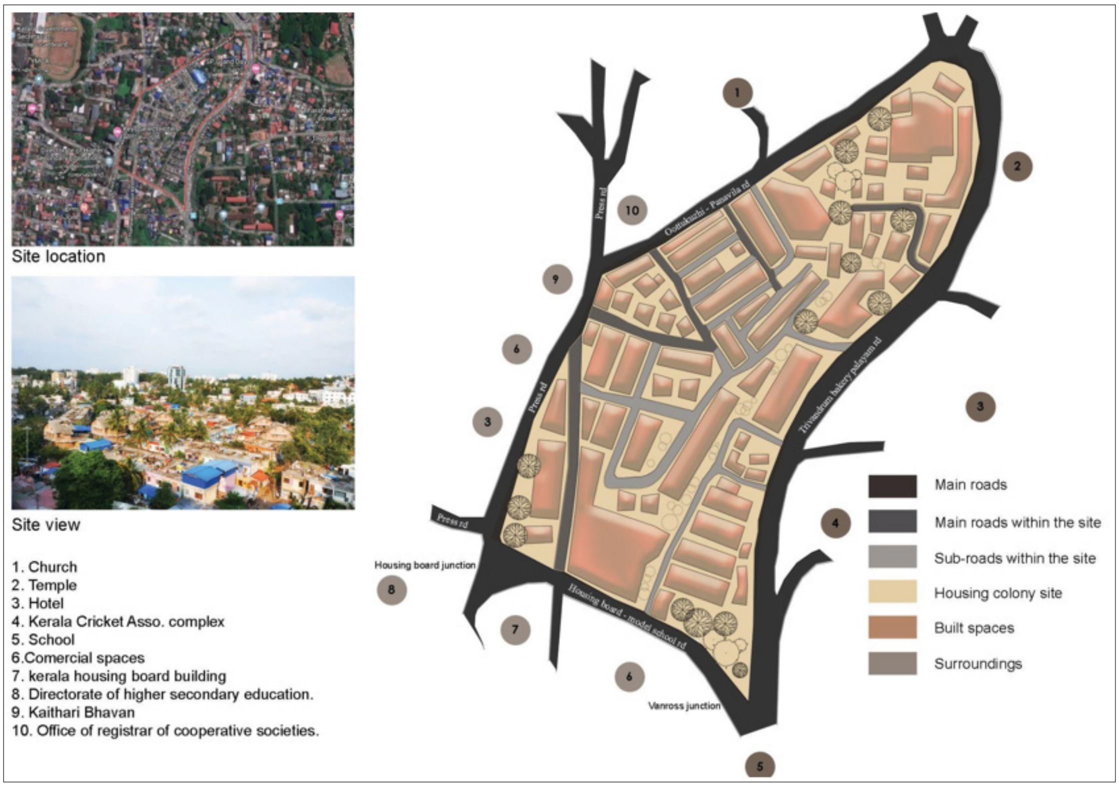


Figure 1: The Site Plan - Chenkalchoola Housing

Housing Typologies

Two typologies of low income housing were identified - a row housing constructed using conventional materials and a vertical stacking multi dwelling constructed using Laurie Baker's sustainable construction Technology.

Type 1: Row housing - plastered. These linear houses in 2 floors were constructed to accommodate about 750 families. Each unit is less than 25 sq m in floor area (Figure 2).

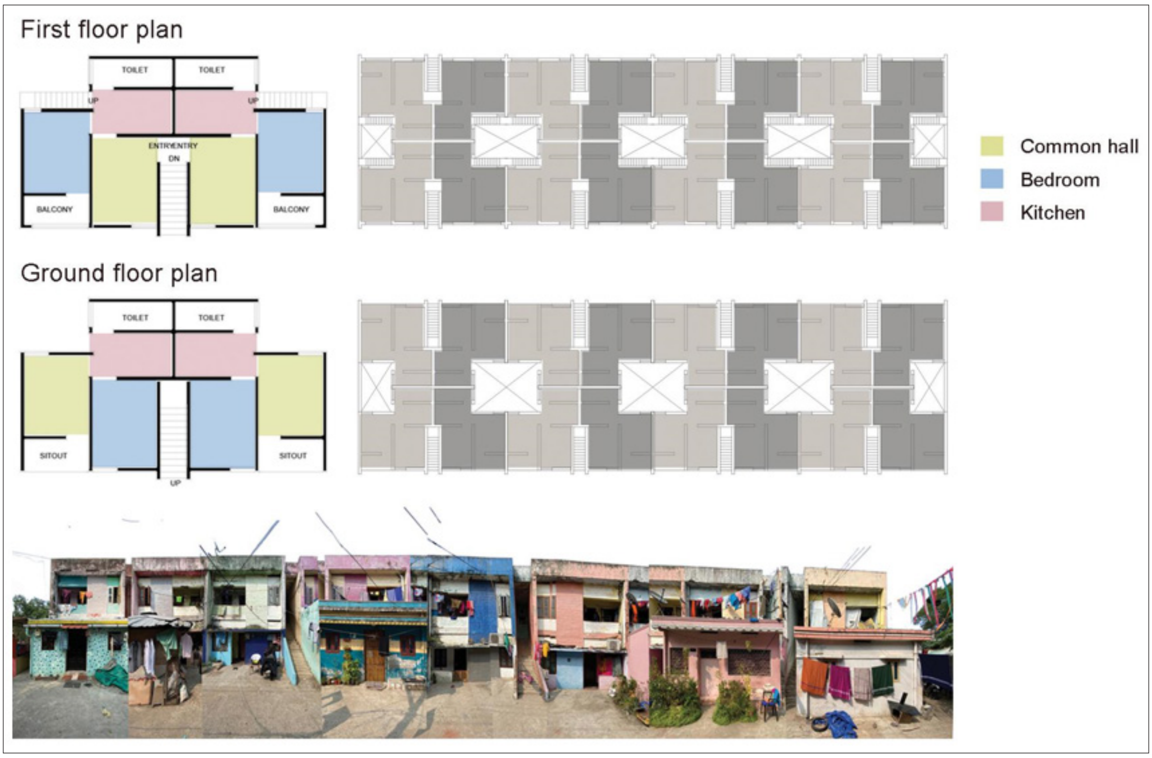


Figure 2: Type 1 housing

Type 2: Vertical stacking - unplastered and curvilinear. These are single units, through a vertical clustered stacking arrangement a single house can afford 10 families in 10 different units. 9 such houses are constructed for a total of 90 families. Units are vertically arranged as 5 units in the ground floor, 3 units in first floor with open terraces and 2 units are arranged in second and third floor with open terraces (Figure 3).

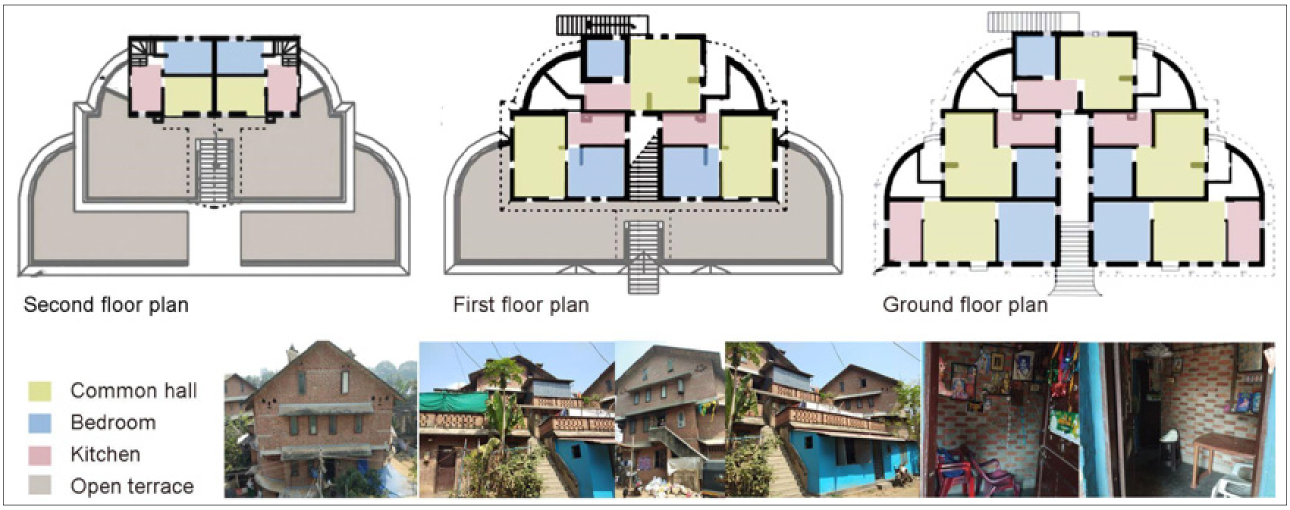
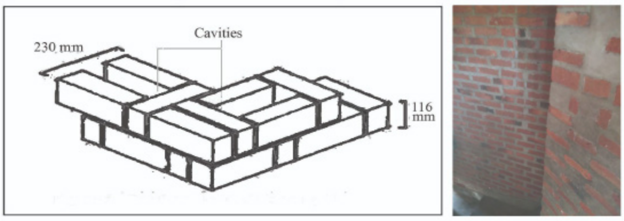
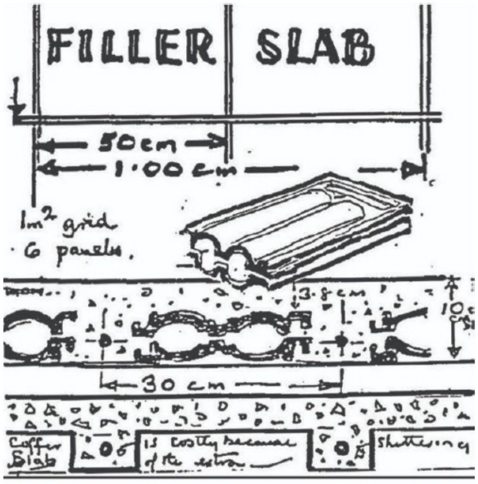
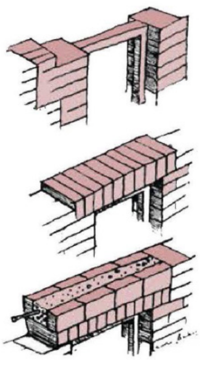


Figure 3: Type 2 Housing

Building Materials and Construction Technologies Used
The building materials and construction technologies used in this housing are shown in Table 1.

Table 1: Building materials used in Both Type of Housing

Components	Type 1 - Row housing	Type 2 - Vertical stacking
Wall	Walls are constructed of a type of cement brick, exported during an earlier stage of the project development. The wall thickness is 15 cm, including the plastering. The wall thickness is 15cm, including the plastering	Rat-trap bond This double-wall technique uses bricks on edge with a cross brick between each and produces a 9-inch thick wall with an insulating air cavity in between [12]. Walls have been unplastered so as to expose the true characteristics of brick, thus reducing the cost of building by 10 percent. The wall thickness is 23 cm (Figure 4).  Figure 4 : The Rat-Trap Bond
Floor	The flooring was of plastered PCC	The flooring was of plastered PCC
Roof	Roofs are flat RCC slabs of 13 cm thickness.	Pitched or sloping roof sheds heavy rain, protecting walls from getting damp and from absorbing heat from sun and providing effective shading (Figure 5).  Figure 5 : Roof - Interior

Slab	Flat RCC slabs of 13 cm thickness (Figure 6).  Figure 6: Flat RCC Slab - Interior	Filler slab Filler slabs are constructed instead of reinforced cement concrete slabs as they are very costly and use a lot of iron and cement. In filler slabs, rcc slabs replace some of the redundant concrete with mangalore tiles or other lightweight materials in order to reduce the overall cost of slab. This reduces the cost by about 30 or 35 % (Figure 7 and Figure 8) [12].  Figure 7: Filler Slab (12)  Figure 8: Filler Slab - Construction Detail [12]
Lintel		A hollow arrangement of brick-on-edge, filled with one or two steel rods in concrete carries the load of wall and roof above effectively. This type of lintel costs less than half the cost of an orthodox reinforced concrete lintel (Figure 9) [12]  Figure 9: Lintels Construction [12]

Thermal Comfort - Field Study and Data Collection

Field study

Measurement samples were taken in 100 houses, and the questionnaire surveyed more than 300 samples, with an average of 3 samples from each house. Out of this 48.8 percent of the population was within a group of 20 to 40 years, 27.9 percent was aged above 40 and 23.3 percent was aged below 20. And 53.5 percent of the surveyed population were male and 46.5 percent were female. The analysis began with compiling, coding and computing raw data obtained from different sources such as meteorological websites, questionnaires and field measurements. This data was sorted and summarised into a Microsoft Excel data set and also computed using CBE thermal comfort tool. Data from questionnaire forms which included personal identifiers, subjective comfort votes, personal variables were coded into excel spreadsheet at the end of each survey day. Outdoor environment data were then matched with the data obtained from the questionnaires using the date and time noted in the filled questionnaire forms.

Climatic parameters. Air temperature (Ta) and globe temperature (Tg) in row housing is greater than vertical stacking, by 2-3 deg C. Relative humidity (RH) is greater than the upper limit suggested in standards (70% IN SP.41 1987, ISHRAE 2019). Relative humidity in vertical stacking is higher than row housing throughout the day. Due to the lack of openings the velocity of air (Va) is almost zero throughout the day. Also kitchens are with zero day lighting (lux value likely to 0) in 90% of the units (Figure 10 and Figure 11).

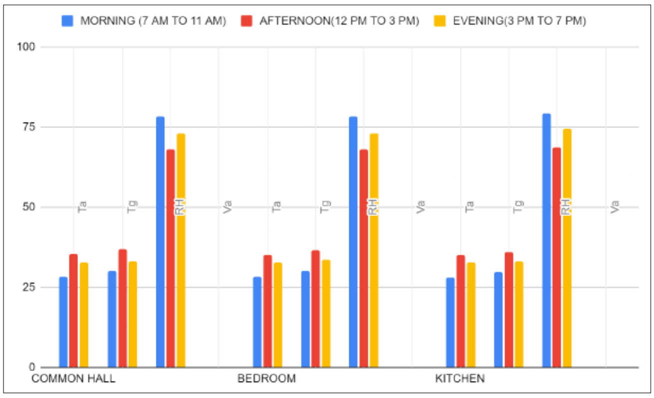


Figure 10: Climatic Parameters - Onsite Measurement in Type 1 House (Row House)

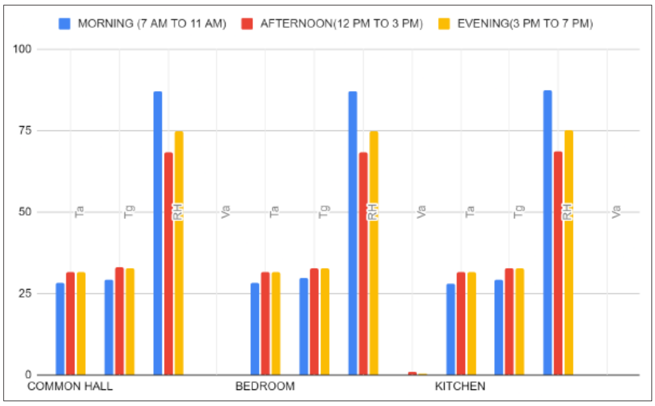


Figure 11: Climatic Parameters - Onsite Measurement in Type 2 House (Vertically Stacked Multi Dwelling)

Operative temperature (OT) and Mean radiant temperature (MRT). Operative temperature varies from 29.16 - 33 deg C in row housing and 28.7 - 32.7 deg C in vertical stacking. This is higher than the comfort limit suggested by NBC 2016 (lower limit 25 - 27.5 - 30 deg C upper limit) (Figure 12 and Figure 13).

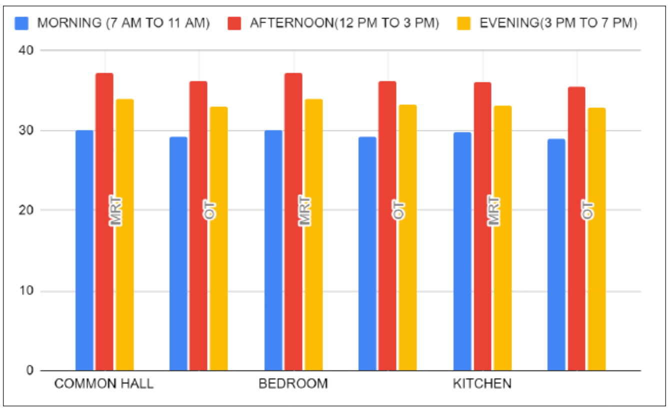


Figure 12: MRT and Operative Temperature Values Derived from Onsite Measurements in Type 1 House (Row House)

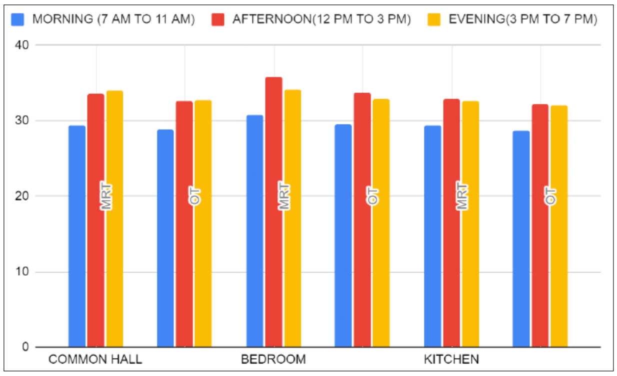


Figure 13: MRT and Operative Temperature Values Derived from Onsite Measurements in Type 2 House (Vertically Stacked Multi Dwelling)

PMV. The Fanger's predicted mean vote model shows that the least value of TSV experienced is 1 (slightly warm) during morning, with 2 (warm) and 3 (hot) throughout the day in vertical stacking and row housing respectively (Figure 14).

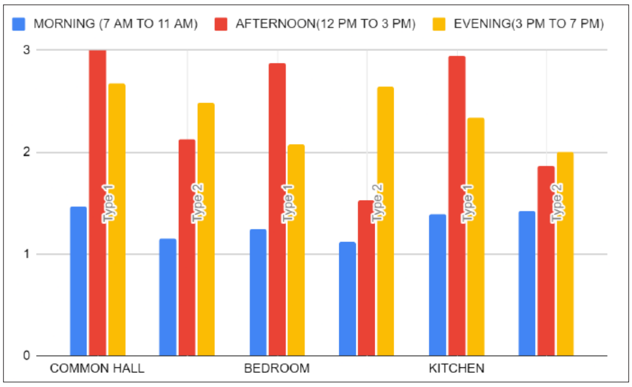


Figure 14: Comparison of Mean PMV in Type 1 and Type 2 Houses

Adaptive comfort temperature. When the monthly mean outdoor temperature is taken an 27.5 deg C, and air velocity up to 0.3 m/s, the acceptable operative temperature for naturally conditioned spaces ranges from 22.8 - 29.8 dec C (80% acceptability) and 23.8 - 28.8 dec C (90% acceptability). In both cases, the adaptive comfort zone is too warm than the acceptable ranges (Figure 15).

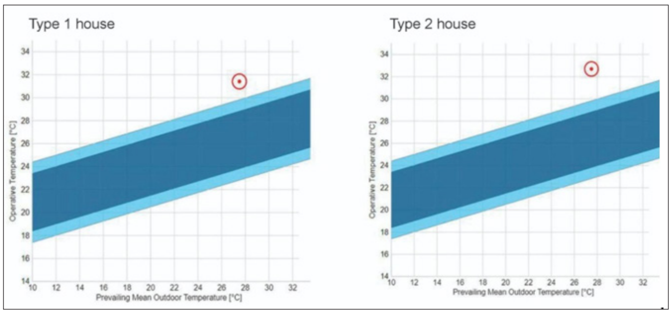


Figure 15: Adaptive Comfort Model

Calculation of Neutral temperature. Neutral temperature is obtained from the subjective thermal evaluation and calculated indoor thermal comfort indices (PMV). Neutral temperature in row housing is 28.8 deg C, and that of vertical stacking is 28 deg C, which is slightly greater than the neutral temperature obtained from TSV (28 deg C) (Figure 16).

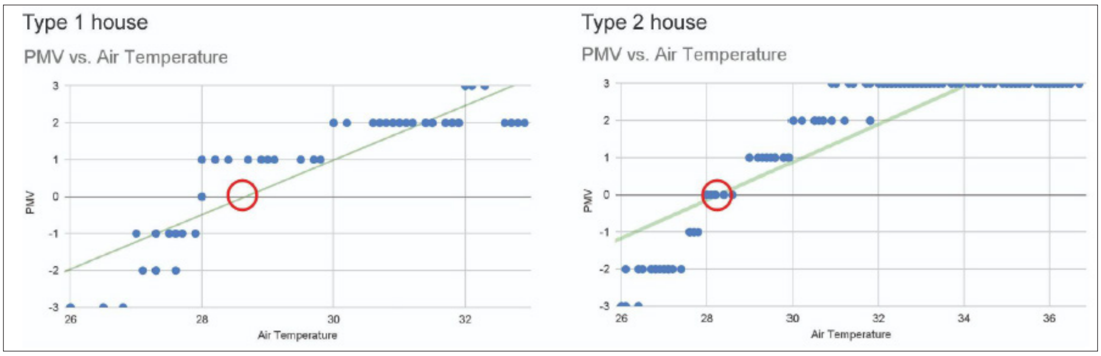


Figure 16: Neutral Temperature

Thermal Comfort - DesignBuilder Simulation

Thermal comfort simulation is done with DesignBuilder software, to assess how the climatic parameters of thermal comfort changes with respect to the change of building material and construction technology. This is done as two cases of simulation:

Case 1 - thermal comfort simulation of the existing case of type 1 house (row housing), where the thermal monitoring study is conducted, with existing building materials, orientation and building density (Figure 17).

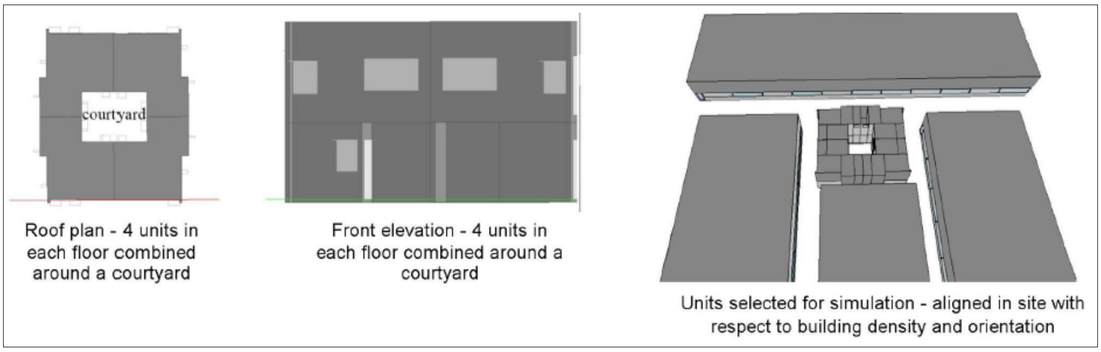


Figure 17: Model of Type 1 House with Existing Conditions - Prepared for Indoor Thermal Comfort Simulation in DesignBuilder

Case 2 - thermal comfort simulation of type 1 house (row housing), by applying the alternative building materials and construction technology used in type 2 house (vertical stacking) (Figure 18).

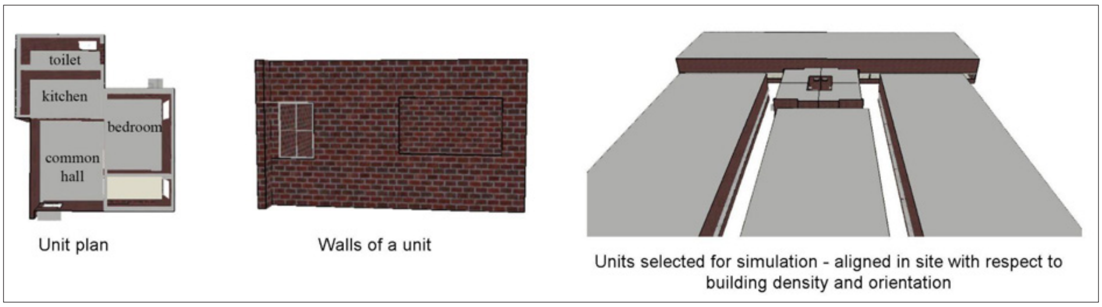


Figure 18: Model of Type 1 House after Changing the Building Materials Used to that of Type 2 House - Prepared for Indoor Thermal Comfort Simulation in DesignBuilder

Air temperature. In the existing case simulation, the average air temperature of the whole house varies from 29.3 deg C to 33.5 deg C. When the building materials and construction technology used in the house are replaced with that of type 2 house, a variation is observed, the average indoor air temperature of the whole house varies from 29.1deg C to 31.5 deg C, with an average decrease of 2 deg C (Figure 19).

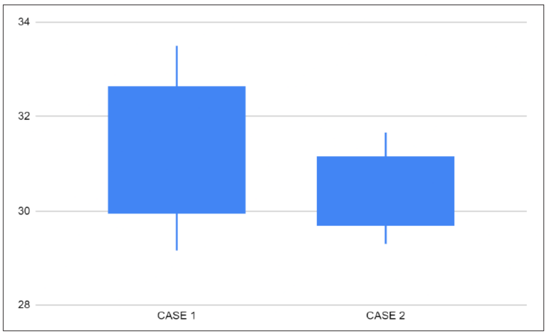


Figure 19: Air Temperature Variation Graph - Results from Simulation

Operative temperature. The average operative temperature of the whole house varies from 29.5 deg C to 32.8 deg C, whereas, after changing the building materials and construction technology used to that of type 2 housing, it decreased and it varies from 29.1 deg C to 31.3 deg C (Figure 20).

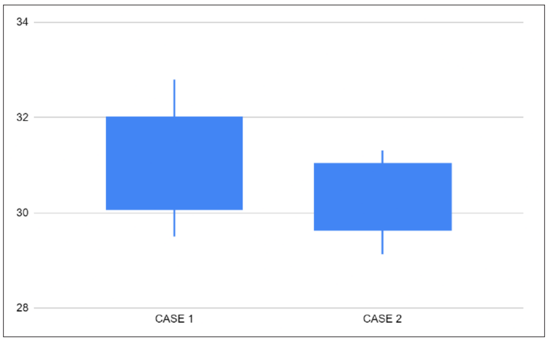


Figure 20: Operative Temperature Variation Graph- Results from Simulation

Relative humidity. In the case of relative humidity, simulation of the existing case shows that the range from 28 percent to 73 percent. But after changing the building materials and construction technology to that of type 2 house, the range is from 29 percent to 68 percent (Figure 21).

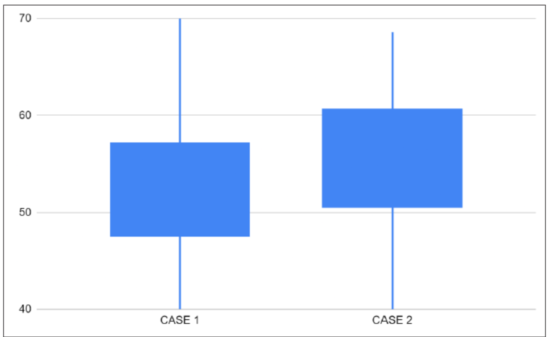


Figure 21: Relative Humidity Variation Graph- Results from Simulation

PMV. The simulation results show a slight decrease in PMV obtained, that is the least value decreased from 1.9 to 1.7 and peak value decreased from 2.6 to 2.2 in the existing case and the case after changing the building materials and construction technology used, respectively (Figure 22).

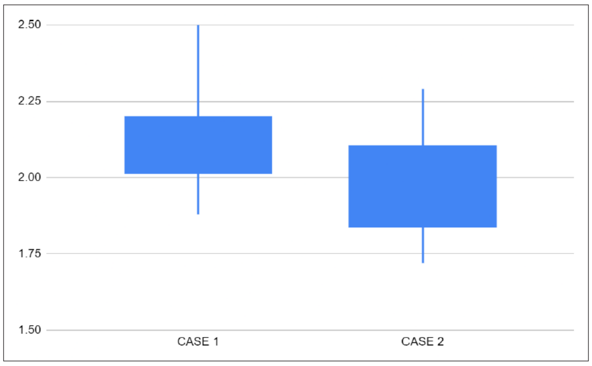


Figure 22: PMV Variation Graph- Results from Simulation

Results and Discussion

The results from field monitoring shows that adaptive comfort of the people in type 2 houses (vertical stacking) is lower than that of the people in type 1 houses (row housing). Also, the neutral temperature derived varies in both cases, that is 28.8 deg C in type 1 house and 28 deg C in type 2 house. In the simulations, when the wall material was changed from hollow brick plastered on both sides, overall thickness of 15 cm to unplastered brick wall construction (in rat trap bond) with thickness of 23 cm, the roof material was changed from RCC slab of 13 cm to filler slab construction of 10 cm thickness, with terracotta roof tiles air cavity with (a total of 5 cm thickness) and reducing glazed windows by adding jali openings, a temperature drop of 2 deg C was attained, along with decrease in humidity range and PMV recorded. This can reduce the indoor air temperature by 10 %, indoor operative temperature 8.5% and relative humidity range by 7% during the peak of noon hours. The PMV obtained decreased by 17.5 % during the peak of noon hours.

The reduction in thermal comfort parameters attained signifies the following:

Thermal mass of walls. Thermal mass has a significant role in improving the indoor thermal comfort of a building. As the external walls are always exposed to heat, it can cause internal heat gain due to the temperature fluctuation in external air, thus thermal mass of the building can reduce the indoor heat gain. Here the thermal mass of the wall material was increased by using rat-trap bond, where the two bricks along with an air cavity in between slow down the heat transmission from exterior to interior. This helps to cool the interior during hot day hours and heat the interior during cold night hours passively, at low cost.

Thermal performance of roof. Roofs are continually exposed to high levels of solar radiation, thus the materials that are used for roof construction usually have low thermal storage and low thermal resistance. A roof with better thermal insulation can reduce the rapid transmittance of heat through the roof. In filler slab construction, a percentage of concrete is replaced by mangalore tiles, which reduces the construction cost by 30 - 35% than the conventional RCC slabs. These terracotta roof tiles are placed back to back with an air cavity in between two tiles, creating a layer of higher thermal mass towards the inner plane of the roof slab. Thus this roof shows a higher thermal resistance.

Properties of opening materials. Openings with more percentage of glazing provides enough light along with solar heat gain in the indoor. The glass used is of higher emissivity allowing heat to pass easily to the interior. As the low E (emissivity) glass is more expensive to use in a low income group housing, an alternative method like low amount of glazing can be used for openings, also enough shading can be provided. Here some of the windows which don't affect the security and privacy of the people were replaced by jali walls.

Use of opaque walls. The results from the field monitoring study shows that kitchen space in type 2 housing has comparatively low air temperature, even though there are very few or no openings. This is due to the presence of opaque walls, which are thermally insulated by rat-trap bonds. This prevents the heat radiation into the interior keeping the space cooler than the rest. This helps in attaining comfort even though relative humidity is higher.

These results are obtained and assessed only based on the character of building materials used and construction techniques, the impact of building density, population density, openings - window to wall ratio, orientation of the buildings, massing of the units etc are not considered. So, further studies on these parameters and their effect on thermal comfort should be conducted.

Conclusion

This study was to understand how the choice of building materials and construction techniques used can impact the indoor thermal comfort in low income housing. The site selected for study consists of two types of housing units - type 1 row housing and type 2 - vertical stacked multi dwelling units. Building materials study was done, type 1 house is of cement hollow block walls with RCC roof slab and cement plaster, whereas type 2 house is of brick walls in rat trap bond and filler slabs, with jali wall openings and unplastered. After conducting thermal monitoring field study and questionnaire survey, a significant difference was noted in the measured parameters within both types of houses. The PMV values in row housing vary from warm to hot, while that in vertical stacking is slightly warm to warm, during evening and afternoon respectively. The adaptive comfort ranges obtained for both houses were too warm than the acceptable ranges, and are even greater than the 90 percent acceptable limits but the type 2 house shows comparatively better condition. The neutral temperature obtained in type 2 housing is 28 deg C, is within the acceptable range, whereas in type 1 housing it is 28.8 deg C, which is greater than the upper limit recommended by the IMAC model. As the second part of the study a thermal performance simulation was conducted to validate and evaluate the impact of alternative building materials and construction techniques in enhancing indoor thermal comfort. The results show that changing the building material and construction technology, to one with higher thermal mass can reduce the indoor air temperature by 10 %, indoor operative temperature by 8.5% and relative humidity range by 7% during the peak of noon hours. The PMV obtained has decreased by 17.5 % during the peak of noon hours. Enhancing indoor thermal comfort using alternative building materials and construction technology is a passive strategy, which reduces the use of energy intensive methods to attain comfort, thus helping in energy efficiency. As the alternative building materials and construction technology used were already proven to be cost effective, this will not overlap the concern of cost effective construction in the case of low income housing [13-15].

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