Analysing indoor thermal comfort in LIG housing with respect building materials and openings, a case of Trivandrum

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Abstract

In India, population growth, demand for housing, and rapid urbanisation have led to higher energy consumption in the building sector. According to the Government of India report, 80% of the buildings that will exist by 2050 are yet to be constructed and a larger percentage is contributed by the housing sector, the population using affordable housing is higher compared to other developed countries. 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 indoor thermal comfort in low income group housing with respect to the building materials and openings used. 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. The first section of the study explores the current scenario of housing based on a thermal comfort field study to understand the current scenario by questionnaire survey and onsite measurements (following ASHRAE class II protocol) and a detailed analysis of the results from the computed data. The second part of the study is software simulation of the existing case with different approaches to improve thermal comfort using design builder simulation. And analysing the results to understand the improvement in indoor thermal comfort with respect to the existing model. From the results, it can be concluded that building material with higher thermal mass can cause a significant reduction in indoor temperatures and PMV thus improving indoor thermal comfort. Passive design strategies to improve indoor thermal comfort with respect to envelope material and openings for future projects at the study area under the low-income housing category, without breaking the concern of cost-effectiveness in affordability, are developed.

Keywords - Thermal comfort, low-income group housing, adaptive comfort, neutral temperature, window-to-wall ratio.

1. Introduction

Housing for all has long been a goal of India's economically disadvantaged groups, especially in metropolitan regions. However, a "home" is made up of more than just four walls and a roof. Affordable housing is really about moving beyond simply framing walls and buildings to creating structures that offer "comfort" to the occupants. The Urban housing shortage survey with respect to socio-economic classes, conducted by MOUHA shows that only 4 percent of the total housing shortage is in MIG/HIG and the rest of 96 percent of the houses are required in economically weaker sectors. (MOUHA, 2013) Studies show that the housing sector is the most energy intrusive sector, so using energy intensive methods for comfort is not feasible for a country with a low energy economy.

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. The comfort of the indoor environment is intimately related to the accessibility and availability of energy. (Singh, 2016) Thermal comfort is defined as 'that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation' (ANSI/ASHRAE Standard 55-2017, 2017). Investigating affordable housing's environmental performance in relation to human comfort is essential, given the importance of affordable housing.

135, Analysing of Trivandrum. in the development of a sustainable built environment. The extent of the associated health implications makes thermal comfort a crucial environmental factor (Malik, 2021).

From the literature reviews referred to, in the Indian context the studies on thermal comfort assessment in social housing projects are not much explored. 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. Using energy intensive methods for comfort is not feasible for our country. This study, identifies passive measures of indoor thermal comfort, is required in this climate to reduce the load on energy consumption. Here, through this study, we are trying to address two aspects - openings and envelope materials, and bring out a better design solution for future construction.

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 used and openings provided, on the indoor thermal comfort, and then 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 openings. As the field study - thermal performance monitoring is carried out only for a period of 7 days,during only a single season, monsoon, in each type of housing, the time constraint is a limitation in getting accurate results. The study will be limited to conditions of the selected LIG housing project in Trivandrum, without considering all passive strategies, focusing more on opening size and material, because natural ventilation and envelope material is more concerned in warm-humid climates.

2. Methodology

This study is conducted using thermal comfort field study and software simulation. The thermal comfort field study was carried out to understand the current scenario by questionnaire survey and onsite measurements (following ASHRAE class II protocol) (Neto 2013). Questionnaire surveys give the subjective judgments of the perceived thermal sensation with respect to the thermal environment condition of the dwelling users (Indraganti 2009). 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 (Gameiro da Silva 2013). The questionnaire was prepared in English and then translated into Malayalam (local language). 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 (Indraganti 2009, 867). 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 (Indraganti 2009, 867). This collected data is simulated and validated by design builder software, then analysis is carried out. 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. The building materials selected for final simulations will be based on the results from thermal performance of the existing case, as the study is limited to conditions of Chenkalchoola Housing Colony.

2.1 Site study

2.1.1 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 Jawaharlal Nehru National Urban Renewal Mission (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 who stayed at home due to health issues or other home related activities, and the ones with small shops and service attached to their house.

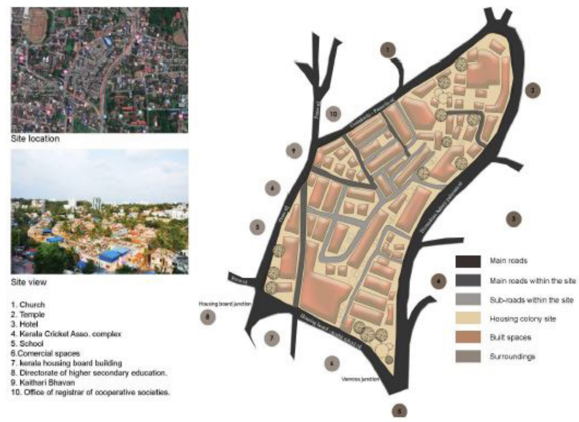

Figure 1 : The site plan - Chenkalchoola housing

2.1.2 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).

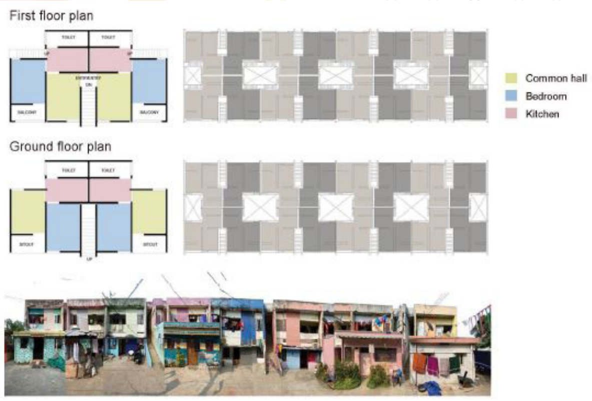

Figure 2 : Type 1 housing

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

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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).

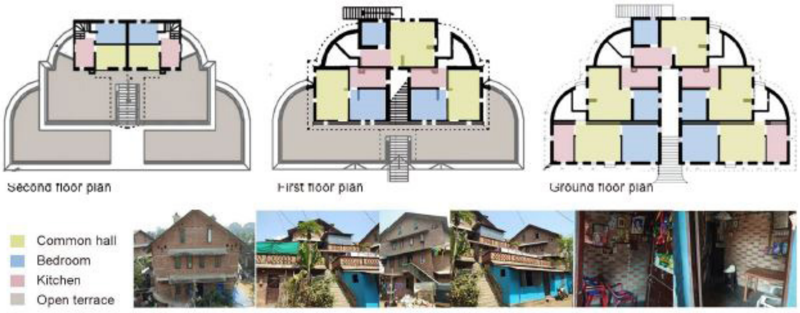
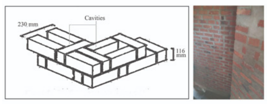
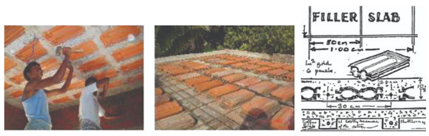
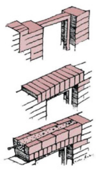


Figure 3 : Type 2 housing

2.2 Building materials and construction technologies used

The building materials and construction technologies used in this housing colony 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 (Tewari 2015). 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 7** : *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 % (Tewari 2015) (**Figure 7**).  **Figure 7** : *Filler slab* (12) (Tewari 2015)
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 (Tewari 2015) (**Figure 8**)  **Figure 8** : *Lintels construction* (Tewari 2015)

3. Results

3.1 Thermal comfort 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 daylighting (lux value likely to 0) in 90% of the units (Figure 9).

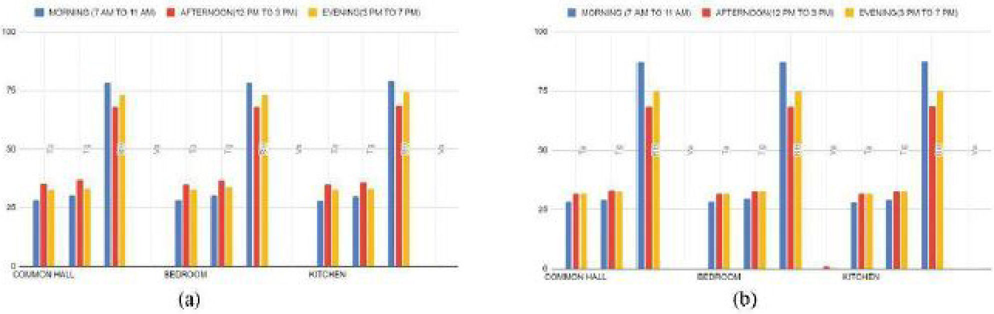


Figure 9: Climatic parameters - onsite measurement in (a) type 1 house and (b) type 2 house

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 10).

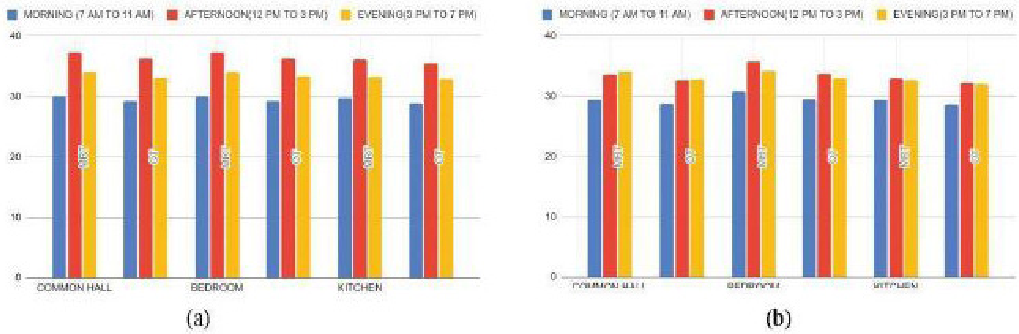


Figure 10: MRT and Operative temperature derived from onsite measurements in (a) type 1 house and (b) type 2 house

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 11).

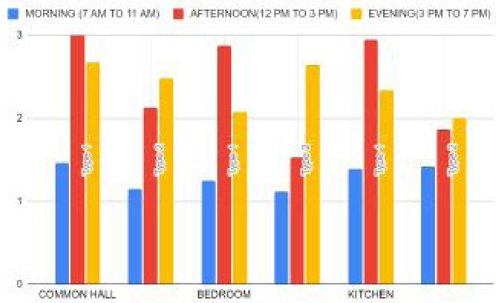


Figure 11: Comparison of mean PMV in Type 1 and Type 2 houses

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 deg C (90% acceptability). In both cases, the adaptive comfort zone is too warm than the acceptable ranges (Figure 12). The adaptive comfort chart shows that the comfort in type 1 houses lies closer to the comfort band than that of type 2 houses with cost effective and energy efficient construction techniques, this is caused due to the very low (nearly zero) air movement from less openings and lack of mutual shading in type 2 houses.

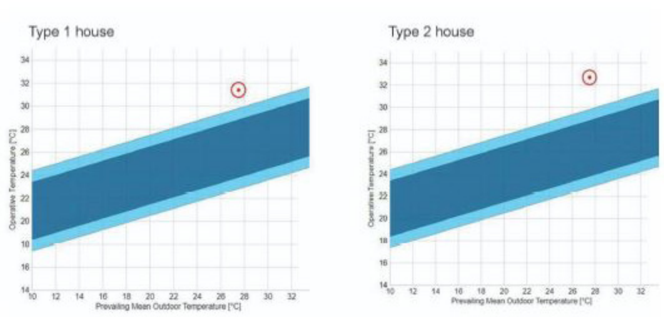


Figure 12: Adaptive comfort model

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 13).

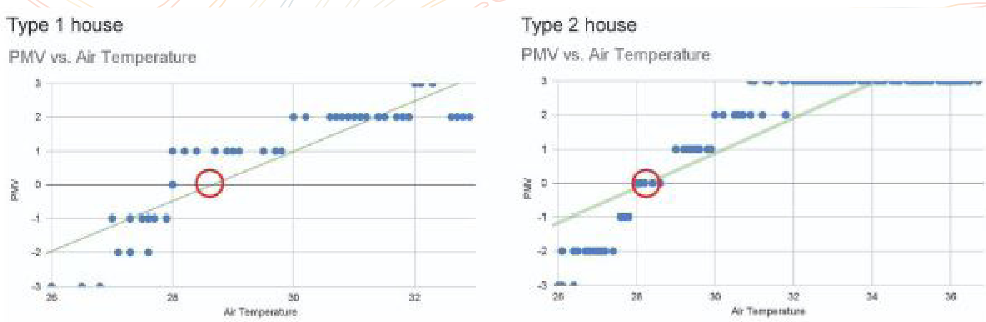


Figure 13: Neutral temperature

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 14).

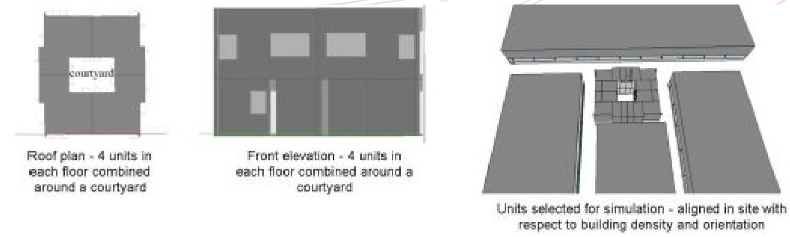


Figure 14: Model of type 1 house with existing conditions - prepared for indoor thermal comfort simulation in DesignBuilder

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 15).

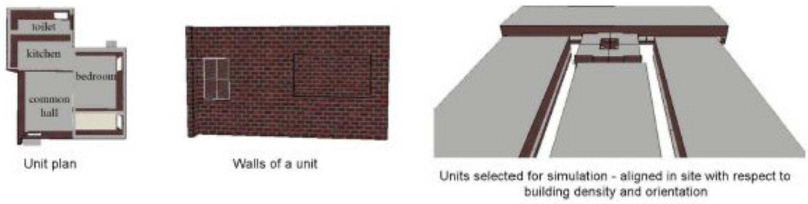


Figure 16: Model of type 1 house after changing the building materials used to that of type 2 house - prepared for indoor thermal comfort simulation in DesignBuilder

Case 3 - thermal comfort simulation of type 1 house with building materials as that used for case 2 simulation, with window wall ratio increased to 5% (in the existing case the window wall ratio is 3.3. - 3.6 %)

Case 4 - thermal comfort simulation of type 1 house with building materials as that used for case 2 simulation, with window wall ratio increased to 7.5%.

Case 5 - thermal comfort simulation of type 1 house with building materials as that used for case 2 simulation, with window wall ratio increased to 10 %.

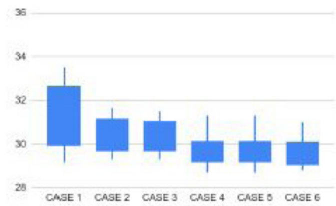
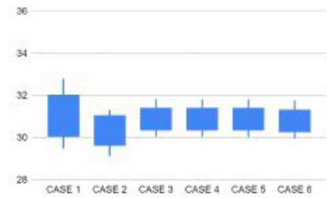
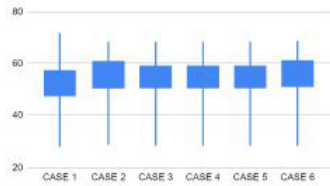
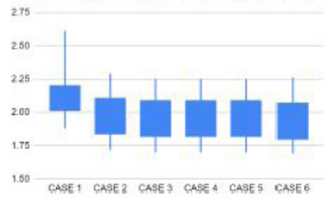
Case 6 - thermal comfort simulation of type 1 house with building materials as that used for case 2 simulation and window wall ratio increased to 10 % as used for case 5 simulation, with building oriented having openings towards the direction where maximum air movement is obtained - South-West (derived from the eco-chart prepared).

4. Discussion

Indoor thermal comfort with respect to envelope materials.

In this study when the wall material was changed from hollow brick plastered on both sides, overall thickness of 17 cm to unplastered brick wall construction (in flemish bond) with thickness of 23 cm, the roof material was changed from concrete 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 3 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 peak noon hours. The PMV obtained decreased by 17.5 % during peak noon hours.

Table 2: Table caption

Parameters	Results in graphical representation
Air temperature The effects of simulation cases on the indoor air temperature can be seen on the graph, from case 1 to case 6. Median value has decreased from 32.7 deg C to 29 deg C , minimum value has decreased from 29.16 deg C to 28.8 deg C and maximum value has decreased from 33.5 deg C to 31 deg C .	 **Figure 17**: *Air temperature improvement graph*
Operative temperature The effects of simulation cases on the operative temperature can be seen on the graph, from case 1 to case 6. Median value has decreased from 32 deg C to 30.3 deg C, minimum value has decreased from 29.6 deg C to 29.5 deg C and maximum value has decreased from 32.8 deg C to 31.77 deg C .	 **Figure 18** : *Operative temperature improvement graph*
Relative humidity The effects of simulation cases on the relative humidity can be seen on the graph, from case 1 to case 6. Median value has increased from 57.1 % to 60.1 % , minimum value has increased from 28.1 % to 28.55 % and maximum value has decreased from 71.85 % to 68.86% .	
PMV The effects of simulation cases on the PMV can be seen on the graph, from case 1 to case 6. Median value has decreased from 2.19 to 1.8, minimum value has decreased from 1.88 to 1.69 and maximum value has decreased from 2.61to 2.26	 **Figure 20** : *PMV improvement graph*

Indoor thermal comfort with respect to openings for natural ventilation.

Window to wall ratio : Window to wall ratio determines the required air flow towards the interior of a building. Providing a large percentage of openings on a single wall will not give enough air movement within the building.

But considering the characteristics of a warm humid climate, air movement is the best strategy to reduce the effect of high humidity, daylighting wasn't assessed before concluding the window to wall ratio due to limitations in the site. Optimum window to wall ratio identified from study is 7.5%. Increasing the window to wall ratio from 3.3% to 7.5% can decrease the indoor air temperature and operative temperature by 3%. Cross ventilation: Indoor thermal comfort is affected by the number of air exchange happenings in that space. Providing enough openings as per window to wall ratio on a single wall cannot cause much effect on the indoor thermal comfort. The number of air exchanges can only be improved by providing enough cross ventilation within the enclosed space. The study shows that the changes in the window to wall ratio in a single wall did not cause any change in the indoor thermal comfort condition.

Orientation of the building: Orienting the building with its openings towards the windward direction can cause a significant improvement in indoor thermal comfort of an enclosed space, even with less cross ventilation. Orienting the units within the site in such a way that the overall layout causes less wind shadow, can increase the air movement within the building thus improving thermal comfort. Also shading and over-hangings of the openings can reduce the internal heat gain, thus improving thermal comfort. Changing the orientation of the building with openings towards windward direction can decrease the indoor air temperature and operative temperature by a minimum of 3%, relative humidity by a minimum of 16% and PMV by 2.5%.

5. Conclusion

This study was to understand the condition of indoor thermal comfort in low income housing. And then develop passive design strategies to enhance the thermal comfort with respect to openings and envelope materials.

● 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 slab roof and plastered, 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 housing were too warm than the acceptable ranges, and are even greater than the 90 percent acceptable limits.

● The neutral temperature obtained in type 2 housing is 28.4 deg C, is within the acceptable range, whereas in type 1 housing it is 28.8 deg C.

As the second part of the study a thermal performance simulation was conducted to understand and analyse the role of building materials and openings in enhancing indoor thermal comfort.

● The results show that changing the building material to one with higher thermal mass and using openings with required window wall ratio in windward orientation can reduce the indoor temperature by 15.5 % and the PMV to slightly warm from hot by 20.5% reduction.

● The optimum WWR, with respect to air movement, required for the housing studied was derived, 7.5 %.

These design strategies developed with respect to building materials and openings for natural ventilation, can enhance the indoor thermal comfort of the housing units in Chengalchoola housing colony, Trivandrum.

7. References

1. ANSI/ASHRAE Standard 55-2017. (2017). Thermal Environmental Conditions for Human Occupancy. https://www.ashrae.org/.http://arco-hvac.ir/wp-content/uploads/2015/11/ASHRAE_Thermal_Comfort_Standard.pdf

2. Berger, T. (2022, August). Low-income residents' strategies to cope with urban heat. https://www.elsevier.com/locate/landusepol

3. Bhikhoo, N. (2017, August). Improving Thermal Comfort of Low-Income Housing in Thailand through Passive Design Strategies. www.researchgate.net. https://www.researchgate.net/publication/319128739_Improving_Thermal_Comfort_of_Low-Income_Housing_in_Thailand_through_Passive_Desi gn_Strategies?enrichId=rgreq-129f4f741c2b215469b99a9a565f4325-XXX&enrichSource=Y292ZXJQYWdlOzMxOTEyODczOTtBUzo1Mjc5MT EwMjAxNz

4. Enescu, D. (2017, November). A review of thermal comfort models and indicators for indoor environments. https://www.sciencedirect.com/. https://doi.org/10.1016/j.rser.2017.05.175

5. Gameiro da Silva, M. C. (2013, August). SPREADSHEETS FOR THE CALCULATION OF THERMAL COMFORT INDICES PMV AND PPD. http://dx.doi.org/10.13140/RG.2.1.2778.0887

6. Indraganti, M. (2009, September). Effect of age, gender, economic group and tenure on thermal comfort: A field study in residential buildings in hot and dry climate with seasonal variations. Energy and Buildings. www.elsevier.com/locate/enbuild

7. Indraganti, M. (2009, September). Thermal comfort in naturally ventilated apartments in summer: Findings from a field study in Hyderabad, India. Applied Energy. http://www.elsevier.com/locate/apenergy

8. Indraganti, M. (2009, December). Adaptive use of natural ventilation for thermal comfort in Indian apartments. Building and Environment. http://www.elsevier.com/locate/buildenv

9. Malik, J. (2021, March 29). Thermal comfort perception in naturally ventilated affordable housing of India. www.tandfonline.com. https://doi.org/10.1080/17512549.2021.1907224

10. MOUHA. (2013). STATE OF HOUSING IN INDIA A STATISTICAL COMPENDIUM 2013. https://mohua.gov.in/. https://mohua.gov.in/upload/uploadfiles/files/Housing_in_India_Compendium_English_Version2.pdf

11. Neto, A. F. (2016, September). Thermal Comfort Assessment. http://dx.doi.org/10.13140/RG.2.2.29416.67849

12. Nguyen, A. T. (2009, March). Passive designs and strategies for low-cost housing using simulation-based optimization and different thermal comfort criteria. http://www.tandfonline.com/loi/tbps20. http://dx.doi.org/10.1080/19401493.2013.770067

13. OECD Economic surveys. (2019). OECD Economic Surveys India. http://www.oecd.org/economy/india-economic-snapshot/

14. SACOSS. (2021, September). Improving thermal efficiency of public and community housing.https://www.sacoss.org.au/sites/default/files/public/Improving%20thermal%20efficiency_Final.pdf

15. Singh, M. K. (2009, October). Study to enhance comfort status in naturally ventilated vernacular buildings of northeast India. www.researchgate.net https://www.researchgate.net/publication/230642027_Study_to_enhance_comfort_status_in_naturally_ventilated_vernacular_buildings_of_northeas t_India?enrichId=rgreq-bfa87abf6270dc42c0b78d6cd72b42ba-XXX&enrichSource=Y292ZXJQYWdlOzIzMDY0MjAyNztBUzoxOTU1NDM5NjA 2

16. Singh, M. K. (2016, May). Defining thermal comfort in residential buildings of North-East India. www.researchgate.net. https://www.researchgate.net/publication/304060818_Defining_thermal_comfort_in_residential_buildings_of_North-East_India?enrichId=rgreq-f8c d3883490209126eec0834417456fe-XXX&enrichSource=Y292ZXJQYWdlOzMwNDA2MDgxODtBUzo0OTQxMDU0MjA0MTkwNzJAMTQ5NDgxNTMyMDIxMA

17. Tewari, S. (2015). Laurie Baker A model for Sustainable Architectural Design. http://www.cumulusmumbai2015.org/