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HIGH-RISE APARTMENT BUILDINGS AS A SUSTAINABLE BUILDING TYPOLOGY IN THE INDIAN SUBCONTINENT

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ABSTRACT

In light of the growing Indian economy and increasing population, it is estimated that a majority of building stock that will exist in Indian cities in 2030, is yet to be constructed. Coupled with rapid urbanization, it is evident that India has a significant potential to reduce future building energy consumption, the building sector being a major source of emissions in the country. Meanwhile, growing comfort standards in average Indian households has led to a surge in cooling energy consumption which is expected to continue as the purchasing power in India rises. Since better insulation and air tightness for Indian houses is not yet a likely alternative due to largely unskilled workforce, high-rise apartment buildings (HRAB) as a major building typology in India has been suggested in this paper.HRABs preserve cooling energy by preventing "coolth" loss through shared ceiling/floor between two apartments, the rate of heat loss being dependent on difference in temperature. IES: virtual environment software is used to verify whether HRABs deliver more cooling plant load reduction than other building typologies prominent in India. Typical wall sections and construction material are modelled and a base plan is formulated and tested. It is found that HRABs consume 34.4% less energy for cooling an apartment than an average detached single-storey house. However, the greatest reduction of 36.9% is delivered by multi-storey row houses, but at the potential cost of urban sprawl and increased transportation energy consumption

KEYWORDS: High-rise Apartment Buildings; Building Envelope; Operating Energy; Air Conditioning

I. INTRODUCTION

Human induced climate change is a largely accepted phenomenon amongst the scientific community worldwide**(Cook, 2013)**. Green House Gases (GHGs) are considered to be the chief reason behind climate change –one of them being carbon dioxide (CO_2). A large amount of CO_2 is released into the atmosphere every year as a by-product of electricity generation in thermal power plants. Therefore, lowering energy consumption can reduce carbon emissions to some extent. As 70% of the overall building stock that will exist in India in 2030 is yet to be built**(Kumar, et al., 2010)**, choosing a more energy efficient-building typology can have a significant collective impact on the country's prospective GHG emissions.Globally, households are responsible for more than a third of all end-use energy consumption. In Western countries like the UK, more than half of this energy is typically used for heating **(DECC, 2013)**. Although space cooling currently amounts to a lower energy share at the international scale, it is mounting rapidly both in high-income countries like the United States and in emergent economies such as India and China **(Isaac & Vuuren, 2009)**.India is home to world's second largest population, about 32% of which live in urban centers **(UN, 2014)**. Various social and economic factors like better living conditions, higher education, and job opportunities are driving the rural population towards the cities **(Nath & Aggarwal, 2007)**. The **(UN, 2014)** report predicts that India's urban population is set to increase to 50% of its total population by 2030, as shown in Figure 1. Furthermore, **(McKinsey&Company, 2010)**claim that India's urban population could increase up to 590 millionby 2030, and that it will have 68 cities with populations of more than 1 million, 13 cities with more than 4 million people and 6 megacities with populations of 10 million or more.

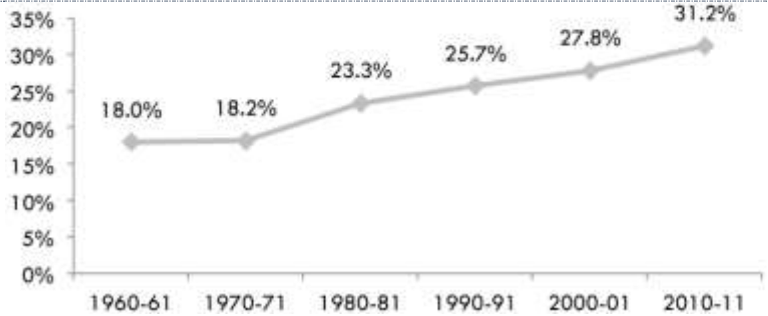

Figure1: Rise in Urban Population in India as % of Total Population (UN, 2014)

Naturally, this growth in urban population is reflected by an increase in urban residential floor area. **(Kumar, 2011)**claim that the constructed floor area will quintuple from 2005 to 2030, figure 2.

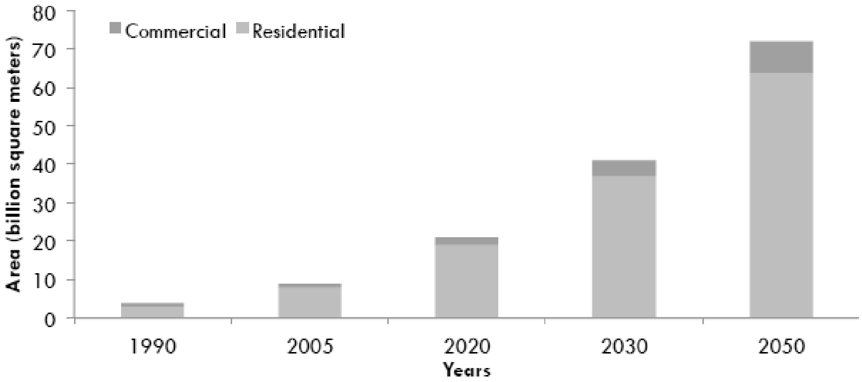

Figure 2: India's Building Stock through The Yrs. And Projections (McKinsey&Company, 2010)

Growing economy, rise in purchasing power and the increasing comfort expectations of India's thriving middle class ensures a surge not only in the number of urban dwellings, but also in their primary energy consumption. The latter is estimated to grow to 2.3 times of its value in 2010 in the next fifteen years, reaching an energy consumption of 40 EJ by 2030 **(Chaturvedi, et al., 2011)**. It has been projected in a Global Buildings Performance Network's **(GBPN, 2014)**report that, of the operational building energy consumption in India in 2050, 85% will be due to residential buildings, see Fig. 3.

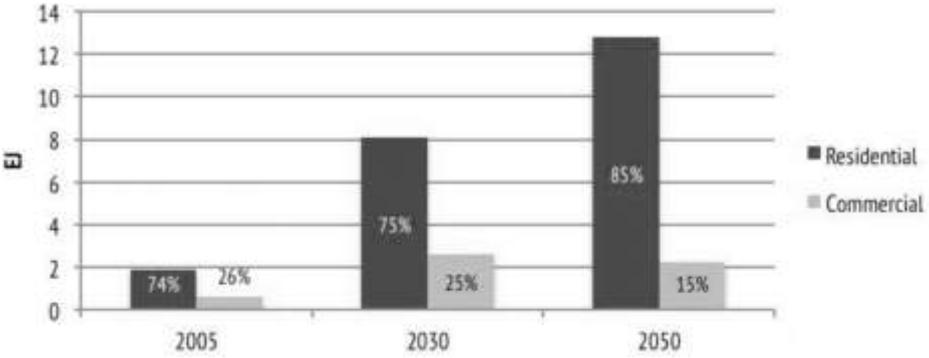

Figure 3: Energy Consumption by Building type over the Years(GBPN, 2014)

Moreover, 87% of urban Indian residential households' energy needs are met by electricity **(Singh & Michaelowa, 2004)**, and currently, about 45% of energy in the Indian residential sector is used to meet occupant thermal comfort requirements, where fans, air conditioners and evaporative coolers are the most common appliances used across the country (figure 4). However, as the urban economy soars, the use of centralised cooling systems and air conditioning units is becoming increasingly prevalent. According to 'India Air Conditioner

Market Forecast & Opportunities 2017', **(TechSci, 2012)** the Indian air conditioner market is forecasted to grow at a compound annual growth rate of 13.6% for the next five years.

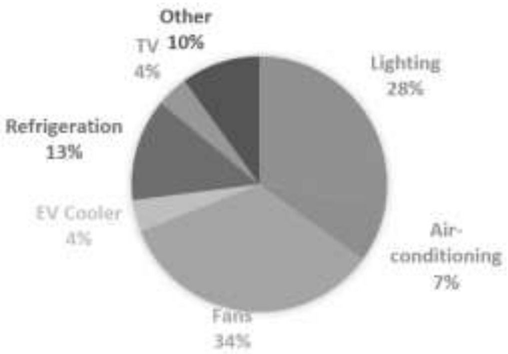

Figure 4: Annual Electricity Consumption By End Use In Indian Buildings (Singh &Michaelowa, 2004)

Moreover, 80% of electricity generation in India is carried out through conventional thermal power plants using coal and natural gas as fuels**(Central Electricity Authority, 2015)**. The situation is worsened by the fact that Indian coal-based thermal power plants are 'some of the most inefficient in the world'**(Central Electricity Authority, 2015)**.

In light of the information presented above, if the rapid upsurge in urbanisation, residential sector and the cooling market is not managed adequately, it will result not only in high greenhouse gas emissions, but it can further lead to reduction in green cover in and around cities through inadequate planning and land allocation. The latter, in turn, can cause deterioration of urban air quality and cause further increment in local temperatures **(Dimoudi & Nikolopoulou, 2003)**.

High-rise apartment buildings - principle

One of the most common solutions to the ecological and social issues linked with urban sprawl is building vertical, i.e. high-rise buildings **(Kavikar & Patil, 2014)**and dense urban developments (Reeds, 2011). However, as there is no universal definition of a high rise building, this study regards the term as it is outlined by the International Building (IBC 2000), i.e. as buildings 75 feet or greater in height measured from the lowest level of fire department vehicle access to the floor of the highest occupiable storey.

Other than conserving urban space, studies like (Wood, 2011)hypothesises that because of their greater surface area -which results in a greater form factor- HRABs are characteristically less sustainable. Still, since the primary area of interest in this report is urban housing projects, the energy consumption shall be calculated in the units of 'per person per square metre', thus normalising the overall surface area factor and giving HRABs a more just representation. Also, since surface insulation is a rare practice among Indian households and real estate developers **(Desjarlais, et al., 2013),** a middle level in a high-rise building theoretically holds a definite advantage over a single storey detached dwelling, as far as 'coolth' loss is considered.

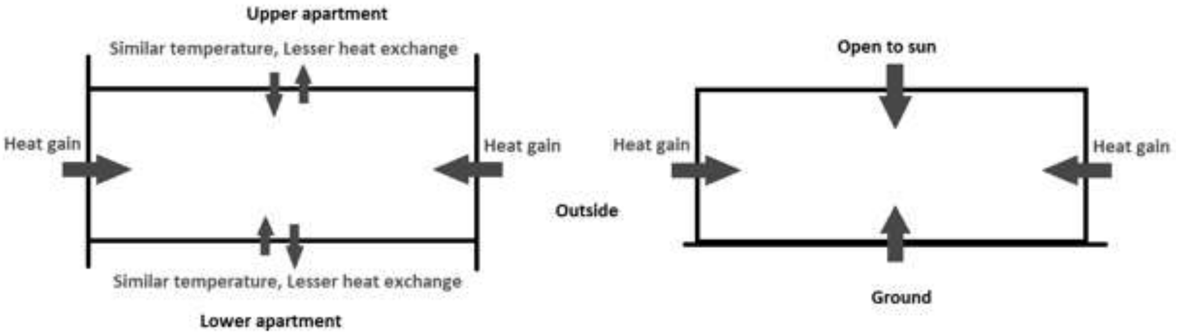

Figure 5: Heat Gain in Middle Storey Vs Detached Single Storey

However, two points must be noted:

- The above does not necessarily justify the construction of HRABS; it can be argued that similar results can be obtained by low-rise or a mid-rise apartment buildings. Also, the effect of the top and bottom levels of HRABs on the overall energy consumption also need to be considered to make any reasonable argument regarding the comparison.
- Better insulation techniques for the external walls, ceiling and floor can achieve similar results too, but it has not been considered in this report as the majority of workforce in India is unskilled and there is little quality control and supervision**(Ashokkumar, 2014)**and poor workmanship nullifies the insulation by leaving holes or thermal bridges in the building envelope. Hence the report deals solely in realistic and deliverable construction details in practice in India.

To summarise, HRABs can potentially:

- Prevent Urban sprawl and save green cover in cities
- Reduce Energy consumption in intra-city transportation
- Solve Housing Problems in light of influx of rural population to urban centres.
- Conserve cooling energy by sharing surfaces with other apartments in light of poor insulation.

Of these, the first three statements have been debated widely in academia and attained some degree of unanimity. But the fourth point, despite being simple in theory, has not been investigated for Indian conditions. This study aims at assessing the point with the help of computer simulations replicating four diverse building typologies.The energy simulation software, IES Virtual Environment, is used to model the typologies and then to perform simulations and to compute the cooling energy requirement in each case. The quantified differences can then be used as evidence to allow useful conclusions to be drawn.

II. THEORETICAL BACKGROUND

Conductive Heat Transfer

For conductive heat transfer through the fabric of a building, the following formula is used:

$$Q_{Total} = \sum \boldsymbol{U.A.\Delta t}$$

Where,

Q = Rate of heat loss/gain through the fabric (W)

U = Thermal transmittance (U-value) of the element considered ($Wm^{-2}k^{-1}$)

A = Area of the element considered (m2)

Δt = temperature difference between the two sides of the element (°C)

Insulation should ideally be introduced in the building fabric in order to reduce the overall U-value of the fabric and thus reduce the rate of heat loss/gain through it. However, it is evident from the equation that the difference in temperatures (Δt) on the two sides of the building element is also directly proportional to the rate of heat loss/gain. Therefore, if Δt is reduced, it will also result in a slower heat transfer. This constitutes the basic premise of this study.

Solar gain

Solar gain is the thermal gain in a building due to the effect of solar radiation. It is achieved through transmittance of sunlight through the windows. The solar heat gain is a sum of heat transfer through direct transmission and absorbed and re-radiated transmission into the interior space.

$$Solar\ heatgain = A_g.R.T.S$$

Where,

A_g = Glazing area (m^2)

R = Incident radiation (W/m^2)

T = Transmission factor

S = Shading factor

In heating-oriented, temperate climates, sunlight can act as a source of heat and daylight, thus reducing the heating and lighting loads of the building respectively. In cooling-oriented climates such as India on the other hand, solar gain can cause overheating and increase in cooling loads.

Thermal comfort

Thermal comfort is a vital part of building design because it enables the designer to calculate the future heating/cooling loads of a project once it is occupied. While the Adaptive Thermal Comfort theory proposes that occupants acclimatise themselves to a broader array of thermal conditions based on parameters like external temperature, clothing, physical activity, etc.**(Nicol & M.A., 2002)**. However, for this study, a fixed temperature setting has been modelled for indoor thermal comfort, which is then used to determine cooling loads. After which the the Predicted Mean Vote-Predicted Percentage Dissatisfied (PMV-PPD) index is used to check the thermal comfort inside the conditioned spaces.

PMV-PPDIndex

It was developed by P.O. Fanger in 1970 through experiments in the controlled environment of a climate chamber, building upon his theory that thermal comfort can be reached when there is heat balance between the human body and its surroundings, if certain other factors were taken into consideration, e.g. clothing layers and perspiration rate, etc.**(Fanger, 1970)**. The obtained 'vote' is then applied to calculate the mean response of a large group of people on a seven-point thermal sensation scale ranging from +3 for 'hot' to -3 for 'cold'. The 0 PMV represents the neutral or comfortable temperature range. The PMV has been expressed by **(Fanger, 1970)**as:

$$PMV = (0.303e^{-0.036M} + 0.028)L$$

Where,

M = Metabolic rate (Met), &
L = thermal load - defined as the difference between the internal heat production and the heat loss to the actual environment - for a person at comfort skin temperature and evaporative heat loss by sweating at the actual activity level

The PMV index quantifies thermal comfort based on a combination and interdependencies of the thermal factors discussed earlier: metabolic activity, clothing insulation, air temperature, mean radiant temperature, air movement and humidity.

PPD expands to Predicted Percentage Dissatisfied. It is a numerical estimation of the thermal comfort of a set of people in a thermal environment, and is plotted against the PMV with maximum dissatisfaction at the PMV fringes ('too hot' and 'too cold') and a 5% dissatisfaction at the PMV of 0 (neutral/ comfortable)

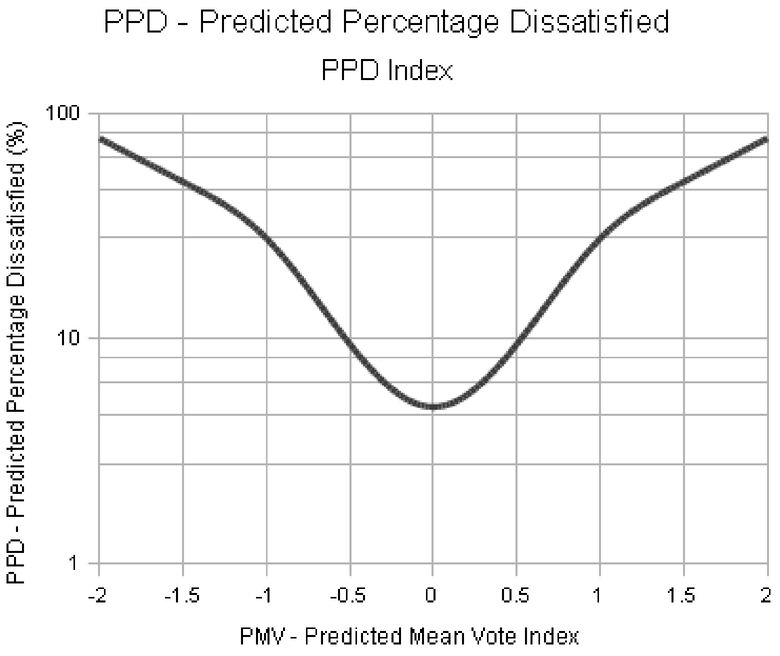

Figure 6: PPD VS PMV GRAPH. SOURCE: Engineeringtoolbox.Com

PPD is quantified in terms of PMV as
$PPD = 100 - 95e^{-(0.03353PMV^{4} + 0.2179\,PMV^{2})}$

The shortcoming, however, of thermal comfort methodologies based on heat balance is that it relies on the designer to make correct assumptions regarding the behaviour of people and typically will not account for a variation of behaviour within a group of people **(Nicol, 2008)**.

III. METHODOLGY

IES: Virtual Environment software has been used for modelling as well as simulations due to its customisability, easy-to-use interface, and faster simulation time.

Base case dimensions

In order to model the apartments in an HRAB and other typologies, a standard apartment plan for a family of four was selected with two conditioned bedrooms, two unconditioned bathrooms, a conditioned kitchen and a conditioned living room. The net floor area of the plan is 102 m^2 while the conditioned floor area is 78m^2. Each room is taken as a separate zone for the purpose of simulation. A rectangular plan was selected both for simplicity and to keep a relatively wall surface area comparable to that of the ceiling and the floor. The building dimensions are as shown in figure 7, while the floor-to-ceiling height has been kept as a standard 3m. As per local practice, the kitchen and living room have been kept towards the south of the plan, and the two bedrooms towards the north. An unconditioned small stairwell/courtyard has been provide on the eastern side in order to account for the elevator /stairs in a simple HRAB.

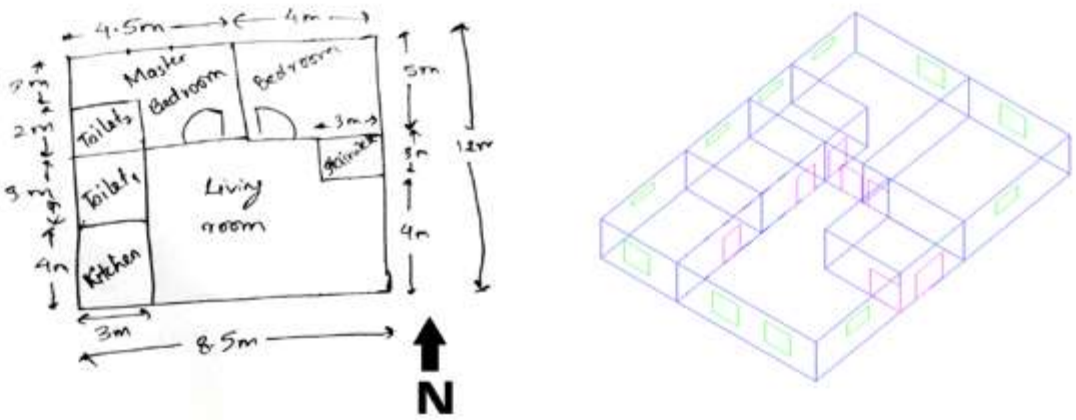

Figure 7 Base Case Plan And Axonometric

Construction Details And Heat Gain

As per standard Indian construction practices, the following sections are assumed for the different elements of the building – namely, wall, ground floor, roof, and intermediate floor.

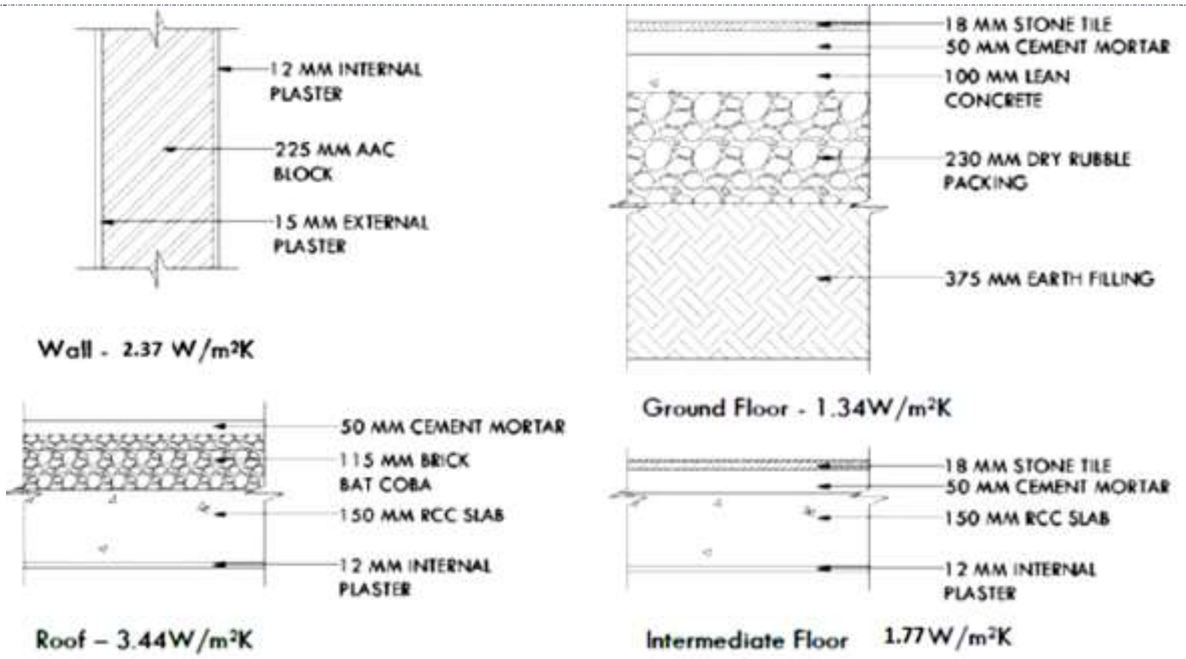

Figure 8: Building Elements' Sectional Details

The section elements and their respective thermal transmittances (U-values) are modelled into the simulations.IES:VEthen computes the heat transfer through the whole building envelope.

IES:VE calculates solar gains through the location-specific incident solar flux, accounting for direct shades with the help of sun path diagrams while other local geographical details are obtained from weather files compatible with the software. The weather data file used for this study was that of Mumbai, because of its composite weather and it being the hub of urban development in India.

Room Internal Heat Gain Profiles

Apart from conduction through building fabric and solar gains, heat is also generatedfrom occupants' body warmth, electrical appliances, etc. For simulation purposes, standard room profiles are created keeping a family of four in mind with a stay-at-home parent and two school going children, as shown in Table 1.

Table 1: Occupancy And Internal Gains Profile

Room type	**Occupancy Schedule**		**Internal Gains**
Bedroom	Weekdays	10pm – 6am	2 occupants, 1 TV, 1 tube light, 1 fan
	Weekends	10pm-6am; 2pm-4pm	
Kitchen	Daily	6am-8am; 12noon-2pm; 7pm-9pm	1 occupant, 1 tube light, 1 fan, 1 refrigerator (always on)
Living/dining room	Weekdays	6am-10pm varying	4 occupants, 1 TV, 8 tube lights

Other Simulation Parameters

Cooling Profile

The cooling profile has been set to operate on the basis of occupancy and indoor air temperature. Keeping the Indian temperature preferences in mind, the air conditioner set point has been kept at 23°C (based on existing practices), while the cooling is turned on when temperature exceeds 28°C. The cooling generator details as fed into the software are mentioned in Table 2.

Table 2: Cooling Generator Details (Modified According To The Indian Market)

Cooling/Ventilation Mechanism	Air conditioning
Fuel	Electricity
Nominal EER kW/kW	2.9
Seasonal EER kW/kW	1.1167

EER – Energy Efficiency Ratio

Window Profile

In order to assess the cooling loads across all the different typologies without bias, natural ventilation is not employed in any of the simulations. The cooling plant meets all the VAC requirements of the building and therefore, all windows are left unopenable.

Infiltration

Infiltration refers to the unintended flow of air through the building by the means of cracks, and opening and closing of doors and windows. In this case, the infiltration value has been taken as the standard IES value of 1.5 ach/hr.

This value may not be necessarily representative of the actual infiltration, since infiltration will also increase marginally upon increasing the altitude, but it has been taken as a constant for the sake of fair comparison.

Lighting Profile

Though solar gains through the windows contribute to the heat balance in the building, the lighting systems in the building have been set to operate on occupancy basis alone and the daylight harvested through the windows has not been used to offset the lighting loads. This has been done because:

a) Within the premise of the urban environment considered in this report, surroundings of a building can be too uncertain to rely on unobstructed daylight.
b) Some typologies simulated in this report don't have the same number of windows (the middle storey in a central terrace house, for instance), therefore rendering the comparison imbalanced, if daylighting as an auxiliary is considered.

IV. RESULTS

The Base Case

Using the construction templates and the profiles from section 3, the base case was simulated in IES:VE. The following results were obtained for cooling loads in the different rooms.

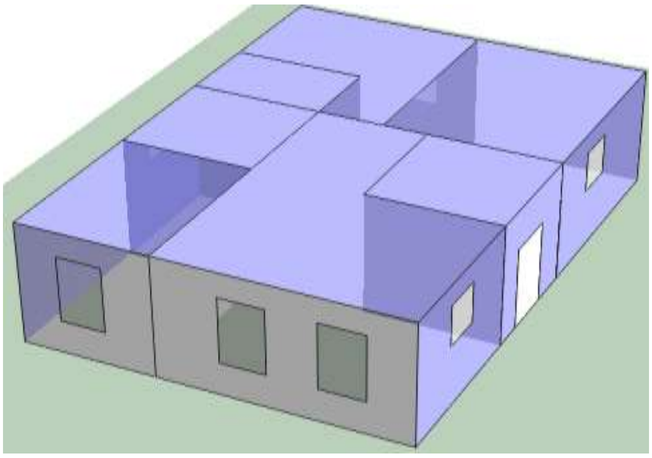

Figure 9: Base Case Axonometric

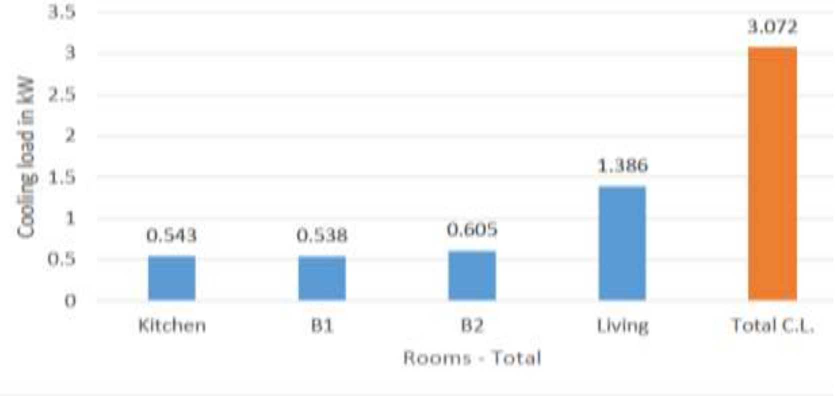

Figure10: Base Case Cooling Plant Load Data

Through the simulations it was observed that the overall cooling plant load for the base case was 3.072 kW, with the living room accounting for the biggest share of 1.386 kW. This may be due to the fact that the living room faces south and has two relatively large windows in that direction.
Cooling load per person per m^2 becomes 7.52 W/person/m^2

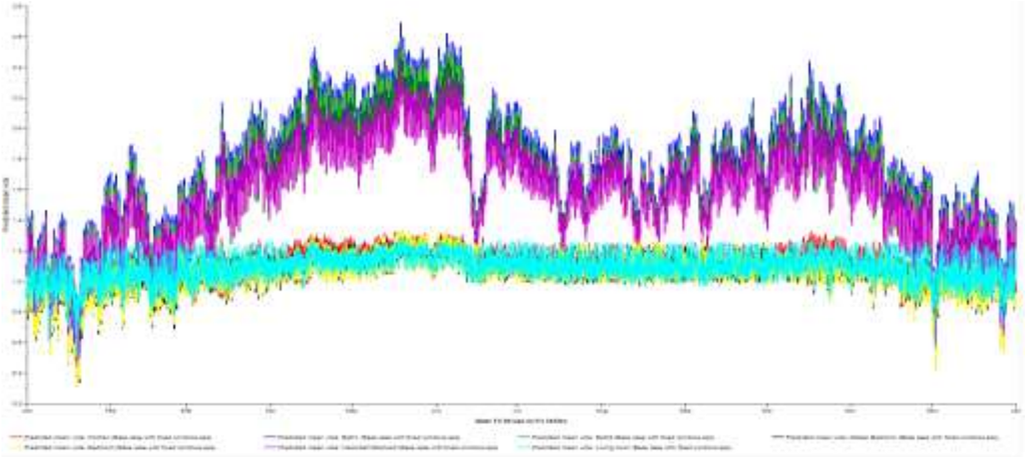

Figure 11: PMV For Base Case All Rooms

In the PMV chart obtained for the base case, it can be observed that the PMV remains more or less at +1 (slightly warm) for all the conditioned spaces. Even on the hottest day of the year. This may be because the air conditioner set point was kept a bit higher at 23°C while it turns at a temperature of 28°C, both of which acceptable for Indian climates.

A positive thing is, however, that the PMV never drops below a PMV of 0 (neutral/comfortable) throughout the year, which indicates that even though there is no heating involved, thermal comfort during winters is maintained. The PMV charts for all the cases following this showed the same trends. In each case, the PMV value for conditioned spaces remained at 1 throughout the year, dropping lower only during winters, though never going below 0. The charts for all of them have not been shown in this report to avoid repetition.
Also, typologies like single-storey duplex and triplex, double storey duplex and triplex and so forth were not simulated because they are the intermediate scenarios between single storey detached and three storey terrace houses (three is the minimum number of levels you need to have a middle floor).

Three Storey Detached

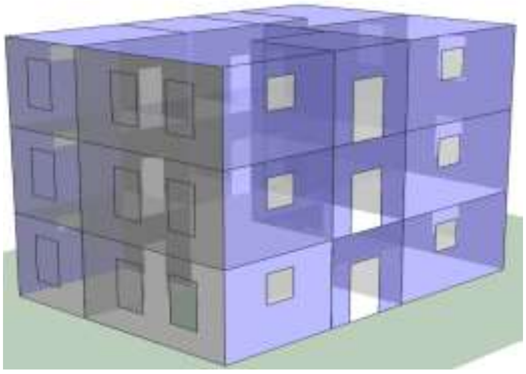

Figure 12: Three Storey Detached Axonometric

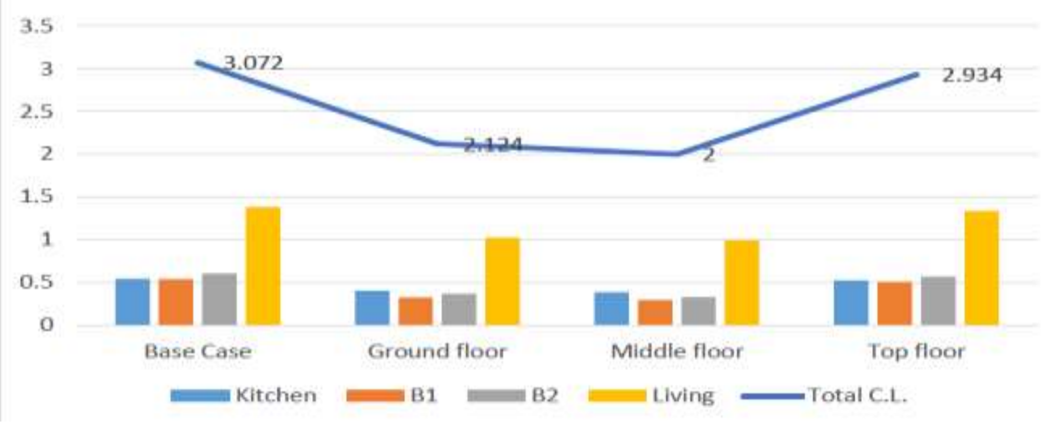

Figure 13: Base Case Vs 3-Storey Detached

The simulations showed that that the average overall cooling plant load for the Three Storey Detached case was 2.35 kW, Cooling load per person per m^2 becomes 5.76 W/person/m^2

Three Storey Terrace

For representative purposes only three 'three-storeyed' buildings have been simulated due to similar statistics for all the central houses. However, for later calculations and comparisons, eight three-storeyed buildings have been taken into consideration with two on either edge and six in middle.

The remaining section has been split into two parts: terrace edge apartments and terrace central apartments.

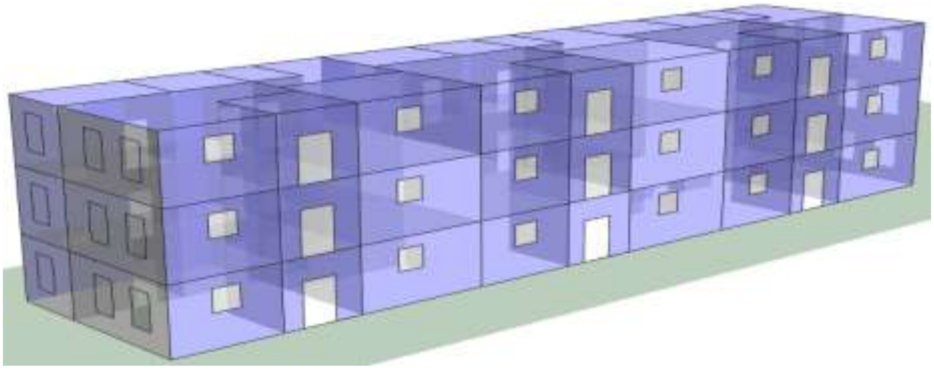

Figure 14: three storey terrace axonometric

Terrace Edge Apartments

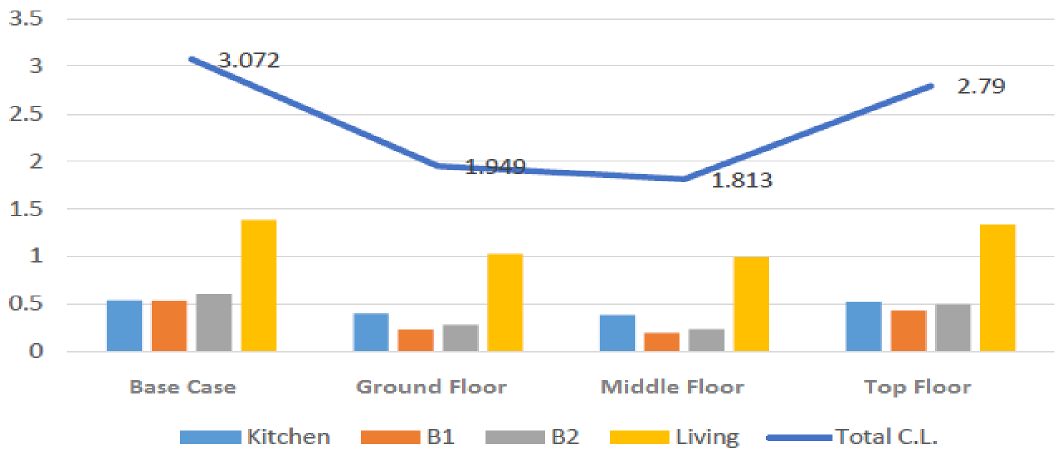

Figure 15: Base Vs Terrace Edge

The simulations showed that that the average overall cooling plant load for the Three-Storey Terrace Edge was 2.184 kW, Cooling load per person per m2 becomes 5.35 W/person/m2

Terrace center apartments

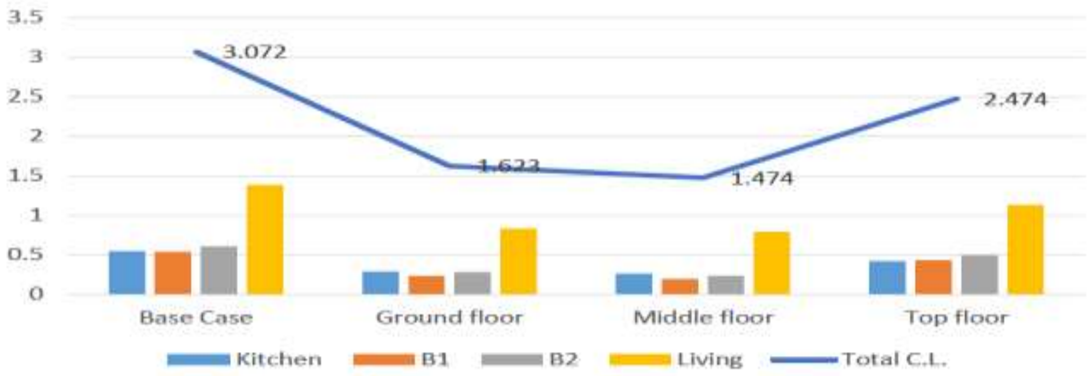

Figure 16: Base Vs Terrace Centre

The simulations showed that that the average overall cooling plant load for the Three-Storey Terrace Centre was 1.86 kW, Cooling load per person per m^2 becomes 4.55 W/person/m^2

The average overall cooling plant load for the Three Storey Terrace with Edge and Centre Combined was 1.94 kW, Cooling load per person per m^2 becomes 4.75 W/person/m^2

It is evident that the centre apartments, sharing more surfaces with other apartments are the most energy efficient in terms of cooling loads. The middle floor of a central apartment, surrounded by other apartments on all sides, shows the minimum energy consumed in cooling at 1.47 kW.

HRAB

For a High-rise apartment building, 30 floors were originally selected, however, followingrepeated crashes during simulations, 24 floors were selected. Also, though simulations were performed on each of the levels, the data from 2nd floor to 20th floor remained the same, with 1st, 21st and 22nd having only infinitesimal differences. Hence only 3 are displayed in Figure 18.

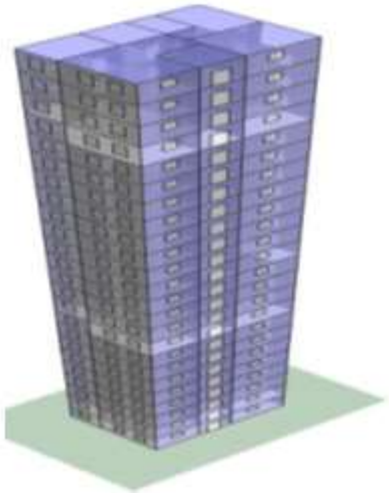

Figure17: HRAB Axonometric

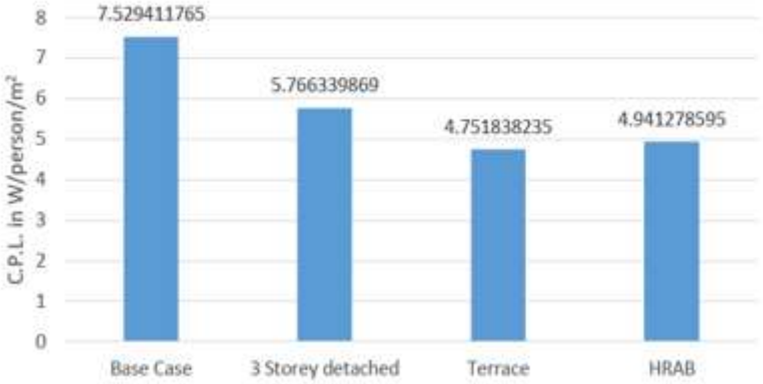

Figure 18: BASE VS HRAB

The simulations showed that that the average overall cooling plant load for the High Rise Apartment Building was 1.86 kW, Cooling load per person per m2 becomes 4.94 W/person/m^2

Comparison of typologies

On comparing and tabulating the cooling plant loads measured in W/person/m^2, the following results were obtained:

Figure 19: Cooling Plant Load Comparsions

Naturally, the building typology with the greatest amount of energy savings was the one with the greatest surface sharing with other apartments; namely, terrace houses. The middle terrace apartment in the centre shared every surface with another apartment except for two. As far as the cooling energy is concerned, what also worked in the favour of middle terrace apartments was the reduction in the number of windows which had a greater U-value than the wall itself. However, the trade-offinvolved in middle-central terrace apartments achieving the greatest cooling energy efficiency also needs to be explored. This simulation did not involve daylight as an offset for electric light due to unreliable nature of surroundings in the premise of this report. Nor did it include natural ventilation which might have tipped the scales in favour of HRAB due to high wind velocity at higher altitudes. Yet if the potential for reduction in lighting loads and cooling loads had been calculated, how much energy would have been saved? – would the efficiency in lighting achieved through windows compensated the energy lost in cooling energy due to worse building envelope? - It remains to be investigated. So are the psychological impacts of living in a continuously dim/artificially lit house.

Another point worth noting is that the area and design of the plan also had somebearingon the differences in the cooling loads of the different buildings typologies. A bigger plan with a greater ceiling area to wall area ratio might have tipped the scales further in HRAB's favour.

Nonetheless, it is clear from the study that, in such a typical case, HRAB will perform better than detached single-storey and detached triple storey structures, and that too without losing any access to daylight.

In this report, three-storey detached building registered a reduction of 23.4% in the cooling plant load, three-storey terrace building registered reduction of 36.9% while the HRAB registered a reduction of 34.4% in the air conditioning demands.

V. CONCLUSION

Climate change has withstoodsubstantial amount of scientific scrutiny, and the need to control greenhouse gas emissions is felt globally. It is therefore very important to conserve energy. Buildingsector, being a major consumer of electricity, needs to be targeted – especially in a country like India where mass urbanisation and urban construction have been forecasted. In such a scenario, HRABs hold the potential not only toreduce transportation energy consumption and preventing the socio-economic ramifications of urban sprawl, but also of diminishing cooling energy consumption by diminishing coolth loss through shared surfaces. The latter potential of HRABS has been assessed in this study by comparing it with other building typologies through simulations.

This report is based on a very basic principle of building physics: rate of heat transfer through a building fabric is directly proportional to the temperature difference on either side of the surface. If this temperature difference is smaller, the rate of transfer of energy will be lower. The rate of flow of energy is also directly proportional to the fabric's U-value. Following this line of thought, it was realised that given the less stringent practices prevalent in the Indian construction industry, which leads to a high U–value, a new building typology could perform better than the established ones.

To verify whether HRABs consume less electricity, a number of simulations are carried out using the software IES: Virtual Environment. Generic and locally applicablevalues were selected for parameters like construction, weather conditions, occupant behaviour, air conditioning etc. were fed into the software. The following results were obtained:

Table 3: Cooling Plant Load Comparison

Typology	**Cooling Plant Load in W/p/m^2**
Base Case	7.529
3 Storey detached	5.766
Terrace	4.751
HRAB	4.941

HRAB registered a cooling energy saving of 34.4% over the base case- single-storey detached building. A greater cooling load reduction, of about 36.9% was achieved through Terrace houses. The simulations results highlighted that the typology with the highest cooling plant load saving was encountered in the building with the greatest amount of surface sharing, which was terrace houses. The middle apartment in the centre of a terrace building shared every surface with another apartment except for the northern and the southern face. The middle apartments also had the advantage of losing their high U-Value windows which were replaced by low U-value wall sections.

The simulation shows that in a typical case, HRABs will perform better than detached single-storey and detached triple-storey structures, without losing any access to daylight (which the terrace buildings do).

In light of the haphazard, unplanned urbanisation, shrinking green cover in cities, and the transportation consideration, an HRAB development can be more suitable than a terrace development. However, more research is needed to be done in order to analyse it and also the impact of natural ventilation and daylight usage on the energy consumption in all the models.

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