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Achieving Energy Efficiency in High-Rise Residential Buildings in Composite Climate Through Fenestrations: A Case Study of Hyderabad

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Abstract: Hyderabad known as one of the emerging cities of India, has been an attraction to several job seekers and opportunists from around the country, this vast migration of people from different states has given rise to residential demands resulting in a boom in the residential sector so forth giving rise to high-rise residential buildings, the outcome of which has resulted in high energy consumption. This study focuses on high-rise residential buildings and aims to reduce annual energy consumption based on fenestration design using building energy simulation (BES) software as a tool. On running various energy simulations on recorded case studies and applying additional WWR with least disruption to existing interior layout, it was found that maximum efficiency was achieved in the case study with most occupancy hours and when fitted with glazing panes with low SHGC values and high VLT values.

Index Terms **- Energy-Efficient, High-rise residential, Hyderabad, Fenestrations, WWR, Glazing Material.**

1.INTRODUCTION

The city of Hyderabad is classified as class 'X' city according to house rent allowance classification of cities under the Government of India norms(O.M, n.d., p. 1). With an expected population of up to 1.84 crore citizens by the year 2031(GOMsNo.33), Hyderabad has become a major attraction for national and international business platforms, which again leads to more opportunities for locals as well as people from other states to come and reside in the city which in turn gives rise to demand for place of stay. The demand of residence is often met by providing people with temporary place of stay, since jobs aren't permanent in the private sector and buying a house is far more expensive than renting an apartment in a class 'X' city. Thus, this choice of stay for people has created demand for high rise residential building construction in Hyderabad (Telangana Today).

1.1 Nomenclature

BHK	Bedroom, Hall, and Kitchen
EPI	Energy Performance Index
kWh	Kilo-Watt hours
sqm	square meters
SHGC	Solar Heat Gain Coefficient
Thk.	Thickness
VLT	Visible Light Transmission
WWR	Window to Wall Ratio

2. NEED OF THE STUDY.

2.1 Existing energy consumption conditions

The state of Telangana recorded the highest growth rate (9.2%) of per capita electricity consumption in the country, up from 1,896 kWh (2018- 19) to 2,071 kWh (2019-20),(TSSA, p. 49).Hyderabad according to the statistics provided by the Government of Telangana has the highest number of domestic power supply connections (17.1 lakh) and industrial power connections and others (4.02 lakh).The Central Electricity Authority's electric power survey in its recent report provided the energy requirement projections of 45 mega cities (except NCR) in the next 10 years. As per the projections, Hyderabad may emerge as the city with greatest energy consumption in the next few years, overtaking Mumbai. As per the report, Mumbai had the highest energy requirement with a demand of "21.475 million units (MU)" in 2018-19 and "21.977 MU" in 2019-20. The article in (*Telangana*

Today, n.d.) indicates Hyderabad was closely behind Mumbai with a requirement of "20.059 MU" in 2018-19 and "21.799 MU" in 2019-20, among other 45 cities.

2.2 Impact of Fenestrations

From the data provided, Hyderabad being a populous megacity that is energy hungry, and which consumes most power supply through its domestic sector, needs to be regulated on the lines of energy consumption and saving energy. Fenestrations in a building serve multiple functions, including providing natural light, natural ventilation, and/or outdoor views. They have long been viewed as instrumental parts of the building as per (Feng et al., 2021).Improper designing of fenestrations in the building such as neglecting the local climatic conditions, orientation, applying improper materials for windows and also neglecting the optimal WWRs leads to bad internal thermal conditions of the building which in turn increases the reliance of the occupants on cooling and heating appliances for balancing the temperatures indoors , such practices increases the consumption of electricity as well as the costs, which is a negative outcome for both the occupants and on a town/city scale , as a whole. In this regard there lacks sufficient studies for energy efficient fenestration design for residential buildings in composite climate zone of India, this paper aims to fulfil that gap in study.

3. METHODOLOGY

The aim of this paper is to achieve energy efficiency in high-rise residential buildings in composite climate through fenestrations, taking case studies in Hyderabad. The approach is to comply with the following objectives.

3.1 Identifying the factors affecting energy consumption due to fenestrations.

Fenestration affects building energy use through four basic mechanisms—thermal heat transfer, solar heat gain, air leakage, and daylighting(Bemisderfer et al.).(Feng et al., 2021) shows that the Fenestration system comprises of the following components.

- Geometry (shape, size, WWR, orientation)
- Glazing (VLT, glazing type, SHGC)
- Shading (type, position, angle)

3.2 Locating case studies.

Case studies were located on the following conditions.

- At least one flat with occupants staying indoors 24/7
- At least one flat with occupants staying indoors during nighttime.
- Has one year of energy consumption data available.
- Has at least 6 stories or 18m in building height.

Highrise building is any building with height more than 18m(*GOMsNO168*, n.d.).

3.3 Identifying the energy consumption of the building in extreme seasons.

- Identifying the month with highest recorded local weather temperatures.
- Identifying the month with Lowest recorded local weather temperatures.
- Identifying month with highest energy consumption in each case study.
- Identifying month with Lowest energy consumption in each case study.

To identify the above-mentioned factors, to corelate data with each case study to get "Energy Performance Index (EPI)". EPI determines the energy consumption of a space with respect to its area, it has been used in many studies for energy efficient performance(Bano & Sehgal, 2018). Obtaining EPI for each case would provide a common ground for comparing case studies with each other.

3.4 Performing an energy analysis with the help of building energy simulations with variable geometrical and glazing properties.

On deriving a set of values based on points 3.1,3.2,3.3 of "Methodology", an energy simulation can be run to match existing conditions. This simulation can help provide different outputs of energy consumption based on varied fenestration designs. However, the goal is to simulate fenestration design options for existing case studies so that their simulated energy consumption is less than existing energy consumption. Achieving fenestration conditions with optimal energy consumption would provide a benchmark for high-rise residential buildings in Hyderabad.

4. CASE STUDY

The data collected from the case studies has been summarized and can be referred to from "Table 1."
Below is a quick overview of the nature of data collected from each case study.

4.1 Case study 1.

Alekhya Windchimes is an 8-storey high-rise residential building located in the Kondapur area of Hyderabad. It has 39 flats, all of which are "3 Bedroom, Hall and Kitchen (BHK)". For this study a flat on the middle floor, i.e., 4th floor was taken. Flat-405 was surveyed as shown in Fig.1, Fig.2 and the following was the data collected.

- The occupants are a family of three.
- Monthly electricity consumption.
- Building material catalogued.
- Electrical appliance and power ratings catalogued.

Refer "Table 1." for a detailed summary.

Fig.1 Typical floor plan highlighting Flat-405 facing Northwest.

Fig.2 Alekhya Windchimes as viewed from the Street.

4.2 Case study 2.

Shahana Manzil is a 7-sorey high-rise residential building located in the Begumpet area of Hyderabad. It has 14 flats and a penthouse, with 2(BHK) and 3(BHK) typical flats on each floor. For this study the entire 1st floor of the building was taken i.e. Flat 101 & 102, see Fig.3. The building's entrance faces west towards the street as can be seen in Fig.4 and has high rise buildings adjacent on both sides, the rear façade opens to a 15 feet wide road with no entrance. A survey was conducted for a typical floor and the following was the data collected.

- Flat-101 is a 3(BHK) and Flat-102 is a 2(BHK).
- The occupants are a family of 5.
- Monthly electricity consumption.
- Building material catalogued.
- Electrical appliance and power ratings catalogued.

Refer "Table 1." for a detailed summary.

Fig.3 Typical floor plan with Flat-101 facing West and Flat-102 facing East.

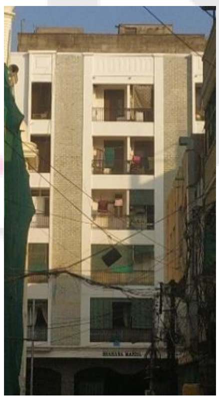

Fig.4 West Façade of the building as viewed from the street.

Flat-101 is at 6ft from its adjacent building on North and South sides whereas Flat-102 is 6ft from its adjacent building on North side and shares its external wall with the adjacent building on the South side without any gap, this makes it impossible to propose any opening on south side of Flat-102.

Table 1. Detailed summary of case-study's 1 and 2.
Thermal Properties of building materials to follow ASHRAE standards

Case Study		Typical Floor Area	Annual Power Consumption	No. of Occupants: *Age Group*	No. of Occupants: *Available Hours*	WWR.	Window Properties		Building Materials	Electrical Appliance Power Ratings
1	Flat-405	167 sqm	4917 kWh	3		18	Glass/Frame Make	Saint Gobain/UPVC	**External Walls:** AAC Blocks, Plaster, Terracotta Tiles(partial)	**Water Heater:** 2000 W x 3 **Split AC:** 1600 W x 5 **LED TV:** 126W x 1 **Microwave Oven:** 1200 W x 1 **LED Batten:** 24 W x 5 **LED Panel:** 15W x 25 **Refrigerator:** 311kWh/year **Ceiling Fan:** 40W x 5 **Washing Machine:** 2250 W
							Thickness/Shade	6mm/ Saint Gobain Dew drop	**Floor:** Vitrified Tiles/RCC Slab	
				30+yrs	7PM-9AM (5days a week) + weekends		SHGC	0.44	**Roof:** RCC Slab, Gypsum, Aluminum	
				10+yrs	4PM-9AM (5days a week) + weekends		VLT	0.45	**Internal Walls:** Burnt Brick, Plaster	
2	Flat-101	165 sqm	13917 kWh	5		14.3	Glass/Frame Make	Local/UPVC	**External Walls:** Burnt Brick, Plaster, Granite Tiles (partial)	**Water Heater:** 2000 W x 5 **Split AC:** 1400 W x 5 **LED TV:** 126W **Microwave Oven:** 1200 W **LED Batten:** 24 W x 20 **LED Panel:** 15W x 20 **Refrigerator:** 326kWh/year **Ceiling Fan:** 40W x 9 **Washing Machine:** 2000 W
				18+yrs	4PM-9AM (5days a week) + weekends		Thickness/Shade	6mm/ Clear	**Floor:** Vitrified Tiles/RCC Slab	
				40+yrs	everyday		SHGC	0.77		
				70+yrs	everyday		VLT	0.88		
	Flat-102	82.5 sqm	4107 kWh	3		7	Glass/Frame Make	Local/UPVC	**Roof:** RCC Slab, Plaster	
							Thickness/Shade	6mm/ Clear		
				18+yrs	6PM-9AM (6 days a week) + weekends		SHGC	0.77	**Internal Walls:** Burnt Brick, Plaster	
							VLT	0.88		

5. ENERGY CONSUMPTION

The electricity consumption for 1 year is taken as per monthly bill records for both case studies. This data is then analyzed to determine highest and lowest consumption months with respect to local weather conditions.

5.1 Energy consumption for case study 1.

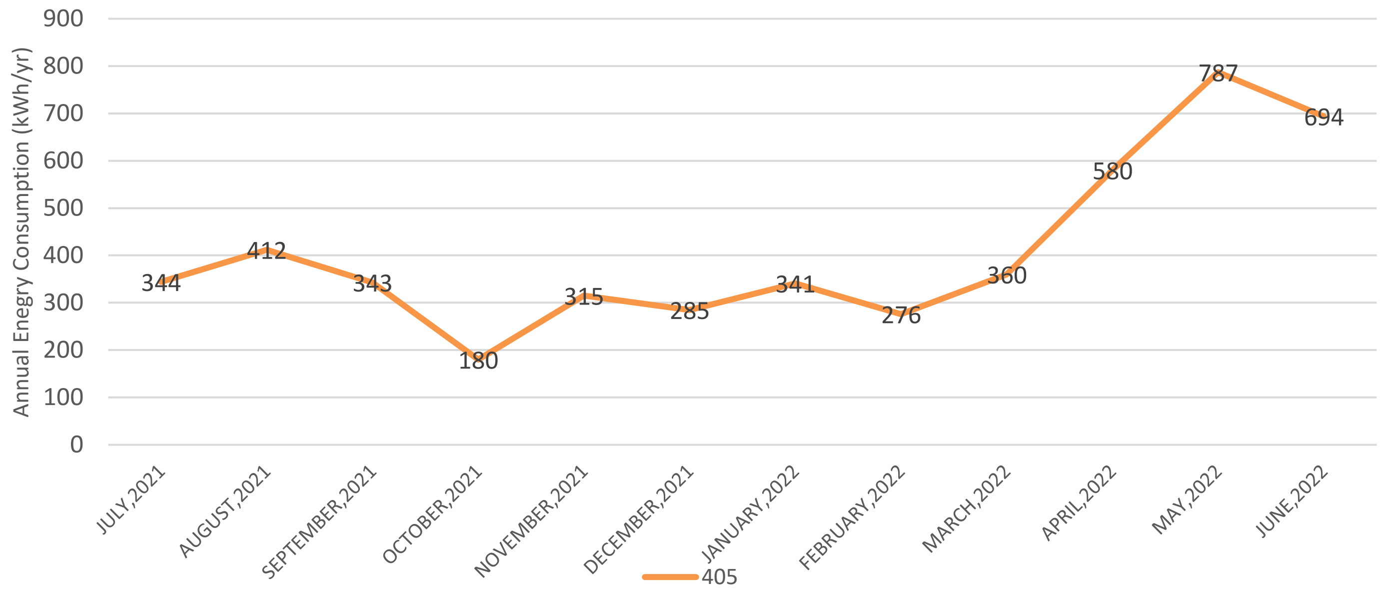

Fig.5 One year reading of power consumption from year 2021-2022 for flat-405, courtesy of administration at *Alekhya Homes* ©

5.2 Energy consumption for case study 2.

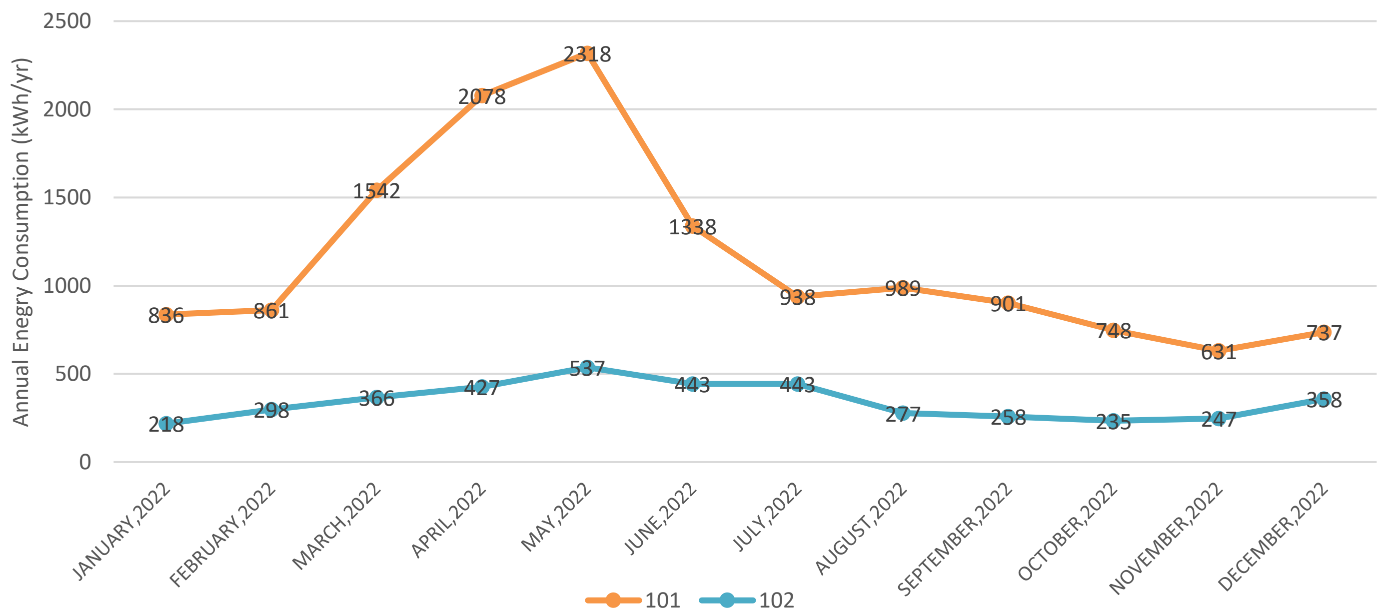

Fig.6 One year reading of power consumption for the year 2022 for flats-101 and 102, courtesy of administration at *Shah Constructions©*

It can be observed from Fig.5 and Fig.6 that the maximum consumption was in the month of May with 787 (kWh) For case-1 and 2855 (kWh) i.e. flat-101 plus 102 for case-2 respectively, there has been a rapid rise in consumption from the month of April to June and the least consumption was in the month of October and November with 180 (kWh) for case-1 and 878 (kWh) for case-2 respectively. Also, in the case of Flat-102 individually, there is a steady rise from the beginning of the year up to the month of May as opposed to a rapid rise in case of Flat-101. Reason being occupants schedule as recorded in Table 1.

Summer season in Hyderabad is observed between the months of march and June, the average minimum and maximum temperatures observed during summer season is 32°C-38°C, respectively (TSDPS, GOI.). This explains the rapid rise in consumption as shown in Fig.5 and Fig.6. Furthermore, Hyderabad observed temperatures above 40°C for 10 days in the month of April 2022 alone (Telangana Today.), explaining the surge in consumption in the month of May.

The sudden rise in consumption during the summer season implies the use of air conditioning units recorded in Table.1, adding cooling loads to the overall loads during the year.

From Table 2. It is observed that there is a huge difference in consumption between flat-101 and flat-405 and yet both flats are similar in size i.e., 165sqm and 167sqm respectively. The EPI per person for flat-101 is 40% more than flat-405 although being similar in floor area. This indicates that area has the least impact on consumption but is largely impacted by the number of occupants which are 3 and 5 for flat-405 and flat-101 respectively.

Table 2. Energy performance index for both case studies.

Case Study		Annual Consumption [kWh]	Floor Area [sqm]	Number of Occupants	Mean Annual Consumption Per person [kWh]	EPI [annual cons./sqm] kWh	EPI [annual cons./person] kWh	EPI [annual cons./person/sqm] kWh
Case Study-1	FLAT-405	4917	167	3	136	29.4	1639	9.81
Case Study-2	FLAT-101	13917	165	5	232	84.3	2783	16.8
	FLAT-102	4107	82.6	3	114	49.7	1369	16.5

6. BUILDING ENERGY SIMULATION

The approach for simulation of the existing case studies to achieve optimal fenestration conditions is as follows.

- simulate case studies 1 and 2 to match their real energy consumption readings.
- limit the margin of error to 5% or less.
- Simulate case studies 1 and 2 with variable glazing properties and WWR to achieve optimal fenestration conditions.

6.1 non-variable parameters

- Local weather data
- Floor area
- Number of occupants
- Occupancy Schedule
- Building materials(Chartered Institution of Building Services Engineers., 1999)
    - Refer Table 1.
- HVAC
    - Cooling setpoint
    - Ventilation

6.2 Variable parameters

- Internal lighting
- Opening
    - WWR
    - Glass pane
    - Frame material

The simulation applications chosen for this study among other available (BES) software's to run the parameters is Design Builder and Energy Plus, these software's have a reputation for being used in many studies for energy evaluation and processing (Amiri Rad & Fallahi, 2019; Boyano et al., 2013).

Table 3. Original simulation parameters.

Case study		WWR	Glass Pane make		Shading	Frame material	No. of occupants	Occupant schedule	Cooling Setpoint	lighting	ventilation
			SHGC	VLT							
1	405	18	Saint Gobain 6mm thk.		Local	Aluminum	3	7PM-9AM (5days a week) + weekends	Cooling:24°C	LED	0.5 (ac/hr)
			0.44	0.45					Setpoint:33°C	100 lux	
2	101	14.3	Local 6mm thk.		local	UPVC	5	24/7	Cooling:24°C	LED	0.5 (ac/hr)
			0.77	0.88					Setpoint:33°C	100 lux	
	102	7	Local 6mm thk.		local	UPVC	3	6PM-9AM (6 days a week) + weekends	Cooling:24°C	LED	0.5 (ac/hr)
			0.77	0.88					Setpoint:33°C	100 lux	

Simulations were run for a period of one year with the parameters from Table 3., the aim was to achieve total end loads similar to the original end loads by an error margin of ≤5% for both the case studies that were originally recorded to be 4917 kWh, 13917 kWh and 4107 kWh for Flat-405, Flat-101 and Flat-102 respectively. Refer Table 2.

Proposed WWR and glazing panes were simulated with a pragmatic approach i.e., provision of additional openings with least disturbance to existing furniture layout. In the case of Flat-405 a maximum of 1.5sqm of additional glazing was proposed in the bedroom wall facing Southwest. Table 4. shows the proposed simulation parameters. In the case of Flat-101 a maximum of 6sqm of additional glazing was proposed on North, West and South facades, and only in Bedrooms that are equipped with air conditioning units, for the purpose of reducing Cooling loads by tackling internal heat gains. The additional proposed openings added 2.9% WWR as shown in Table 4. Three number of Glazing panes of variable SHGC and VLT values were simulated to achieve optimal condition i.e., least energy consuming glazing pane as shown in Table 4.

The simulations were sensitive to surface shadows i.e., the shade from the surrounding buildings affected the internal gains and illuminance within the cases of Flat-101 and Flat-102 as can be seen in Fig.8. Simulations were also sensitive to Ventilation with an air change rate of 0.5 (ASHRAE-62_1-2010, p. 15), the software simulates weather conditions with respect to surrounding conditions and tries to maintain the assigned air change rate within the case study, as shown in Fig.8 Flat-101 is flanked on adjacent sides with high-rise buildings with a gap of less than 8 feet which limits airflow into the building unit through windows opening in these gaps. These limitations lead to bad natural ventilation conditions in the building units and lead to internal heat gains (Alwetaishi, 2019) . The simulation software then tries to counter these heat gains through sensible cooling adding to cooling loads.

All case studies are modeled as per real conditions to simulate original values with utmost accuracy and least margin of error, see Fig.7. This has been achieved as evident in Fig.10. In both case studies the top and bottom stories are also added to simulate its thermal impact on Flat-101 and 102.Although in case study 2 not more than one storey is taken above as any additional storey were found to have negligible to no thermal impact on the target floor i.e., first floor, once simulated.

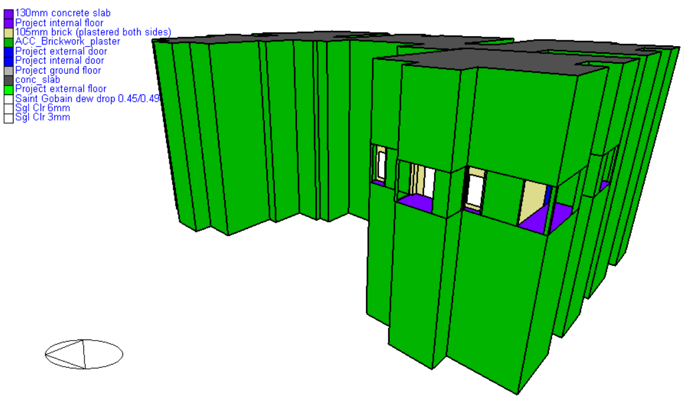

Fig.7 3-D model of Flat-405 with rest of the building

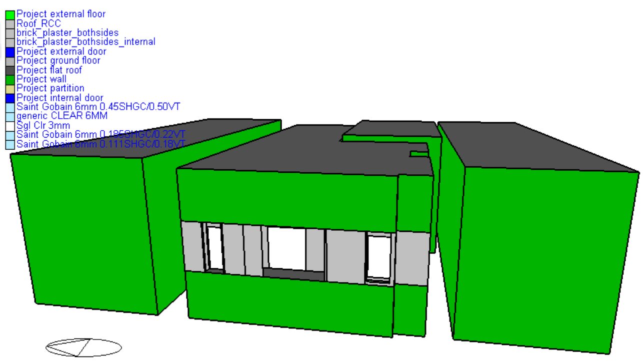

Fig.8 3-D model of Flat-101/102 with surrounding buildings

7. RESULTS

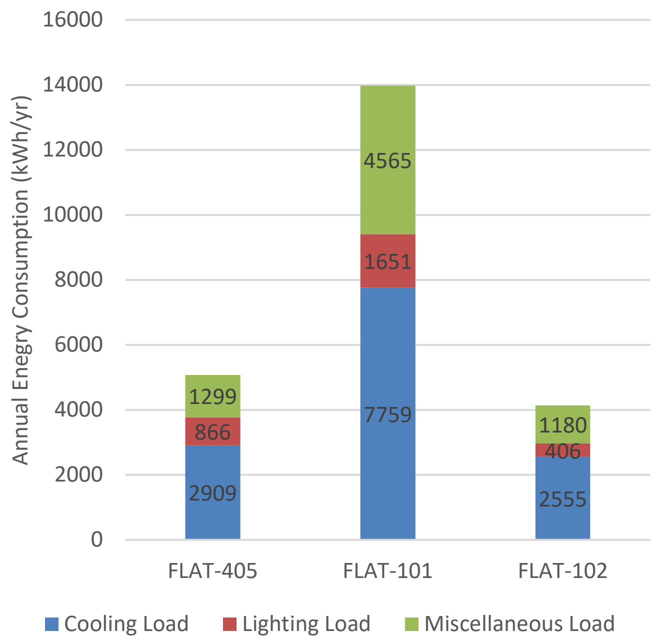

Fig.9 Simulated end user loads breakdown in kWh/year.

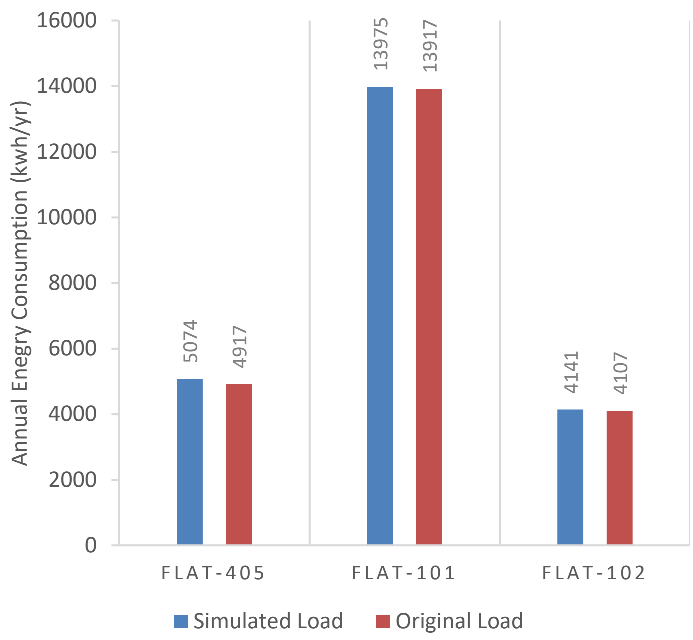

Fig.10 Simulated end user loads breakdown in kWh/year.

Minimum margin of error between the simulated loads and original loads was achieved in the case of Flat-1 with just 0.41% where Flat-102 and Flat-405 had error margin of 0.82% and 3% respectively.

Table 4. Proposed simulation parameters.

<table>
<tr><th colspan="2" rowspan="2">Case study</th><th rowspan="2">WWR</th><th colspan="2">Glass Pane make</th><th rowspan="2">Shading</th><th rowspan="2">Frame make</th><th rowspan="2">No. of occupants</th><th rowspan="2">Occupant schedule</th><th rowspan="2">Cooling Setpoint</th><th rowspan="2">lighting</th><th rowspan="2">ventilation</th></tr>
<tr><th>SHGC</th><th>VLT</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">405</td><td rowspan="4">18.125</td><td colspan="2">Saint Gobain 6mm thk. coated</td><td rowspan="4">Local</td><td rowspan="4">Alumi-num</td><td rowspan="4">3</td><td rowspan="4">7PM-9AM (5days a week) + weekends</td><td>Cooling:24 °C</td><td>LED</td><td rowspan="4">0.5 (ac/hr)</td></tr>
<tr><td>0.11</td><td>0.18</td><td rowspan="3">Setpoint:33 °C</td><td rowspan="3">100 lux</td></tr>
<tr><td>0.30</td><td>0.76</td></tr>
<tr><td>0.047</td><td>0.022</td></tr>
<tr><td rowspan="8">2</td><td rowspan="4">101</td><td rowspan="4">17.2</td><td colspan="2">Saint Gobain 6mm thk. coated</td><td rowspan="4">local</td><td rowspan="4">UPVC</td><td rowspan="4">5</td><td rowspan="4">24/7</td><td rowspan="2">Cooling:24 °C</td><td rowspan="2">LED</td><td rowspan="4">0.5 (ac/hr)</td></tr>
<tr><td>0.30</td><td>0.76</td></tr>
<tr><td>0.45</td><td>0.49</td><td rowspan="2">Setpoint:33 °C</td><td rowspan="2">100 lux</td></tr>
<tr><td>0.11</td><td>0.18</td></tr>
<tr><td rowspan="4">102</td><td rowspan="4">9.1</td><td colspan="2">Saint Gobain 6mm thk. coated</td><td rowspan="4">local</td><td rowspan="4">UPVC</td><td rowspan="4">3</td><td rowspan="4">6PM-9AM (6 days a week) + weekends</td><td rowspan="2">Cooling:24 °C</td><td rowspan="2">LED</td><td rowspan="4">0.5 (ac/hr)</td></tr>
<tr><td>0.30</td><td>0.76</td></tr>
<tr><td>0.45</td><td>0.49</td><td rowspan="2">Setpoint:33 °C</td><td rowspan="2">100 lux</td></tr>
<tr><td>0.11</td><td>0.18</td></tr>
</table>

Simulations were run for both case studies with variable glazing values and increased WWR as shown in Table 4. For accurate results the local shading from adjacent buildings as well as roof shading in exterior balcony windows opening into the bedrooms were considered, the schedule of the occupants obtained from the survey were also utilized in simulation software to simulate real time occupancy data. The occupancy schedule seemed to impact the energy consumptions drastically in case of Flat-101 where most occupants stayed in during day and night hours. As seen in Fig.6 the Flat-102 has a very subtle increase in consumption during summers whereas Flat-101 shows a drastic hike in consumption being on the same floor.Furthermore, the cooling setpoint was set to 33℃ to reach an indoor temperature of 24℃ i.e., as the interior temperature reaches 33℃ the sensible cooling function in the Simulation software brings the temperature down to 24℃, the amount of power utilized by the cooling equipment to bring down the temperature from 33℃ to 24℃ would be added to cooling loads.

In the case of Flat-101 the cooling loads amount to 55.5% of the total loads, this indicates a high amount of internal heat gain. To control this heat gain through fenestration, low valued SHGC glass panes are proposed as shown in Table 4.

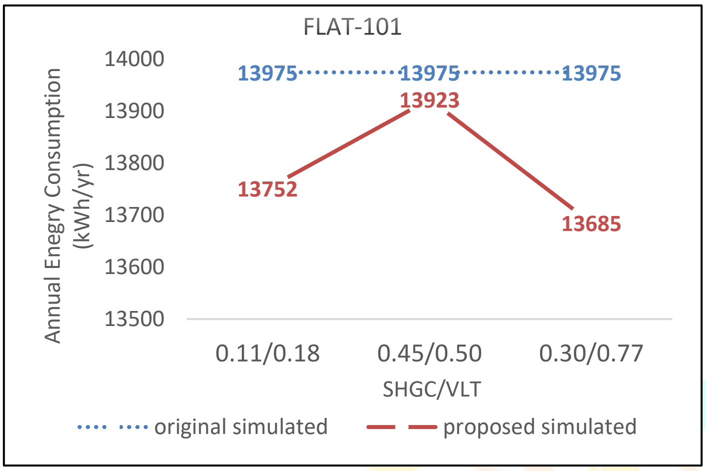

Fig.11 Simulated and original results of Flat-101.

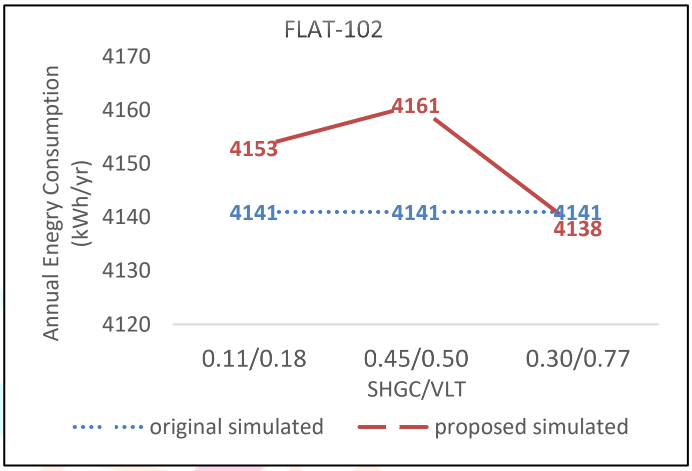

Fig.12 Simulated and original results of Flat-102.

It was observed in the cases of Flat-101 and Flat-102 that when SHGC of glass pane decreases along with the VLT the energy consumption increased. Solar radiation enters the space directly and a portion of it is absorbed by the fenestration while the rest enters the interior in form of infrared radiation or by convection leading to the internal heat gains and adding to the cooling loads, (Lu et al., 2017). This would explain the reduction in simulated energy consumption with lower SHGC values in the case of Flat-101. In the case of glazing panes having SHGC and VLT values as 0.45/0.50 the consumption increased as the lighting loads increased with respect to cooling loads as shown in Fig.11 and Fig.12. The glazing pane with results amounting to least energy consumption was having SGHC and VLT values as 0.30/0.77. However, the difference between the original simulated and proposed simulated results in the case of Flat-101 amount to 2.07% whereas in case of Flat-102 it is only 0.1%.

In the case of Flat-102 the occupancy schedule amounts to approximately 126hrs a week whereas in case of Flat-101 the schedule amounts to 160hrs a week, this difference in occupancy adds or reduces energy consumption. The number of occupancy hours with respect to the area also largely affects optimization as shown in Fig.14.

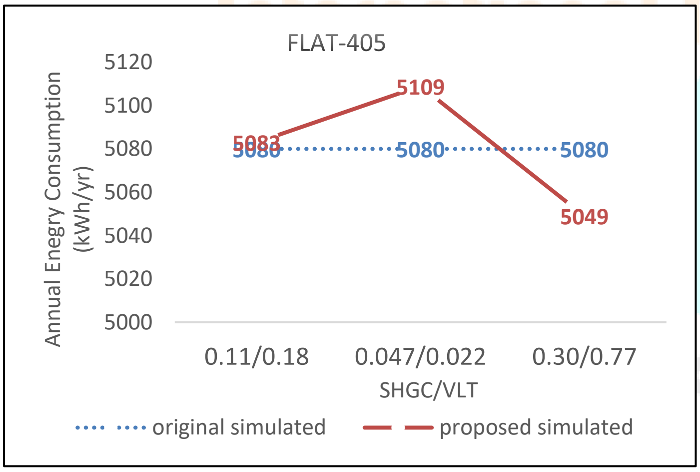

Fig.13 Simulated and original results of Flat-405.

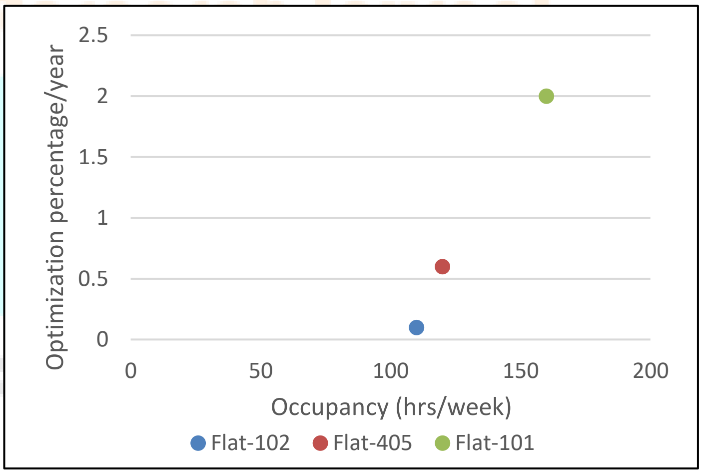

Fig.14 Fenestration Optimization

Similar to cases in Flat-101 and Flat-102 the most efficient glazing pane proved to be one with the highest VLT and comparatively lower SGHC. In case of Flat-405 the difference between the original simulated result to the proposed simulated glazing pane with utmost efficiency was only 0.6%. This is a result of low occupancy time schedule especially during daylight hours. The occupancy schedule amounts to 110hrs a week which is the least in all case studies.

In all the cases the most efficient glazing pane had SHGC of 0.30 and VLT of 0.77 with additional glazing of 0.125% WWR in case of Flat-405,2.9% WWR in case of Flat-101 and 2.1% WWR in case of Flat-102.The maximum amount of energy saved was found to be in case of Flat-101 with 2.07% optimization then Flat-405 with 0.6% and Flat-102 with 0.1% optimization annually, see Fig.14.

8. CONCLUSION

The conclusions of this study are summarized below.

- The proposed methodology can be instrumental in designing multi-retrofit building fenestrations to minimize indoor heat gain during summers and maximize daylighting during monsoon and winters in composite climate of India.
- The study identifies key aspects effecting cooling and lighting loads through fenestrations i.e., occupancy hours, WWR, and glazing properties such as SHGC and VLT, it was found among all case studies that maximum efficiency is achieved when occupancy hours are high during the week, and when SHGC values are low and VLT values are high.
- The results from the case study-2; Flat-101, shows maximum optimization of 2.07% from one residential unit in a high-rise building, given typical conditions for the rest of the building, energy savings would reach to a maximum of 13% annually. The net energy saving by replicating the optimized design in thousands of such high-rise buildings can certainly be a big leap towards energy sustainability in the country.

9.ACKNOWLEDGMENT

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