ASSESSING THERMAL PERFORMANCE OF BUILDING ENVELOPE OF NEW RESIDENTIAL BUILDINGS USING RETV

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ABSTRACT

Recently launched Eco Niwas Samhita 2018 or Energy Conservation Building Code for residential buildings uses a parameter called Residential Envelope Transmittance Value (RETV) to define thermal performance of the building envelope (excluding roof) for the cooling dominated climates. RETV provides a quantitative measure of the average heat gains over the cooling period through the building envelope. The code defines a maximum RETV value of 15 W/m^2.

This paper presents evaluation of RETV of sample residential projects located in composite (Noida, Mohali) and warm-humid (Chennai, Pune and Thane) climate regions. The methodology consisted of collecting construction drawings, door-window schedule and construction details from the builders, calculation of RETV as per the method prescribed in Eco-Niwas Samhita and evaluating RETV compliance.

The study covers both individual and multi storey apartments. The Window-to-wall ratio (WWR) of the sample projects range from 12% to 41%; while window-to-floor area ratio range from 7% to 25%. The sample projects covers a variety of walling materials: monolithic concrete walls, AAC blocks, Fly ash bricks and brick cavity walls. The RETV of the projects was found to vary from 7 W/m^2 to 24.5 W/m^2. The analysis show that proper choice of walling material and optimum design of shading of windows is critical in meeting RETV compliance.

Keywords—Eco Niwas Samhita, Thermal performance, Building envelope, Residential Envelope Transmittance Value, Heat gain

INTRODUCTION

As per the GBPN report (Rajan Rawal *et al.*, 2014) the residential buildings are expected to increase by 2-fold in terms of floor area by 2030. In terms of electricity consumption, residential buildings consumed 255 TWh electricity in 2017 which is estimated to multiply by more than 3 times and reach to 850 TWh by 2030 (NITI Aayog, 2015). Increased used of decentralised air conditioning units in households to achieve thermal comfort is the prime reason contributing to increase in electricty consumption (BEE, 2018).

In India, most parts have cooling-dominated climate.The indoor temperatures (thermal comfort) and sensible cooling demand is heavily influenced by the building envelope design. It is critical that the new residential buildings have better quality of building envelope.

ECO-NIWAS SAMHITA 2018

The new Eco-Niwas Samhita 2018 (Part 1:Building Envelope) sets minimum building envelope performance standards (BEE, 2018). It has the following provisions:

1. To minimize the heat gain in cooling dominated climate or heat loss in heating dominated climate;
   - Through the building envelope (excluding roof):
     a. It uses a parameter called Residential Envelope Transmittance Value (RETV) to define thermal performance of the building envelope (excluding roof) for the cooling dominated climates (Composite Climate, Hot-Dry

Climate, Warm-Humid Climate, and Temperate Climate)

b. Maximum U-value for the cold climate

- Through the Roof: Maximum U-value for Roof

2. For natural ventilation potential
   - Minimum openable window-to-floor area ratio with respect to the climatic zone
3. For daylight potential
   - Minimum visible light transmittance with respect to window-to-wall ratio

The code focuses on building envelope and aims to improve the thermal comfort and reduce the energy required for cooling and lighting in new dwellings.

The present study assesses the thermal performance of building envelope of eight new residential projects located in Warm and Humid and Composite climates zones of India using Eco Niwas Samhita code provisions. This involves calculation of RETV (Equation 1), U_{roof} and drawing inferences on the factors that influence them.

The selection of projects have not been done as per any scientific sampling technique. The objective while selecting these residential projects was to highlight RETV results with varied walling and roofing construction materials and different storeyed (low-rise, mid-rise and high-rise) buildings. Based on this criteria, some builders were approached to provide the required information voluntarily. The analysis of these projects is presented in this paper.

METHODOLOGY

The assessment of sample residential projects was conducted using the following steps-

DATA COLLECTION

Architectural drawings, door-window schedule and construction details for wall, roof and glass specifications were collected from the builders.

BUILDING ANALYSIS

Each of the block was analysed for the climate type, orientation, location, carpet area, number of dwelling units, type of dwelling units, height of the block, opening area, WWR, shading devices and material construction details.

CALCULATING THE RETV FOR SAMPLE RESIDENTIAL PROJECTS

RETV is the net heat gain rate (over the cooling period) through the building envelope (excluding roof) of the dwelling units divided by the area of the building envelope (excluding roof) of the dwelling units (BEE, 2018).

Equation 1: Equation to calculate RETV

$$RETV = \frac{1}{A_{envelope}} \left[\underbrace{\left\{ a \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\}}_{\text{Term I}} + \underbrace{\left\{ b \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\}}_{\text{Term II}} + \underbrace{\left\{ c \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\}}_{\text{Term III}} \right]$$

- $A_{envelope}$: envelope area (excluding roof) of dwelling units (m^2). It is the gross external wall area (includes the area of the walls and the openings such as windows and doors).
- A_{opaque}: areas of different opaque building envelope components (m^2)
- U_{opaque}: thermal transmittance values of different opaque building envelope components ($W/m^2.K$)
- $A_{non\text{-}opaque}$: areas of different non-opaque building envelope components (m^2)
- $U_{non\text{-}opaque}$: thermal transmittance values of different non-opaque building envelope components ($W/m^2.K$)
- $SHGC_{eqi}$: equivalent solar heat gain coefficient values of different non-opaque building envelope components
- ω_i: orientation factor of respective opaque and non-opaque building envelope components; it is a measure of the amount of direct and diffused solar radiation that is received on the vertical surface in a specific orientation.
- U_{wall}: U- value of walling material in $W/m^2.K$
- U_{roof}: U- value of roofing material in $W/m^2.K$
- U_{glass}: U-value of glass material in $W/m^2.K$
- $SHGC_{equivalent}$ (Weighted average value) : SHGC Equivalent is the SHGC for a non-opaque component with a permanent external shading projection. It is calculated by multiplying the External Shading Factor (ESF) with the SHGC of unshaded non-opaque component.

As per the code provision, the RETV of the building envelope (except roof) for four climate zones: Composite, Warm-Humid, Hot-Dry and Temperate should not be more than 15 $W/m^2.K$ for RETV compliance.

As per the code provision, to comply for roof, the U-value of roof should be less that 1.2 $W/m^2.K$.

The calculation requires thermal properties, shading, areas and orientation of building envelope components. Where,

- RETV equation has three terms – Term I, Term II and Term III.
- To calculate Term I, U value of the wall construction material is calculated (thermal conductivity is required), envelope lengths and height of the tower are measured from the architectural drawing.
- For Term II, window areas are referred from the door window schedule drawing and glass specifications is referred from the material test certificate.
- For Term III, H and V values are measured for shading devices overhang and side fin from the architectural dwawings (Figure 1,Figure 2)

CALCULATING THE U_{roof} FOR SAMPLE RESIDENTIAL PROJECTS

The U_{roof} of the roof assembly was calculated using the information on roof construction and thermal properties of various materials used for roof construction.

ASSESSING THE THERMAL PERFORMANCE ON THE BASIS OF RETV & U_{roof} RESULTS

The thermal performance of the sample residentials projects is evaluated by studying the impact of different design decisions on RETV.

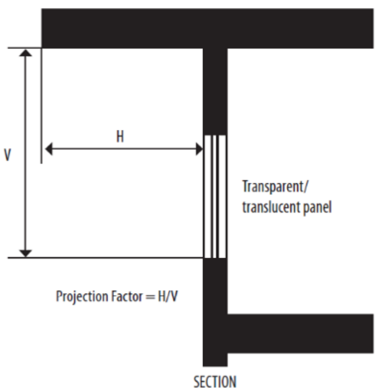

Figure 1:Measuring H and V values for overhang (section)

RESULTS AND ANALYSIS

Table 1 presents:

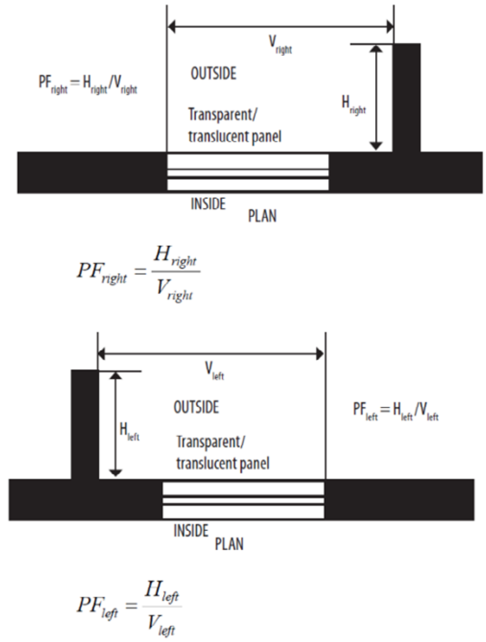

Figure 2:Measuring H and V values for side fin (left and right) in plan

- Project Details (Orientation, Location and no. of storeys)
- Construction Details (Walling, roofing and glass details)
- Results (WWR, $SHGC_{equivalent}$ and RETV)

The residential projects are located in Warm & Humid and Composite climate zones (Figure 3). The height varies from 2 to 26 storeys. The architectural details of the projects are provided in the annexure. The projects have walling of different types such as Monolithic concrete, AAC Blocks, Fly ash brick, Industrial slag brick and Brick cavity walls. The WWR(%) lies in the range of 12.6 to 41.3%. The RETV varies from 7 to 24.5 W/m^2.

* *The cost calculations are done as per CPWD DSR 2018. The rates are likely to vary significantly across the country.*

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Table 1: Project wise U_{roof} and RETV results

	Project Details			Construction Details			Results		
	Orientation	Location	No. of storeys	Walling details	Roofing details	Glass details	WWR (%)	SHG C_{eq}	**RETV** W/m^2
Project 1	Longer sides face E-W orientation	Chennai	19-storey	15mm Plaster (External); 170mm Monolithic concrete wall, 10mm Plaster (Internal) **U_{wall}=3.20 W/m^2.K**	15mm Plaster (External)+150mm RCC+10mm Plaster, **U_{roof}= 3.3 W/m^2.K**	6mm Single clear glass, U_{glass}=5.7 W/m^2.K, SHGC=0.83	17%	0.54	**21.1**
Project 2	Longer sides face N-S orientation	Chennai	4-storey	20mm Plaster (external); 200mm Monolithic concrete wall; 15mm Plaster (Internal), **U_{wall}=3.0 W/m^2.K**	40mm white reflective tile; 50 mm mud phuska; Brick Bat Coba; 120 mm RCC; 10 mm (interior plaster), **U_{roof}= 1.86 W/m^2.K**	6mm Single reflective glass, U_{glass}=5.8 W/m^2.K, SHGC=0.59	19.3%	0.46	**17.5**
Project 3	Longer sides are orienting towards NW-SE	Chennai	2-storey	15 mm Exterior plaster; 230mm Industrial Slag Brick; 10mm Interior plaster, **U_{wall}=0.93 W/m^2.K**	10mm white reflective tile; 50mm screed concrete; 50mm Weathering course; 200mm RCC slab; 10mm Interior plaster, **U_{roof}= 1.82 W/m^2.K**	6mm Single clear glass, U_{glass}=5.7 W/m^2.K, SHGC=0.83	12.6%	0.67	**10.9**
Project 4	Longer sides are orienting towards NW-SE	Pune	15-storey	20mm Plaster (external); 150mm Fly Ash brick; 15mm Plaster (Internal), **U_{wall}=2.6 W/m^2.K**	15mm Plaster (External);150mm RCC;10mm Plaster, **U_{roof}= 3.3 W/m^2.K**	6mm Single clear glass, U_{glass}=5.8 W/m^2.K, SHGC=0.82	20%	0.62	**20.1**
Project 5	Square planform	Thane	18-storey	20mm Plaster (external); 200mm AAC blocks; 10mm Plaster (Internal), **U_{wall}=0.77 W/m^2.K**	Roof: 15mm Plaster (External);150mm RCC;10mm Plaster, **U_{roof}= 3.3 W/m^2.K**	6mm Single reflective glass, U_{glass}=5.7 W/m^2.K, SHGC=0.55	41.3%	0.40	**16.0**

	Project Details			Construction Details			Calculated		RETV
	Orientation	Location	No. of storeys	Walling details	Roofing details	Glass details	WWR (%)	$SHGC_{eq}$	Total W/m²
Project 6	Longer sides are facing N-S orientation	Thane	15-storey	20mm Plaster (external); 200mm AAC; 10mm Plaster (Internal), **U_{wall}=0.77 W/m².K**	20mm Plaster (External); 50 mm thick XPS insulation; 200 mm thick concrete slab; 150 mm thick brickbat coba; 10mm Plaster, **U_{roof}= 0.12 W/m².K**	6mm Single reflective glass, U_{glass}=5.7 W/m².K, SHGC=0.55	16.1%	0.34	**7.0**
Project 7	Longer sides face E-W orientation	Mohali	Stilt+5 storey	20mm Plaster (external) 230 mm Brick wall; 40 mm air cavity; 115 mm brick wall **U_{wall}=1.2 W/m².K**	White reflective tile (external); 40mm PUF insulation; 150mm RCC slab; 12mm Plaster (Internal), **U_{roof}= 0.73 W/m².K**	6mm Single reflective glass, U_{glass}=5.7 W/m².K, SHGC=0.55	16.6%	0.38	**12.8**
Project 8	Longer sides face E-W orientation	Ghaziabad	26-storey	20mm Plaster (external); 200mm Monolithic concrete; 15mm Plaster (Internal), **U_{wall}=3.0 W/m².K**	40mm china mosaic tiles; 50 mm mud phuska; Brick Bat Coba; 150 mm RCC; 10 mm (interior plaster); Inside roof surface, **U_{roof}= 1.86 W/m².K**	6mm Single clear glass, U_{glass}=5.8 W/m².K, SHGC=0.83	20.1 %	0.56	**24.5**

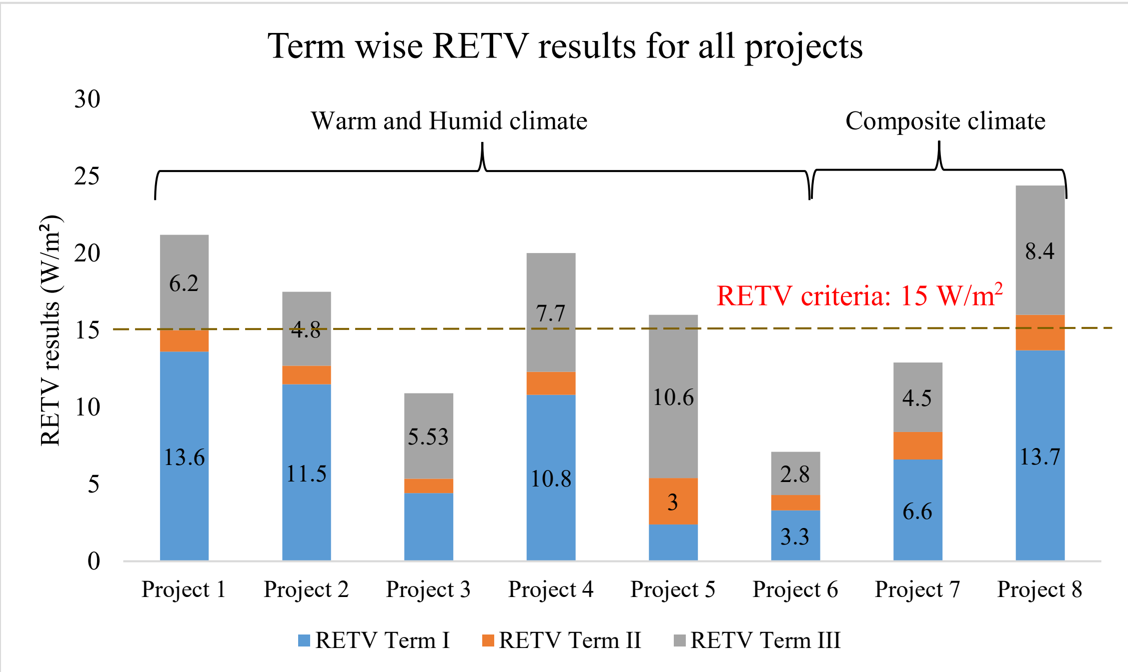

Figure 3: Term wise RETV results for all residential projects

* *The cost calculations are done as per CPWD DSR 2018. The rates are likely to vary significantly across the country.*

Figure 3 summarises term-wise RETV results for all eight residential projects. As mentioned before, RETV Term I is dependant on wall construction properties, Term II is dependant on thermal conductivity of the glazing used and Term III is dependant on external shading and SHGC of the glazing used.

Explanation of results are as follows-

Project 1: The RETV is 21.1 W/m^2. There is excess heat gained from wall conduction due to East-West facing orientation and walling made of monolithic concrete (large Term I) . Although, the residential block for

- Project 2: The RETV is 17.5 W/m^2. This residential sample presents an interesting case where inspite of having wall material as 200mm monolithic concrete, the overall RETV value is less as compared to Project 1, this is due to longer sides oriented towards N-S and use of single reflective glass.
- Project 3: The RETV is 10.9 W/m^2. It is relatively less due to use of industrial slag brick which has low thermal conductivity and has reduced the impact on wall conduction significantly. However, due to inadequate shading, the impact of window transmittance is still high.
- Project 4: The RETV is 20.1 W/m^2. The reduced thickness (150 mm) of fly brick wall results in higher U value of wall (2.6 W/m^2.K) as compared to a standard 230mm brick wall (2 W/m^2.K). Due to inadequate shading (only overhang) and choice of single clear glass (high SHGC), Term III is also high.
- Project 5: The RETV is 16 W/m^2. This sample presents an interesting case where inspite of using AAC blocks (U-Value: 0.77 W/m^2.K), single reflective glass and box-type shading as energy efficiency measures, it is not meeting RETV compliance requirements. This is due to high WWR~41.3% which is impacting Term II and Term III.
- Project 6: This project achieves lowest RETV of 7 W/m^2 which is much below the code compliance criteria of 15 W/m^2. Use of AAC blocks reduces the amount of heat gained due to wall conduction, thus Term I is less. There is no exposure to solar radiation from east and west facades through window openings, adequate shading has been provided for north and south facades. Single reflective glass which has lower SHGC (0.55) as compared to a single clear glass (0.83) has been used. This residential sample distinctly highlights that use of an efficient building envelope, including the roof assembly that meets the ECBC-R compliance criteria for roof (<1.2 W/m^2.K) can easily meet the RETV compliance requirements for the code.
- Project 7: The RETV is 12.8 W/m^2. Usage of brick cavity wall with 40mm air gap has reduced the heat gained due to wall conduction. Also, use of single reflective glass instead of single clear glass and adequate shading has also reduced heat gained due to window transmittance.
- Project 8: The RETV is 24.5 W/m^2 which is a high-rise apartment. There is excess heat gained from wall conduction due to East-West facing orientation and walling made of monolithic concrete. Openings facing east and west orientation have inadequate shading such as overhangs which are not able to fully shade the openings. Therefore, heat gained due to window conduction and window transmittance is also high.

CONCLUSION

While reading the conclusions of the study, it should be remembered that the study presents results of only limited number of building projects. These projects may not cover all types of construction and hence are not fully representative of the new residential construction taking place in the country. However, the analysis of the project data does provide useful information on building materials and building design features which can help in meeting the code compliance. While this study presents results of only eight building projects, if such an analysis is carried on for a large number of residential projects, it can also help in future code development and revision of the code.

The measures recommended below are for new construction as per the code.

a) The RETV of the building projects varies from a minimum of 7.0 W/m^2 (Project 6) to a maximum of 24.5 W/m^2 (Project 8). Three projects (project 3, 6 & 7) meet the RETV compliance (RETV ≤15 W/m^2)

b) Term I and Term III have the largest influence on RETV.

c) The Term I, depends primarily on the U_{wall}. Projects 1,2& 8 (monolithic concrete construction) and project 4 (150 mm fly ash brick wall) have high U_{wall} ($U_{wall} \geq 2.6$ W/m^2.K) and consequently have large Term I; all these four projects does not meet RETV compliance. Use of AAC block (Project 5&6), industrial slag brick (Project 3) and cavity wall (Project 7) results in low U_{wall} ($U_{wall} \leq 1.22$ W/m^2.K) and smaller term I. Three out of these four projects meet the RETV compliance. It can be concluded that the choice of walling material assembly is critical for RETV compliance.

d) The Term II is relatively small compared to Term I and III and has less influence on RETV. However, Project 5 has largest Term II (Term II = 3.0 W.m^2), primarily due to large WWR (WWR =41.3 %). This means that for projects with large WWR, use of double glazing can bring substantial reduction in RETV.

e) Term III which depends on WWR, shading and SHGC of glazing varies from a minimum of 2.8 W/m^2 (Project 6) to the maximum of 10.6 W/m^2 (Project 5). Projects having high WWR, higher glazed area oriented towards east and west, and having higher $SHGC_{equivalent}$ are observed to have large Term III. Project 6 has the minimum term III of 2.8 W/m^2.K, this project has a WWR of 16.1 % and low equivalent SHGC of 0.34.

f) For the ENS code provision of U-value of the roofing material, out of the eight projects, two projects i.e. Project 6 and 7 (Figure 4) are able to achieve a U_{roof} value of less than 1.2 W/m^2.K by use of insulation materials such as XPS (Extruded Polystyrene) and PUF (Polyutherane foam).

g) The typical cost of measures to reduce RETV and U_{roof} are given in

h) Table 2 provides typical cost of some measures to reduce RETV and U_{roof} as per CPWD DSR 2018 (Indo-Swiss BEEP, 2019)

Table 2: Typical cost of some of the measures to reduce RETV and Uroof as per CPWD DSR 2018 (Indo-Swiss BEEP, 2019)

	Measures	Cost
Wall (The cost of 230mm brick wall with finishing is ₹2400*/m^2).	230mm Brick cavity wall with 40 mm insulation	₹3000*/m^2
	200mm AAC blocks	₹2000*/m^2
	200mm Hollow clay blocks	₹2700*/m^2
Roof (The cost of 150 RCC roof with finishing is ₹ 1800*/m^2)	RCC slab with 50mm PUF insulation	₹3150*/m^2
	RCC slab with 100mm foam concrete insulation	₹2650*/m^2

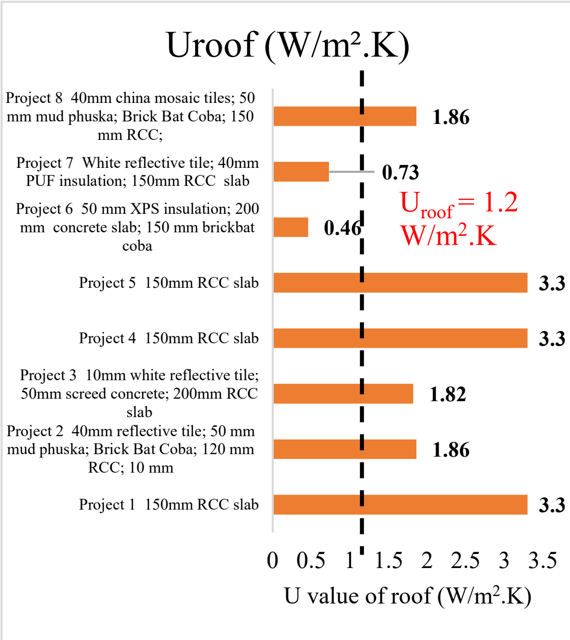

Figure 4: U-values of roofing material for all residential projects

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APPENDIX

A.1 Project wise details

a) Project 1: Warm & Humid climate

This completed apartment project (2018) is located in Chennai comprising of 2,3 bedroom, hall and kitchen (BHK) units. The RETV evaluation is carried for 3-typical towers of 19-storey each. Each tower consists of 152 dwelling units with a carpet area ranging from 75-110 s m^2 per unit. Longer sides faces E-W orientation (Figure 5).

Shading: Box type shading provided, $SHGC_{equivalent}$=0.54

Figure 5: Typical floor plan for Project 1

b) Project 2: Warm & Humid climate

This completed (2016) apartment project is located in Chennai comprising of 2-BHK units. It is a 4-storey building comprising of 56 dwelling units. The carpet area ranges from 58-65 m^2 per unit. Longer sides face N-S orientation (Figure 6).

Shading: Most openings have left and right side fins, openings enclosed with balconies have box-type shading, $SHGC_{equivalent}$=0.46

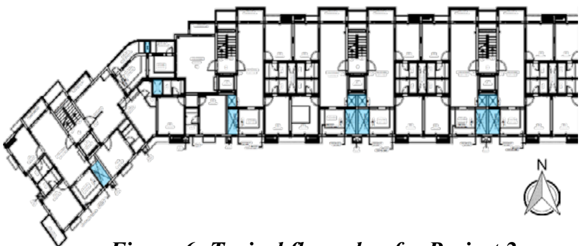

Figure 6: Typical floor plan for Project 2

c) Project 3: Warm & Humid climate

This is an indvidual low-rise housing project located in Chennai, its construction has been completed. It is a G+1 building with a carpet area of 257 m^2. Longer sides are orienting towards NW-SE (Figure 7).

Shading: No shading provided on NW orientation and some SE openings. Side-fin provided on other openings and overhang on balcony facing openings, $SHGC_{equivalent}$=0.67

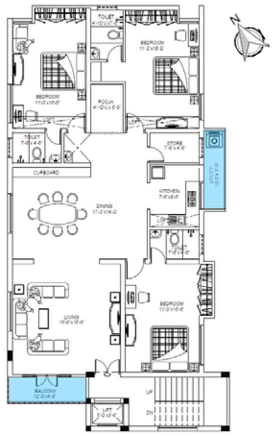

Figure 7:Second floor plan for Project 3 (G+1 storey)

d) Project 4: Warm & Humid climate

This is an EWS housing block of an apartment society in Pune, the project is at its design stage. The block is 15-storey comprising of 150, 1-BHK dwelling units with a carpet area of 40 m^2 per unit. Longer sides are orienting towards NW-SE (Figure 8).

- Shading: Maximum no. openings at North-West orientation with 0.6m overhang, building projection acting as a side-fin for some openings. No openings provided at South-East orientation. $SHGC_{equivalent}$=0.62

Figure 8: Typical floor plan for Project 4

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e) Project 5: Warm & Humid climate

This project design is proposed under state government authority at Thane. It is a G+17 storey building with 42, 1-BHK dwelling units. The carpet area ranges from 23-51 m^2 per unit. It has a square planform (Figure 9).

- Shading: Balcony slabs and building projections acting as shading devices. $SHGC_{equivalent}$=0.40

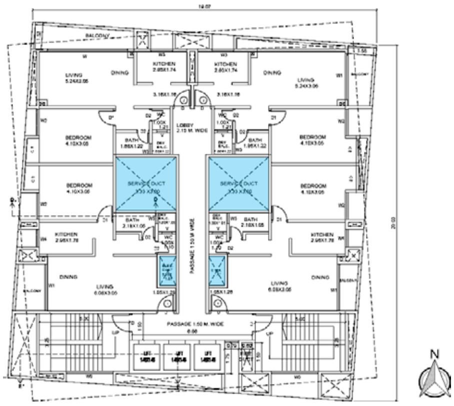

Figure 9:Typical floor plan for Project 5

f) Project 6: Warm & Humid climate

An under construction low cost housing project under state government authority at Thane, it comprises of 82, 1-RK units with a carpet area of 26.3 m^2 per unit.. It is a 17-storey building with 15 floors of residential units and remaining 2 floors of commercial shops. Longer sides are facing N-S orientation (Figure 10).

Shading: East and West facades do not have openings. In North and South facades, all openings have box-type shading (0.5m), $SHGC_{equivalent}$=0.34

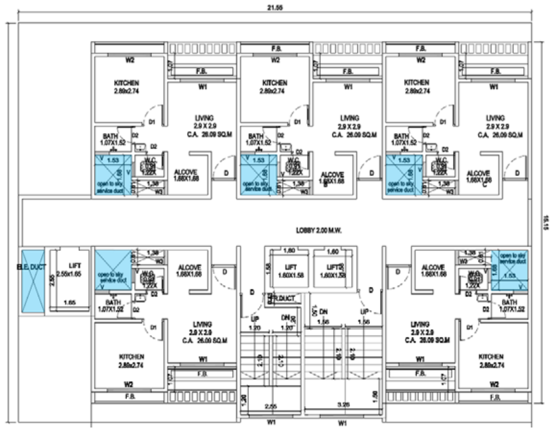

Figure 10:Typical floor plan for Project 6

g) Project 7: Composite climate

This project is a residential quarters (only block II) build for a development financial institution (DFI, India) at Mohali which is under construction. It is a Stilt+5 storey building with 20 dwelling units. The carpet area of these 2-BHK units range from 81-97 m^2 per unit. Longer sides face E-W orientation (Figure 11).

Shading: Balcony slabs and building projections acting as shading devices. More opening area towards east and west orientation. Most of the openings have box type shading on north and south face. $SHGC_{equivalent}$=0.38

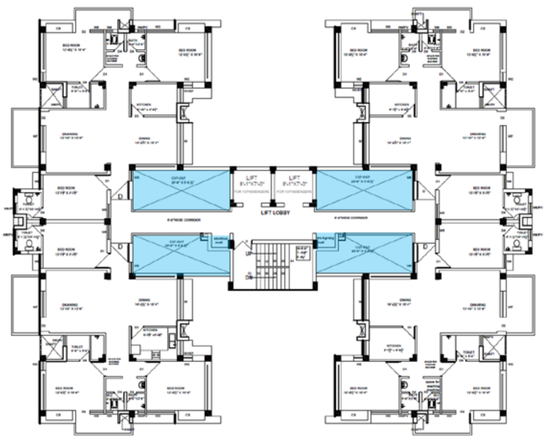

Figure 11:Typical floor plan for Project 7

* *The cost calculations are done as per CPWD DSR 2018. The rates are likely to vary significantly across the country.*

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h) Project 8: Composite climate

An under-construction apartment housing project located in Ghaziabad. A 26-storey block comprising of 240 dwelling units. The carpet area of these 3-BHK units are 74 m^2 per unit. Longer sides face E-W orientation (Figure 12).

- Shading: Balcony slabs and building projections acting as shading devices. East and west facades consist of box-type shading, openings with maximum area at north and south facades have overhangs shading the balcony openings. $SHGC_{equivalent}$= 0.56

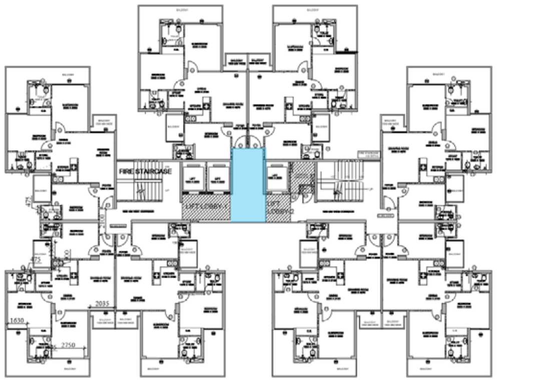

Figure 12:Typical floor plan for Project 8

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