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Energy use in Building Envelope of a Residential Apartment Building in the Warm and Humid Climate of Guwahati, Assam

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Abstract: ***In recent years, Guwahati city is witnessing a rapid urban growth due to ever-increasing human population sacrificing existing green pockets. This constant increase of built form is resulting in environmental imbalances and microclimate changes, contributing in a rise of indoor air temperature and that ultimately results a gradual increase in the energy consumption to maintain indoor thermal comfort in the inner-city areas. Although the urban growth pattern of Guwahati is controlled by prevailing GMDA building bye-laws, these building parameters are unable to control the organic growth of the city since there is no climate-sensitive approach available in the GMDA bye-laws. This paper aims to discuss the energy use in the building envelope by analysing the energy efficiency of a residential apartment building of Guwahati and reviews most common energy efficient codes that influences the heat gain or loss, natural ventilation, and day lighting, which, in turn, determines indoor temperatures, thermal comfort, and sensible cooling or heating demand inside urban residential buildings. Four relationships of building parameters are studied and analysed their impact on energy use. The amount of heat gain or loss, natural ventilation and day lighting that are allowed by building envelop will be calculated for each relationships and compared. All the relationships specify building envelope design that helps to improve the energy efficiency in residential building, but none suggested a basis for its proportion. This paper analyses the use of daylight and natural ventilation within a building envelope helps to minimise the energy consumption. A climate conscious urban design approach associating common energy codes such as window to floor area (WFR) ratio, Visual light transmittance (VLT) and residential envelope transmittance value (RETV) against average daylight and natural ventilation can be utilised as preliminary urban design techniques in development control regulations especially in the residential zones in the inner-city areas of Guwahati metropolitan development authority (GMDA).***

Keywords : Building envelope, energy efficiency, WFR ratio, RETV

I. INTRODUCTION

In recent years, sustainable development is the most crucial challenge we face in the urban scenario. Rapid and extensive urbanisation is leading to an uncontrolled urban heat island (UHI) effecting indoor and outdoor thermal comfort conditions in inner-city areas. High energy consuming and environmentally detrimental buildings are no longer being considered as sustainable. To achieve gradual improvements that are necessary in building performance, there should be a better association among all involved in buildings – the users, builders, governments, NGO's, teachers, architects and urban designers. Passive and low energy consuming climate responsive design significantly reduces the economic and environment costs of buildings. A climate responsive sustainable design is important at every level of human life. The energy consumption in residential sector is very high in India which is 22% and it is growing by 8% every year which is alarmingly high. To establish a minimum standard for energy efficient building design and construction of building, the energy conservation building codes (ECBC) are introduced by Bureau of energy efficiency (BEE). These energy efficient codes for buildings are important regulatory measures for calculating energy efficiency in the building. These energy codes regulates a minimum standard of energy efficiency in building envelope in different climatic zones of India and sets up five correlations between parameters of building envelope and daylight or ventilation factor. The building envelope consists of walls, roof, and fenestration (openings including windows, doors, vents, etc.). Design proposal of building envelope influences heat gain or loss, natural ventilation, and day lighting which determines indoor temperatures, thermal comfort, and sensible cooling or heating demand. The building envelope has the highest impact on thermal comfort, and consequently on the energy use in residential buildings. It is also the permanent component of the building with the longest life cycle. An early and efficient introduction of this code in the GMDA building bye-laws will improve the sustainable design and development of new residential building stock of Guwahati in the near future. Introduction of these codes will appreciably reduce the anticipated energy demand for comfort cooling especially in the residential building sector in times to come. This decisive speculation in building envelope design and construction will harvest the benefits of reduced green house gas (GHG) emissions for the lifetime of the buildings. This study initiates to study and analyse the energy use of a residential housing complex in Guwahati using energy codes to check the code of energy efficiency compliances of the dwelling units of the residential neighbourhood.

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II. ENERGY EFFICIENT BUILDING CODE

Energy-efficient building code sets minimum performance standards for building envelope to limit heat gains for cooling dominated climates and heat loss for heating-dominated climates. Building Envelope is the element of a building that separates the habitable spaces of dwelling units from the exterior and is exposed directly to external air and solar radiation. It has window openings in outer surface wall and door openings into balconies. Envelope area (excluding the roof) of the building is the gross external wall area including the area of the openings such as windows and doors, where measurement is taken horizontally from outside surface to outside surface and vertically from the ground level to the top of the roof level. This code gives specific and clear provisions for building envelope, thermal transmittance value as follows:

- Building Envelope excluding roof provides
  - Maximum value of residential envelope transmittance value (RETV) for building envelope excluding roof applicable for Composite Climate, hot-Dry Climate, Warm-humid Climate, and temperate Climate.
  - Maximum value of thermal transmittance of building envelope excluding roof for Cold Climate zone ($U_{envelope,cold}$).
- Roof of the building envelope provides maximum value of thermal transmittance of roof (U_{roof}) for all climate zones.

Energy efficient code also proposes minimum building envelope performance standard for adequate natural ventilation potential by specifying minimum openable window-to-floor area ratio (WFR_{op}) and minimum building envelope performance standard for sufficient daylight probability by specifying minimum visible light transmittance (VLT) for the non-opaque building envelope components.

This energy efficient building code specifies any building in which sleeping space is provided for normal residential purposes with cooking and dining facilities as residential buildings. It also narrates that there are two types of residential building.

1. One or two family individual houses include any residential house, which is occupied by members of one or two families and has total sleeping spaces for not more than 20 persons.
2. Apartment buildings are the structures within which residential units are accommodated for more than two families, living separately of each other and with independent cooking facilities.

A. Provisions of energy efficient building code

The energy efficient building code provides five relationships of building parameters that helps to calculate the energy use of the building envelop and determines the energy efficiency of the building. The provisions are as follows:

i. Openable window-to-floor area ratio (WFR_{op})

Openable window-to-floor area ratio indicates the potential use of external air for ventilation. A minimum value of WFR_{op} for different climatic zones ensures proper natural ventilation, improvement in thermal comfort, and reduction in cooling energy use. WFR_{op} is that the ratio of openable area of openings (windows, ventilators and door) to the carpet area of dwelling units.

$$WFR_{op} = A_{openable} / A_{carpet}$$

Where,

$A_{openable}$: It includes the openable area (m^2)of all windows and ventilators, opening directly to the external air, and the openable area of the doors opening directly into an open balcony.

A_{carpet} : It is the net usable floor area (m^2) of a dwelling unit, excluding the area covered by the external walls, services shafts, balcony area but includes the area covered by the internal partition walls of the dwelling unit.

The national building code (NBC) 2016 specifies minimum WFR percentage for different five climatic zones of India as shown in table: 1. For warm and humid climate of Guwahati, the minimum WFR specification is 16.66 %.

Table: 1 Minimum requirement of $WFR_{op\ for}$ different climatic zones

Climatic Zone	Minimum WFR_{op} (%)
Composite	12.50
Hot-Dry	10.00
Warm and Humid	16.66
Temperate	12.50
Cold	8.33

Source: National Building Code of India 2016

ii. Visible light transmittance (VLT)

Visible light transmittance (VLT) of non-opaque building envelope components indicates the potential use of daylight in building envelope. A minimum value of VLT for different climatic zones ensures in improving day lighting inside the building envelope, thereby reducing the energy required for artificial lighting**.** The VLT requirement is applicable as per the window-to-wall ratio (WWR) of the building. WWR is the ratio of the area of non-opaque building envelope elements of dwelling units to the envelope area (excluding roof) of dwelling units.

$$WWR = A_{non\text{-}opaque} / A_{envelope}$$

The national building code (NBC) 2016 specifies minimum VLT percentage for different WWR ratios as shown in table: 2. WWR and VLT are inversely proportional means as the WWR ratio goes higher the VLT percentage goes lower.

Table: 2 Minimum requirement of VLT for different WWR

Window to Wall Ratio (WWR)	Minimum VLT (%)
0 - 0.15	40
0.16 - 030	27
0.31 – 0.40	20
0.41 – 0.50	16
0.51 – 0.60	13
0.61 – 0.70	11

Source: National Building Code of India 2016

iii. Thermal transmittance of roof (Uroof)

Thermal transmittance (U_{roof}) indicates the thermal performance of the roof of a building. Restricting the U_{roof} helps in reducing heat gains or losses from the roof, by this means improve the indoor thermal comfort and reduce the overall energy consumption for cooling or heating of the dwelling units.

BEE proposes that the thermal transmittance of roof shall conform to the maximum U_{roof} value of 1.2 W/m^2K.

$U_{roof} = 1 / A_{roof}$

Where,

A_{roof} : Total area of the roof (m^2)

U_i : Thermal transmittance values of different roof constructions ($W/m^{2o}C$)

A_i : Areas of different roof constructions (m^2)

iv. Residential envelope transmittance value (RETV) for building envelope (excluding roof)

Residential Envelope Heat Transmittance (RETV) is the net heat gain rate (over the cooling period) through the building envelope (excluding roof) of the dwelling units divided by the surface area of the building skeleton cover (excluding roof) of the residential units. The unit of RETV is W/m^2.

RETV formula takes into account three major factors as follows:

- Heat conduction through opaque building envelope components such as wall, opaque panels in doors, windows, ventilators, etc.
- Heat conduction through non-opaque building envelope components such as transparent/translucent panels of windows, doors, ventilators, etc.
- Solar radiation through non-opaque building envelope components such as transparent/translucent panels of windows, doors, ventilators, etc.

The maximum RETV for the building envelope (excluding roof) for four climatic zones of India such as Composite Climate, hot-Dry Climate, Warm-humid Climate, and temperate Climate is 15 W/m^2**.**

$$RETV = 1/ A_{envelope} X \ [\{ a X (A_{opaque} X U_{opaque} X w_i)\} + \{ b X (A_{non\text{-}opaque} X U_{non\text{-}opaque} X w_i)\} + \{ c X (A_{non\text{-}opaque} X U_{non\text{-}opaque} X w_i)\}]$$

Where,

$A_{envelope}$: Building envelope area (excluding roof) of residential accommodations (m^2)

A_{opaque} : Areas of different opaque building envelope components (m^2)

U_{opaque} : Thermal transmittance values of different opaque building envelope components ($W/m^{2\,o}C$)

$A_{non\text{-}opaque}$: Areas of different non-opaque building envelope components (m^2)

$U_{non\text{-}opaque}$: Thermal transmittance values of different non - opaque building envelope components ($W/m^{2\,o}C$)

$SHGC_{eqi}$: Equivalent Solar Heat Gain Coefficient values of different non-opaque building envelope components

W_i : Orientation factor of respective opaque and non-opaque building envelope components; it is a measurement of direct and diffused solar radiation received on the vertical surface in a specific orientation The national building code (NBC) 2016 specifies different value for coefficient a, b, and c for REVT formula as shown in table: 3 for five different climatic zone of India.

Table: 3 Coefficients (a, b, and c) for RETV formula

Climate Zone	a	b	c
Composite	6.06	1.85	68.99
Hot-Dry	6.06	1.85	68.99
Warm-Humid	5.15	1.31	65.21
Temperate	3.38	0.37	63.69

Source: National Building Code of India 2016

v. Thermal transmittance of building envelope (excluding roof) for cold climate (Uenvelope,cold)

Thermal transmittance ($U_{envelope,cold}$) characterizes the thermal performance of the building envelope (excluding roof). Restraining the $U_{envelope,cold}$ helps in reducing heat losses from the building envelope, thereby improving the thermal comfort and reducing the energy required for heating.

The thermal transmittance of the building envelope (excluding roof) for cold climate should comply with the maximum of 1.8 $W/m^{2o}C$.

$U_{envelope,cold} = 1 / A_{envelope,cold}$

Where,

$A_{envelope,cold}$: Total area of the building envelope (m^2)

U_i : Thermal transmittance values of different roof constructions ($W/m^{2o}C$)

A_i : Areas of different roof constructions (m^2)

III. CHECKING OF ENERGY EFFICIENT CODE OF COMPLIANCES

A. Case study area: National games village at Borsojai, Guwahati

The case study area is a housing complex comprising of 22 residential apartment building blocks of size 25.00m x 20.50m. All the building blocks are G+6 storied with a height of 21.6m from existing ground level. This housing complex was developed in the year 2006 to accommodate 616 dwelling units following the prevailing urban zoning code and building regulations of GMDA. The residential complex is selected for case study because the construction technique of this complex was unique of its kind where 150mm thick RCC shear walls were used instead of conventional RCC Column beam frame structure for speedy construction and to become more earth quake resistant. No conventional brick works were used for wall paneling. Buildings are housed from the ground floor itself. No stilt floor was proposed for car parking not to allow any soft-story formation. Car parking was proposed in steel structures covered with pre-coated iron roofing sheet. All the Structures are standing over a group of 25m long pile foundations with a diameter of 500mm.

Fig: 1 Existing views of housing complex of national games village

Fig: 2 Existing views of housing complex of national games village

The residential complex of National games village is analysed to comply with the energy efficient building code. Each residential tower of the complex has 28 dwelling units and the carpet area of each dwelling unit (DU) is 105.00 m^2. There are three types of windows (W1, W2, and W3), a type of door (D) and ventilator type (V) in each DU exposed to ambient temperature and external air. The windows are fully glazed and are sliding windows. The door is opaque with Block board Flush Door. Each DU has two ventilators (V) in the toilets, which face an exterior wall.

Fig: 3 Floor plan of residential apartment building of National Games Village

Fig: 4 Plan of Typical Dwelling Unit of National Games Village

B. Area calculation of each type of exposed doors, windows, and ventilators

The detail area calculation of exposed door, windows, and ventilator are shown in table: 4. Transparent area and opaque area for each opening are calculated and shown separately.

Table: 4 Details of exposed doors, windows, and ventilators

opening window/ door/ ventilator	opening width (m)	opening height (m)	opening area (m^2)	width of glass in opening (m)	height of glass in opening (m)	Glass area in opening (m^2)	opaque area (m^2)
W1	1.00	1.80	1.80	0.84	1.68	1.41	0.39
W2	1.50	1.80	2.70	1.30	1.68	2.18	0.52
W3	1.00	1.40	1.40	0.84	1.28	1.08	0.32
D	0.90	2.1	1.89	0.00	0.00	0.00	1.89
V	0.60	0.90	0.54	0.48	0.78	0.37	0.17

Fig: 5 East side and north side elevation

Fig: 6 West side and south side elevation

C. Construction materials

Mainly RCC is used as primary building materials in the construction of different elements of building envelope. The details of various materials used in the building envelope are shown in the Table: 5.

Table: 5 Construction materials of the DU

Building element	Composition	Thickness (mm)
External Wall	Outside Cement Plastering	25 mm
	RCC wall	150 mm
	cement plastering	15 mm
Internal wall	Cement Plastering	15 mm
	RCC wall	150 mm
	Cement Plastering	15 mm
Roof Slab	Tiles flooring	50 mm
	RCC slab	125 mm
	Cement Plastering	15 mm
Flooring	Tiles flooring	50 mm
	RCC slab	125 mm
	Cement Plastering	15 mm
Door	Wood	40 mm
Window	Glazing	4 mm

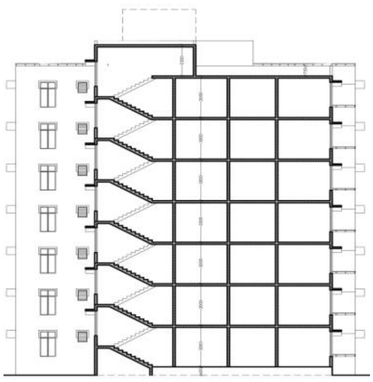

Fig: 7 Section of the apartment block

IV. METHODOLOGY

Every of the 22 residential towers needs to conform to the code for the building project to be compliant. Although the towers are identical, their orientations differ. The longer walls of Block 1-18 face north-south, i.e., 0° and 180°. Blocks 19-22 face 90° and 270°. As per Figure: 3.6.3.2, Blocks 1-18 can be considered having the same orientation. Thus, for this project, compliance can be analysed for Block - 11. Since Guwahati falls in the warm and humid climatic zone the code compliance is done in following 4 steps:

Step-1: Openable window-to-floor area ratio will be calculated from the data available from the apartment block and compare the result with the minimum WFR_{op} values as suggested by National building code (NBC)

Step-2: window-to-wall ratio (WWR) of non-opaque building envelope components will be calculated from the data available and related value of VLT will be compared with the prescribed value of VLT of non opaque component.

Step-3: Thermal transmittance (U value) of roof shall be calculated from the building data and compare the result with the maximum U_{roof} value as suggested by national building code (NBC).

Step-4: Residential envelope transmittance value (RETV) for building envelope (excluding roof) shall be calculated from the building data and compare with the maximum RETV suggested by NBC

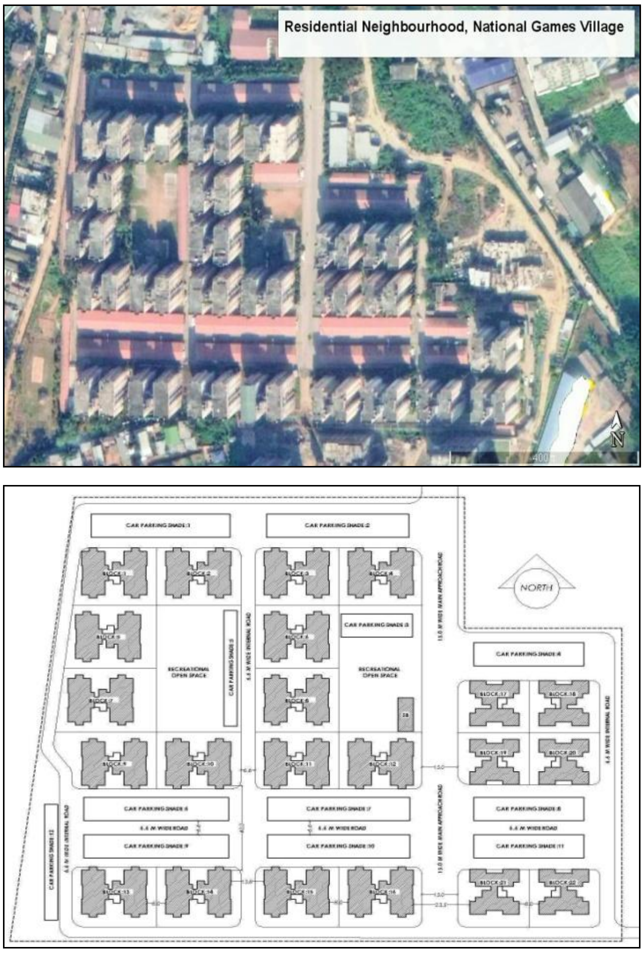

Fig: 8 Master plan of National Games Village, Borsajai, Guwahati

A. Orientation Factor

The orientation factor (ω) is a measure of the amount of direct and diffused solar radiation that is received on the vertical surface in a particular orientation. This factor accounts for and gives weight age to the fact that the solar radiation falling on different orientations of walls is not same. It has been defined for the latitudes ≥23.5˚N and latitudes <23.5˚N (Table: A.1). Table: 6 should be read in conjunction with Figure: 9.

Table: 6 Orientation factor (ω) for different directions

Orientation	Latitudes ≥23.5˚N	Latitudes <23.5˚N
North (337.6˚–22.5˚)	0.550	0.659
North-east (22.6˚–67.5˚)	0.829	0.906
East (67.6˚–112.5˚)	1.155	1.155
South-east (112.6˚–157.5˚)	1.211	1.125
South (157.6˚–202.5˚)	1.089	0.966
South-west (202.6˚–247.5˚)	1.202	1.124
West (247.6˚–292.5˚)	1.143	1.156
North-west (292.6˚–337.5˚)	0.821	0.908

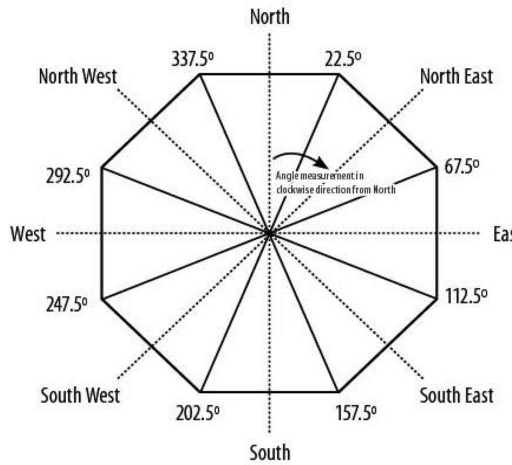

Fig: 9 Primary orientations for determining the orientation factor W

V. RESULTS

The longer sides of this Block-11 face north-south. It has 28 dwelling units (DUs) in seven floors (Fig: 4 and 5) , 4 DUs on each floor (Fig: 3) . Half of the DUs face north and the rest face south. Proper orientation of the building is expressed by the study of the proportion of exposed façade areas. The following Table: 7 show the study and observations of the percentage of facade areas exposed in different directions.

The total envelope area (excluding roof) of one 3 BHK apartment block (all four sides) = 3132.00 m^2.

Table: 7 Envelope area of the building

orientation	total wall length (m),	total wall height (m),	Envelope area (m^2)	%	Remarks
North	51.50	21.60	1112.40	35.52%	The percentage of north and south exposure of the building is more compared to the east and west exposure.
South	51.50	21.60	1112.40	35.52%	
East	21.00	21.60	453.60	14.48%	
West	21.00	21.60	453.60	14.48%	
Envelope area (m^2), excluding roof			3132.00		

A. Checking of Openable window-to-floor area ratio (WFR_{op})

a.1 Calculation of total openable area ($A_{openable}$)

Each floor consists of 4 DUs with 30 windows, 8 doors openings to the balcony, and 8 ventilators. As all of them are Sliding openings, 50% and 67% of the opening area is considered openable.

Table: 8 Openable area calculation

opening name	opening area (m^2)	openable area (m^2)	Nos of Opening	Total openable Area (m^2)	Remarks
W1	1.80	0.90	8	7.20	50% openable
W2	2.70	1.80	18	32.40	67% openable
W1	1.40	0.70	4	2.80	50% openable
D	1.89	1.70	8	13.60	90% openable
V	0.54	0.27	8	2.16	50% openable
Openable area of each floor				58.16	
Openable area of building envelope (28 DUs)				407.12	

a.2 Calculation of total carpet area (A_{carpet})

A_{carpet} = no. of Floors x carpet area of 1 Floor (including lobby area) = 7 x 431.10 = 3017.70 m^2

a.3 Calculation of the openable window-to-floor area ratio (WFR_{op})

$WFR_{op} = A_{openable} / A_{carpet} =$ 407.12 / 3017.70 = 13.47%

The result shows the window-to-floor area ratio (WFR_{op}) is 13.47% which is less than the minimum NBC norms of 16.66% for warm and humid climate zone if India (table:1). This indicates that the ventilation inside the rooms is less resulting use mechanical ventilation inside the rooms and hence increases in energy consumption.

B. Checking of Visible light transmittance (VLT)

b.1 Calculation of window-to-wall ratio (WWR)

There are seven windows, two doors and two ventilators in each DU exposed to ambient and two windows in the common areas. The windows are fully glazed. The doors are opaque with Block board panel. There are three types of windows W1,W2, and W3, one type of door D and ventilator V. windows are glazed anodized aluminum sliding windows, ventilator is glazed louvered ventilator and door is opaque type laminated flush door. These three openings are considered for WWR calculation.

Table: 9 Calculation of Window-to-Wall Ratio

orientation	opening name	opening area (m^2)	Non-opaque (glass) area in opening (m^2)	No. of openings	total opening area (m^2)	total non-opaque (glass) area (m^2)
North	W1	1.80	1.41	14	25.20	19.74
North	W2	2.70	2.18	21	56.70	45.78
North	D	1.89	0.00	14	26.46	0.00
North	V	0.54	0.37	14	7.56	5.18
East	W1	1.80	1.41	14	25.20	19.74
East	W2	2.70	2.18	42	113.40	91.56
East	W3	1.40	1.08	14	19.60	15.12
East	D	1.89	0.00	14	26.46	0.00
East	V	0.54	0.37	14	7.56	5.18
South	W1	1.80	1.41	14	25.20	19.74
South	W2	2.70	2.18	21	56.70	45.78
South	D	1.89	0.00	14	26.46	0.00
South	V	0.54	0.37	14	7.56	5.18
West	W1	1.80	1.41	14	25.20	19.74
West	W2	2.70	2.18	42	113.40	91.56
West	W3	1.40	1.08	14	19.60	15.12
West	D	1.89	0.00	14	26.46	0.00
West	V	0.54	0.37	14	7.56	5.18
				Total	616.28	404.60

b.2 WWR = $A_{non\ opaque} / A_{envelope}$ = 404.60 / 3132.00 = 0.129

The result of window to wall area ration (WWR) is 0.129 which suggests a minimum visual transmittance value (VLT) as per NBC norms is 40% (table:2). Here, VLT of the glass used is 80% and hence the it comply with the code.

C. Checking of thermal transmittance of roof (Uroof)

c.1 Calculation of thermal transmittance of roof (U_{roof})

The roof of this building comprises of five different layers of different thicknesses. Ceramic tile, PCC concrete for slope, cement screed with water proofing materials, RCC slab and internal cement plastering are used for the construction of the roof of this building. These construction materials are having different thermal conductivity value K. Detail U value calculations of the roof is shown in the table: 10.

Table: 10 U value calculations of roof

Sl. No	Building Component	Conductivity-K ($W/m^2\ ^oC$)	Thickness – D in M	R=D/K ($m^2\ ^oC/W$)
R_1	Ceramic tile	0.008	1.500	0.005
R_2	Concrete (laid to slope)	0.075	1.740	0.043
R_3	Cement screed	0.020	0.720	0.028
R_4	RCC slab	0.150	1.580	0.095
R_5	Internal plaster	0.015	0.720	0.021
R_{SE}	External surface Resistance			0.04
R_{SI}	Internal surface Resistance			0.17
Sum of all material thermal resistance, $R = R_{SI} + R_{SE} + R_1 + R_2 + R_3 + R_4 + R_5$				0.402
U value =1/R				2.49 $W/m^2\ ^oC$

c.2 The thermal Transmittance of roof, U_{roof} value = 2.49 $W/m^2\ ^oC$

The result of U_{roof} value is 2.49 $W/m^2\ ^oC$ which is very high than the maximum BEE norms of 1.2 $W/m^2\ ^oC$ for warm and humid climate. This indicates increase in indoor air temperature inside the building which results more energy consumption.

D. RETV of the building envelope (excluding roof)

d.1 Calculation of building envelope area

The table: 11 shows the detail area calculation of different building envelope elements in every direction. U values of various elements are also shown.

Table: 11 Calculation of envelope area for each orientation

Orientation	Building envelope elements	area (m^2)	U value ($w/m^2.K$)
North	Non-opaque (glass) area	70.62	5.80
	Opaque area 1 (RCC wall)	1015.32	2.49
	Opaque area 2 (Block Board panel in doors)	26.46	4.97
East	Non-opaque (glass) area	131.60	5.80
	Opaque area 1 (RCC wall)	295.54	2.49
	Opaque area 2 (Block Board panel in doors)	26.46	4.97
South	Non-opaque (glass) area	70.62	5.80
	Opaque area 1 (RCC wall)	1015.32	2.49
	Opaque area 2 (Block Board panel in doors)	26.46	4.97
West	Non-opaque (glass) area	131.60	5.80
	Opaque area 1 (RCC wall)	295.54	2.49
	Opaque area 2 (Block Board panel in doors)	26.46	4.97
Total Envelop Area, $A_{envelop}$		3132.00	

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d.2 Total Envelope Area, $A_{envelepe}$ = 3132.00

d.3 Calculation of RETV of building envelope (excluding roof)

Guwahati is in the Warm and Humid climatic zone. Thus, the national building code (NBC) 2016 suggests the RETV equation, with applicable coefficients, is as follows: where a = 5.15, b = 1.31 and c = 65.21 (table: 3)

RETV = 1/ $A_{envelope}$ X [{ 5.15 X (A_{opaque} X U_{opaque} X w_i)} + {1.31 X ($A_{non-opaque}$ X $U_{non-opaque}$ X w_i)} + {65.21 X ($A_{non-opaque}$ X $U_{non-opaque}$ X w_i)}]

Table: 12 Calculation of 3 terms of RETV formula

Calculation for TERM-I

orientation	component	(a) area (m^2)	(b) U value ($w/m^{2o}C$)	(c)orientation factor*	(a) x (b) x (c)
North	Opaque area 1 (RCC wall)	1015.32	2.49	0.550	1390.48
	Opaque area 2 (Door Panel)	26.46	4.97	0.550	72.33
East	Opaque area 1 (RCC wall)	295.54	2.49	1.155	849.96
	Opaque area 2 (Door Panel)	26.46	4.97	1.155	151.89
South	Opaque area 1 (RCC wall)	1015.32	2.49	1.089	2753.15
	Opaque area 2 (Door Panel)	26.46	4.97	1.089	135.43
West	Opaque area 1 (RCC wall)	295.54	2.49	1.143	841.13
	Opaque area 2 (Door Panel)	26.46	4.97	1.143	150.31
				TERM-I Total	6344.68

Calculation for TERM-II

orientation	component	(a) area (m^2)	(b) U value (w/m^2.K)	(c) orientation factor*	(a) x (b) x (c)
North	Non-Opaque area 2 (Glass Panel)	70.62	5.80	0.550	255.28
East	Non-Opaque area 2 (Glass Panel)	131.60	5.80	1.155	881.59
South	Non-Opaque area 2 (Glass Panel)	70.62	5.80	1.089	446.05
West	Non-Opaque area 2 (Glass Panel)	131.60	5.80	1.143	872.43
				TERM-II Total	2455.35

Calculation for TERM-III

orientation	component	(a) area (m^2)	(b) Equivalent SHCG	(c) orientation factor	(a) x (b) x (c)
North	W1	19.74	.560	0.550	6.08
North	W2	45.78	.607	0.550	15.28
North	V	5.18	.451	0.550	1.28
East	W1	19.74	.537	1.155	12.24
East	W2	91.56	.559	1.155	59.12
East	W3	15.12	.529	1.155	9.24
East	V	5.18	.428	1.155	2.56
South	W1	19.74	.414	1.089	8.90
South	W2	45.78	.458	1.089	22.83
South	V	5.18	.318	1.089	1.79
West	W1	19.74	.564	1.143	12.73
West	W2	91.56	.478	1.143	50.02
West	W3	15.12	.527	1.143	9.11
West	V	5.18	.441	1.143	2.61
				TERM-III Total	213.79

d.4 RETV = 1/3132 X [(5.15 X 6344.68) + (1.31 X 2455.35) + (65.21 X 213.79)] = 15.91 W/m^2

Residential envelope transmittance value (RETV) for the apartment block is found out to be 15.91 W/m^2 which is more than the maximum allowable RETV of 15 W/m^2 as per NBC. This result indicates a higher indoor air temperature inside the building envelope that will lead to indoor thermal discomfort, resulting more use of mechanical ventilation systems during summer months and hence energy consumption will be high. The following table: 13 show the result of four relationships of building parameters used as energy codes that influences the indoor thermal comfort condition and energy efficiency in residential building.

Table: 13 Results of various energy codes

Energy code	Study result	NBC norms	Remark
WFR_{op}	13.47%	16.66%	resulting increase in Energy consumption
VLT	80%	40%	OK
U_{roof} value	2.49 W/m^2 ^oC	1.2 W/m^2 ^oC	resulting increase in Energy consumption
RETV	15.91 W/m^2	15.00 W/m^2	resulting increase in Energy consumption

VI. ANALYSIS AND DISCUSSION

Guwahati falls under the Warm and Humid climatic zone of India. Due to the presence of high humidity, indoor spaces of building envelope requires sufficient cross ventilation to maintain a suitable thermal comfort condition. National building code (NBC) 2016 suggests a minimum WFR_{op} for this climate is 16.66 % as shown in the table: 2.1. Since the WFR_{op} of the block-11 is found to be 13.47%, it is below the minimum requirement of NBC norms of 16.66%. The ventilation rate inside the building is not sufficient enough to ventilate out the hot air naturally and require artificial ventilation to bring down the temperature to a comfort level that increases the energy consumption. Thus, the housing complex of National games Village at Borsajai, Guwahati does not comply with the WFR_{op} requirement. Window area of the dwelling units is required to be increased to meet the minimum NBC standard to get more natural ventilation and to reduce energy consumption during summer months. National building code (NBC) 2016 suggests that the minimum VLT required for WWR of 0.129 (range 0–0.30) is 40% as shown in table: 4.3.1.1. The glass used in this project has a VLT of 80% (as per certified specification for the product). The building envelope gets sufficient daylight during the day and does not required artificial lighting inside the rooms. Thus; the WWR of this project complies with the minimum standard norms of NBC 2016. Also, it complies with the recommended value. The National building code suggests that the maximum transmittance value for roof of the residential building U_{roof} in warm and humid climate is 1.2 W/m^2 ^oC. In this case study, the calculated U_{roof} value of roof is found out to be 2.47 W/m^2 ^oC which is very higher than the NBC value. Hence it does not comply with the standard norms suggested by NBC. The dwelling units are thermally uncomfortable during summer as well as winter since heat transfer is very high. Building is not energy efficient during summer as the energy consumption is very high. RETV value of block-11 of residential complex of National games village, Borsajai, Guwahati is 15.91 W/m ^{2} that is more than the maximum allowable RETV of 15 W/m^2 as suggested for warm and humid climate zone in NBC. Hence the building envelope of residential block-11 does not comply with RETV requirement. Thus the mean radiant temperature (MRT) of indoor spaces will be very high during summer months and mechanical ventilation or cooling will be required to maintain thermal comfort inside the apartment building. This will lead to more energy use during summer.

It has been observed that due to the use of RCC concrete in the external wall instead of conventional clay brick the U value (2.77 W/m^2 ^{O}C) of the external wall is very high as compared to brick wall and that is found to be the primary reason of high RETV value of the building blocks.

VII. CONCLUSION

This research paper discussed and analysed four relationships of building parameters that influences the energy use in the building envelope of residential apartment building in the warm and humid climate of Guwahati. The study concludes in general that the efficient use of these relationships of building parameters can provide sufficient indoor thermal comfort especially residential apartment buildings of Guwahati. These energy codes can help to develop a climate conscious urban development approach in reducing overall energy consumption especially in the residential buildings of Guwahati. Incorporating these energy codes in prevailing GMDA bye-laws can provide more access to daylight and natural ventilation inside building and enhance the thermal efficiency in buildings. This will reduce the environmental imbalance and urban microclimate changes of Guwahati city leading to a climate conscious growth of the city fabric.

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