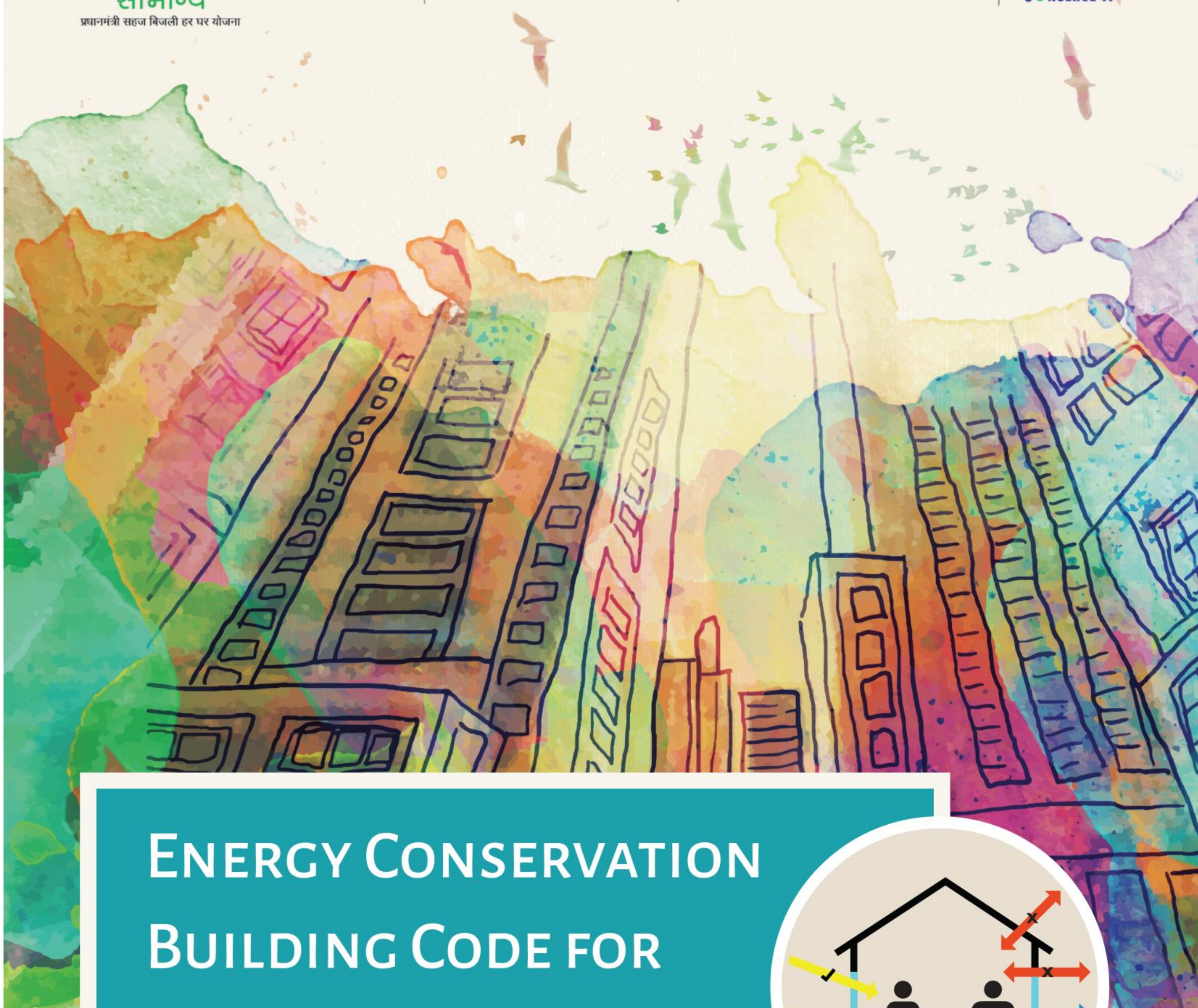
Ministry of Power
Government of India



Energy Conservation Building Code for Residential Buildings 2017

Part I: Building Envelope

Draft for Comments

BEEP
BUILDING ENERGY EFFICIENCY PROJECT

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Agency for Development and Cooperation SDC

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Chapter 1. Background

1.1 India's Nationally Determined Contributions commit to reducing emission intensity of its GDP to 35% below 2005 levels by 2030. Any effort to achieve this target is contingent upon the increase in efficiency of energy use across all sectors, especially in the building sector. The building sector in India consumes over 30% of the total electricity consumed in the country annually and is second only to the industrial sector as the largest emitter of greenhouse gases. Building energy codes for new buildings are an important regulatory measure for ushering energy efficiency in the building sector. They are particularly relevant for countries like India where the building stock is rising rapidly. The commercial sector among buildings has been addressed by the Energy Conservation Building Code (ECBC) for Commercial Buildings. The first version of ECBC was released in 2007 and a revised version was issued in June 2017. Given the current and anticipated rapid growth in residential building stock across India and the consequent opportunities as well as the necessity for energy conservation in this sector the Energy Conservation Code for Residential Buildings is being established by the Ministry of Power.

1.2 Out of the total electricity consumed in the building sector, around 75% is used in the residential buildings. The gross electricity consumption in residential buildings has been rising sharply – it was around 50 TWh in 1995 and has increased by more than four times in next 20 years and was around 220 TWh in 2015. Projections show it rising to anywhere between 600 -900 TWh by 2030. Among various reasons, increased use of decentralized room based air conditioning units in homes is one of the important reasons contributing to this rapid increase in the electricity use in residential buildings. This increasing demand for air-conditioned thermal comfort, that will continue its exponential growth with improvement in household incomes, will become the most contributor to GHG emissions nation-wide. This calls for an urgent and immediate energy conserving action plan.

1.3 Building envelope consists of the walls, roof, windows and fenestration. Major parts of India have hot and humid climates. Research presented in the National Building Code (NBC) and Handbook on Functional Requirement for Buildings (SP: 41), both published by the Bureau of Indian Standards, has established a direct correlation between the design of building envelop and the heat gains from the building envelope. Heat gains in turn determine the indoor temperatures, thermal comfort and sensible cooling demand. Current designs of building envelope are often not guided by considerations of heat gain and resultant cooling requirement to achieve indoor thermal comfort. It is seen current practices of residential buildings design and construction show a large variation in heat gains and hence in the sensible cooling demand. The ratio between the minimum to maximum sensible cooling demand can vary by as much as 1:4.

1.4 The production of residential building stock in urban areas is shifting quickly toward multi-storey residential buildings from the earlier mode of building individual homes. It is expected that, with the economics of land and the need for cities to be geographically compact, multi-story residential buildings will be the dominant form of meeting the demand for housing in urban areas. This will be the trend for housing for people across the socio-economic spectrum, from low-income to the middle and high-income categories. This form of housing will be in the formal sector and subject to the building byelaws and urban development regulations of the Local Urban Bodies (ULBs). Importantly, a large section of the multi-storey housing e.g. Group

Housing will also be supported by the professional services of registered architects and engineers. The initiation of the Energy Conservation Building Code for Residential Buildings (Part I: Building Envelope Design), addresses this category of residential buildings.

1.4 Energy Conservation Building Code (Part I: Building Envelope Design) has been prepared to set minimum building envelope performance standards to limit heat gains (for hot climates) and to limit heat loss (for cold climate) as well as for ensuring adequate natural ventilation and day lighting. The code is applicable to all residential use building projects built on plot area ≥ 250 m^2. The code has been developed with special consideration for its adoption by the Urban Local Bodies (ULBs) into building byelaws. This strategy enables the majority of new urban housing stock to be brought into the net for capturing the opportunities and the benefits of energy efficiency in residential buildings.

1.5 The Part I – Building Envelope Design, is the first component of the Energy Conservation Building Code for Residential Buildings to be launched. Its early and immediate introduction is to improve the construction and design of new residential building stock, as it is being built currently and in the near future, to significantly curtail the anticipated energy demand for comfort cooling in times to come. This critical investment in envelope construction and design made today will reap benefits of reduced GHG emissions for the lifetime of the buildings.

1.6 The code is designed in a simple-to-apply format, requiring only arithmetic tabulation based on the architectural design drawings of the residential buildings. This will be usable by architects as well as engineers and will not require any specialized skills or simulation softwares. This also enables the Code to be readily adopted in the Building Byelaws and regulatory instruments such as Environmental Clearance for Large Projects.

1.7 In the subsequent years, new components will be added to the Energy Conservation Building Code for Residential Buildings, which will address other aspects such as, Energy Efficiency in Electro-Mechanical Equipment for Building Operation, Renewable Energy Generation, Embodied Energy of Walling Materials and Structural Systems.

Chapter 2. Scope

The code aims at limiting heat gains/loss from building envelope and for ensuring adequate natural ventilation and day lighting.

To limit the heat gain/loss from the building envelope, the code specifies:

- Maximum value of Residential Envelope Transmittance Value (RETV) for building envelope (except roof) applicable for four climate zones[1], viz. Composite Climate, Hot-dry Climate, Warm-humid Climate and Temperate Climate.
- Maximum value of thermal transmittance of building envelope (except roof) for Cold Climate zone ($U_{envelope,cold}$)
- Maximum value of thermal transmittance of roof (U_{roof}) for all climate zones

To ensure adequate natural ventilation, the code specifies

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

To ensure adequate day-lighting, the code specifies

- Minimum Visible Light Transmittance (VLT) for the non-opaque building envelope components

The code is applicable to all residential use building projects built on plot area ≥ 250 m^2. The type of building projects includes, but not limited to:

- Group housing projects[2]: Building unit or units constructed or to be constructed with one or more floors having more than two dwelling units having common service facilities where land is shared and commonly used by the dwelling units, and the construction is undertaken by one agency.
- Mixed Land Use Building projects[3]: With buildings partly used for non-residential uses and partly for residential use.
- Multi-dwelling unit building on residential plots.

[1] For climate classification refer to Annexure 6.
[2] Adapted from Model Building Bye-Law, 2016, TCP
[3] ibid

Chapter 3. Code Provisions

Residential Envelope Transmittance Value (RETV) for building envelope (except roof) for four climate zones, viz. Composite Climate, Hot-dry Climate, Warm-humid Climate and Temperate Climate

Residential Envelope Transmittance Value ($RETV$) for building envelope (except roof) for four climate zones, viz. Composite Climate, Hot-dry Climate, Warm-humid Climate and Temperate Climate, shall comply with the maximum $RETV$[4] of 15 W/m^2.

Residential Envelope Heat Transmittance ($RETV$) is the net heat gain rate (over the cooling period) through building envelope (excluding roof) divided by the area of building envelope (excluding roof). Its unit is W/m^2.

$RETV$ characterizes thermal performance of the building envelope (except roof). Limiting the $RETV$ value helps in reducing heat gains from building envelope, thereby improving thermal comfort and reducing the electricity required for cooling.

$RETV$ formula takes into account following:

i. Heat conduction through opaque building envelope components (wall, opaque panels in doors and windows, etc.),
ii. Heat conduction through non-opaque building envelope components (transparent/ translucent panels of windows, doors, etc.),
iii. Solar radiation through non-opaque building envelope components (transparent/ translucent panels of windows, doors, etc.)

$$RETV = A * (1 - WWR) * U_{opaque} + B * WWR * U_{non-opaque} + C * WWR * SHGC_{equivalent} \qquad (1)$$

where,

$RETV$: residential envelope transmittance value (W/m^2)

WWR: window-to-wall ratio; it is the ratio of the non-opaque building envelope components area to the envelope area (excluding roof) of dwelling units

U_{opaque}: thermal transmittance of opaque building envelope components (wall, opaque panels in doors and windows, etc.) (W/m^2.K)

$U_{non-opaque}$: thermal transmittance of non-opaque building envelope components (transparent/ translucent panels of windows, doors, etc.) (W/m^2.K)

$SHGC_{equivalent}$: equivalent solar heat gain coefficient; it is the fraction of incident solar radiation admitted through a non-opaque building envelope component including permanent external shading

[4] BEE plans to improve the RETV norm to 12 W/m^2 in near future and the building industry & regulating agencies are encouraged to aim for it.

projection, both directly transmitted, and absorbed and subsequently released inward through conduction, convection and radiation (for calculation, refer to Annexure 2)

$A, B \& C$: coefficients (values given in Table 1)

$RETV$ is calculated using the formula (Equation 1), with coefficients given in Table 1, for different climate zones (for classification, refer to Annexure 6).

Table 1: Coefficients for RETV formula

Climate zone	**A**	**B**	**C**
Composite / Hot-Dry	6.11	1.90	70.94
Warm-humid	5.19	1.34	66.70
Temperate	5.27	0.95	78.92

Thermal transmittance of building envelope (except roof) for cold climate ($U_{envelope,cold}$)

Thermal transmittance of building envelope (except roof) for cold climate shall comply with the maximum $U_{envelope,cold}$[5] of 1.8 W/m^2.K.

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

$U_{envelope,cold}$ takes into account the following:

i. Heat conduction through opaque building envelope components (wall, opaque panels in door and window, etc.),

ii. Heat conduction through non-opaque building envelope components (transparent/translucent panels in windows, doors, etc.),

$$U_{envelope,cold} = \frac{(U_{opaque} \times A_{opaque}) + (U_{non-opaque} \times A_{non-opaque})}{(A_{opaque} + A_{non-opaque})} \quad (2)$$

where,

$U_{envelope,cold}$: thermal transmittance of building envelope (except roof) for cold climate (W/m^2.K)

U_{opaque}: thermal transmittance of opaque building envelope components (W/m^2.K)

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

$U_{non-opaque}$: thermal transmittance of non-opaque building envelope components (W/m^2.K)

$A_{non-opaque}$: area of non-opaque building envelope components (m^2)

[5] BEE plans to improve the weighted U-value norm to 1.2 W/m^2.K in near future and the building industry & regulating agencies are encouraged to aim for it.

Thermal transmittance of roof (U_{roof})

Thermal transmittance of roof shall comply with the maximum U_{roof} value of 1.2 W/m²·K.

Thermal transmittance (U_{roof}) characterizes thermal performance of the roof of the building. Limiting the U_{roof} helps in reducing heat gains or losses from the roof, thereby improving thermal comfort and reducing the energy required for cooling or heating.

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

Openable window-to-floor area ratio shall comply with the minimum WFR_{op} values as given in Table 2.

Openable window-to-floor area ratio (WFR_{op}) indicates potential of using external air for ventilation. Ensuring minimum WFR_{op} helps in ventilation, improvement in thermal comfort and reduction in cooling energy.

The openable window-to-floor ratio (WFR_{op}) is the ratio of openable area to the built-up area of dwelling units.

$$WFR_{op} = \frac{A_{openable}}{A_{built-up}} \quad (3)$$

where,

WFR_{op}: openable window-to-floor ratio

$A_{openable}$: openable area (m^2); openable area of all windows and ventilators area, excluding doors, opening directly to the external air or into an open balcony or "verandah"

$A_{built-up}$: built-up area of dwelling units (m^2); the covered area of all dwelling units, including the area covered by walls, but excepting the balcony area

The openable window-to-floor area ratio, (WFR_{op}), shall not be less than the values given in Table 2.

Table 2: Minimum requirement of window-to-floor area ratio, WFR_{op}

Climatic Zone	Minimum WFR_{op}
Composite / Hot and dry	10.00%
Warm and humid	16.66%
Temperate	12.50%
Cold	8.33%

(Source: adapted from model building bye-laws, 2016)

Visible Light Transmittance (VLT)

Visible Light Transmittance (VLT) of the non-opaque building envelope components shall comply with the minimum VLT values as given in Table 3.

Visible Light Transmittance (VLT) of the non-opaque building envelope components (transparent/translucent panels in windows, doors, etc.), indicate the potential of using daylight. Ensuring minimum VLT helps in improving daylighting, thereby reducing the energy required for artificial lighting.

The glass used on non-opaque building envelope components (transparent/translucent panels in windows, doors, etc.) shall comply with the requirements given in Table 3. The VLT requirement is applicable as per the window-to-wall ratio of the building.

Table 3: Minimum Visible Light Transmittance (VLT) requirement

Window-to-wall ratio	**Minimum VLT**
WWR ≤ 20%	≥ 75%
20% <WWR ≤ 30%	≥ 50%
30% <WWR ≤ 35%	≥ 40%

Chapter 4. Code Compliance

Each building block in a project is required to comply with the code. For compliance following conditions shall be met.

Composite Climate, Hot-dry Climate, Warm-humid Climate and Temperate Climate

Step 1: Openable window-to-floor area ratio shall comply with the minimum WFR_{op} values as given in Table 2 of section 3.4. For calculation of WFR_{op} refer to Annexure 4.

Step 2: Visible Light Transmittance (VLT) of the non-opaque building envelope components shall comply with the minimum VLT values as given in Table 3 of section 3.5.

a) For calculation of WWR refer to Annexure 3.
b) Refer product specifications to know VLT of the transparent / translucent panels in windows and doors.

Step 3: Thermal transmittance of roof shall comply with the maximum U_{roof} value of 1.2 W/m^2.K (refer section 3.3). For checking the U value of typical roof or to calculate U values of roof, refer to Annexure 1.

Step 4: Residential Envelope Transmittance Value (RETV) for building envelope (except roof), shall comply with the maximum RETV of 15 W/m^2 (refer section 3.1)

a) Equation 1 is to be used for the calculation of RETV, with coefficients selected from Table 1 as per the climate zone.
b) For calculation of U values refer to Annexure 1.
c) For calculation of Equivalent SHGC refer to Annexure 2.
d) For calculation of WWR refer to Annexure 3.

An example of code compliance is given to Annexure 5 (Example 1).

Cold Climate

Step 1: Openable window-to-floor area ratio shall comply with the minimum WFR_{op} values as given in Table 2 of section 3.4. For calculation of WFR_{op} refer to Annexure 4.

Step 2: Visible Light Transmittance (VLT) of the non-opaque building envelope components shall comply with the minimum VLT values as given in Table 3 of section 3.5.

a) For calculation of WWR refer to Annexure 3.
b) Refer product specifications to know VLT of the transparent / translucent panels in windows and doors.

Step 3: Thermal transmittance of roof shall comply with the maximum U_{roof} value of 1.2 W/m^2.K (refer section 3.3). For checking the U value of typical roof or to calculate U values of roof, refer to Annexure 1.

Step 4: Thermal transmittance of building envelope (except roof) for cold climate shall comply with the maximum $U_{envelope,cold}$ of 1.8 W/m^2.K (refer section 3.2).

a) Equation 2 is to be used for the calculation of $U_{envelope,cold}$.
b) For calculation of U values refer to Annexure 1.

An example of code compliance is given to Annexure 5 (Example 2).

Annexure 1. Calculation of Thermal Transmittance (U value) of roof and wall

U values for typical wall and roof can be taken from Table 4 and Table 5. In case, U value has to be calculated, the procedure for calculation has been explained in A1.1.

Table 4: U value of typical wall

S. No.	Specification of wall	U value (W/m².K)	Source
1	1.25 cm cement plaster + 20.00 cm brick + 1.25 cm cement plaster	2.28	(1)
2	1.25 cm cement plaster + 22.5 cm brick + 1.25 cm cement plaster	2.13	(1)
3	1.25 cm cement plaster + 7.5 cm brick + 5.0 cm air gap + 7.5 cm brick + 1.25 cm cement plaster	1.80	(1)
4	1.25 cm cement plaster + 11.25 cm brick + 5.0 cm air gap + 11.25 cm brick + 1.25 cm cement plaster	1.55	(1)
5	1.25 cm cement plaster + 2.5 cm expanded polystyrene + 22.5 cm brick + 1.25 cm cement plaster	0.85	(1)
6	1.25 cm cement plaster + 22.5 cm brick + 2.5 cm expanded polystyrene + 1.25 cm cement plaster	0.85	(1)
7	20 cm dense concrete-hollow block (2 holes)	3.01	(1)
8	20 cm dense concrete-hollow block (3 holes)	2.79	(1)
9	1.25 cm cement plaster + 5 cm foam concrete + 11.25 cm concrete+ 1.25 cm cement plaster	0.99	(1)
10	1.25 cm cement plaster + 20 cm AAC Block + 1.25 cm cement plaster	0.78	(1)
11	1.25 cm cement plaster + 30 cm AAC Block + 1.25 cm cement plaster	0.55	(1)
12	15 cm monolithic concrete	3.50	(1)
13	20 cm Hollow burnt clay block – 750-850 kg/m³	1.30	(2)
14	20 cm Hollow burnt clay block – 694 kg/m³	1.00	(2)

Source:

(1) Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) SP: 41 (S & T) -1987

(2) https://wienerberger.in/facts/wall-solutions-porotherm-smart-bricks

Table 5: U value of typical roof

S. No.	Specification of roof	U value (W/m².K)	Source
1	100 mm RCC	3.59	(1)
2	100 mm RCC + 100 mm lime concrete	2.78	(1)
3	100 mm RCC + 50 mm foam concrete + waterproofing	1.08	(1)
7	100 mm RCC + 50 mm cinder concrete + 50 mm brick tile	2.07	(1)
8	100 mm RCC + 75 mm cinder concrete + 50 mm brick tile	1.76	(1)
9	115 mm RCC + 50 mm mud phuska + 50 mm brick tile	2.31	(1)
10	115 mm RCC + 75 mm mud phuska+ 50 mm brick tile	2.01	(1)
11	100 mm RCC + Inverted clay pots with mud phuska	2.344	(1)
12	100 mm RCC + Extruded polystyrene 25 mm-36 kg/m3	0.749	(1)
13	100 mm RCC + Extruded polystyrene 30 mm-36 kg/m3	0.658	(1)
14	100 mm RCC + Extruded polystyrene 40 mm-36 kg/m3	0.528	(1)

S. No.	Specification of roof	U value ($W/m^2.K$)	Source
15	100 mm RCC + Expanded polystyrene 25 mm-24 kg/m3	0.931	(1)
16	100 mm RCC + Expanded polystyrene 30 mm-24 kg/m3	0.823	(1)
17	100 mm RCC + Expanded polystyrene 40 mm-24 kg/m3	0.670	(1)
18	100 mm RCC + Expanded polystyrene 60 mm-24 kg/m3	0.482	(1)
19	100 mm RCC + Phenolic foam 25 mm-32 kg/m3	0.725	(1)
20	100 mm RCC + Phenolic foam 30 mm-32 kg/m3	0.641	(1)
21	100 mm RCC + Phenolic foam 40 mm-32 kg/m3	0.511	(1)
22	100 mm RCC + Polyurethane spray 25 mm-42 ± 2 kg/m3	0.664	(1)
23	100 mm RCC + Polyurethane spray 30 mm-42 ± 2 kg/m3	0.579	(1)

Source:

(1) NBC 2016: Part 11 Approach to Sustainability (Page.27)

A1.1 Calculation procedure for U value of wall and roof

a) Calculate thermal resistance R of each uniform material layer which constitutes the building component, as follows:

$$R_i = \frac{t_i}{k_i} \qquad (4)$$

where, R_i is the thermal resistance of material i, $m^2.K/W$
t_i is the thickness of material i, m
k_i is the thermal conductivity of material i, W/(m.K)

b) Find the total thermal resistance, R_T, as follows:

$$R_T = \frac{1}{h_i} + \frac{1}{h_o} + R_1 + R_2 + R_3 + \cdots \qquad (5)$$

where, R_T is the total thermal resistance, $m^2.K/W$
h_i is the inside air heat transfer coefficient, $W/(m^2.K)$
h_o is the outside air heat transfer coefficient, $W/(m^2.K)$
R_1 is the thermal resistance of material 1, $m^2.K/W$
R_2 is the thermal resistance of material 2, $m^2.K/W$
R_3 is the thermal resistance of material 3, $m^2.K/W$

Use these default values[6] for calculation,

$$h_i = 9.36\ W/(m^2.K)$$
$$h_o = 19.86\ W/(m^2.K)$$

Thermal conductivity of commonly used building material[7] is given in Table 6, which can be used to calculate thermal resistance (R value).

[6] Source: Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) SP: 41 (S & T) - 1987
[7] ibid

c) Calculate the thermal transmittance (or the overall heat transfer coefficient or U value) of a wall or roof assembly, as follows:

$$U = \frac{1}{R_T} \quad (6)$$

where, U is the overall heat transfer coefficient, W/(m^2.K)

In case, thermal conductivity values measured using the appropriate IS codes is available, those can also be used for calculations.

Table 6: Thermal Properties of Building and Insulating Materials

S.No.	Type of Material	Density	Thermal Conductivity	Specific Heat Capacity	Source
		kg/m^3	*W/m.K*	*kJ/kg.K*	
I. Building Materials					
1	Solid burnt clay brick	1,920	0.81 to 0.98	0.80	(1)
2	Solid burnt clay brick	1,760	0.71 to 0.85		(1)
3	Solid burnt clay brick	1,600	0.61 to 0.74		(1)
4	Solid burnt clay brick	1,440	0.52 to 0.62		(1)
5	Perforated burnt clay brick	1,520	0.631	0.99	(4)
6	Fly ash brick	1,650	0.856	0.93	(2)
7	Fly ash brick	1,240	0.639		(4)
8	Solid concrete block 25/50	2,427	1.396		(4)
9	Solid concrete block 30/60	2,349	1.411		(4)
10	Aerated autoclaved concrete (AAC) Block	642	0.184	0.79	(4)
11	Cement stabilized soil block (CSEB)	1700-1900	0.84-1.3	0.94-1.10	(5)
12	Dense concrete	2,410	1.74	0.88	(3)
13	RCC	2,288	1.58	0.88	(3)
14	Brick tile	1,892	0.798	0.88	(3)
15	Lime concrete	1,646	0.730	0.88	(3)
16	Mud *Phuska*	1,622	0.519	0.88	(3)
17	Cement mortar	1,648	0.719	0.92	(3)
18	Cement plaster	1,762	0.721	0.84	(3)
19	Gypsum plaster	1,120	0.512	0.96	(3)
20	Cellular concrete	704	0.188	1.05	(3)
21	AC sheet	1,520	0.245	0.84	(3)
22	GI sheet	7,520	61.06	0.50	(3)
23	Timber	480	0.072	1.68	(3)
24	Timber	720	0.144	1.68	(3)
25	Plywood	640	0.174	1.76	(3)
26	Glass	2,350	0.814	0.88	(3)
27	Tar felt (2.3 kg/m^2)		0.479	0.88	(3)
II. Insulating Materials					
1	Expanded polystyrene	16.0	0.038	1.34	(3)

S.No.	Type of Material	Density	Thermal Conductivity	Specific Heat Capacity	Source
		kg/m³	*W/m.K*	*kJ/kg.K*	
2	Expanded polystyrene	24.0	0.035	1.34	(3)
3	Expanded polystyrene	34.0	0.035	1.34	(3)
4	Foam glass	127.0	0.056	0.75	(3)
5	Foam glass	160.0	0.055	0.75	(3)
6	Foam concrete	320.0	0.070	0.92	(3)
7	Foam concrete	400.0	0.084	0.92	(3)
8	Foam concrete	704.0	0.149	0.92	(3)
9	Cork slab	164.0	0.043	0.96	(3)
10	Cork slab	192.0	0.044	0.96	(3)
11	Cork slab	304.0	0.055	0.96	(3)
12	Rock wool (unbonded)	92.0	0.047	0.84	(3)
13	Rock wool (unbonded)	150.0	0.043	0.84	(3)
14	Mineral wool (unbonded)	73.5	0.030	0.92	(3)
15	Glass wool (unbonded)	69.0	0.043	0.92	(3)
16	Glass wool (unbonded)	189.0	0.040	0.92	(3)
17	Resin bonded mineral wool	48.0	0.042	1.00	(3)
18	Resin bonded mineral wool	64.0	0.038	1.00	(3)
19	Resin bonded mineral wool	99.0	0.036	1.00	(3)
20	Resin bonded mineral wool	16.0	0.040	1.00	(3)
21	Resin bonded mineral wool	24.0	0.036	1.00	(3)
22	Exfoliated vermiculite (loose)	264.0	0.069	0.88	(3)
23	Asbestos mill board	1,397.0	0.249	0.84	(3)
24	Hard board	979.0	0.279	1.42	(3)
25	Straw board	310.0	0.057	1.30	(3)
26	Soft board	320.0	0.066	1.30	(3)
27	Soft board	249.0	0.047	1.30	(3)
28	Wall board	262.0	0.047	1.26	(3)
29	Chip board	432.0	0.067	1.26	(3)
30	Chip board (perforated)	352.0	0.066	1.26	(3)
31	Particle board	750.0	0.098	1.30	(3)
32	Coconut pith insulation board	520.0	0.060	1.09	(3)
33	Jute fibre	329.0	0.067	1.09	(3)
34	Wood wool board (bonded with cement)	398.0	0.081	1.13	(3)
35	Wood wool board (bonded with cement)	674.0	0.108	1.13	(3)
36	Coir board	97.0	0.038	1.00	(3)
37	Saw dust	188.0	0.051	1.00	(3)
38	Rice husk	120.0	0.051	1.00	(3)
39	Jute felt	291.0	0.042	0.88	(3)
40	Closed cell flexible elastomeric foam - NBR	40-55	0.043	1.20	(3)

Source:

(1) ASHRAE Fundamental, 2009
(2) K. Gourav, et al., "Studies into structural and thermal properties of building envelope materials", Energy Procedia 122 (2017) 104-108
(3) Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) SP: 41 (S & T) -1987

(4) ECBC 2017
(5) Balaji N.C, et al., "Influence of varying mix proportions on thermal performance of soil-cement blocks", Building Simulation Applications BSA 2015

In case, the construction also has air layer, use values of thermal resistance of air layer given in Table 7 for U value calculation.

Table 7: Thermal resistance of air gaps

S. No.	Thickness of air gaps	Thermal conductance	Thermal resistance (R)
		W/m^2.K	*m^2.K/W*
1.	Closed space, 1.88 cm wide or more:		
a)	Bounded by ordinary building material	5.67	0.1764
b)	One or both sides faced with reflective insulation	2.84	0.3521
2.	Closed space, 0.62 cm wide:		
a)	Bounded by ordinary building material	8.75	0.1143
b)	One or both sides faced with reflective insulation	5.67	0.1764
3.	Open space, 1.88 cm wide or more	8.75	0.1143

Source: Handbook on Functional Requirements of Buildings (Other than Industrial Buildings) SP: 41 (S & T) -1987

A1.2 Calculation procedure for U value of fenestration (non-opaque building envelope component)

U-values, SHGC, or visible light transmittance of fenestration systems (non-opaque building envelope components) certified, and labeled in accordance ISO 15099 shall be assigned the certified values.

Unlabeled fenestration (non-opaque building envelope component), both operable and fixed, shall be assigned the U-factors as per Table 8.

Table 8: Defaults for Unrated Vertical Fenestration (Overall Assembly including the Sash and Frame)

Frame Type	*Glazing Type*	*U-Value (W/m^2.K)*
All frame types	Single Glazing	7.1
Wood, vinyl, or fiberglass frame or metal frame with thermal break	Double Glazing	3.4
Metal and other frame type	Double Glazing	5.1

(Source: ECBC 2017)

Annexure 2. Calculation of Equivalent SHGC

(As per ECBC 2017)

The calculation needs to be done for fenestration located in 8 cardinal directions i.e. North, East, South, West, North-east, South-east, South-west & North-west. Vertical fenestration on non-cardinal direction, shall be categorized under a particular cardinal direction if its orientation is within ± 22.5° of that cardinal direction.

a) Calculate the projection factor (PF) for permanent external projection, including but not limited to overhangs, side fins, box frame, verandah, balcony, and fixed canopies, using the formula:

   i. Projection factor, overhang: the ratio of the horizontal depth of the external shading projection (H) to the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection (V), in consistent units.

$$PF = \frac{H}{V} \quad (7)$$

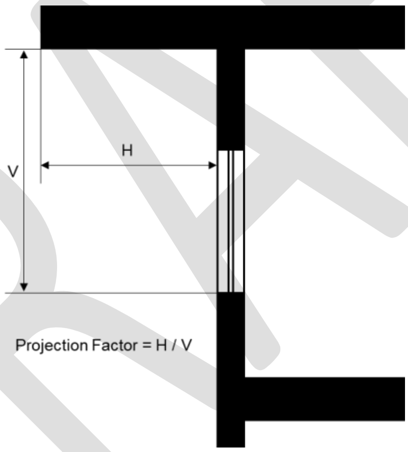


Figure 1: Projection factor

   ii. Projection factor, side/vertical fin: the ratio of the horizontal depth of the external shading projection to the distance from the window jamb to the farthest point of the external shading projection, in consistent units.

   iii. Projection Factor, overhang and side/vertical fin: average of ratio projection factor for overhang only and projection factor of side fin only.

b) Calculate the Shading Equivalent Factors (SEF), using the formula:

$$SEF = C_3 \times PF^3 + C_2 \times PF^2 + C_1 \times PF + C_0 \quad (8)$$

This formula is developed for PF ranging from 0.25 to 1.0. If the PF calculated for the shading is below 0.25, then a value of 0.25 shall be used. Similarly, If the PF calculated for the shading is above 1.0, then a value of 1.0 shall be used.

C_3, C_2, C_1 and C_0 are the coefficient of SEF, listed in Table 9 and Table 10

Table 9: Coefficients of Shading Equivalent Factors for Latitudes greater than or equal to 15ºN

	Overhang + Fin				Overhang				Fin*			
Coefficients	C3	C2	C1	C0	C3	C2	C1	C0	C3	C2	C1	C0
North	-0.03	-0.23	1.09	0.99	-0.02	-0.10	0.43	0.99	0.14	-0.39	0.62	0.99
East	4.49	-6.35	4.70	0.52	-0.05	0.42	0.66	1.02	0.12	-0.35	0.57	0.99
South	-4.09	8.14	-0.73	1.32	-1.01	1.91	0.24	1.12	0.53	-1.35	1.48	0.88
West	-1.21	3.92	-0.56	1.28	1.52	-2.51	2.30	0.76	0.02	-0.15	0.46	1.01
North-East	-0.95	1.50	0.84	1.18	2.19	-3.78	2.62	0.72	-1.64	3.07	-1.05	1.30
South-East	2.67	-4.99	5.68	0.32	-0.93	1.37	0.76	0.99	0.68	-1.47	1.35	0.88
South-West	-0.50	1.36	2.45	0.73	-3.23	5.61	-1.56	1.32	1.86	-3.81	2.71	0.69
North-West	-6.85	11.7	-3.92	1.89	-0.22	0.19	0.74	1.01	-2.02	2.63	-0.18	1.14

* Coefficients are for side fins on both sides of fenestration. For side fins on only one side, divide the coefficients mentioned in this table by 2.

Table 10: Coefficients of Shading Equivalent Factors for Latitudes less than 15ºN

	Overhang + Fin				Overhang				Fin*			
Coefficients	C3	C2	C1	C0	C3	C2	C1	C0	C3	C2	C1	C0
North	-0.09	-0.29	1.41	1.05	-0.05	-0.10	0.54	1.02	0.10	-0.40	0.77	1.01
East	-0.55	0.89	1.28	0.97	-0.62	0.88	0.51	1.02	0.15	-0.41	0.56	0.98
South	-4.09	6.98	-1.92	1.41	-2.49	4.89	-2.45	1.43	1.57	-3.35	2.62	0.59
West	-1.99	3.82	-0.19	1.18	-0.16	0.10	0.89	0.97	0.06	-0.22	0.48	0.99
North-East	-1.73	3.45	-0.02	1.23	0.10	-0.55	1.15	0.92	-0.26	0.30	0.48	1.02
South-East	-2.06	4.32	-0.96	1.41	-0.60	0.90	0.37	0.94	0.83	-1.42	1.22	0.92
South-West	-2.06	4.48	-1.13	1.40	-0.39	0.50	0.60	0.87	1.56	-3.17	2.41	0.73
North-West	-0.53	0.72	1.79	0.93	0.10	-0.38	0.96	0.96	0.24	-0.57	0.90	0.97

* Coefficients are for side fins on both sides of fenestration. For side fins on only one side, divide the coefficients mentioned in this table by 2.

c) Calculate the equivalent SHGC of the fenestration ($SHGC_{Equivalent}$), by dividing the SHGC of the unshaded fenestration product ($SHGC_{Unshaded}$) with the Shading Equivalent Factor (SEF), using the formula:

$$SHGC_{Equivalent} = \frac{SHGC_{Unshaded}}{SEF} \quad (9)$$

Annexure 3. Calculation of window-to-wall ratio (WWR)

a) Calculate total non-opaque (transparent/ translucent panels of windows, doors, etc.) area for the dwelling units of the building, excluding those on roof: For each wall, exposed to ambient[8], calculate the total non-opaque area by adding the glazed area of windows, glazed area (if any) of the doors and any other non-opaque area. Add the non-opaque area for all the walls to get the total non-opaque area for the building.

$$A_{non-opaque} = A_{non-opaque_{window}} + A_{non-opaque_{door}} + A_{non-opaque_{other}} \quad (10)$$

b) Calculate the total envelope area (excluding roof) of dwelling units: For each wall, exposed to ambient, calculate the gross wall area (i.e. overall area of a wall including openings such as windows and doors, with measurement taken horizontally from outside surface to outside surface and measured vertically from top of the floor to the top of the roof). Add the gross wall area for all walls to get the total envelope area (excluding roof) for the building. Walls facing semi-open common areas like corridors, lift lobbies, staircases etc. are to be excluded.

$$A_{envelope} = A_{gross-wall_1} + A_{gross-wall_2} + A_{gross-wall_3} + \cdots \quad (11)$$

c) Calculate the window-to-wall ratio (WWR) by calculating the ratio of total non-opaque area to the total gross wall area.

$$WWR = \frac{A_{non-opaque}}{A_{envelope}} \quad (12)$$

[8] exposed to ambient: exposed directly to external air. Does not include walls facing open corridors and enclosed shafts

Annexure 4. Calculation of window operable area to floor area ratio (WFR_{op})

a) Calculate the openable area by adding the openable area of windows and ventilators (excluding doors) of all the dwelling units, which opens directly to the external air, ventilation shaft or into an open balcony or "verandah".

$$A_{openable} = A_{openable_{window}} + A_{openable_{ventilator}} \tag{13}$$

If case exact openable area is not known, following default values can be used:

Table 11: Default openable area to opening area ratio

Type of window	Openable area / opening area
Casement window	0.9
Sliding window (2 panes)	0.5
Sliding window (3 panes)	0.67

b) Calculate the built-up area by adding the built-up area of all the dwelling units (DU). This includes area covered by the walls but excludes the balcony area.

$$A_{built-up\ area} = A_{built-up\ area_{DU1}} + A_{built-up\ area_{DU2}} + A_{built-up\ area_{DU3}} + \cdots \tag{14}$$

c) Calculate the window operable area to floor area ratio (WFR_{op}) by calculating the ratio of openable area to the built-up area.

$$WFR_{op} = \frac{A_{openable}}{A_{built-up\ area}} \tag{15}$$

Annexure 5. Examples of Code Compliance

<u>Example 1</u>: A 7-storey housing project in Rajkot is trying to comply with the residential code. There are 11 residential towers in this project. The built-up area of each dwelling unit (DU) is 32.65 m^2.

There are 3 windows (W, W1, W2) and 1 door (D2) in each DU exposed to ambient. The windows are either fully glazed or partially glazed (glass and PVC panels) and are casement windows. The door is opaque with PVC panel. Each DU has 2 ventilators (V) in the bath and toilet, which face a ventilation shaft. The details of the exposed door, windows, and ventilators are given below.

Table 12: Details of exposed door, windows and ventilators

Opening (Window/Door/ ventilator) Name	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)
W	1.20	1.60	1.92	1.2	0.53	0.64	1.28
W1	0.80	1.30	1.04	0.8	0.43	0.35	0.69
W2	0.80	1.60	1.28	0.80	1.60	1.28	0.00
D2	0.75	2.50	1.88	0	0	0.00	1.87
V (2 nos.)	0.65	0.40	0.26	0.65	0.40	0.26	0.00

Material details are as follows:

Table 13: Details of construction material

Wall	200mm AAC blocks with plaster on both sides
Roof	150mm RCC with 40mm polyurethane foam (PUF) insulation
Glass in windows	Single clear glass with SHGC 0.8, VLT 85% and U-value 5.8 W/(m^2.K)
PVC panel	4mm thick PVC panel used in doors and windows

Does this project comply with the code?

Figure 2: Layout plan of the project

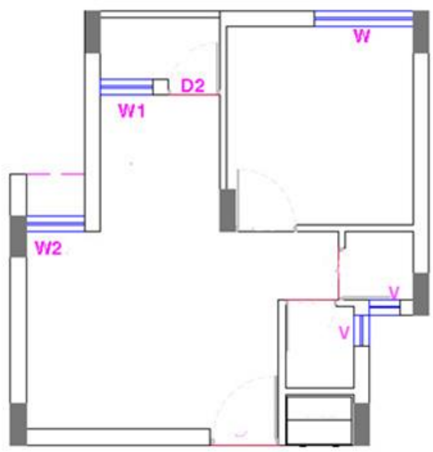


Figure 3: Plan of a typical DU

Compliance check:

Each of the 11 residential towers will need to comply with the code for the building project to be compliant. The compliance of one of the towers, as marked in the Figure 4, is being shown.

Figure 4: Building for compliance check on the layout of project

The longer sides of this tower face north-south. It has 112 dwelling units (DUs), 16 DUs on each floor. Half of the DUs face north and the rest face south.

Table 14: Wall areas of the building

Orientation	Total wall length (m), exposed to ambient	Total wall height (m), exposed to ambient	Gross wall area (m^2)
North	51.58	21.06	1086.27
South	51.58	21.06	1086.27
East	31.00	21.06	652.86
West	31.00	21.06	652.86
		Envelope Area (m^2), excluding roof	3478.26

Step 1: Calculation of openable window-to-floor area ratio (WFR_{op})

1.1: Calculation of total openable area $(A_{openable})$

Each flat consists of 3 windows and 2 ventilators. As all the windows are casement windows, 90% of the window opening area is considered openable. The ventilators have fixed glass i.e. are not openable.

Table 15: Openable area calculation

Opening Name	Opening Area (m^2)	Openable area (m^2)	Remarks
W	1.92	1.73	90% openable (Table 11)
W1	1.04	0.94	
W2	1.28	1.15	
V (2 nos.)	0.52		Not openable
Openable area for each flat		3.82	
Openable area for 112 flats $(A_{openable})$		427.84	

1.2: Calculation of total built-up area $\left(A_{built-up\ area}\right)$

$$A_{built-up\ area} = no.of\ DUs\ \times\ built-up\ area\ of\ 1\ DU$$
$$= 112\ \times\ 32.65 = 3656.80\ m^2$$

1.3: Calculate the window operable area to floor area ratio $\left(WFR_{op}\right)$

$$WFR_{op} = \frac{A_{openable}}{A_{built-up\ area}} = \frac{427.84}{3656.80} = 11.7\%$$

Rajkot is in the composite climate. As per Table 2, the minimum WFR_{op} for this climate is 10%. Thus, this project complies with this requirement.

Step 2: Calculation of visible Light Transmittance (VLT)

2.1: Calculation of window-to-wall ratio (WWR)

There are 3 windows and 1 door in each DU exposed to ambient. The windows are either fully glazed or partially glazed (glass and PVC panels). The door is opaque with PVC panel.

Table 16: Calculation of window-to-wall ratio

Orientation	Opening Name	Opening Area (m²)	Non-opaque Area in opening (m²)	No. of openings	Total Opening area (m²)	Total Non-Opaque Area (m²)
North	W	1.92	0.64	56	107.52	35.84
North	W1	1.04	0.35	56	58.24	19.41
North	W2	1.28	1.28	56	71.68	71.68
North	D2	1.88	0.00	56	105.00	0.00
South	W	1.92	0.64	56	107.52	35.84
South	W1	1.04	0.35	56	58.24	19.41
South	W2	1.28	1.28	56	71.68	71.68
South	D2	1.88	0.00	56	105.00	0.00
Total					684.88	253.86

$$WWR = \frac{A_{non-opaque}}{A_{envelope}} = \frac{253.86}{3478.26} = 0.073$$

As per Table 3, the minimum VLT for WWR ≤ 20% is 75%. The glass used in this project has a VLT of 85% (as per certified specification for the product). Thus, this project complies with this requirement.

Step 3: Thermal transmittance of roof $(\boldsymbol{U_{roof}})$

3.1: Calculation of Thermal transmittance of roof (U_{roof})

The roof of this building comprises of the following material layers

Table 17: Roof construction details

Material Layer	Thickness, t (m)	Thermal conductivity, k (W/m.K)	Thermal resistance of material, R= t/k (m^2.K/W)
China mosaic tile	0.007	1.5	0.005
Concrete (laid to slope)	0.050	1.74	0.029
Polyurethane foam (PUF)	0.040	0.037	1.081
Cement screed	0.020	0.72	0.028
RCC slab	0.150	1.58	0.095
Internal plaster	0.015	0.72	0.021
Sum of all material thermal resistance			1.259

Total thermal resistance,

$$R_T = \frac{1}{h_i} + \frac{1}{h_o} + R_1 + R_2 + R_3 + \cdots$$
$$= \frac{1}{9.36} + \frac{1}{19.86} + 1.259 = 1.415 \text{ m}^2.\text{K/W}$$

Thermal transmittance of roof,

$$U_{roof} = \frac{1}{R_T} = 0.71 \text{ W/ m}^2.\text{K}$$

This is less than the maximum U_{roof} value of 1.2 W/m^2.K. Hence it complies with this requirement.

Step 4: Calculation of RETV for the building envelope

4.1: $RETV$ formula

Rajkot falls in the composite climate. Thus, the applicable RETV equation is,

$$RETV = 6.11 * (1 - WWR) * U_{opaque} + 1.9 * WWR * U_{non-opaque} + 70.94 * WWR * SHGC_{equivalent}$$

4.2: Calculation of window-to-wall ratio (WWR)

As shown in step 2.

$$WWR = 0.073$$

4.3: Calculation of Thermal transmittance of opaque building envelope component (U_{opaque})

U_{opaque} = Thermal transmittance of opaque building envelope component
= Area-weighted average of U values of all opaque building envelope components

There are two opaque building envelope components:

- AAC block wall with 15mm plaster on both side (U value = 0.7 W/m^2.K)
- PVC sheet used in opaque panels of window (U value = 5.61 W/m^2.K) (as per certified specification for the product)

[U value of AAC block and PVC sheet is calculated the same way as that shown for the roof. Thermal conductivity of AAC block is 0.162 W/m.K and that of PVC is 0.19 W/m.K.]

$$U_{opaque} = \frac{(AAC\ block\ wall\ area * U\ value\ of\ AAC\ wall) + (Opaque\ window\ area * U\ value\ of\ PVC)}{AAC\ block\ wall\ area +\ Opaque\ window\ area}$$

$$= \frac{(2793.38 * 0.7) + (431.02 * 5.61)}{2793.38 + 431.02} = 1.356\, W/m^2 . K$$

Note:
- AAC block area = Envelope area - Total opening area
- Opaque window area = Total opening area - Total non-opaque area

4.4: Calculation of thermal transmittance of non-opaque building envelope component $(U_{non-opaque})$

$U_{non-opaque}$ = Thermal transmittance of non-opaque building envelope component = 5.8 W/m^2.K

In this example, single clear glass with U value of 5.8 W/m^2.K (as per certified specification for the product) is used in all glazed areas. In case different types of glass is used in different areas, $U_{non-opaque}$ will be calculated by the area-weighted average method, considering all glass types used.

4.5: Calculation of equivalent SHGC $(SHGC_{equivalent})$

$SHGC_{equivalent}$ = Area weighted average of $SHGC_{equivalent}$ of all non-opaque building envelope components

In this example, single clear glass with SHGC 0.8 is used in all glazed areas. The effective SHGC of all non-opaque building envelope components is calculated based on the shading provided in the table below, which is then averaged.

Table 18: Equivalent SHGC calculation

Orientation	Opening Name	Width of Glass in Opening (m)	Height of Glass in Opening (m)	No. of openings	Glass Area (m^2)	Shading type	Shading dimension (m)	Equivalent SHGC (calculated as per Annexure 2)
North	W	1.2	0.53	56	35.84	Overhang + sidefin	0.4	0.5
North	W1	0.8	0.43	56	19.41	Overhang	1.1	0.6
North	W2	0.8	1.60	28	35.84	Overhang + sidefin	0.47	0.6
South	W	1.2	0.53	56	35.84	Overhang + sidefin	0.4	0.3
South	W1	0.8	0.43	56	19.41	Overhang	1.1	0.4
South	W2	0.8	1.60	28	35.84	Overhang + sidefin	0.47	0.4

$$SHGC_{equivalent} = \frac{(Glass\ area_1\ * Effective\ SHGC_1) + (Glass\ area_2 * Effective\ SHGC_2) + \cdots + (Glass\ area_n * Effective\ SHGC_n)}{(Glass\ area_1 + Glass\ area_2 + \cdots + Glass\ area_n)} = 0.452$$

4.6: Calculation of $RETV$

$$RETV_{Composite/Hot-Dry} = 6.11 * (1 - WWR) * U_{opaque} + 1.90 * WWR * U_{non-opaque} + 70.94 * WWR * SHGC_{equivalent}$$

$$= 6.11 * (1 - 0.073) * 1.356 + 1.90 * 0.073 * 5.8 + 70.94 * 0.073 * 0.452 = 10.82\ W/m^2$$

This is less than the maximum RETV of 15 W/m^2. Hence it complies with this requirement.

The building complies with all four requirements and hence complies with the code.

Example 2: The same project given in Example 1 is built in Shimla. All specifications of the project remain the same excepting that all windows (W, W1, W2) are fully glazed. The details of the exposed door, windows, and ventilators for this project are given below.

Table 19: Details of exposed door, windows and ventilators

Opening (Window/Door/ ventilator) Name	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)
W	1.20	1.60	1.92	1.2	1.60	1.92	0.00
W1	0.80	1.30	1.04	0.8	1.30	1.04	0.00
W2	0.80	1.60	1.28	0.80	1.60	1.28	0.00
D2	0.75	2.50	1.88	0	0	0.00	1.87
V (2 nos.)	0.65	0.40	0.26	0.65	0.40	0.26	0.00

Material details are as follows:

Table 20: Details of construction material

Wall	200mm AAC blocks with plaster on both sides
Roof	150mm RCC with 40mm polyurethane foam (PUF) insulation
Glass in windows	Single clear glass with SHGC 0.8, VLT 85% and U-value 5.8 W/(m^2.K)

Does this project comply with the code?

Compliance check:

Each of the 11 residential towers will need to comply with the code for the building project to be compliant. The compliance of one of the towers is being shown.

The longer sides of this tower face north-south. It has 112 dwelling units (DUs), 16 DUs on each floor. Half of the DUs face north and the rest face south.

Table 21: Wall areas of the building

Orientation	Total wall length (m), exposed to ambient	Total wall height (m), exposed to ambient	Gross wall area (m^2)
North	51.58	21.06	1086.27
South	51.58	21.06	1086.27
East	31.00	21.06	652.86
West	31.00	21.06	652.86
Envelope Area (m^2), excluding roof			3478.26

Step 1: Openable window-to-floor area ratio (WFR_{op})

1.1: Calculation of total openable area $(A_{openable})$

Each flat consists of 3 windows and 2 ventilators. As all the windows are casement windows, 90% of the window opening area is considered openable. The ventilators have fixed glass i.e. are not openable.

Table 22: Calculation of openable areas

Opening Name	Opening Area (m^2)	Openable area (m^2)	Remarks
W	1.92	1.73	90% openable (Table 11)
W1	1.04	0.94	
W2	1.28	1.15	
V (2 nos.)	0.52		Not openable
Openable area for each flat		3.82	
Openable area for 112 flats ($A_{openable}$)		427.84	

1.2: Calculation of total built-up area $(A_{built-up\ area})$

$$A_{built-up\ area} = no.of\ DUs\ \times\ built-up\ area\ of\ 1\ DU$$
$$= 112\ \times\ 32.65 = 3656.80\ m^2$$

1.3: Calculate the window operable area to floor area ratio (WFR_{op}*)*

$$WFR_{op} = \frac{A_{openable}}{A_{built-up\ area}} = \frac{427.84}{3656.80} = 11.7\%$$

Shimla is in the cold climate. As per Table 2, the minimum WFR_{op} for this climate is 8.33%. Thus, this project complies with this requirement.

Step 2: Visible Light Transmittance (VLT)

2.1 Calculation of window-to-wall ratio (WWR)

There are 3 windows and 1 door in each DU exposed to ambient. The windows are fully glazed. The door is opaque with PVC panel.

Table 23: Calculation of window-to-wall ratio

Orientation	Opening Name	Opening Area (m^2)	Non-opaque Area in opening (m^2)	No. of openings	Total Opening area (m^2)	Total Non-Opaque Area (m^2)
North	W	1.92	1.92	56	107.52	107.52
North	W1	1.04	1.04	56	58.24	58.24
North	W2	1.28	1.28	56	71.68	71.68
North	D2	1.88	0.00	56	105.00	0.00
South	W	1.92	1.92	56	107.52	107.52
South	W1	1.04	1.04	56	58.24	58.24
South	W2	1.28	1.28	56	71.68	71.68
South	D2	1.88	0.00	56	105.00	0.00
					684.88	474.88

$$WWR = \frac{A_{non-opaque}}{A_{envelope}} = \frac{474.88}{3478.26} = 0.136$$

As per Table 3, the minimum VLT for WWR ≤ 20% is 75%. The glass used in this project has a VLT of 85% (as per certified specification for the product). Thus, this project complies with this requirement.

Step 3: Thermal transmittance of roof (U_{roof})

3.1 Calculation of thermal transmittance of roof (U_{roof})

The roof of this building is the same as that of Example 1, i.e., U_{roof} is 0.71 W/m^2.K. This is less than the maximum U_{roof} value of 1.2 W/m^2.K. Hence it complies with this requirement.

Step 4: Thermal transmittance of building envelope (except roof) for cold climatic zone $(\boldsymbol{U_{envelope,cold}})$

Shimla is in the cold climate zone. Hence, thermal transmittance of the building envelope (except roof) will be calculated.

4.1 Calculation of thermal transmittance of building envelope $(U_{envelope,cold})$

In this case, the U values of the wall (i.e. AAC block with 15mm plaster on both sides), the opaque door component (i.e. PVC sheet) and the non-opaque components (glass used in windows) needs to be averaged

$$U_{envelope,cold} = \frac{(Net\ AAC\ block\ wall\ area * U\ value\ of\ AAC) + (Opaque\ door\ area * U\ value\ of\ PVC) + (Non-opaque\ area * U\ value\ of\ glass)}{Net\ AAC\ block\ wall\ area + Opaque\ window\ area + Non-opaque\ area}$$

$$= \frac{(2793.38 * 0.7) + (210 * 5.61) + (474.88 * 5.8)}{2793.38 + 210 + 474.88} = 1.693\ W/m^2 . K$$

Note:

- Net AAC block area = Envelope area - Total opening area
- Opaque window area= Total opening area - Total non-opaque area
- U value of AAC block and PVC sheet is calculated the same way as that shown for the roof. Thermal conductivity of AAC block is 0.162 W/m.K and that of PVC is 0.19 W/m.K
- U value of the glass used is given as 5.8 W/m^2.K (as per certified specification for the product)

This is less than the maximum $U_{envelope,cold}$ value of 1.8 W/m^2.K. Hence it complies with this requirement.

The building complies with all four requirements and hence complies with the code.

Annexure 6. Climatic Zone & Classification of Cities

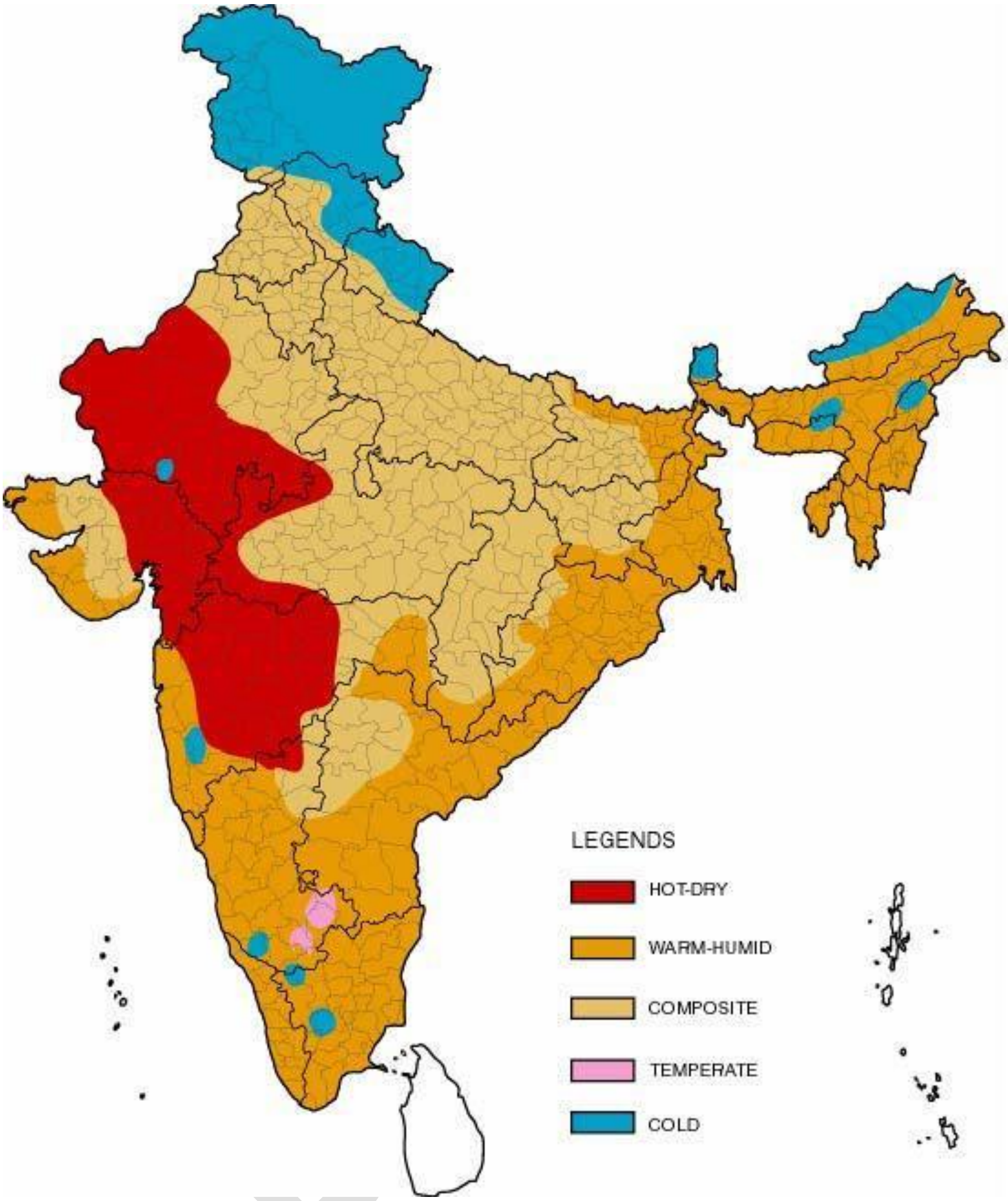


Figure 5: Climate zone map of India

Table 24: Climate Zone for Major Indian Cities

City	Climate Type	City	Climate Type
Ahmedabad	Hot & Dry	Kurnool	Warm & Humid
Allahabad	Composite	Leh	Cold
Amritsar	Composite	Lucknow	Composite
Aurangabad	Hot & Dry	Ludhiana	Composite
Bangalore	Temperate	Chennai	Warm & Humid
Barmer	Hot & Dry	Manali	Cold
Belgaum	Warm & Humid	Mangalore	Warm & Humid
Bhagalpur	Warm & Humid	Mumbai	Warm & Humid
Bhopal	Composite	Nagpur	Composite
Bhubaneshwar	Warm & Humid	Nellore	Warm & Humid
Bikaner	Hot & Dry	New Delhi	Composite
Chandigarh	Composite	Panjim	Warm & Humid
Chitradurga	Warm & Humid	Patna	Composite
Dehradun	Composite	Pune	Warm & Humid
Dibrugarh	Warm & Humid	Raipur	Composite
Guwahati	Warm & Humid	Rajkot	Composite
Gorakhpur	Composite	Ramgundam	Warm & Humid
Gwalior	Composite	Ranchi	Composite
Hissar	Composite	Ratnagiri	Warm & Humid
Hyderabad	Composite	Raxaul	Warm & Humid
Imphal	Warm & Humid	Saharanpur	Composite
Indore	Composite	Shillong	Cold
Jabalpur	Composite	Sholapur	Hot & Dry
Jagdelpur	Warm & Humid	Srinagar	Cold
Jaipur	Composite	Sundernagar	Cold
Jaisalmer	Hot & Dry	Surat	Hot & Dry
Jalandhar	Composite	Tezpur	Warm & Humid
Jamnagar	Warm & Humid	Tiruchirappalli	Warm & Humid
Jodhpur	Hot & Dry	Trivandrum	Warm & Humid
Jorhat	Warm & Humid	Tuticorin	Warm & Humid
Kochi	Warm & Humid	Udhagamandalam	Cold
Kolkata	Warm & Humid	Vadodara	Hot & Dry
Kota	Hot & Dry	Veraval	Warm & Humid
Kullu	Cold	Vishakhapatnam	Warm & Humid

Annexure 7. Terminology and Definitions

Building Envelope: The elements of a building that separate conditioned spaces from the exterior or from unconditioned space.

Built-up area (for calculation of WFR_{op}) of dwelling units: the covered area of all dwelling units, including the area covered by walls, but excepting the balcony area.

Group housing: Building unit or units constructed or to be constructed with one or more floors having more than two dwelling units having common service facilities where land is shared and commonly used by the dwelling units, and the construction is undertaken by one agency.

Non-opaque building envelope components: It includes transparent/translucent panels in windows, doors, etc.

Opaque building envelope components: It includes wall, opaque panels in door and window, etc.

Openable Window-to-Floor Ratio $(WFR)_{op}$: The openable window-to-floor ratio $(WFR)_{op}$ is the ratio of total openable area (addition of openable area of all windows and ventilators area, excluding doors, opening directly to the external air or into an open balcony or "verandah") to the total built-up area of dwelling units (the covered area of all dwelling units, including the area covered by walls, but excepting the balcony area).

Projection Factor, overhang: the ratio of the horizontal depth of the external shading projection to the sum of the height of the fenestration and the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection, in consistent units.

Projection Factor, side fin: the ratio of the horizontal depth of the external shading projection to the distance from the window jamb to the farthest point of the external shading projection, in consistent units.

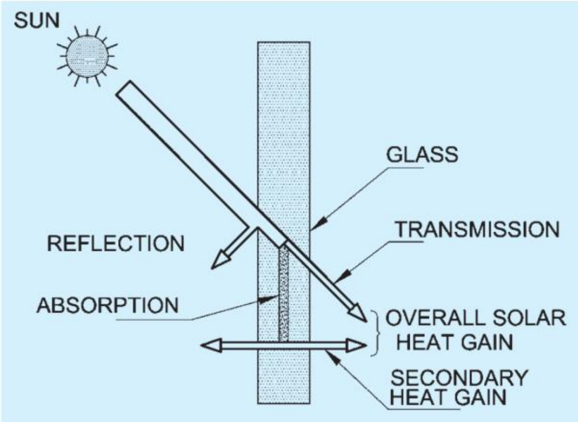
Projection Factor, overhang and side fin: average of ratio projection factor for overhang only and projection factor of side fin only.

RETV: Residential Envelope Heat Transmittance ($RETV$) is the net heat gain rate (over the cooling period) through building envelope (excluding roof) divided by the area of building envelope (excluding roof). Its unit is W/m^2.

Solar Heat Gain Coefficient (SHGC)[9]: SHGC is the fraction of incident solar radiation admitted through a fenestration, both directly transmitted, and absorbed and subsequently released inward through conduction, convection and radiation.

$$\text{SHGC} = \frac{\text{Transmission} + \text{Secondary heat gain}}{\text{Incident solar radiation}}$$

[9] Source: NBC 2016



Equivalent SHGC[10]: SHGC for a fenestration with a permanent external shading projection. It is calculated using the Projection Factor (PF) of the permanent external shading projection and Shading Equivalent Factor (SEF).

U value: Thermal transmittance (U value) is the heat transmission in unit time through unit area of a material or construction and the boundary air films, induced by unit temperature difference between the environments on either side. Unit of U value is $W/m^2.K$. U value for the wall/roof/glazing indicates its ability to transfer heat through conduction.

VLT: The visible light transmittance (VLT) is a measure of the transmitted light in the visible portion of the spectrum through a material.

Window to Wall Ratio (WWR): It is the ratio of the non-opaque building envelope components area to the envelope area (excluding roof) of dwelling units. Envelope area (excluding roof) of dwelling units is the overall area of external walls of dwelling units (including openings such as windows and doors, with measurement taken horizontally from outside surface to outside surface and measured vertically from top of the floor to the top of the roof).

[10] Source: ECBC 2017

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