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List of topics

Development of RETV (Residential Envelope Transmittance Value) Formula for Cooling Dominated Climates of India for the Eco-Niwas Samhita 2018[1]

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Abstract

In India, there was no code for building envelope of residential buildings until the recently (14 December 2018) launched code, “Eco-Niwas Samhita 2018”. Among different code provisions, a maximum RETV value is defined for cooling dominated climates, calculated by a simple (RETV) formula. It gives a quantitative measure of heat gains through the building envelope (excluding roof).

Energy simulation were done with various combinations (floor plan, climate and building envelope) of inputs to calculate the RETV. RETV formula included key envelope parameters and multiple linear regression analysis was done to minimize the error between the simulated RETV and calculated RETV.

The results show that the Average coefficient of determination (R-squared) between $RETV_{simulated}$ and $RETV_{formula}$ as 0.95. While complying with RETV provision helps in reducing cooling energy and improving thermal comfort; the RETV formula can also be used as a design tool, to quickly evaluate and compare various design alternatives and material options, for their thermal performance.

Introduction

In India, the residential buildings floor area is estimated to double (16.0 billion m^2 to 31.6 billion m^2) and residential energy consumption is estimated to triple (246 TWh/y to 748 TWh/y) between 2017 and 2030 (NITI Aayog, 2015). About 20 million new affordable homes in urban areas are planned under Pradhan Mantri Awas Yojana (PMAY) between 2015-2022 (MoHUPA, 2015).

Till 2017-18, approximately 8% of the dwellings had room air conditioners and it is anticipated to rise to 21% and 40% in 2027-28 and 2037-38, respectively. The room air conditioner stock in dwellings of 25 million units in 2017-18 is expected to rise to 96 and 345 million units in 2027-28 and 2037-38, respectively. (MoEFCC, 2018)

Therefore, it is important to improve thermal comfort in new dwellings, so that: a) the installation of air-conditioner is either avoided or delayed substantially, b) the capacity of the cooling system required is reduced and c) the operating hours of cooling system is reduced. This will help in reducing the energy required for cooling in residential buildings.

Eco-Niwas Samhita 2018 (BEE, 2018) is the new Energy Conservation Building Code for Residential Buildings (ECBC-R) which has following provisions:

1. To minimize the heat gain in cooling dominated climate or heat loss in heating dominated climate,
    a. Through the building envelope (excluding roof):
        i. Maximum RETV for cooling dominated climate (Composite Climate, Hot-Dry Climate, Warm-Humid Climate, and Temperate Climate)
        ii. Maximum U-value for the cold climate
    b. Through the Roof: Maximum U-value for Roof
2. For natural ventilation potential
    a. Minimum openable window-to-floor area ratio with respect to the climatic zone
3. For daylight potential
    a. Minimum visible light transmittance with respect to window-to-wall ratio

This 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 paper deals with the development of RETV formula for cooling dominated climates of India for the Eco-Niwas Samhita 2018.

The concept of RETV has already been used in residential building code in Singapore and Hong Kong (BCA, 2008; Buildings Department, 2014; Chua and Chou, 2010).

Methods

Residential envelope transmittance value is the net heat gain rate (over the cooling period) through the building envelope of dwelling units (excluding roof) divided by the area of the building envelope (excluding roof) of dwelling units. The heat gains include conduction through the opaque building envelope components (e.g. external walls, opaque door, opaque windows, etc.), conduction through the non-opaque building envelope components (e.g. transparent / translucent panels in windows, doors, ventilators, etc.) and radiation through the non-opaque building envelope components. The unit of RETV is W/m^2.

The aim of developing the RETV formula (Equation 11) was to be able to characterize heat gains from the building

[1] an Energy Conservation Building Code for Residential Buildings (ECBC-R)

https://doi.org/10.26868/25222708.2019.211019

envelope (excluding roof) in a simple way to estimate sensible cooling loads. The key steps taken for the development of RETV are shown in Figure 1.

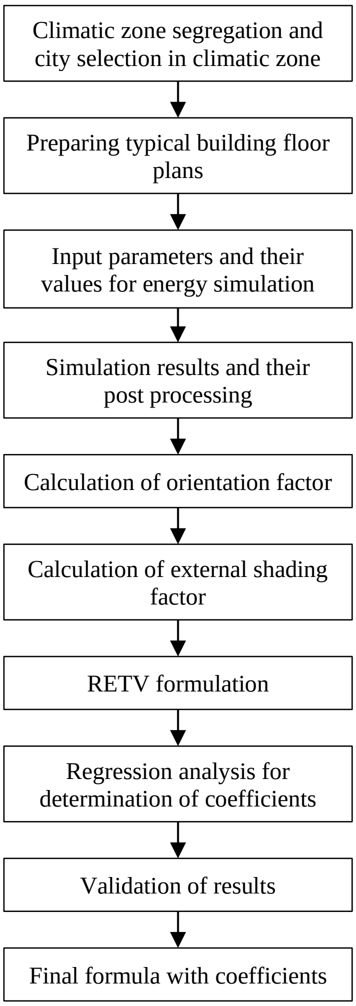

Figure 1: Methodology for RETV formula development

Climatic zone segregation and city selection in climatic zones

India has five climatic zones: hot-dry, composite, warm-humid, temperate and cold (BIS, 2016). Except the cold climate, other four climatic zones need cooling over long periods for thermal comfort and for these climatic zones, RETV formula was developed. Further, hot-dry and composite climatic zones have been clubbed together. List of cities, taken for energy simulation in each climatic zone, are given in Table 1.

Table 1: Climatic zones & cities

Climatic Zone	Cities
Hot-dry / Composite	Delhi, Ahmedabad & Nagpur (3 cities)
Warm-Humid	Mumbai, Chennai & Kolkata (3 cities)
Temperate	Bengaluru (1 city)

Preparing typical building floor plans for simulation

Majority of the new urban houses in India are in the form of multi-storey apartment buildings. A survey, covering 40 residential projects (multi-storey apartment buildings in urban area), was conducted to understand the characteristics of residential buildings. The survey results were used to develop a typical floor plan for doing the energy simulations.

It was observed that the two building typologies are prevalent in India: Point Block and Doubly Loaded Corridor. Both building typologies were adequately covered in the sample of 40 residential projects. As the code focused on building envelope, it was decided to look at the relationship between the building envelope (excluding roof) and the volume of the house. For each project, building envelope (excluding roof) area to indoor volume ratio was calculated. For point block type, it varied from 0.30 to 0.58 m^{-1} and for doubly loaded corridor type, it varied from 0.22 to 0.47 m^{-1}. The dwelling unit size varied from 30 to 120 m^2.

Based on this survey, the plan for a typical dwelling unit of 80 m^2 was developed (Figure 2), which was used to develop the floor plan for the point block (Figure 3) and doubly loaded corridor type (Figure 4). The building envelope (excluding roof) area to indoor volume ratio was kept 0.4 m^{-1} and 0.3 m^{-1} for the point block and doubly loaded corridor type, respectively.

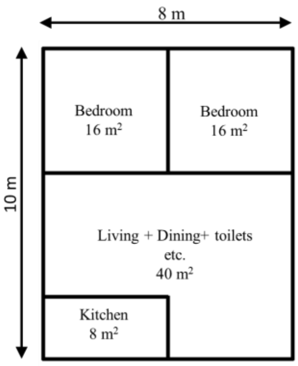

Figure 2: Dwelling unit plan (Area = 80 m^2)

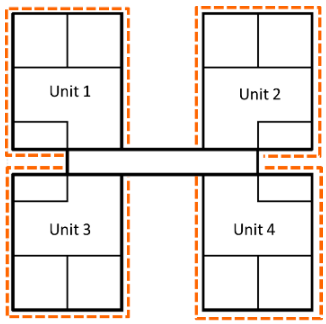

Figure 3: Floor plan for point block type

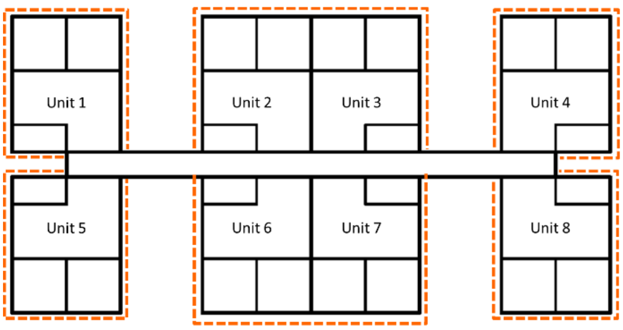

Figure 4: Floor plan for doubly loaded corridor type

Input parameters and their values for energy simulation

A total of 27,360 simulation cases were prepared with the combination of parameters as explained below.

External wall: Different types of external wall construction considered for energy simulation and its U-value is given in Table 2.

Table 2: External wall configurations

Construction	U-value ($W/m^2.K$)
150 mm Reinforced Cement Concrete (RCC) Wall	3.27
200 mm Solid Concrete Block (SCB) Wall with Cement Plaster	2.82
230 mm Brick Wall with Cement Plaster	1.94
200 mm Autoclaved Aerated Concrete (AAC) Block Wall with Cement Plaster	0.69
300 mm AAC Block Wall with Cement Plaster	0.48

Glazing: Different types of glazing construction considered for energy simulation and its key properties, U-value, solar heat gain coefficient (SHGC) and visual light transmittance (VLT), are given in Table 3.

Table 3: Glazing configurations

Construction	U-value ($W/m^2.K$)	SHGC	VLT
6 mm Single Clear Glass	5.78	0.82	0.88
6 mm Double Clear Glass with 12 mm air gap	2.67	0.70	0.78
6 mm Single Reflective Glass	5.72	0.51	0.34
Double-Glazed High-Performance Glass	2.65	0.27	0.40

Shading: Window shading parameters were varied as:

- No shading
- 300 mm overhang
- 600 mm overhang

Window-to-wall ratio (WWR): During the residential projects survey, window-to-wall ratio (WWR) was also calculated for all projects. WWR varied from 8.4% to 21.6%, with an average value of ~15%. For the energy simulation, WWR values were varied from 10% to 35% with a step of 5% (i.e. 10%, 15%, 20%, 25%, 30% & 35%). However, for warm-humid and temperate zones, the minimum WWR kept as 15% to meet the minimum window openable area to floor area ratio as per the National Building Code of India 2016 (BIS, 2016).

Openable area: Natural ventilation was considered in the energy simulations and the openable window area was also varied. The values of openable window area taken were:

- 50% (for a two pane sliding window)
- 90% (for a casement window)

Orientation: The orientation of the building was varied for the doubly loaded corridor type; keeping the longer façade facing North-South and in the other case longer façade facing East-West.

Cooling scenario: All the cases prepared by combination of different building envelope, were simulated with two cooling scenarios:

- 100% air-conditioned with priority given to natural ventilation i.e. if by opening the window the setpoints can be achieved then the cooling system remains OFF.
- 100% naturally ventilated with no mechanical cooling

However, the RETV formula was developed from the results of case '100% air-conditioned with priority given to natural ventilation'. The '100% naturally ventilated with no mechanical cooling' cases were used to check the consistency of building envelope performance i.e. building envelope with low RETV in air-conditioed case should also result in better thermal comfort in naturally ventilated case.

Overall simulation cases: With the combination of location, floor plan, building envelope parameters and cooling scenario, simulation cases (Table 4) were prepared.

Table 4: Simulation variables and their values

Variable	No. of values
Locations	7
Floor plan	2
External Wall	5
Glazing	4
Shading	3
WWR	6 (for 3 locations of composite / hot-dry climatic zone) 5 (for 4 locations of warm-humid / temperate climatic zone)
Openable area	2
Orientation	1 (for point block) 2 (for doubly loaded corridor)
Cooling scenario	2

Simulation results and their post processing

The key energy simulation results were calculated for each energy simulation run, for the air-conditioned case. A 'cooling period', when cooling is required for thermal comfort, was defined for each climatic zone. For the warm-humid climatic zone, it was considered as 10 months (February to November) and for other climatic zones (composite, hot-dry & temperate) is was considered as 8 months (March-October). Key results for air-conditioned cases were:

- Sensible cooling load ($Q_{sensible}$, kWh_{th}/m^2): It is the total sensible heat load of the dwelling unit during the cooling period (which the cooling system needs to remove for thermal comfort), divided by the built-up area of the dwelling unit.
- Residential envelope transmittance value ($RETV_{simulated}$, W/m^2): RETV value calculated through the energy simulation.

All the energy simulations were done using 'EnergyPlus' simulation engine with a parametric generator (jEPlus) to prepare the input files for energy simulation. A customised programming was developed using 'Visual Basic for MS-Excel' to read and collect the data from

'EnergyPlus' simulation result files. All the key simulation input parameters along with the results were compiled in one place for further processing.

Calculation of orientation factor (ω)

An octagonal simulation model was prepared having façade on 8 directions (four cardinal directions i.e. North, South, East, West and four intercardinal directions i.e. Northeast, Southeast, Southwest and Northwest). Energy simulation (for the cooling period) provided 'incident solar radiation' for all 8 directions and its average was calculated as the 'average incident solar radiation' (average value of 'incident solar radiation' for 8 directions). The orientation factor (ω) for an orientation was calculated as the ratio of 'incident solar radiation (I)' in that orientation to the 'average of incident solar radiation ($I_{Average}$)' e.g. orientation factor for 'North' would be,

$$\omega_{North} = \frac{I_{North}}{I_{Average}} \qquad (1)$$

The analysis was done for a set of cities with the respective cooling period (as per the climatic zone) and cities were clubbed together based on its latitude category i.e. latitudes ≥ 23.5˚N and latitudes < 23.5˚N (Table 5).

Table 5: Cities and cooling period for orientation factor calculation

Latitude	City	Cooling Period
≥ 23.5˚N	Amritsar	March-October (8 months)
	Delhi	March-October (8 months)
	Jaipur	March-October (8 months)
< 23.5˚N	Ahmedabad	March-October (8 months)
	Kolkata	February-November (10 months)
	Nagpur	March-October (8 months)
	Mumbai	February-November (10 months)
	Chennai	February-November (10 months)
	Bengaluru	March-October (8 months)

For each orientation, an average value of all cities falling in the same latitude category was calculated e.g. for latitude ≥ 23.5˚N,

$$\omega_{North} = \frac{\omega_{North_{Amritsar}} + \omega_{North_{Delhi}} + \omega_{North_{Jaipur}}}{3} \qquad (2)$$

The final values of orientation factor are given in Table 8, which should be read with Figure 8 for clarification on orientations.

Calculation of external shading factor (ESF)

Similar to orientation factor model, an octagonal simulation model was prepared having façade on 8 directions (four cardinal directions i.e. North, South, East, West and four intercardinal directions i.e. Northeast, Southeast, Southwest and Northwest) and one window on each direction. ESF values were defined based on the projection factor (PF) of permanent external shading projection (overhang and side fins).

Projection factor, overhang: the ratio of the horizontal depth of the external shading projection ($H_{overhang}$) to the sum of the height of a non-opaque component and the distance from the top of the same component to the bottom of the farthest point of the external shading projection ($V_{overhang}$), in consistent units.

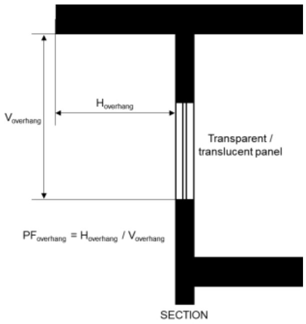

Figure 5: Projection factor for overhang

$$PF_{overhang} = \frac{H_{overhang}}{V_{overhang}} \qquad (3)$$

Projection factor, side/vertical fin: the ratio of the horizontal depth of the external shading projection to the distance from a non-opaque component to the farthest point of the external shading projection, in consistent units. In case of single side/vertical fin, it could be on the 'Right' or 'Left' or there could be side/vertical fins on both the sides. A 'Right' side/vertical fin would be located on the right side of the window while looking out from the building and similarly, a 'Left' side/vertical fin would be located on the left side of the window while looking out from the building.

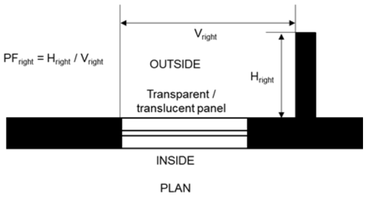

Figure 6: Projection factor for sidefin - right

$$PF_{right} = \frac{H_{right}}{V_{right}} \qquad (4)$$

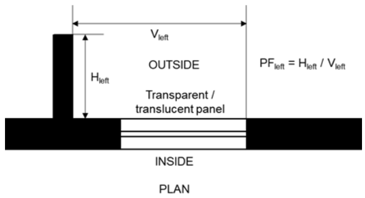

Figure 7:Projection factor for sidefin - left

$$PF_{left} = \frac{H_{left}}{V_{left}} \qquad (5)$$

Projection factor was varied from 0.1 to 1.0 with a step of 0.1 (i.e. 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 & 1.0) for each type of shading (i.e. overhang, sidefin - right & sidefin - left) in the energy simulation model and 'window transmitted solar radiation rate (WT)' was calculated for all 8 orientations. Another variant of the model was prepared 'without shading' and similar results were gathered. The ESF was calculated, for specific shading type, in specific orientation with specific projection factor (e.g. overhang in north orientation with projection factor 0.4), as the ratio of 'window transmitted solar radiation rate' with the shading to that 'without shading' i.e.

$$ESF_{overhang_{North_{PF=0.4}}} = \frac{WT_{overhang_{North_{PF=0.4}}}}{WT_{no\ shading_{North}}} \quad (6)$$

Calculations were done for all combinations of shading type, orientation and projection factor mentioned in Table 6.

Table 6: Parameters for ESF calculation

Shading Type	Orientation	Projection Factors
• Overhang • Sidefin - Right • Sidefin - Left	• North • South • East • West • Northeast • Southeast • Southwest • Northwest	• 0.1 • 0.2 • 0.3 • 0.4 • 0.5 • 0.6 • 0.7 • 0.7 • 0.8 • 0.9 • 1.0

The analysis was done for a set of cities with the respective cooling period (as per the climatic zone) and cities were clubbed together based on its latitude category i.e. latitudes ≥ 23.5˚N and latitudes < 23.5˚N (Table 1).

For each combination of shading type, orientation & projection factor, an average value of all cities falling in the same latitude category was calculated e.g. for latitude ≥ 23.5˚N,

$$ESF_{overhang_{North_{PF=0.4}}} = \frac{1}{3} \times \begin{pmatrix} ESF_{overhang_{North_{PF=0.4}}{}_{Amritsar}} \\ +ESF_{overhang_{North_{PF=0.4}}{}_{Delhi}} \\ +ESF_{overhang_{North_{PF=0.4}}{}_{Jaipur}} \end{pmatrix} \quad (7)$$

Finally, six ESF table were prepared:

- $ESF_{overhang}$ for LAT ≥ 23.5˚N
- $ESF_{overhang}$ for LAT < 23.5˚N
- ESF_{right} for LAT ≥ 23.5˚N
- ESF_{right} for LAT < 23.5˚N
- ESF_{left} for LAT ≥ 23.5˚N
- ESF_{left} for LAT < 23.5˚N

Each table had ESF value for all combinations of orientation and projection factor as mentioned in Table 6.

For the combination of shading types, total external shading factor (ESF_{total}) was defined as,

$$ESF_{total} = ESF_{overhang} \times ESF_{sidefin} \quad (8)$$

where,

$$ESF_{sidefin} = 1 - [(1 - ESF_{right}) + (1 - ESF_{left})] \quad (9)$$

The equivalent SHGC of the fenestration ($SHGC_{eq}$) was defined as the multiplication of SHGC of the unshaded fenestration product ($SHGC_{Unshaded}$) and the total external shading factor (ESF_{total}):

$$SHGC_{eq} = SHGC_{Unshaded} \times ESF_{total} \quad (10)$$

RETV formulation

The formulation of RETV formula included three key parameters:

- thermal transmittance of different opaque building envelope components
- thermal transmittance of different non-opaque building envelope components
- equivalent solar heat gain coefficient values of different non-opaque building envelope components

The RETV formula included three terms, one with each of the key parameter. Each term included one key parameter along with respective areas, orientations and a coefficient (Equation 11).

RETV formula was also checked for multi-collinearity and the variable influence factors were found well below the recommended value.

Regression analysis for determination of coefficients

The method of 'least squares' was used for regression analysis to calculate the coefficients of RETV formula. The error was calculated as the difference between $RETV_{simulated}$ and $RETV_{formula}$ and sum of square of error was done for all the simulation cases for one location. The combination of values of coefficients of RETV formula, which minimised the sum of square of error, was considered as the final solution for that location.

Final formula with coefficients

Based on the regression analysis, the coefficients for each location were calculated. The final formula was developed for the climatic zone, by taking the average values of the coefficients for different cities falling in that climatic zone.

Validation of results

The key objective of developing RETV formula was to be able to compare different building envelope alternatives 'quantitatively', without doing any energy simulation. The key validation criteria was that the RETV calculated from the formula ($RETV_{formula}$) should have very strong correlation with the sensible cooling loads calculated through energy simulation ($Q_{sensible}$).

Therefore, for the validation of results, the 'coefficient of determination (R-squared)' was calculated between:

- $Q_{sensible}$ and $RETV_{simulated}$
- $RETV_{simulated}$ and $RETV_{formula}$
- $Q_{sensible}$ and $RETV_{formula}$

The entire process (assumptions, inputs, process followed and the results) of RETV formula development, was validated by a steering and technical committee, consisting of professionals, industries, academics, and government officials of India.

Results

The study resulted in the development of RETV formula (Equation 11), which can closely predict $Q_{sensible}$. The calculation requires thermal properties, shading, areas and orientation of building envelope components. Thus, not-requiring any energy simulation, yet giving results very close to energy simulation.

$$RETV_{formula} = \frac{1}{A_{envelope}} \times \left[\left\{ a \times \sum_{i=1}^{n} (A_{opaque_i} \times U_{opaque_i} \times \omega_i) \right\} + \left\{ b \times \sum_{i=1}^{n} (A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i) \right\} + \left\{ c \times \sum_{i=1}^{n} (A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i) \right\} \right] \quad (11)$$

Table 7: Coefficients (a, b, and c) for RETV formula

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

Table 8: Orientation factor (ω) for different orientations

Orientation	Orientation factor (ω)	
	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

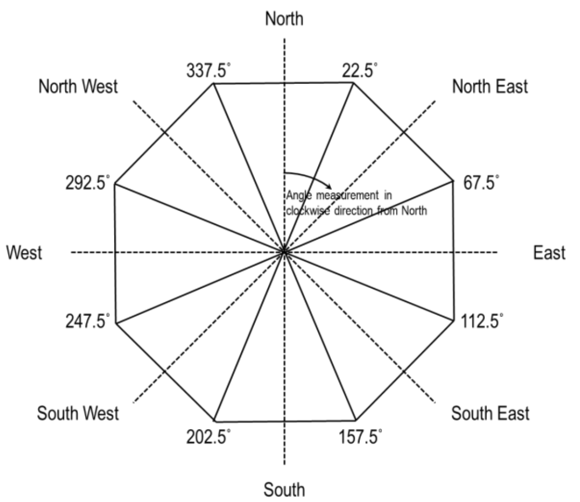

Figure 8: Primary orientations for determining the orientation factor

The quality of the multiple linear regressions obtained was comparable to Singapore (Chua and Chou, 2010), which has relatively constant temperature climates. Figure 9, Figure 10 and Figure 11 below show the graph for R-squared for point block model at Delhi.

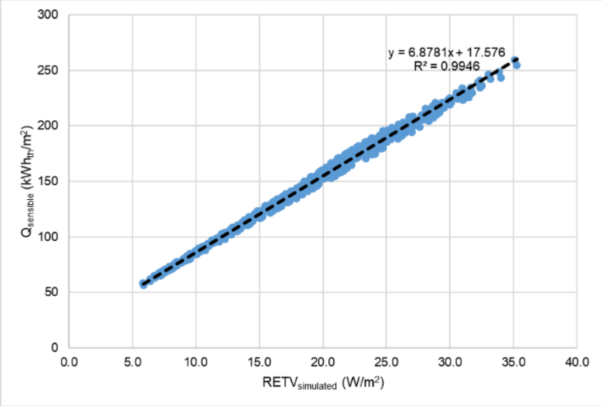

Figure 9: Correlation between $Q_{sensible}$ and $RETV_{simulated}$ for point block model at Delhi

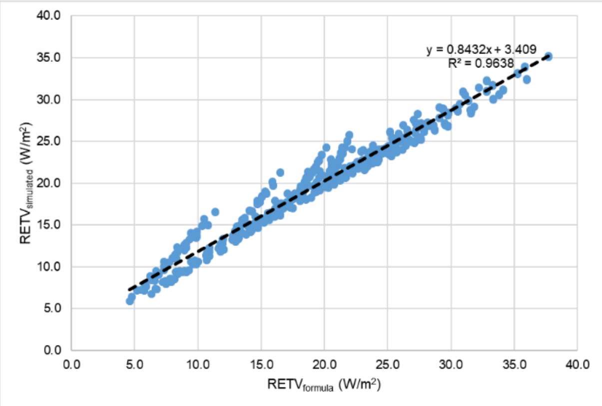

Figure 10: Correlation between $RETV_{simulated}$ and $RETV_{formula}$ for point block model at Delhi

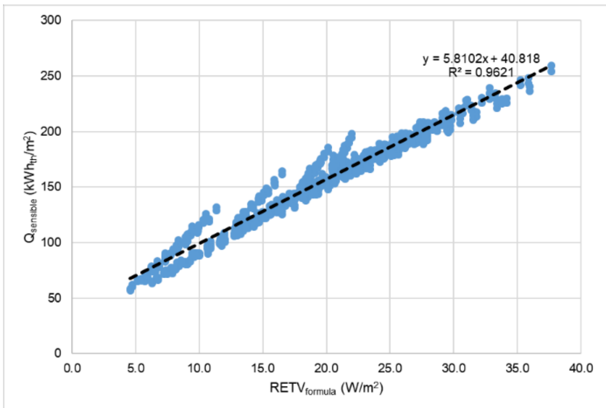

Figure 11: Correlation between $Q_{sensible}$ and $RETV_{formula}$ for point block model at Delhi

Similar results of R-squared for the two building typologies and seven cities are given in Table 9.

Table 9: R-squared results for different cities and building typologies

Building type	City	R-squared between		
		$Q_{sensible}$ & $RETV_{simulated}$	$RETV_{simulated}$ & $RETV_{formula}$	$Q_{sensible}$ & $RETV_{formula}$
Point Block	Delhi	0.9946	0.9638	0.9621
	Ahmedabad	0.9980	0.9735	0.9697
	Nagpur	0.9869	0.9692	0.9634
	Mumbai	0.9894	0.9492	0.9466
	Chennai	0.9966	0.9611	0.9573
	Kolkata	0.9904	0.9518	0.9518
	Bengaluru	0.8480	0.9178	0.8510
Doubly Loaded Corridor	Delhi	0.9959	0.9480	0.9462
	Ahmedabad	0.9972	0.9657	0.9593
	Nagpur	0.9903	0.9599	0.9551
	Mumbai	0.9901	0.9359	0.9329
	Chennai	0.9972	0.9498	0.9458
	Kolkata	0.9918	0.9399	0.9401
	Bengaluru	0.8405	0.8836	0.8113

- Average coefficient of determination (R-squared) between $Q_{sensible}$ and $RETV_{simulated}$: 0.97
- Average R-squared between $RETV_{simulated}$ and $RETV_{formula}$: 0.95
- Average R-squared between $Q_{sensible}$ and $RETV_{formula}$: 0.94

The small spread of data points (as seen in Figure 9, Figure 10 and Figure 11) and the high values (>0.9) of R-squared, show the applicability of presented method and also validates the RETV formulation.

Discussion

During the energy simulation, the values of key building envelope parameters were considered to include its minimum and maximum, based on the present construction practice in India e.g. WWR is taken from 10% to 35%, which would cover most of the residential buildings in India. However, the applicability of RETV formula needs to be checked for one or more parameter falling outside the simulation range.

The simulation model had priority given to cooling through natural ventilation and also had varied openable area. Hence, the 'R-squared' value for Bengaluru was lowest, because it has temperate climate which gives good potential for cooling through natural ventilation as compared to other climatic zones.

It is estimated that the implementation of Eco-Niwas Samhita 2018 has huge potential for electricity saving and greenhouse gas (GHG) reduction. The potential is estimated as 125 billion kWh of electricity saving and 100 million tonnes of CO_2 abatement for period 2018-2030. This energy saving is only for the air-conditioned residential buildings. For the unconditioned residential buildings, there would significant improvement in the indoor thermal comfort conditions, if the buildings comply to the RETV criteria of Eco-Niwas Samhita 2018.

Conclusion

Developing countries have limited resources for the implementation of Energy Conservation Building Codes. The experience with the implementation of ECBC in commercial buildings in India, indicated the need for a code with simple compliance check. Developing RETV formula for Eco-Niwas Samhita 2018 simplifies the compliance check; thus, making it easy to implement.

During the process of code development, the entire methodology was thoroughly tested and established. So, if similar formula needs to be developed for a specific location (not for the entire climatic zone), it is possible follow the methodology and come up with location specific RETV formula with the coefficients.

The RETV formula can be used as a design tool, to quickly evaluate and compare various design alternatives and material options, for their thermal performance. Along with other factors (e.g. material availability, cost, etc.), one can opt for the best possible design option.

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Nomenclature

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 (values given in Table 8 for different orientations as shown in Figure 8). This factor accounts for and gives weightage 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.

a, b & c: coefficients of RETV formula; values given in Table 7 for different climate zones

$A_{envelope}$: 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).

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

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

ESF: external shading factor (dimensionless)

I: incident solar radiation over the cooling period in one direction (kWh)

$I_{Average}$: average of incident solar radiation over the cooling period in all 8 directions (kWh)

PF: Projection factor (dimensionless)

$Q_{sensible}$: sensible cooling load calculated through energy simulation (kWh_{th}/m^2)

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

$RETV_{formula}$: RETV calculated through the RETV formula (W/m^2)

$RETV_{simulated}$: RETV calculated through the energy simulation (W/m^2)

$SHGC_{eq_i}$: equivalent solar heat gain coefficient values of different non-opaque building envelope components with a permanent external shading projection (overhang and side fins) (dimensionless)

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

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

WT: window transmitted solar radiation rate over the cooling period (W)

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