building envelope, ENS and cooler homes

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A good building envelope design can improve thermal comfort drastically by reducing heat gains. The design of the building envelope should be seen as key to reducing the cooling demand. The Eco Niwas Samhita (ENS) sets minimum building envelope performance standards to limit heat gains and for ensuring adequate natural ventilation and daylight potential.

Residential buildings account for 24 per cent of the electricity consumed in India (Ministry of Statistics and Programme Implementation, 2019) and will soon take a one-third share. This increase is due to the rise in construction and the increasing use of air-conditioners.

India has among the most cooling degree days (CDDs) in the world – more than 300. CDD is a measure of cooling requirement. It measures how much (in degrees), and for how long (in days), the average outdoor air temperature was above a certain level (the reference temperature being 18°C). While the reference temperature for CDD in India may be up for debate, there is no doubt about the colossal requirement of cooling, which will continue to increase because of the rising temperatures. The demand, and more importantly, the need, for cooling will increase. Different studies have estimated that cooling (through fans, air-coolers and air-conditioners) uses between 25-32 per cent of the electricity consumption in residences in India[1]. Monitoring of specific apartments in Delhi[2] and Chennai[3] (2-3 BHK units), in 2009 and 2013 respectively, showed that cooling constitutes between 33 to 65 per cent of their total electricity consumption.

Today, 7 per cent of Indian households own air-conditioners[4]. As affordability and access to reliable electricity supply increases, this number will rise driving up the cooling electricity consumption. However individual air-conditioners are energy guzzlers and use high GWP refrigerants, possibly being one of the largest end-use risks to our climate. But, often, a crucial element of the building design – the building envelope – is ignored; its effect on the "need" for air-conditioned cooling is significant.

Building envelope

Heat gains in a building are from several sources--external heat through the building envelope, heat from equipment and lighting used inside the building, heat generated by the building occupants. In residential buildings, the main contributor is external heat from the envelope, unlike commercial buildings where internal loads of the occupants and equipment contribute equally, if not more, to its heat load. The envelope mostly remains unchanged through the building lifetime. A good building envelope design can improve thermal comfort drastically by reducing heat gains in the hot climates and save significant energy over the building lifetime. The design of the building envelope should be seen as key to reducing the cooling demand for homes, consequently reducing cooling electricity consumption. Current urban residential buildings have veered towards material and design trends that not just ignore this aspect but are doing the opposite.

The objective of the Eco-Niwas Samhita Part I is to arrest this trend. Unlike a certification or rating system, that is aspirational in nature and, for the most part, voluntary, "codes are designed to be implemented as a regulation dictating mandatory minimum action"[5]. While certifications and rating systems continuously improve building practices, best practice does not become standard practice until all buildings begin to incorporate them. An effective way to achieve this is through development and implementation of better codes. ENS part I sets a minimum standard for the thermal performance of the building envelope in residential buildings.

Eco-Niwas Samhita

The Eco-Niwas Samhita (ENS) is the energy conservation code for residential buildings, launched by the Bureau of Energy Efficiency (BEE). Part I of the code was launched in December 2018 and it focuses on the building envelope (Fig 1). The code sets minimum building envelope performance standards to limit heat gains (for cooling dominated climates) and to limit heat loss (for heating dominated climates), as well as for ensuring adequate natural ventilationand daylighting potential.

For cooling-dominated or hot climates, the provisions of the code are:

1) For natural ventilation potential: a minimum openable window-to-floor area ratio with respect to the climatic zone

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[1] Prayas (Energy Group), December 2016. Residential Electricity Consumption in India: What do we know?

[2] BEE (Bureau of Energy Efficiency). 2014. Design Guidelines for Energy-Efficient Multi-Storey Residential Buildings (Composite and Hot-Dry Climates).

[3] BEE (Bureau of Energy Efficiency). 2016. Design Guidelines forEnergy-Efficient Multi-Storey Residential Buildings (Warm-Humid Climates).

[4] Lalit,R., &Kalanki, A. (2019, May 15). How India is solving its cooling challenge. Retrieved from https://www.weforum.org/agenda/2019/05/india-heat-cooling-challenge-temperature-air-conditioning/

[5] Burt, L., Sigmon, J., Dean, B., & Haack, C. (2012). '"Green" Codes and Rating Systems: A Framework for Evaluating the Tools and the Measuring Sticks to Create Better Buildings'. ACEEE Summer Study on Energy Efficiency in Buildings.

Ministry of Power

ECO-NIWAS SAMHITA 2018

(Energy Conservation Building Code for Residential Buildings)

PART I: BUILDING ENVELOPE

BUREAU OF ENERGY EFFICIENCY (BEE)

Figure 1. Eco Niwas Samhita

2) For daylight potential: a minimum visible light transmittance with respect to window-to-wall ratio

3) For heat gains through the roof: a maximum U-value of 1.2 W/m^2.K for the roof assembly is prescribed in all climate zones

4) For heat gains through the building envelope, except roof (i.e., walls and windows): a maximum Residential Envelope Transmittance Value (RETV) of 15 W/m^{2}for all cooling-dominated climate zones in India (hot-dry, composite, warm-humid and temperate). (See Box 1 for the RETV equation)

RETV considers heat gains through:

- 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.

These are signified in Terms 1, 2 and 3 of the RETV equation respectively.

Box 1: RETV equation

RETV 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. It signifies how much heat from outside (in watts) is transferred inside by unit area of the envelope (walls & windows together) over the cooling period or hot period of the year. Its unit is W/m^2 and it calculated using the following equation.

$$RETV = \frac{1}{A_{envelope}} \times \begin{bmatrix} \left\{ a \times \sum_{i=1}^{n} \left(A_{opaque_i} \times U_{opaque_i} \times \omega_i \right) \right\} \\ + \left\{ b \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times U_{non-opaque_i} \times \omega_i \right) \right\} \\ + \left\{ c \times \sum_{i=1}^{n} \left(A_{non-opaque_i} \times SHGC_{eq_i} \times \omega_i \right) \right\} \end{bmatrix}$$

where,

a, b, c: coefficients, based on climatic zone

$A_{envelope}$: envelope area (excluding roof) of dwelling units (m^2)

A_{opaque_i}:areas of wall / opaque part (m^2)

$A_{non-opaque_i}$: areas of glass / non-opaque part (m^2)

U_{opaque_i}: thermal transmittance values of wall / opaque part (W/m^2.K)

$U_{non-opaque_i}$: thermal transmittance values of glass / non-opaque part (W/m^2.K)

$SHGC_{eq_i}$: equivalent solar heat gain coefficient values of glass / non-opaque part

ω_i: orientation factor

The coefficients of this equation are derived from nearly 28000 energy simulations that were carried out considering different combinations of parameters. All these parameters were based on current building envelope design trends. For e.g. wall U-values of 0.48 W/m^2.K to 3.27 W/m^2.K were taken, to consider wall assemblies with the range of U-values in use in India.The same with the glass properties, window-to-wall area ratios, shading features etc.

This RETV equationwill be applicable or valid for material assemblies with densities that are equivalent to the density range of materials generally used today.

The RETV equation allows the design flexibility to vary individual parameters that influence it to arrive at an envelope design complying with a maximum limit of 15 W/m^2. These parameters are:

- the window and wall area,
- wall material (specifically its U-value)
- window glass properties (specifically its U-value & SHGC)
- shading design for the window, which in turn affects the effective SHGC of the
- window, and
- orientation of each wall and window

Lower heat gains

A conventional residential building today consists of external walls made of 230 mm thick fired-clay bricks, window-to-wall area ratio (WWR) of 15 per cent, single clear glazing on its windows and none to very little shading over them. The RETV of this building will be in the range of 18-20 W/m^2. In this building, walls are the biggest contributor of heat gains (nearly 60 per cent), followed by radiation heat gains through the glass used in the windows and doors (33 per cent).Walls let in the most heat because of the larger area share. As the WWR considered here is quite optimized, the only way to impact heat gains through walls is to look at the U-value of the wall assembly. Radiation through windows is impacted by the glass SHGC and window shading. Single clear glass is the most prevalent glazing in homes and low-SHGC glass is expensive. Thus, shading design is key in reducing heat gains.

On the top floor, a conventional roof (150mm RCC; U value ~3 $W/m^2.K$) will contribute approximately another 18-25 W/m^2 of roof area, depending on the climate zone. In this case too, the way to impact heat gains is to look at the U-value of the roof assembly.

Using insulation on the roof in compliance with roof assembly U-value of 1.2 $W/m^2.K$ can halve the heat gains from the roof to around 11 W/m^2, in the composite climate.

Let's take an example of housing project in Rajkot, which is in the composite climate. The typical floor plan of one block is shown in Figure 2. The long faces of the building are towards the north and south.

- Case 1 is constructing this building the conventional way (as described earlier). This results in a RETV of 18.34 W/m^2, with 60 per cent coming in through the walls and 33 per cent as radiation from windows (See 1st and 3rd term in Table 1).
- Case 2 is when the windows are shaded, here with 600 mm deep overhang and side fins. This reduces radiation heat gains through windows (3rd term) by 40 per cent, resulting in RETV of nearly 16 W/m^2.
- In Case 3, we replace the brick wall with 200 mm thick AAC blocks. The windows were shaded as in Case 2. Heat gains from walls are lowered by 40 per cent, resulting in RETV of 11.6 W/m^2. This already makes it compliant to the RETV requirement of ENS.
- Case 4 is how this building has been actually built. In addition to the window shading and AAC blocks, the WWR is reduced to 8 per cent by having partially glazed windows (1/3rd of the window was glazed) instead of fully glazed windows. This reduces radiation gains from the windows by another 40 per cent and also reduces conduction gains from windows by more than 45 per cent. The resultant RETV is 9.5 W/m2, which is well below the maximum RETV limit in ENS.

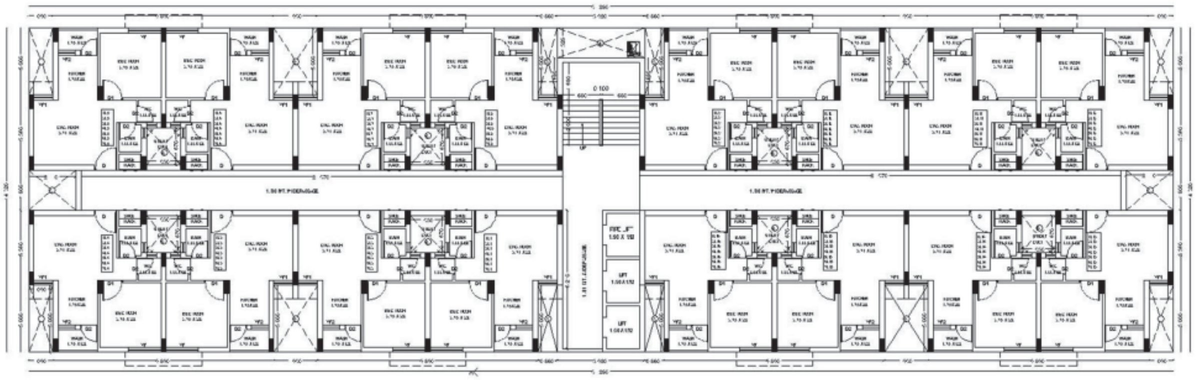

Figure 2. Typical floor plan of one block in affordable housing project in Rajkot

Using insulation on the roof in compliance with the ENS standard (roof assembly U-value of 1.2 W/m^2.K) can halve the heat gains from the roof to around 11 W/m^2, in the composite climate.

In the RETV calculations, it is implicit that the maximum potential of natural ventilation is used. In other words, whenever the outdoor temperature is lower than the inside temperature, in order to enable inside cooling all windows are opened and the openable-window-to-floor area ratio complies with the ENS standard.

So, it is possible to limit the heat transferred through the envelope with design features and materials available today. And doing this has far-reaching impacts. The effect of these envelope changes in this building is that the inside temperature on a peak summer day will be around 33°C - a reduction of 5°C from the conventional case, increasing the number of comfortable hours and reducing the need for air-conditioning.

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Complying with ENS provisions

In recent years, the trend has been to go in for monolithic concrete construction for group housing using various technologies. In this type of construction all components like walls, slabs, staircases etc. are cast monolithically at one time using concrete. The use of monolithic concrete has gained momentum mainly due to its apparent construction speed. However, due to the high conductivity of concrete, this makes the homes very uncomfortable in summer, turning them into literal furnaces in the extreme heat situations, necessitating the use of air conditioners. It is also imperative to slow this trend. This is not to say concrete is not a feasible material. However, using only concrete as walling material for external walls is risky – it requires the addition of insulative materials to reduce its thermal transmittance (U-value). If we were to use, in the example of the project in Rajkot, 150 mm concrete walls instead of brick walls, RETV for Case 1 would have shot to nearly 25 W/m^2 (Table 2). Even with all other measures mentioned in Case 4, it would still be higher than the ENS standard.

Due to larger wall areas in comparison to glazed areas, choice of walling material is the most important decision as far as the thermal performance of the building envelope is concerned. As has been shown, complying with ENS standards is possible with design features and materials that are available today. These could be:

Table 1. Impact of different envelope materials and components on RETV of the housing project in Rajkot (composite climate)

	RETV 1st Term *(Wall conduction gains)*	**RETV 2nd Term** *(Window conduction gains)*	**RETV 3rd term** *(Window radiation gains)*	**RETV Total**
Case 1: *230mm thk brick wall + WWR 15% + single clear glass + no shading*	11.02	1.19	6.12	18.34
Case 2: *230mm thk brick wall + WWR 15% + single clear glass + 600mm deep overhang & side fins*	11.02	1.19	3.51	15.72
Case 3: *200mm thkAAC block walls + WWR 15% + single clear glass + 600mm deep overhang & side fins*	6.89	1.19	3.51	11.59
Case 4: *200mm thkAAC block walls + WWR 8% + single clear glass + 600mm deep overhang & side fins*	6.89	0.63	1.94	9.46

Table 2. Impact of concrete wall construction on RETV of the housing project in Rajkot (composite climate)

	RETV 1st Term *(Wall conduction gains)*	**RETV 2nd Term** *(Window conduction gains)*	**RETV 3rd term** *(Window radiation gains)*	**RETV Total**
Case 1a: *150mmthkconcrete wall + WWR 15% + single clear glass + no shading*	17.18	1.19	6.12	24.49
Case 4a: *150mmthkconcrete wall + WWR 8% + single clear glass + 600mm deep overhang & side fins*	17.18	0.63	1.94	19.75

- Walls
  - Bricks/ blocks with low thermal conductivity e.g., autoclaved aerated concrete (AAC) blocks, hollow clay blocks, cellular lightweight concrete (CLC) blocks
  - Addition of ready-to-use finished insulation

    products on brick / concrete walls e.g., glass wool, mineral wool, expanded polystyrene (EPS), expanded polystyrene
  - Construction technologies like insulating concrete forms (ICF), monolithic insulated concrete systems (MICS), various types of expanded polystyrene (EPS) panel system, aerocon panels

- Windows and other glazed components
  - Adding external movable shading systems e.g., roller blinds, vertical louver system, bamboo chicks, lamella blinds
  - High performance single glazing and clear double-glazing units

- Roof
  - Adding tiles with low thermal conductivity e.g., hollow clay roofing tile, expanded clay roofing tile, cool roof tiles
  - Adding liquid spray foam like polyurethane foam.
  - Addition of ready-to-use finished insulation products over the roof slab e.g., glass wool, mineral wool, expanded polystyrene (EPS), extruded polystyrene (XPS)

Apart from these materials and technologies, there are others at the research stage such as aerogel-based plaster and finishes and radiative films.

The cost of a shift from a conventional building (RETV of 18-20 W/m^2; roof U-value 2.5 - 3 W/m^2.K) to ENS-compliant building envelope is minimal. The incremental cost for complying with the requirements of the Eco-Niwas Samhita entails only a very small (1.2 per cent) increase in construction cost. What is needed is awareness of these materials and incentivizing their use.

There was no national standard as to how a residential building should thermally perform. Given the nature and type of stakeholders involved, this standard also needs to be as simple as possible. The ENS is this standard. It maintains simplicity in understanding while allowing the designer the scope for design expression and innovation.

Impact at the national level

In the hot climates, efficient building envelope helps in extending the time period when the building is able to provide a thermally comfortable environment by reducing heat through the walls, windows and roof. This also benefits the households that can afford cooling technologies by reducing the time for operation of active cooling, leading to significant energy savings.

> If all our building stock – existing and new – is to remain at today's RETV and roof U-value, we are looking at a cooling energy requirement of 3365 TWh_{th}/y by 2050; nearly four times the requirement today.

Urban residential built-up area in India is estimated to increase from 5.9 billion m^2 (2020) to 22.2 billion m^2 (2050). If all our building stock, existing and new is to remain at today's RETV and roof U-value, we are looking at a cooling energy requirement (amount of thermal energy that needs to be removed to maintain thermal comfort condition) of 3365 TWh_{th}/y by 2050, nearly four times the requirement today if everybody in the urban areas has access to and can afford thermal comfort. If we move nearly all existing and all new residential stock towards complying with the standards in ENS or even lower, we can have a cooling energy requirement of 2000 TWh_{th}/y by 2050. This, aided by better efficiencies (average CoP equivalent of 7.52) and low GWP of new air-conditioning technologies, can result in cooling electricity demand of 267 TWh/y in 2050, which is almost 58 per cent less compared to when we let things remain as they are today.This translates to nearly500 GW of avoided power generation capacity addition, which is equivalent to an avoided investment of Rs.20,00,000 crores on power plants (Considering investment of Rs.4 crore/M W)[6].

It will also ensure that access to thermal comfort is affordable to all, even those who cannot afford an air conditioner.

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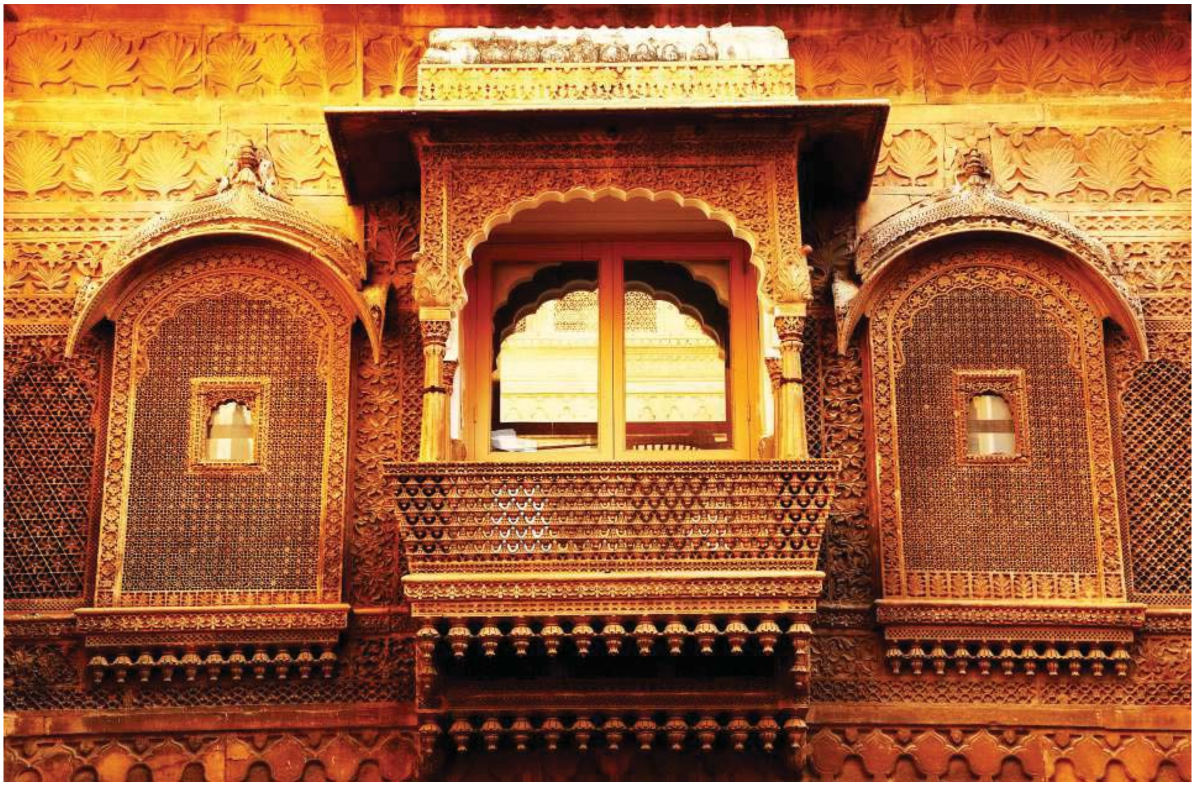
[6] Analysis carried out by Greentech Knowledge Solutions Pvt. Ltd. (GKSPL), Energe-se, and CEPT Research & Development Foundation (CRDF) under the project "Developing cost-effective and low-carbon options to meet India's space cooling demand through 2050." This project is funded by Shakti Sustainable Energy Foundation.



What will it take to get there?

Part 1 of Eco-Niwas Samhita was launched in 2018 and was designed as a simple standard requiring simple calculations. Getting the implementation started through a process of notification and making it mandatory through building bye-laws is an important step in getting the full potential of this code. However, this must be accompanied by,

- Acceptance and use of the ENS by the building industry, especially the design professionals: This requires more awareness-raising and encouraging architects and engineers to use the code provisions as a tool during the design process.
- Market transformation: This could mean
    - o Ensuring that all building envelope materials are tested and their thermal properties like conductivity are readily available to designers
    - o incentivizing the manufacture and use of ENS compliant materials and assemblies;
    - o capacity building and training of contractors, masons and fabricators on how to use them in construction
    - o further product development R & D and field tests
- Awareness raising of the home buyer: It is important that the home buyer knows that thermal comfort and energy is an aspect that needs to be considered while buying, and that a code exists for it.

As new building materials and construction technologies are introduced, it is crucial that we also question and put to test how they will impact our comfort and cooling demands. The ENS 2018 is the first-generation code for energy efficiency in residential buildings in India and will undergo revisions in future to reflect changing conditions and changing potentials. If its potentials are fully utilized, ENS 2018 will not only save lots of energy, but will also help achieve "thermal comfort for all".

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