ENERGY EFFICIENT BUILDING ENVELOPE & VENTILATION STRATEGIES FOR MULTI-STOREY RESIDENTIAL BUILDINGS IN INDIA

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ABSTRACT

India is witnessing a rapid increase in the residential building floor space. A survey of electricity use in middle class multi-family housing shows that electricity use for cooling and ventilation accounts for 30-60% of the annual electricity consumption. Thus, the new residential building stock should be designed to maximize thermal comfort, and to minimize energy requirement for cooling and ventilation.

This paper is based on research on energy use in dwellings and energy modelling of typical spaces in dwellings. The paper presents key strategies for designing energy efficient multi-storey residential buildings:

1. Strategies to reduce solar heat gains through the building envelope by proper sizing and shading of windows (external fixed and/or movable), insulation of roof and walls.
2. Strategies to improve ventilation, when desired, inside flats through window design and assisted ventilation.

The paper presents the results of integrating energy-efficient envelope and ventilation strategies in sample bedrooms of 3 multi-storey residential projects located at Indore (composite climate), Chennai (warm and humid climate) and Rajkot (composite climate). The experience from these 3 projects shows that a reduction in peak operative temperatures in a range of 4 - 7°C is possible by implementing these strategies.

INTRODUCTION

Globally, buildings use about 40% of energy, and in the process, emit approximately 1/3rd of GHG emissions (UNEP, SBCI). In India, buildings account for 1/3rd of the electricity consumption, second only after industries. Of this residential buildings and commercial buildings account for ~23% and ~8%, respectively, of the total electricity consumption in year 2014-15. Projection done by NITI Aayog under different scenarios shows that the electricity consumption for the residential sector is expected to increase 6-13 times from 2012-2047. This increase of electricity consumption in residential buildings is primarily attributed to the increase in building stock, with residential sector built-up area expected to increase by ~4 times, during 2012 to 2047; expansion of electrification in rural areas as well as to the increased intensity of electricity consumption in urban buildings, mainly due to rapid growth of air conditioning.

A survey of electricity use in middle class multi- family housing show that the measured mean Energy Performance Index (EPI) for sample residential flats of 2-3 bedrooms in composite (National Capital Region) and warm and humid (Chennai) climate for the year 2009 are calculated as 48 kWh/m^2/annum and 43 kWh/m^2/annum respectively (BEEP, 2014; BEEP, 2016). The surveyed flats operated on mixed mode cooling, with most of the flats owning one or two room air-conditioners. It was found that energy consumption for comfort cooling varied from 1/3rd to 2/3rd of the total annual energy consumption, based on number of occupants and the number of air- conditioners. The study also indicated that in some of the flats having greater air-conditioner use, the EPI was more than 70 kWh/m^2/annum. The survey results were used to develop design guidelines for energy- efficient multi-storey housing. The guidelines put significant emphasis in designing an appropriate building envelope to reduce solar heat gains and improving natural ventilation potential to achieve thermal comfort and reduce energy use for comfort cooling in residential buildings.

Heat gains from the envelope play the most significant role in influencing thermal comfort and consequently energy efficiency in residential buildings. Residential buildings have large exposed façade area to built-up area ratio, resulting in the space cooling loads dominated by heat gains from the envelope. The penetration of air-conditioners in residential buildings is negligible, meaning the envelope characteristics are vital in maintaining thermal comfort. The paper presents the results of integrating energy-efficient envelope and ventilation strategies in 3 multi-storey residential projects located at Indore (composite climate), Chennai (warm and humid climate) and Rajkot (composite climate). The results of building energy simulations studies to understand the impact of these measures are presented. The simulations were carried out during design workshops conducted to recommend practical strategies for improving thermal comfort and reduce energy required for cooling and ventilation in these building projects.

METHODOLOGY

The methodology stated here follows that adopted during a 3-4 day design workshop carried out for 3 residential projects. The main purpose of the design workshops was to provide design recommendations for improving thermal comfort and energy efficiency, specific to the requirements and constraints of the project. Given the nature and duration of the design workshop, only a few practical design strategies were simulated and analysed.

1. Selection of sample bedrooms: As the design workshop takes place over a short duration, it is important to select the critical spaces for simulation instead of the whole building, or in case of residential projects, multiple building blocks. In residences, bedrooms are the most used spaces, with maximum occupancy in evenings and nights. These are also the spaces were air-conditioners are most likely to be installed. Thus sample bedrooms were selected in all 3 projects to analyse the impacts of the design recommendations. The sample bedrooms were selected based on their orientation to account for different levels of solar and wind exposure.
2. Simulating the base case: Energy models of the sample bedrooms were developed in DesignBuilder software. Inputs of the existing design are entered, viz, details of the building envelope and internal loads. These are non- conditioned spaces, as in residences air- conditioning is a matter of the residents' choice. The simulation is carried out to predict the peak operative temperature in the bedroom on a typical summer week or day. These inputs for the base case are shown in **Table 1** and **Table 2**.
3. Simulation of the proposed envelope and ventilation strategies: Envelope and ventilation strategies are applied on the worst of the sample bedrooms of the base case, i.e., the bedroom with the highest peak operative temperature. Simulation predicts the peak operative temperature of the same summer week or day as the base case, after applying these strategies.

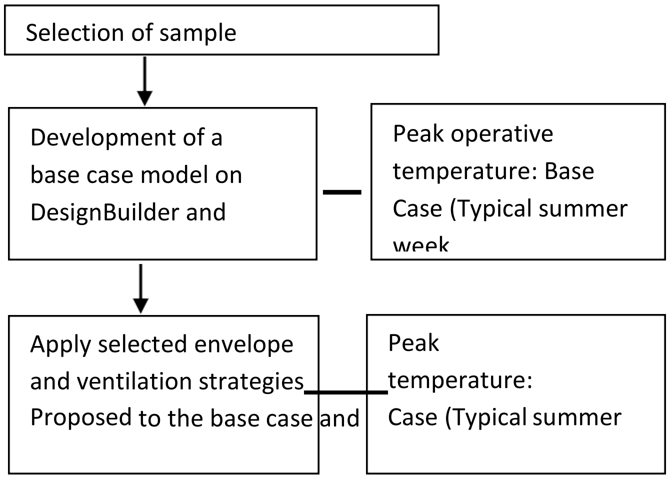

Figure 1: Flow chart showing the methodology

Table 1: Details of internal loads

Parameter	Value	Unit	Schedules
Occupancy	2	persons/ bedroom	Weekdays: 2 persons (21:00 to 7:00) Weekends: 2 persons (23:00 to 7:00) & (14:00 to 17:00)
Lighting	30 W T-5 light (1 no.)		18:00 to 23:00
Equipment	--		None

RESULTS

Project 1, Indore

This Middle-Income-Group (MIG) housing project is consists of 1743 units in 13 towers varying in height from "Stilt (S)+10" to S+14 storeys in height.

Base case simulation results: The base case simulation was carried out for 4 bedrooms of 4 flats in different orientations (**Figure 2**).

1. Bedroom with north façade exposed with window
2. Bedroom with south façade exposed with window
3. Corner Bedroom with south and west façade exposed with window on the south façade
4. Bedroom with south and west façade exposed with window and glass door on west façade

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Table 2: Building envelope inputs for the 3 residential projects

	Project 1, Indore	Project 2, Chennai	Project 3, Rajkot
External wall	230 mm burnt brick with 15 mm plaster on both sides	200 mm fly ash brick with 12 mm plaster on both sides	230 mm Autoclaved Aerated Concrete (AAC) block with plaster
External wall (U value)	2.00 W/ m^2.K	1.90 W/ m^2.K	0.70 W/ m^2.K
Floor & ceiling	Considered adiabatic for intermediate floors		
Roof (U value)	3.70 W/ m^2.K	3.70 W/ m^2.K	2.70 W/ m^2.K
Glazing: 6 mm single clear glass U-factor Solar Heat Gain Co-efficient (SHGC) Visual Light Transmittance (VLT)	 5.80 W/ m^2.K 0.81 0.88	 5.80 W/ m^2.K 0.81 0.88	 5.80 W/ m^2.K 0.81 0.88
Window size	1 sliding window or window +door in 1 bedroom • Window: 1800mm x 1585mm • Window and glass door: 1900mm x 2285mm	2 sliding windows in 1 bedroom • W1: 2150mm x 1200mm • W2: 600mm x 1200mm	1 sliding window in 1 bedroom • 1450mm x 1220mm
Window-to-Wall Ratio (WWR) of sample bedroom	• Bedroom with window: 29% • Bedroom with window and glass door: 43%	15%	20%
Window operation	• 50% openable • Window opens when inside temperature ≥ outside temperature by 1°C	• 50% openable • Window opens when inside temperature ≥ outside temperature by 2°C	• 50% openable • Window opens when inside temperature ≥ outside temperature

Figure 2: Site plan of Project 1, Indore. The 4 bedrooms selected for simulation are marked

Energy simulation was carried out in all four bedrooms to calculate peak operative temperature inside the flats on a typical summer day. This was done for an intermediate floor as well as the top floor.

- On the intermediate floor, there was a temperature difference of around 5°C between the coolest bedroom (~34°C Bedrooms 1 & 2) and the hottest bedroom (38.4°C in Bedroom 4).
- The top floor bedrooms had higher inside temperatures than the corresponding bedrooms on the intermediate floor. Temperature difference between the coolest and hottest bedrooms (37.9°C and 40.4°C in Bedrooms 1 and 4 respectively) of the top floor is around 2.5°C (**Figure 3**).
- On the intermediate floors, the walls and windows contribute most of the heat gains, depending upon the orientation. On the top floor, the heat gain from the roof is most dominant.

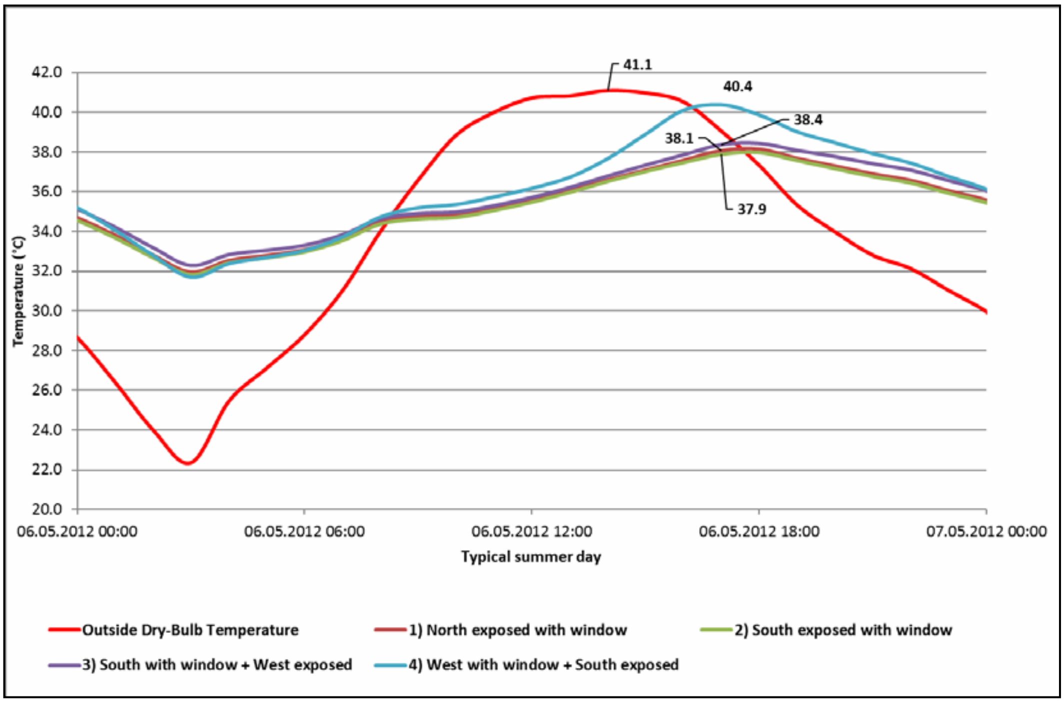

Figure 3: Peak operative temperatures for the base case on a typical summer day on the top floor (Project 1, Indore)

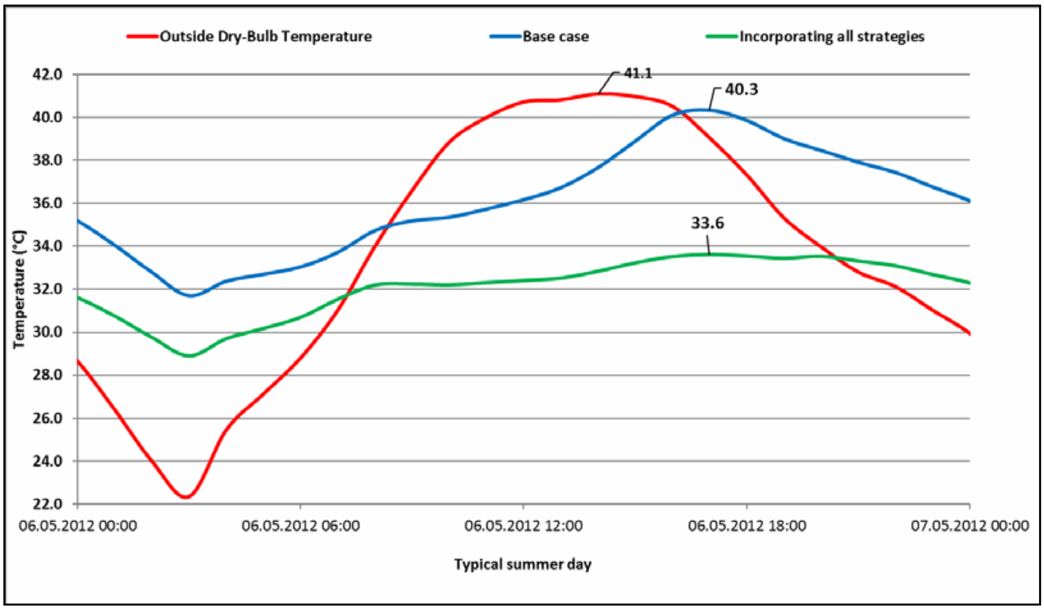

Figure 4: Peak operative temperature of Bedroom 4 on the top floor on a typical summer day- in the base case & after incorporating the strategies (Project 1, Indore

Proposed strategies: The following strategies were proposed:

- Reduce WWR to 20-30 %
- External movable shading on windows
- 200mm thick AAC blocks for walls instead of burnt brick
- 100mm XPS insulation on the roof

These strategies were simulated for the worst of the sample bedrooms, i.e. Bedroom 4 (Bedroom with south and west façade exposed with window / glass door on west façade) on the top floor. It was seen that, with the above strategies, the inside temperature can be reduced by ~7°C (**Figure 4**), bringing the peak operative temperature from 40.4°C to ~33°C. If air-conditioned, the cooling load of this bedroom will be reduced to 1/3rd from that in the base case.

Project 2, Chennai

This project consisted of 874 units (2 and 3 BHK) distributed in nine towers, predominantly facing the east and west (**Figure 5**). The towers vary in height between 14 and 17 storeys. This project had a "sky-deck" above the top floor, effectively covering the roof.

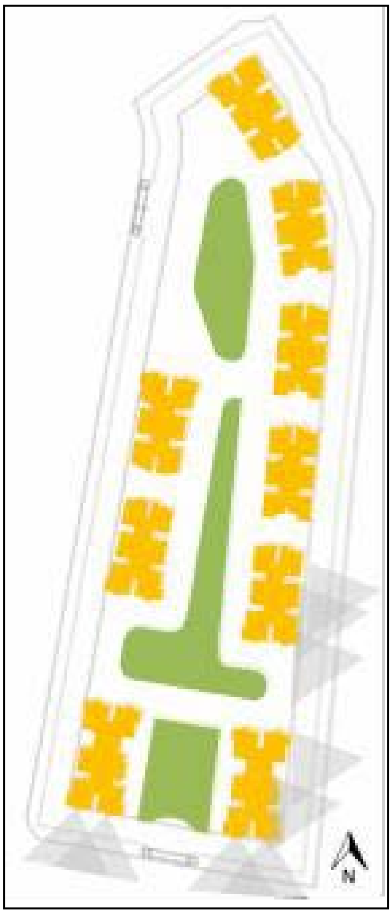

Figure 5: Site plan of Project 2, Chennai

Base case simulation results: The east-facing bedroom was considered for simulation as it was found to have higher day-time temperature. Two cases were simulated for this bedroom: when wind was available i.e. a wind-facing flat (taking wind speed as per climate file) and when wind was not available, i.e., the lee ward facing flat (wind speed 0 m/s).

This was done as Chennai is in the warm-humid climate, where the wind plays a role in maintaining thermal comfort.

- Peak operative temperature in the bedroom reach 37.8°C on a typical summer day, for flats on the windward side (**Figure 6**).
- For flats on the leeward side (wind speed 0 m/s), the peak operative temperature calculated on a typical summer day is 38.2°C.
- Most of the heat gains were occurring through the glazed windows, which faced east – west.

Proposed strategies: The following strategies were proposed:

- Shade the windows well with external movable shading and overhangs; and
- Replace the sliding windows with casement windows to improve ventilation.

The analysis shows that external movable shading has the most prominent effect in reducing inside peak temperatures and thus improving thermal comfort. While fixed shading reduces inside temperatures by 1.5°C, external movable shading reduces it by 4.2°C (**Figure 7**). Even for leeward flats, with no wind speed, peak internal temperature is reduced by about 4°C by external movable shading.

The improvement in thermal comfort due to this is also seen over the year. The number of hours in a year when the operative temperature was below 30°C is improved from 65% in the base case to 95% for wind-ward flats; and from 40% to 74% for the leeward flats.

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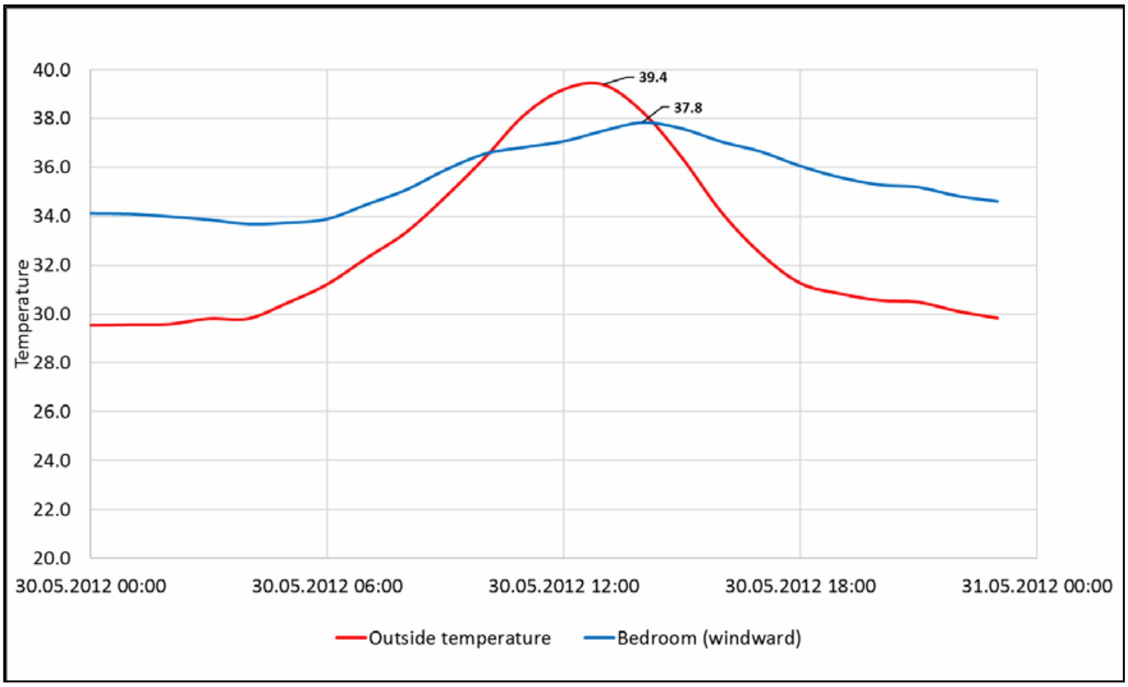

Figure 6: Peak operative temperatures for the base case on a typical summer day in a windward facing bedroom (Project 2, Chennai)

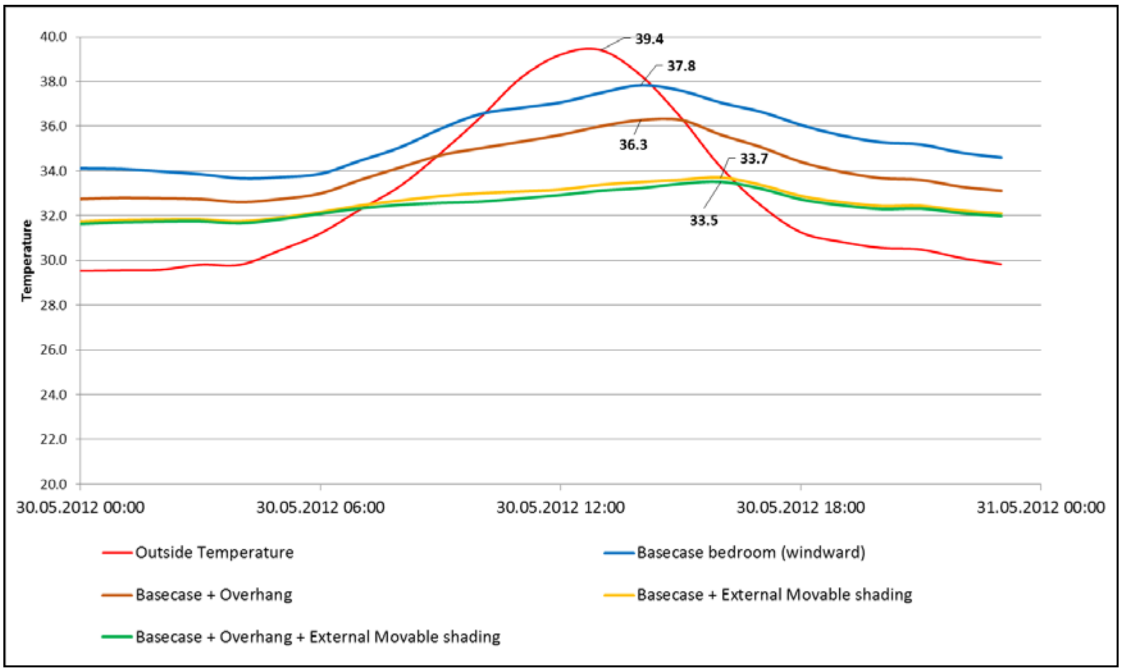

Figure 7: Peak operative temperature of a wind-ward bedroom on a typical summer day- in the base case and with different external shading (Project 2, Chennai)

Project 3, Rajkot

This affordable housing project consisted of 1176 dwelling units with the built-up area of each flat around 30 m^2. These flats were designed in 11 towers of 7 storeys with stilt parking (S+7).

Base case simulation results: The base case simulation was carried out for 4 bedrooms of 4 flats in different orientations (**Figure 8**).

- On the intermediate floors, bedrooms facing north and south are coolest in summer (**Figure 9**). There is a difference of around 3.5°C between the south

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facing bedroom (peak operative temperature 34.7°C) and the west facing bedroom (peak operative temperature 38.3°C).

- On the top floor, a similar temperature difference is found between the bedrooms facing north and south and those facing east and west, with the annual peak temperature ranging between 38°C to 41°C.
- The operative temperature inside the sample bedrooms remain below 30°C for 25% - 40% of annual hours.
- Highest heat gains occur through the glazed windows.

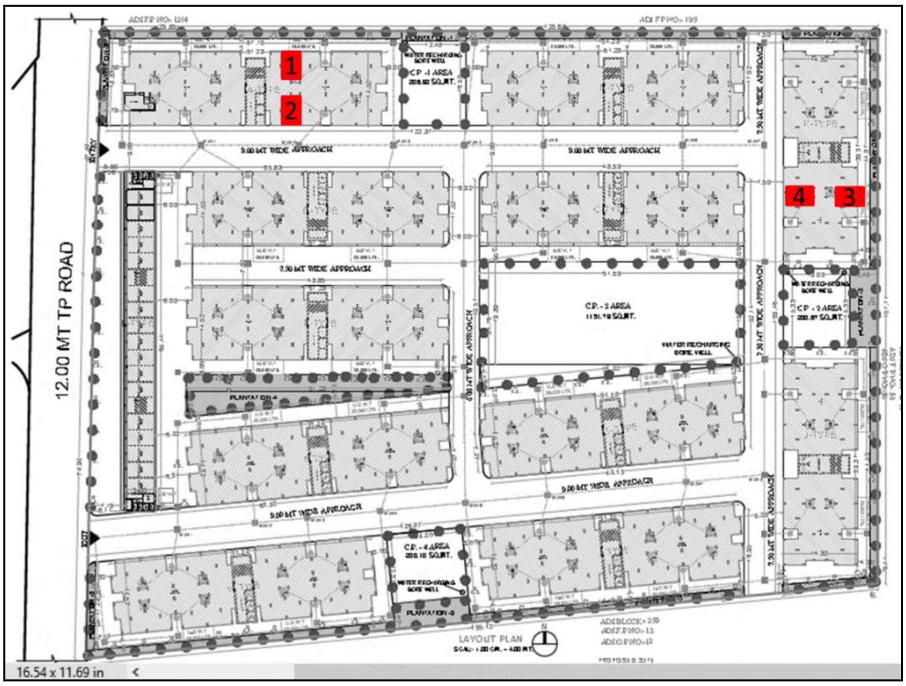

Figure 8: Site plan of Project 3, Rajkot. The bedrooms selected for simulation are marked

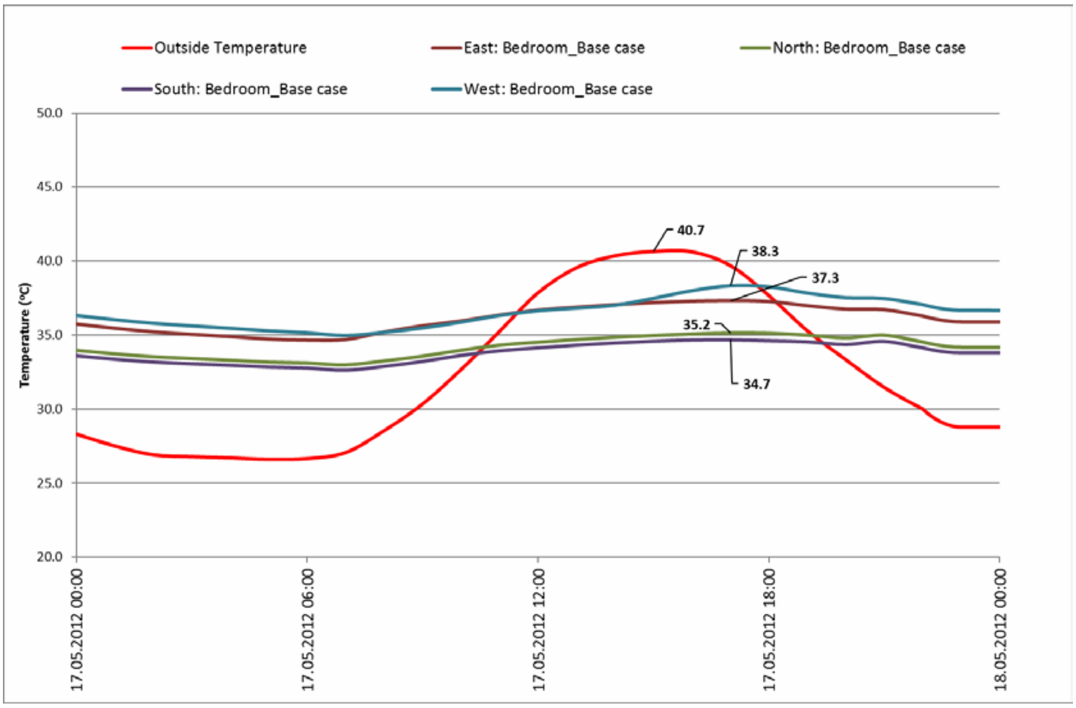

Figure 9: Peak operative temperatures for the base case on a typical summer day on an intermediate floor (Project 3, Rajkot)

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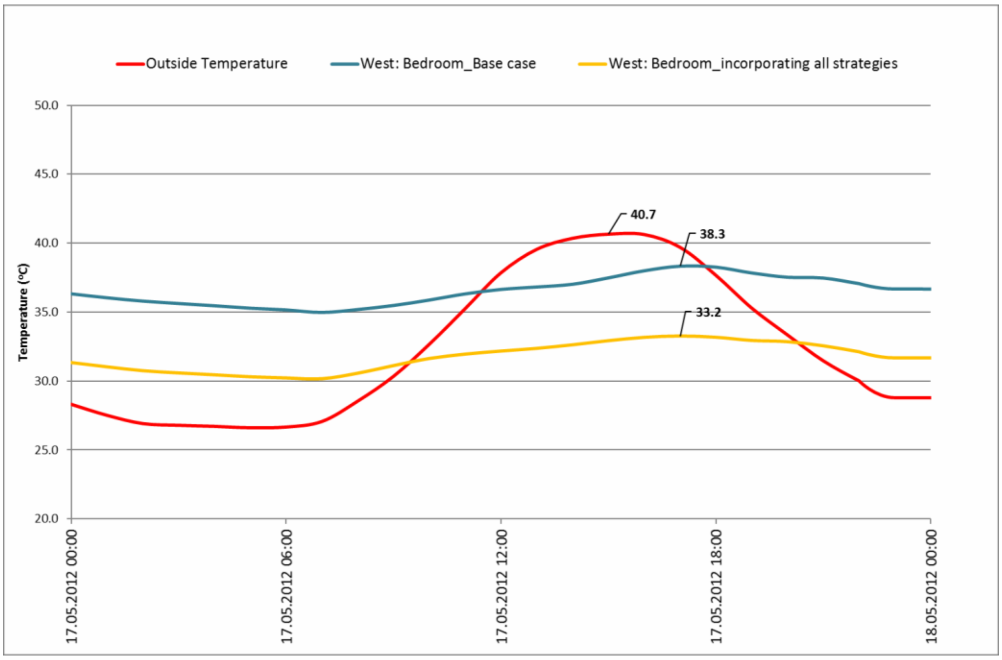

Figure 10: Peak operative temperature of a west-facing bedroom on an intermediate floor in a typical summer day- in the base case and with all strategies (Project 3, Rajkot)

Proposed strategies: The following strategies were proposed:

- External movable shading on windows or opaque window shutters with 20% glazing for daylight
- Casement windows instead of sliding windows for better ventilation
- Assisted ventilation through central shaft when ambient temperature is cooler than inside temperature
- 40 mm polyurethane foam (PUF) insulation on the roof

Using the envelope measures of shading and casement windows, the inside peak operative temperature on the intermediate floor is found to reduce by 4°C over the base case. Adding assisted ventilation through a central shaft reduces the peak temperature by another 1-2°C. This is shown in **Figure 10**.

On the top floor, these measures were found to reduce the peak temperature by 4-5°C. Adding roof insulation would reduce the peak temperature further by ~3°C.

The number of hours in a year when the operative temperature was below 30°C is improved from 25% in the base case to 72%.

CONCLUSIONS

The experience from these 3 projects shows that a reduction in peak operative temperatures in a range of 4 - 7°C is possible by implementing a few key envelope and ventilation strategies.

- Reducing window-to-wall ratio where required;
- Providing fixed shading: Fixed horizontal shading for the south and north façade can reduce direct solar radiation from entering the building from these facades. However, fixed shades are not effective in cutting the diffuse solar radiation which can form a large part of the total solar radiation given the high level of particulate matter and dust in several Indian cities.
- External movable shading: External movable shades are the most effective in cutting of solar gains from windows. They are particularly recommended on the west and east facades. Using external movable shading allows less than 15% of the solar heat falling on the window inside. The use of such systems on windows facing east and west can reduce the solar heat gains by 60%–80%.
- Roof insulation: A large reduction in heat gains is possible for the top floor with roof insulation.
- Wall insulation: Wall insulation works best in regions when the diurnal temperature range is high like in Indore and Rajkot, but not in Chennai.
- Casement windows (100% openable) instead of sliding windows (50% openable) for better natural ventilation potential
- Provision for cross ventilation in the room or through the flat

- Natural or assisted ventilation through the central shaft of the buildings to induce air flow in buildings.

The analysis done during the development of the design guidelines, and the simulation results from the 3 projects highlights the importance of reducing heat gains through the building envelope and improving natural ventilation as being central for improving thermal comfort and energy efficiency in multi-storey residential buildings in most of the Indian climates.

It is to be noted that several countries, e,g, Singapore has codes on envelope thermal performance of buildings . The Singapore code defines a Residential Envelope Transmittance Value (RETV), which takes into consideration the three basic components of heat gain through the external walls and windows of a building i.e.
a) heat conduction through opaque walls,
b) heat conduction through glass windows, and c) solar radiation through glass windows. These three components of heat input are averaged over the whole envelope area of the building to give an RETV that represents the thermal performance of the whole envelope. For the purpose of energy conservation, the maximum permissible RETV has been set at 25 W/m^2.

At a broader policy level, it is necessary to develop similar codes to be included in the building bye-laws and national building code. This is necessary to make the new residential building stock in India adhere to minimum levels of thermal comfort and energy efficiency.

REFERENCES

UNEP, SBCI. Retrieved from http://staging.unep.org/sbci/AboutSBCI/Background. asp

NITI Aayog. 2015. India Energy Security Scenarios. Retrieved from http://www.indiaenergy.gov.in/

BEEP. 2014. “Design Guidelines for Energy Efficient Multi-storey Residential Buildings- Composite & Hot-Dry Climates”.

BEEP. 2016. “Design Guidelines for Energy Efficient Multi-storey Residential Buildings- Warm-Humid Climate”.