GUIDELINES FOR AFFORDABLE HOUSING IN TELANGANA

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A CSE Evaluation of Government Supported Housing for Thermal Comfort, Resource Efficiency and Sustainability

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An initiative supported by

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SUSTAINABLE ENERGY FOUNDATION

Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that support renewable energy, energy efficiency and the adoption of sustainable transport solutions.

Maps used in this document are not to scale.

Published by
Centre for Science and Environment
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The mandate

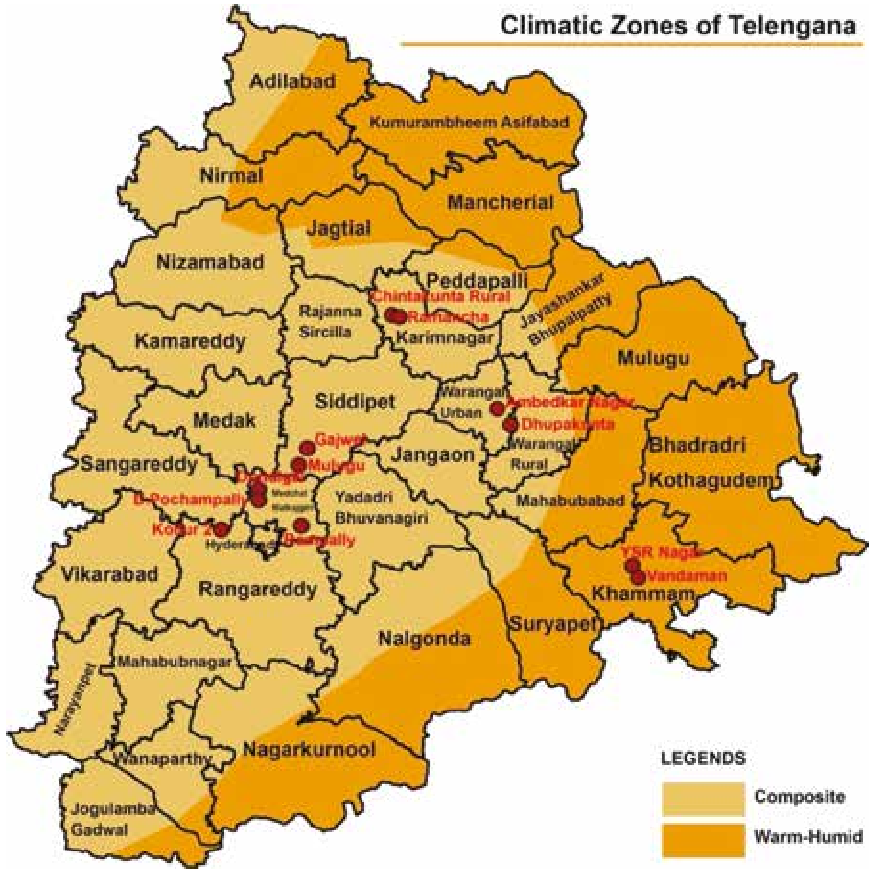
The COVID-19 pandemic has reinforced the linkages between thermal comfort and energy efficiency of residential buildings with the health and life of their residents. After India's Cooling Action Plan (ICAP) provided for thermal comfort requirement in buildings, the pandemic has underscored the need to expedite India's efforts to enable thermal comfort. An operational framework is now required to set the terms for mass construction of housing that is expanding rapidly in states.

To achieve the goals set out in ICAP as well as enable green recovery in post-COVID housing, it is necessary to have a mandate, detailed guidelines, and modified building bylaws related to architectural features, design layout, and materials that influence thermal comfort and livability in buildings. This can ensure improved ventilation, adequate lighting, and appropriate temperature conditions inside the houses to improve comfort, and also reduce risk of diseases such as COVID-19. It is imperative to gauge the performance of the current affordable housing regime to recalibrate it with respect to a 'new normal'.

The Centre for Science and Environment (CSE) has initiated a process to assess the current housing stock that is emerging under affordable housing programmes like the Pradhan Mantri Awas Yojana (PMAY) to identify the areas which can be worked on to improve thermal comfort and livability of buildings. Towards this end, in-depth field investigation has been carried out in Telangana—the newest state of India that is constructing affordable housing with great vigour. The key areas being assessed in a wide housing portfolio are—the state's approach to planning, layouts, and choice of materials and their coherence to the native climate zone; penetration of alternate walling technologies; policy framework for affordable housing; incentives to speed up construction; etc. .

The key objective of this exercise is to inform the building of thermally efficient spaces, with a focus on walling assembly, meeting the goals of ICAP. This can be done by learning from the affordable housing constructed so far and improving upon them to strengthen mass housing schemes that will come in the future. This assessment has specifically considered criteria that influence thermal comfort in buildings including ventilation, orientation, exposure, thermal transmittance properties of materials, building elements like shading devices, etc. For livability and energy efficiency, daylighting and locational characteristics of sites have been considered as well. For this purpose, building design, layout of building clusters, and use of material in selected sites in Telangana have been simulated to understand the performance of the existing design and material choices as well as to gauge the nature of efforts and fiscal strategies required to enable thermal comfort and livability in the mass housing sector. Assessments of this kind are important as the construction sector is transforming and the central government is making efforts to upscale new materials and construction technologies.

Map 1: Study carried out in different climate zones in Telangana



Source: CSE

Under this assessment, simulations have been done in reference to the National Building Code 2016 and Eco-Niwas Samhita 2018—India's latest regulatory tool for energy conservation in residential buildings. This helped to understand the combined impact of design and materials. The alternative materials and construction technologies promoted by the Building Material Technology Promotion Council (BMTPC) were also assessed mainly for their bearing on thermal comfort and energy efficiency. This study looked at different typologies in the climate zones in Telangana. It may be noted that the 2BHK scheme is being implemented mainly in three typologies: high-rise (ground+7 to ground+11), mid-rise (ground+3 to ground+5), and low-rise (independent plots to ground+1).

Therefore, this initiative involves samples to investigate affordable housing in different districts, climate zones, and building typologies in Telangana (see *Map 1: Study carried out in different climate zones in Telangana*). This has been done in cooperation and consultation with the state department of Municipal Administration and Urban Development (MAUD) and Telangana State Housing Corporation Ltd (TSHCL). The two bodies are involved with implementation of the 2BHK scheme; MAUD specifically in the Hyderabad Metropolitan Development Area (HMDA) and TSHCL in the rest of the state. Under MAUD, Greater Hyderabad Municipal Corporation (GHMC) is executing more than a third of the total dwelling units taken up under the scheme till date in HMDA. GHMC has taken up such a high volume of affordable housing construction for the first time. CSE's cooperation with TSHCL and MAUD involved on site assessment of several 2BHK schemes, discussions with project engineers, developers, materials providers, and exchange of data related to progress reports, typologies, site plans, layouts, material specifications, etc.

The engagement with MAUD and TSHCL has stimulated discussions in Telangana on how to implement the objectives of ICAP and mainstream the idea of thermal comfort in affordable housing. Multiple stakeholders have been engaged in this initiative. They include GHMC, TSHCL, urban local bodies and other housing sector representatives, academics, Administrative Staff College of India (ASCI) which is a dedicated nodal agency for Energy Conservation Building Code (ECBC), members of ECBC state chapter, alternative material and technology providers, and others in the built environment community involved in affordable housing. This has not only helped to sensitize but also identify and shape a network of stakeholders who can enable action towards combining planning and designing for energy efficiency and thermal comfort.

In Telangana, the state government's 2BHK scheme, called Dignity Housing, involves allotment of 560 sqft dwelling units to poor households at no cost. This hefty investment is partly financed by the central government's support through PMAY, but the state government bears a major proportion of the cost. The scheme has started to use alternative materials and construction technologies, such as monolithic concrete structures, for quick delivery and completion of its targets. This is also in line with the technology transition promoted by the central government. This effort helps the state to build a knowledge base by way of developing demonstration projects, the same as the projects at Gachibowli in Hyderabad which are using Coffor technology, glass fibre reinforced gypsum, and other innovative products developed by Nirmiti Kendra.

While this new assessment investigates different aspects of design, layout, and material, it also identifies key guidelines to inform best practices. Strategic planning needs to be strengthened for affordable housing with improvements in layout planning, building envelope design and choice of materials, and adoption of environmental services. There is also an enormous opportunity for research, technical support, and hand-holding at the state level to guide the process. Telangana's current efforts are extensive and its experience is rich enough for the state to set its own benchmarks and nomenclature for affordable housing. This is an opportunity for bottom up change. The guidelines can inform the building bylaws and building approval process to scale up interventions needed for thermal comfort and energy efficiency goals.

Key highlights of assessment

This assessment has considered wide ranging criteria that influence thermal comfort in buildings including ventilation, orientation, exposure, thermal transmittance properties of materials, and building elements like shading devices, among others. For livability and energy efficiency, daylighting and locational characteristics of sites (in terms of access to basic services including mobility, water, sanitation, waste management, and access to renewable energy) have been considered as well. For this purpose, building design, layout of building clusters, and use of material in selected sites in Telangana have been reviewed and simulated to understand the nature of the design and material choices.

Selected building clusters in Kollur II, D Pochampally, Dundigal, Ambedkar Nagar, Dhupakunta, Gajwal, Mulugu, YSR Nagar, Vandanam, and Chintakunta have been assessed. This has helped to identify several implications and potentials associated with the kind of planning, clustering, architectural design and choice of materials used in these sites towards thermal comfort, energy efficiency and livability. Summarized below are some of the key findings and recommendations on performance, resilience, and adaptability of mass affordable housing initiative in the state of Telangana.

Locational characteristics and city master plans: Locational aspects of affordable housing clusters need policy attention to ensure easy access to services. In fact, location of housing sites determines distance, volume, and cost of travel. Zonal and master plans need to ensure easy access to workplaces, markets, schools, health care units, and other social and physical infrastructure and services. If not addressed, these issues can increase the cost burden for the beneficiaries of affordable housing.

PMAY has a mandatory condition to earmark appropriate land for affordable housing in the city master plan to avail support under the scheme. The government of Telangana has initiated a 'Telangana Municipal Development Project' to target preparation of master plans and geo-spatial databases for ULBs. The government of Telangana is also rehabilitating slums in-situ under its 2BHK scheme to cater to the location and livability aspects of the beneficiaries. Out of about 124 slum sites spread in Hyderabad and Rangareddy districts under HMDA, 83 are being rehabilitated in-situ and 41 on vacant land due to site constraints. Currently, the state is also reserving housing units or plots for the economically weaker section (EWS) and lower income group (LIG) populations in town planning schemes or group housing schemes. This reservation ranges from five per cent to 25 per cent. There is much potential for the state government to guide the rapidly urbanizing towns by dedicating locations for affordable housing in their master plans.

Proximity analysis for self-sufficient neighbourhoods: To understand the status of locational advantages, social and physical infrastructure in close proximity of sites has been analyzed. Telangana's 2BHK scheme has the provision of mixed-use development in some of the projects in Hyderabad. Other smaller sites are dependent on the centralized infrastructure in the town For sustained occupancy of the housing structures, it is necessary to incorporate provisions of essential infrastructure within close proximity of sites, as per the Urban and Regional Development Plans Formulation and Implementation (URPDFI) norms.

Better space standards in the wake of COVID-19: Telangana's 2BHK scheme has leapfrogged and prevented the issues of congestion or maintaining physical distancing in homes by setting adequate carpet area of the dwelling units at 430 sqft (40 sqm) as compared to the national standard 323 sqft (30 sqm).

Thermal comfort and energy efficiency of housing stock: To assess the thermal comfort levels and energy efficiency of the housing stock, CSE has simulated layout of the sites as well as the buildings for a deeper understanding of the effect of layout planning, design, and materials used in the 2BHK scheme. Sites with different typologies were visited in Telangana's two climate zones—composite and warm-humid. In composite climate zone, design and material of D Pochampally, Kollur II (high-rise typology), and Gajwel (ground+1) were simulated. For warm-humid climate zone, YSR Nagar (ground+2) was chosen. These sites have been checked for their compliance with Eco Niwas Samhita 2018 or Energy Conservation Building Code for residential buildings (ECBC-R).

The results of thermal comfort simulation and residential envelope transmittance value (RETV)—that measures heat gain through building envelope—as per ECBC-R, were reviewed and compared. Impact of solar shading devices and alternative walling materials and technologies promoted by Building Materials and Technology Promotion Council was also assessed. This shows the direction of change needed for thermal comfort and energy efficiency strategies in the affordable housing sector. Cost implication of these strategies related to better layout, design, and choice of materials has been analyzed to inform the national goal of providing thermal comfort for all and of fulfilling energy efficiency objectives.

Compliance of the 2BHK scheme sites with ECBC-R: To curb energy consumption in residential buildings, the Bureau of Energy Efficiency (BEE) has launched Eco Niwas Samhita or ECBC-R to set performance standards for building envelope to limit heat gains or losses. Heat gain or loss through the building envelope takes place due to its orientation, extent of opaque and non-opaque building components, and surfaces like doors, windows, projections (*chajjas*), and walling materials, and their characteristics like ability to shade, insulate, and ventilate. ECBC-R provides performance criteria specific to different climate zones.

This assessment checks the identified sites—D Pochampally, Gajwel, YSR Nagar, and four blocks of Kollur II—on three parameters:

i) Openable window-to-floor area ratio (WFRop) that indicates the potential of using natural wind for ventilation in the building. It is the ratio of total openable area of all the windows to the total carpet area of dwelling units.
ii) Visible Light Transmittance (VLT) that indicates the potential of using daylight in the building. It is applicable as per the Window to Wall Ratio of the building.
iii) RETV that indicates the thermal performance of a building envelope (except roof). It is the net heat gain rate through the building envelope of dwelling units divided by total area of building envelope. A lower RETV indicates lower heat gains through the building envelope. The maximum RETV for composite, temperate, hot-dry, and warm-humid climate zones has been kept at 15 W/m^2 in ECBC-R. It takes into account heat conduction through opaque building envelope components, heat conduction through non-opaque building envelope components, and solar radiation through non-opaque building envelope components.

- **Heat gain and loss (RETV)**: For this simulation analysis, the housing blocks were rotated by 45 degrees to get the maximum and minimum RETV for eight cardinal directions. Telangana has much opportunity to work towards achieving requisite RETV. To be compliant, the RETV must be within 15 W/m^2 for both composite and warm-humid zones. Among the sites, D Pochampally adheres to the code with RETV at 14.3 W/m^2 when the block is oriented with its longer façade facing the north-south direction. This lays emphasis on the orientation of the buildings. Since the choice of walling material plays a crucial role in RETV, the compliant values of D Pochampally can also be attributed to better materials.

- **WFRop:** The minimum value of WFRop for a building to be compliant with ECBC-R in composite climate zone is 12.5 per cent and in warm-humid climate is 16.66 per cent. All the blocks analyzed were found to be compliant, except D Pochampally. The WFRop value of 11.7 per cent in D Pochampally can be improved with minor corrections to make it compliant.

- **VLT analysis:** The visible light transmittance or VLT is a function of window to wall area ratio (WWR). WWR in the identified sites was calculated and found ranging from six per cent (in Kollur II Linear and 'L' blocks) to 9.8 per cent (in D Pochampally). Based on the WWR values, the VLT results for the identified sites fell within the threshold compliance limit set by ECBC-R.

While most of the sites are adhering to WWR, VLT, and WFRop thresholds, there is opportunity to work towards and improve the results in the sites for RETV.

Daylighting analysis of the 2BHK scheme: The Kollur II site was simulated to understand daylight penetration into the structures. Normally, low-rise typologies perform well due to lesser mutual shading among the building blocks. The lowest habitable floor, middle floor, and top floor were simulated to understand daylight ingress into the dwelling units. Two scenarios were simulated, one with no other building in the vicinity to obstruct its daylight, and the other with surrounding buildings that may affect daylight. Areas receiving illumination less than required daylight factor are considered under lit. National Building Code (NBC) 2016 recommends that a project should achieve minimum 25 per cent daylit area.

Different block types result in substantial variation in daylight ingress in Kollur II. For example, with respect to spatial coverage of daylight, 'O' block received daylight in 50.6 per cent of the floor area, 'U' block received daylight in 50.9 per cent; linear blocks received daylight in 32 per cent of the total floor area and 'L' shaped blocks received daylight in 33 per cent of their respective total floor areas. This analysis has revealed that certain types of blocks are performing well in a compact layout such as the 'O' and 'U' blocks which receive daylight from the courtyard side of the block. These learnings are crucial as the daylight ingress varies substantially when simulated with actual site conditions with adjacent buildings obstructing daylight ingress.

VLT as an indicator for daylighting: ECBC-R relies on VLT as an indicator for daylight ingress in buildings. The results of this assessment suggest that VLT (calculated for an individual block) may not be defining the level of daylight as received by the occupant of the building. For instance, there is a drop of 17 to 34 per cent drop in day lighting on the first floor when simulated with site conditions, while all the blocks otherwise adhere to ECBC-R for daylight performance. Daylighting area coverage reduces by 7–31 per cent for the lower floors when simulated with surrounding buildings.

Therefore, ECBC-R's reliance on VLT may be conveying the performance of the 'hardware' and not the level of services (of daylighting) that the beneficiary is actually receiving. This learning is crucial for the states who are aiming towards excellence—beyond compliance to the ECBC-R—or even improving the codes for better performance. In order to achieve this, states will require to work on the affordable housing layouts and designs to provide better daylighting to the beneficiary in order to reduce energy consumption in buildings and avoidable financial implications for the beneficiary. The distance between the buildings becomes a crucial parameter for ideal daylight penetration.

Need ventilation strategies—wind flow analysis of the 2BHK scheme: As the number of high-rise buildings increase, wind flow gets disturbed in the micro-climate around the high-rise building clusters. This issue of variation in natural ventilation due to high-rise buildings has caught attention in other countries as well. Several countries have come up with ventilation strategies. For instance, the city of London has drawn Wind Microclimate Guidelines that ask for performance based on certain criteria to ensure quality and usability of outdoor areas primarily with regard to comfort and safety. India also needs to identify ventilation strategies for mass housing. This assessment has carried out wind flow analysis using IES-VE Macroflo software for outdoor wind flow around the buildings in the site of Kollur II. The findings are vital to address and regulate natural ventilation in high rise mass housing of the future.

Need to stagger buildings to reduce or eliminate 'tunnel effect': When the wind is flowing from the west and perpendicular to the buildings, several cases of Venturi effect or tunnel effect are found on the site. In these cases, the wind velocity is higher but only outside, without getting into the buildings. Wind in these 'tunnels' reaches up to 3.5 m/s. These high wind velocities can dissuade occupants from opening up their windows even when the weather is favourable. Therefore, this elevated wind velocity is unable to provide comfort from the wind and can rather damage the windows if they are the side hung type. The facades facing these high wind zones are affected. Stagger the buildings to negate the tunnel effect. On staggering, the wind shadows (low or least velocity zones) do not fall on the adjacent building and instead occupy the void between the buildings. The spread of wind across the site is better than it is when flowing from the west. This streamlining of wind flow completely cancels out the tunnel effect as well.

Wind flow is better in mid-rise developments**.** A significant decrease in wind shadow areas was observed in mid-rise buildings compared to high-rise buildings. Stilts increase wind flow at the ground level**.** Wind velocity increases due to stilts and can be attributed to the tunnel effect at ground level alone. This shows that stilted floors can contribute in dissipation of heat absorbed by the paved surfaces and improving pedestrian thermal comfort. Wind shadows were found to be least in this case.

Indoor ventilation analysis: Air movement is affected by form, height, distances between blocks, and clustering and placement of the blocks. Blocks must be staggered or oriented with respect to the streets in a way that favourable wind direction hits the buildings diagonally rather than in a perpendicular fashion. To understand the impact of wind on indoor ventilation, annual ventilation flow rates of entire dwelling units facing different directions on the lowest floor, intermediate floor, and top floor were calculated. This correlates air changes per hour (ACH) or the indoor ventilation rate to outside wind speed for the intermediate floor. About 40 per cent of the blocks in the site are receiving appropriate ventilation which is neither under ventilated or facing extremely windy conditions. States can increase this percentage by working on and regulating layouts. Adequate natural ventilation lowers indoor temperatures and dissipates any indoor air pollution. Too low a ventilation rate will increase reliance on mechanical means of ventilation and cooling.

Thermally comfortable hours in 2BHK units: This assessment has simulated three sites of 2BHK scheme with different typologies for thermal comfort. The assessment used the adaptive thermal comfort model of NBC 2016 and whole building energy and thermal simulation approach. Different orientations were tested by rotating the design by 45 degrees (east–west), 90 degrees (north east–south west), and 135 degrees (north–south). The performance of these orientations is further understood by evaluating and comparing annual hours of discomfort due to overheating. The units with the least amount of annual overheating are considered to be better performing. The discomfort due to under heating, i.e. when the operative temperature goes below the thermal comfort limit, is not considered because that can be addressed by heavier clothing.

Whereas, the overheating hours, i.e. operative temperature above the thermal comfort limit, cannot be addressed by adjusting clothing and will require energy intensive solutions like air conditioning or evaporative cooling technologies.

The overheated hours or the period for which the dwelling units will not be thermally comfortable due to excessive heat have been simulated for the Kollur II Linear block, Kollur II 'O' block, and Gajwel. These hours have been calculated for different materials. The annual overheating period for Kollur II Linear block ranges from 10.6 per cent to 21.8 per cent of the year. For Kollur II 'O' block, the annual overheating period ranged from 10.6 per cent to 21.2 per cent of the year. Low-rise typology of Gajwel resulted in annual overheating from 10.8 per cent to 24 per cent of the year. Walling that performed consistently well for thermal comfort in the three sites involved insulation and, mainly, autoclaved aerated concrete (AAC) blocks.

RETV as an indicator of thermal comfort: ECBC-R relies on RETV as an indicator of thermal comfort in buildings. To see how consistent RETV is with thermal comfort simulation results, this study compared both the RETV and thermal comfort analysis using different materials ranging from the design case (Case 1—concrete blocks) to the best performing material. According to the results, RETV showed a proportionate relationship with thermal comfort (in terms of improvement in overheating hours from the base case), but only in cases involving insulation.

The relationship between RETV and thermal comfort particularly showed inconsistency with Compressed Stabilized Earthen Blocks (CSEB). CSEB, in spite of having a U-value (or thermal transmittance value) more than fly-ash bricks, resulted in higher RETV and outperformed fly-ash bricks in thermal comfort simulation. Similarly, a combination of 150 mm reinforced concrete cement (RCC) and 100 mm AAC on the inside of the walling assembly performed better than fly ash bricks by a huge margin, even when their U-values are very similar—1.3 and 1.5 W/m^2 K respectively.

It appears that RETV's reliance on U-value may not always deliver better thermal comfort. CSEB is delivering better thermal comfort due to its higher thermal mass than fly ash bricks. This shows that thermal mass properties of the materials improve thermal comfort which are not recognized by the ECBC-R. State governments need to take a note of this and have tremendous opportunity to address thermal comfort by an informed choice of materials.

Walling assemblies combining materials with high thermal mass and insulation can result in better thermal comfort and thus need to be explored. Indian Standard SP:41 (S&T) (about performance of walling) states that time taken to transfer heat through a wall increases by up to three times when the insulation is placed on the outside of the regular masonry external wall compared to when it is placed on the inside of the same wall. This means the sequence of the layers of materials makes a difference in the thermal comfort of an occupant, although U-value remains the same in both the cases.

Impact of materials on thermal comfort: The 2BHK scheme sites are mostly using concrete blocks, followed by fly ash bricks, as walling materials. However, a few projects have also used AAC blocks. The walling assembly with a combination of insulation and shading devices delivered the best thermal comfort in all three types of blocks evaluated. This has the potential to provide an additional 272 to 333 annual thermal comfort hours.

Fly ash bricks and various thicknesses of AAC blocks provide more annual thermal comfort hours when compared with the base case of concrete blocks used widely in Telangana. A combination of 100 mm AAC along with 150 mm monolithic concrete blocks increases about 114 to 158 thermal comfort hours in the building. This combination provides the advantage of faster construction. Alternatively, combinations like monolithic concrete in the interior load bearing walls and insulating materials such as AAC in the exterior wall can be used for mass housing. This can allow faster construction (due to poured concrete used for load bearing walls) as well as enhanced thermal comfort hours due to AAC blocks as exterior walls.

Another finding of this analysis highlights the limitation of insulation properties of walling materials. As the thickness of AAC in exterior walls increases from 150 mm to 200 mm, the gain in thermal comfort hours is between 17.52 to 26.28 hours. But increasing the AAC wall thickness from 200 mm to 250 mm yields a gain of just eight to nine thermal comfort hours. This highlights that insulation properties of a walling material can contribute towards thermal comfort to some extent. Beyond a certain thickness of insulation material, the thermal comfort hour gains stop rising in proportion to it.

Impact of building envelope on thermal comfort: Building geometry plays a role in the amount of heat ingress that takes place through the building envelope. There is a proportional relationship between the amount of building surfaces exposed to the exterior and heat gain into the dwelling unit. The ratio of total envelope area to the carpet area—envelope factor—can provide a picture of the heat gain into the unit and its effect on thermal performance. The envelope factor is capable of capturing the efficiency of the building geometry for all designs. On a scale of 0.5 to 2.0, the more the envelope factor is towards the former value, the better the envelope performance will be.

A positive correlation was found between envelope factor and thermal comfort. Two blocks of Kollur II and Gajwel project were assessed for their envelope factor and percentage of overheated hours keeping the same material specifications in all cases. Gajwel that is exposed to the exterior on almost three sides results in highest overheated hours (14.6 per cent) among all the three cases.

Impact of building orientation on thermal comfort: In order to understand and quantify the impact of orientation in 2BHK scheme projects in Telangana, RETV comparison of all the sites was done while keeping the material constant.

If fly ash bricks are kept constant, almost all projects start complying with the RETV requirement of 15 W/m^2 as per ECBC-R. Changing materials from concrete blocks to fly ash bricks gives an improvement of approximately 9 W/ m^2 in all projects. This improvement shows a major impact of materials on thermal comfort and energy efficiency according to ECBC-R.

To see why other projects and blocks did not show much impact of orientation on RETV, this study checked the form of the blocks in each project. This has brought out limitation of blocks in YSR Nagar and Kollur II which have net surfaces exposed to a worse orientation to a worse orientation. The ratio of building surface areas facing north–south (N–S) to east–west (E–W) directions has a role to play in energy efficiency and thermal performance of buildings. The Kollur II Linear block and YSR Nagar project have effective surface area facing E–W direction even when the block is oriented to face N–S directions at length. Their surface exposure ratio explains the low variation in RETV with the worst and best orientation. This analysis demonstrates that there is potential to improve thermal performance of buildings with better orientation and form.

Combined impact of orientation and materials on thermal comfort: An assessment was made to find out how material combined with appropriate orientation can improve thermal comfort in the current designs of 2BHK schemes of Telangana. Surface exposure ratio has a role to play in the performance of orientation for thermal comfort. The gain in annual thermal comfort hours in Kollur II Linear block is estimated to range from 165 to 403 hours; in Kollur II 'O' block from 158 to 420 hours; and in Gajwel block from 158 to 464 hours. It is thus important to pay attention to material and orientation together to prolong comfort hours to contain increased energy consumption due to mechanical cooling post occupancy.

Uninformed designs and material choice can result in energy penalty: Walling materials can reduce the annual hours of thermal discomfort once the potential of good orientation is exhausted. Materials with high thermal mass or materials with insulation properties or a combination of both are options to enable this reduction. Thermal comfort increases even further when shading devices are combined with the walling material in the building envelope according to the simulation results.

The assessment reveals that an Energy Performance Index (EPI) of roughly 38 kWh/m^2/year can be maintained for a naturally ventilated scenarios per the simulated blocks. This is the EPI that our regulatory frameworks such as state energy policy should strive to target. Our regulatory frameworks need to harness the potential of good layouts, designs, and materials to help residents avoid mechanical cooling systems for a longer time. North–south orientation along with a higher NS:EW surface exposure ratio are simple criteria that can reduce annual hours of thermal discomfort substantially. These criteria hardly bear any additional financial implication or simulation studies. The government can easily incorporate these as guidelines for construction of mass housing, or in their building bylaws.

Operations and maintenance (O&M)**:** According to the 2BHK scheme guidelines, operation and maintenance of common infrastructure and utilities such as water supply system, sewage treatment plants (STPs), and lighting in common areas is to be conducted by the beneficiaries. This includes contribution of costs by them. Also, the O&M costs are expected to peak after a few years of operation, requiring high investments. For instance, sewage treatment plants (STPs) require recapitalization in about 20 years and a diesel generator in 10 years. GHMC has provided commercial areas in their projects to facilitate and enable some of the recurring O&M costs to be met through commercial rent. Similar strategies are needed in all of the upcoming housing that also sustain for a long term.

Water and wastewater paradigm of affordable housing: Urban areas including the Greater Hyderabad Metropolitan Region (GHMR) face water supply shortages during peak summer. The government of Telangana has launched Mission Bhagiratha which involves establishing a water supply system. Additionally, a 10 per cent rebate on property tax is offered on installation of rainwater harvesting structures, according to the State Building Rules, 2012. The 2BHK scheme projects have provided for rainwater harvesting pits for groundwater recharge. However, their upkeep by the beneficiaries and associated capacity building needs attention.

Managing solid waste in affordable housing: The 2BHK scheme requires scientific collection, transportation, treatment, and disposal of solid waste daily. Solid Waste Management Rules, 2016, mandate three-way segregation and the Environmental Impact Assessment (EIA) guidelines encourage on-site treatment of organic waste using natural techniques. However, municipal bodies are yet to adopt the rules and ensure their effective implementation. A calculation reveals that on-site treatment of organic waste using non-mechanized methods such as composting require less than five per cent of unpaved or green space, which is a minuscule portion of the site area. Financial requirement is only towards payment of daily wages to manual labourers to ensure segregation of waste and to look after composting.

Linking renewable energy with affordable housing: Telangana Solar Policy, 2015 provides many incentives on taxes and duties vis-à-vis solar power. The Residential Rooftop Solar Policy, 2018 provides 30 per cent subsidy from Ministry of New and Renewable Energy (MNRE) and 30 per cent from the state government. State Building Rules also provide a 10 per cent rebate on property tax on use of solar water heaters and solar-powered street lighting. EIA guidelines mandate five per cent of connected load from renewable energy. Telangana can harness the potential of its solar rich geography. Further, Renewable Energy Service Company (RESCO) is offering competitive prices including establishment, and operation and maintenance costs for solar power plants. On-site solar rooftop power generation has tremendous scope in Telangana towards promoting a cleaner energy transition.

Next steps

Covid-19 will have a significant bearing on many definitions and associated provisions which were an integral part of the urban space. Thermal comfort (adaptability of structures that promote passive cooling and limit use of active cooling), inclusive planning, and decentralized services will require more focussed approach in the planning of habitat from here onwards.

While buildings will have to be designed from the perspective of thermal comfort, health, livability, and safety, performance of neighbourhoods in terms of access to essential services and infrastructure related to management of wastewater, solid waste, and mobility services will require special attention.

The Government of India is providing financial support to developers for affordable housing projects. Currently, there is no performance criteria linked to this financial support. A strategy that ties together performance criteria and the release of fiscal support can shape an effective mechanism to regulate thermal as well as environmental performance in mass housing. Telangana, with this documentation of its 2BHK scheme projects and evaluation of their performance, has opportunity to spearhead and address this strategy in its housing scheme and other regulatory frameworks. This will draw a learning curve for the rest of the country.

For instance, EIA requires information from the project proponents on use of materials in the project. Performance criteria can be linked to materials used. Approval and completion certificates can also be linked with usage of better performing materials and walling assembly approaches. Urban local bodies can monitor and ensure that these materials are used. If compliance is not found, any government support to the project, for instance in the form of extra floor area ratio (FAR), floor space index (FSI), or transferable development rights (TDR), will need to be surrendered, or a corresponding monetary penalty can be imposed. This will enable stringent implementation of green performance in mass housing.

Similarly, thermal comfort gains need more explicit link with layouts. Orientation of buildings with respect to the predominant wind direction, their clustering, form, height, etc. contribute to indoor as well as outdoor thermal comfort or micro-climate at the site. In view of this, some priority steps are needed immediately.

Telangana paves the path for green recovery in post-COVID housing: ECBC-R is a code for buildings that evaluates the energy performance inside a building based on the physical features of that building. This analysis has revealed that ECBC-R evaluates thermal performance of the building envelope through RETV. Expressed in W/m^2, RETV evaluates and indicates the performance of the building envelope in terms of heat ingress per unit area of the envelope. If a site has different types of blocks, one block may perform well in terms of RETV, while another may not. Even with an averaged out RETV complying to the thresholds given in the code, beneficiaries living in the blocks with higher RETV will have to live in thermally uncomfortable dwellings and face higher operational costs due to mechanical cooling.

Further, simulation analysis shows that a building that performs in adherence to RETV may not deliver on thermal comfort for a certain period of the year. Based on a building-scale evaluation, the objective of ECBC-R to regulate heat gain in residential buildings by RETV is weakened by not addressing layout and the site context. Similar issues were observed with VLT, used to evaluate daylighting, and WFRop used as an indicator for ventilation in buildings as per ECBC-R. WFRop evaluates ventilation in a building based on the ratio of openable area of windows and the floor area of the dwelling unit, which is again an isolated assessment. Computational flow dynamics (CFD) analysis has revealed that the air movement is affected by form, height, distances between buildings, clustering, and placement of the blocks on the site. It will be inadequate to evaluate a building on only one or two of the factors. Telangana has an opportunity to improve upon these issues when it ratifies ECBC-R and demonstrate achieving excellence in energy performance to the rest of the states of India.

State housing guidelines need to factor in the role of thermal mass in thermal comfort: This study has compared RETV and thermal comfort simulation analysis to check their consistency. RETV showed a proportionate relationship with thermal comfort (in terms of improvement in overheating hours from the base case) in cases involving insulation. It particularly showed inconsistency with a case involving CSEB. CSEB performance was better with fly ash bricks, in spite of having a higher U-value that results in higher RETV. Similarly, a combination of 150 mm RCC and 100 mm AAC on the inside of the walling assembly performed better than fly ash bricks by a huge margin, even when their U-values are very similar. These results show that RETV's reliance on U-value may not always deliver better thermal comfort. Thermal mass properties of the materials substantially improve thermal comfort and must be addressed either during adoption of ECBC-R or via state housing guidelines to enable thermally comfortable housing.

Evaluate daylighting performance in a site context to incorporate the impact of layout: Daylight simulation showed that the percentage of daylit area varies substantially for a unit when it is simulated in isolation as compared to when it is simulated with site conditions. Daylit area in a block at 38 per cent when in isolation can drop to a meagre seven per cent in the lower floors when observed in the real ground situation as planned. Even in the middle floors (sixth floor), daylit area in most cases that were simulated could not reach the compliance threshold of 25 per cent as given by NBC 2016. Blocks with a central courtyard performed relatively better. Surprisingly, all these cases showed a very good compliance to VLT that is promoted as an indicator for daylight ingress under ECBC-R. Simulation results suggest that VLT, which is calculated for an individual block, may not be an adequate indicator for daylight performance. Therefore, Telangana may need to work on a more effective performance indicator to deliver affordable housing layouts and designs that provide better daylighting to the beneficiary. This is important as artificial lighting is substantially responsible for energy consumption in buildings and will have financial implications for the beneficiary that could be completely avoided with better designs. Therefore, it is important to assess daylighting in a site context wherein buildings are mutually shading each other for a better understanding of energy implications of artificial lighting.

Ventilation analysis in high-rise mass housing is a must: A simulation analysis of the largest 2BHK scheme project in Telangana reveals that about 40 per cent of the blocks in the site are neither under ventilated nor are facing extremely windy conditions. Too low a ventilation rate results in stagnation of indoor air and pushes the beneficiary to switch to mechanical means of ventilation and cooling. If the ventilation rate is on the higher side, it may cause damage to the windows due to fluttering, therefore, increasing capital cost and posing a threat to human safety. Natural ventilation is required in the buildings to lower indoor temperatures and dissipate any indoor air pollution. Therefore, studying the predominant wind direction in detail and determining the appropriate typology of blocks, along with their clustering and layout, is an exercise that should be taken up during the planning stage. Based on that, future high-rise housing in Telangana can be planned for either wind calming or wind enhancing measures such as leaving an empty floor in the middle of the building.

With several incentives for affordable housing construction under government schemes, such as extra FAR/FSI, the typology for affordable housing is shifting towards high rise development in major cities. Ventilation strategies need to be sought in that case to negate the adversities of high-rise development on micro climate. CFD simulations reveal that these adversities are much lesser in mid-rise developments. Such analysis can help in understanding the impact of wind and its crucial role for thermal comfort, energy efficiency, and health and safety. The CFD analysis for Kollur II has made it clear that the air movement is affected by the form, height, distance between buildings, clustering, and placement of the blocks on the site. Blocks must be staggered or oriented with respect to the streets in a way that the favourable wind direction hits the buildings diagonally rather than in a perpendicular fashion. This reduces wind shadow area and the tunnel effect. There is a common understanding that height of the building and width of the abutting road need to be planned in tandem. This relationship can be exemplified from several building bylaws such as G.O. M.s. No. 168 for Hyderabad, wherein height of the building is suggested in correspondence to the width of the abutting road. This relationship is important for ventilation and daylighting as both are affected by spacing between the buildings and therefore need to be addressed effectively.

Telangana can achieve substantial thermal comfort gains just by working on orientation and building envelope: The simulations have shown that north–south orientation along with a higher NS:EW surface exposure ratio can reduce annual hours of thermal discomfort substantially—around 132 hours. Similarly, *envelope factor*—the ratio of total envelope area to the carpet area—is an effective indicator to evaluate the efficiency of the building envelope for heat gain. It has shown a positive correlation with the number of overheated hours in a building. The higher the envelope factor, the more inefficiently it tends to perform with respect to thermal comfort. Just looking at these two factors translates to a lot of energy savings for a household that otherwise would have required mechanical cooling measures. The state government can easily incorporate these criteria as guidelines for construction of mass housing or in their building bylaws as they hardly bear any financial implication and do not require any simulation studies.

Need focus on materials to ensure thermal comfort for all: Walling materials offer to reduce the annual hours of thermal discomfort once the potential of good orientation is exhausted. Telangana is widely using 150 mm concrete blocks in the 2BHK scheme projects. Materials with better insulation properties such as AAC blocks have resulted in a gain ranging from 193 to 245 annual thermal comfort hours with 250 mm thick walling. To internalize the associated energy savings, Telangana can provide for or even prioritize thermal comfort by materials, especially insulation. For an affordable mass housing context, strategies such as using a combination of 100 mm AAC along with 150 mm monolithic concrete walling, which has enabled a gain of 114 to 158 annual thermal comfort hours, can be used. This case provides the advantage of faster construction as well. Alternatively, monolithic concrete can be used in the interior load bearing walls while AAC blocks can be used in the exterior wall. This combination will still have the advantage of fast-paced construction (due to poured concrete used for load bearing walls) but more annual thermal comfort hours due to AAC blocks in the exterior walls. Thermal comfort increases even further when shading devices are combined with the walling material in the building envelope according to the simulation results. Further, similar strategies can improve thermal performance when the layouts have been planned and the building envelope has been designed wrongly or there are other site limitations and there is no scope to change them. In such cases, strategies such as increasing insulation in exterior walls will help in ensuring thermal comfort. These interventions however will incur a cost since materials with insulation properties are more expensive than the conventional materials. The government will need to support that additional cost for the benefit of the household who will occupy these dwelling units.

Telangana can spearhead and develop fiscal strategies and instruments of accountability to minimize cost of improving thermal comfort: A sound fiscal strategy is needed to support the incremental cost from new construction technologies, material, and thermal comfort approaches. This is needed in favour of the beneficiary so that operational cost burden linked with under-performing structures can be minimized. Currently, the government of India is providing a support package to developers in the form of incentives such as extra FAR/FSI/TDR and tax holidays. A number of incentives are already available to the developer. Linking these with performance regulations is necessary. Currently, EIA Form 1 seeks information from the project proponent on use of materials in the project. There is opportunity to integrate this segment with materials that have a good thermal performance. Completion certificate can be linked with usage of better performing materials. Urban local bodies can monitor and ensure that these materials are used. If compliance is not found, any government support to the project like extra FAR/FSI/TDR availed will need to be surrendered or a corresponding monetary penalty can be imposed. This will enable stringent implementation of green performance in mass housing. Existing regulatory frameworks such as building bylaws and PPP models or procurement guidelines for affordable housing need to incorporate similar performance indicators and instil healthy competition among developers based on green performance of affordable housing.

Invest in architectural design and layouts of affordable housing: Design and approvals currently account for only one per cent of the cost of government affordable housing projects in Telangana, whereas the cost is nearly twice in the private sector. Although the state government of Telangana has fixed the layout for a dwelling unit, the private sector—developers, architects, and engineers—involved may not have a direction or a guideline to follow for the layout and design of the structures. This lack of direction has resulted in layouts and designs that will place a cost burden on the beneficiary and impact their quality of life. This burden is completely avoidable with guided designs and layouts. Simulation analysis such as computational flow dynamics for ventilation, building energy simulation for thermal comfort, and daylighting simulation for visual comfort and energy efficiency have become essential due to several goals placed by India for thermal comfort, energy security, resource sufficiency or circularity, emission reduction, and, most importantly, reducing vulnerability and uplifting livability of the poor under Sustainable Development Goals (SDG) 11.

Telangana addresses livability of the poor and urban form but needs instruments to ensure appropriate location of future affordable housing: The government of Telangana recognizes the dependence of the poor on the city's infrastructure through a two-pronged approach. Under one approach, it is rehabilitating beneficiaries living in the slums in-situ and promoting mixed use development in some of the high-density projects in Hyderabad. In the other approach, it includes reservation for EWS and LIG in any residential scheme. In order to ensure that all future housing schemes in the state follow the current path, mechanisms that ensure identification of suitable locations for affordable housing and access to social and physical infrastructure can be integrated with master plans and zoning regulations. PMAY guidelines make it mandatory to earmark these locations in master plans. But this is an area of intervention for the state government. As Telangana is updating the master plans for its major urban centres, these plans can be reinforced with criteria that identify and enable strategically planned affordable housing primarily by linking it with the public transport network. Effective criteria for master plans, in favour of beneficiaries, are developed based on socio-economic and spatial studies that can inform an affordable housing strategy for the city. Other key requisites regarding location of affordable housing are given in CSE's publication—*Beyond the Four Walls of PMAY*.

Augment building bylaws for encouraging environmental services in affordable housing: Telangana is converging several of its initiatives on resource conservation and efficiency with the 2BHK scheme; such as with Mission Bhagiratha and Swachh Bharat Mission. The 2BHK scheme has also shown the other states the way for sustainable brownfield and greenfield development by working on existing site enhancements and new provisioning for environmental services like wastewater treatment, safe water supply and sanitation and conservation practices. For a resource-efficient and post-COVID housing, other initiatives such as Telangana solar rooftop policy, ECBC-R, EIA guidelines, etc. can be mandated or integrated with the housing scheme. Building bylaws are important regulatory tools that bind to deliver on set requirements. Telangana's building bylaws scribed in G.O. Ms. 168 offer 10 per cent property tax rebate on installation of solar heating or lighting, rainwater harvesting, and wastewater recycling. These measures not only enable sustainability, but also improve access to basic services for the beneficiary; aside from being cost-effective in the long term. Other states have mandated many of these measures by augmenting their building bylaws with requirements such as meeting five per cent of connected load by solar rooftop energy. Now is a great opportunity for Telangana to weave the provisions and incentives under various policies together and standardize them to enable low-impact affordable housing construction.

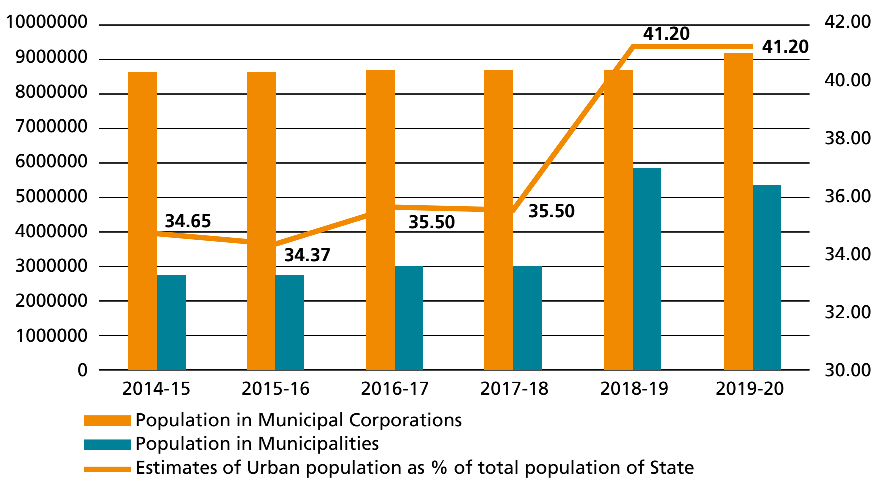
Expand knowledge base on climate-appropriate design, materials, and associated tools and techniques: There is a need for recognizing and learning new tools and techniques to deliver affordable housing in line with India's thermal comfort, resource efficiency, and sustainability goals. These tools such as simulation software and analysis should be made part of academic curricula of the architecture, planning, and engineering courses. Academia needs to be familiarized with these analyses and their importance given the several challenges and objectives of the country. The construction industry, comprising of both government bodies like CPWD, NBCC, etc. and private developers, also needs to do the same. Developer associations like CREDAI need to be particularly engaged and trained on the subject to make them ready to receive and deliver on the requirements for thermal comfort, resource efficiency, and sustainability. Much depends on human behaviour when it comes to thermal comfort and associated space cooling consumption. Awareness programmes are needed for the civil society to create a demand for thermal comfort and enable contribution towards the ICAP objectives from the bottom-up as well.

Section 1: Housing in Telangana

Urban growth: Telangana has witnessed rapid urban growth during the last decade. Ten districts of this erstwhile part of Andhra Pradesh are now restructured into 33 districts, which have around 38.67 per cent of its population living in urban areas according to Census 2011. According to an integrated household survey conducted in 2014, the state has a population of 3,68,76,544.Telangana had a gross domestic product (GDP) growth rate of 10.4 per cent (higher than the national growth rate of 4.37 per cent) in 2017–18. With Hyderabad as its capital and the largest urban centre, Telangana registered a steep increase in urban population in 2018 according to the Department of Municipal Affairs and Urban Development.

While the population in municipal corporations showed stagnation, the bulk of new urban dwellers were seen in municipalities, where urban population almost doubled in a year (see *Graph 1: Urbanization trends in Telangana*). This indicates that the smaller municipalities and urban centres require specific attention to guide urban development in the state. This has implications for housing demand.

Graph 1: Urbanization trends in Telangana



Source: Telangana Socio-Economic Outlook 2020

Housing scheme in Telangana: Telangana launched the 2BHK scheme in 2015 to meet its housing shortage of 2,631,739 units—for both urban and rural areas. Under this scheme, the state government is providing a 560 sqft dwelling unit to the households in the below poverty line (BPL) segment and in backward classes at no cost. No other state is doing anything like this. The units are being constructed by private developers on land provided by the government at a capped construction cost (varying from city to city) ranging from Rs 950–1400 per sqft.

Telangana State Housing Corporation Ltd is the state level nodal agency (SLNA) under PMAY and is looking after implementation and monitoring of the scheme. According to TSHCL, 57 per cent of the state's housing demand is urban and 43 per cent rural. As of 31 January 2020, 283,401 dwelling units were sanctioned, of which 100,000 are being constructed by GHMC across HMDA, according to the data received from TSHCL. About 39 per cent of these units are at 90 per cent completion stage. It is reported that only 14 per cent units were completed as of 31 January 2020. In Hyderabad, the pace of construction is faster as around 76,895 units (76.9 per cent) are nearing completion and 8,052 units (eight per cent) were complete in every respect.

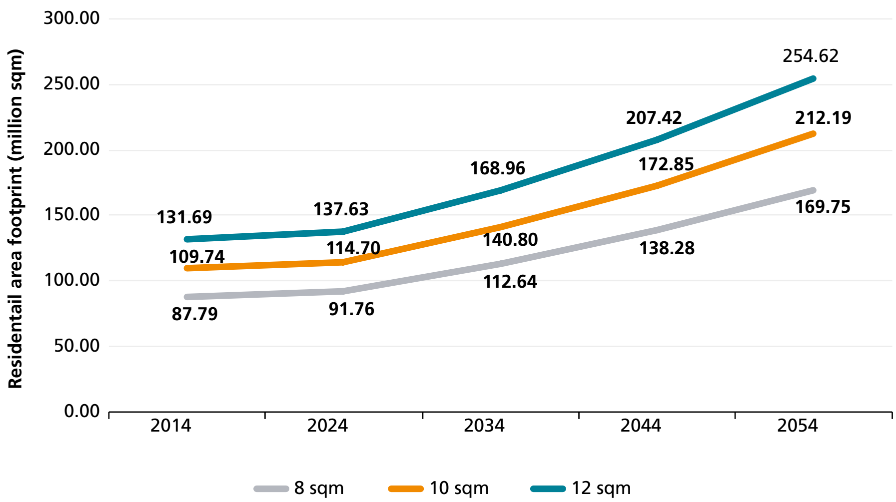
Residential area footprint and housing shortage: Post the bifurcation of Andhra Pradesh, Telangana conducted an integrated household survey (Samagra Kutumba Survey) in 2014. The resulting housing shortage of 2,631,739 units accounts for roughly 25.32 per cent of its total number of households as per the survey. This shortage includes all households that do not have a house anywhere in the state and are living on rented accommodation or a temporary kutcha house. This excludes people living in government provided dwelling units.

With the growing population this shortage is going to increase. The current pace of housing supply under Telangana government's 2BHK scheme has met 5.64 per cent of its housing shortage as of January 2020 since its launch in November 2015. Considering the same pace of housing schemes, Telangana is estimated to mitigate at least 10 per cent of its housing shortage in a decade. Measures are needed to fasten up this pace and bridge the housing demand-supply gap as more and more households add to the housing shortage due to natural growth, affordability gap, and obsolescence of existing structures.

Telangana's housing shortage is extrapolated based on an average decadal population growth rate of 22.76 per cent and a consistent housing shortage at 25.32 per cent of the state's total number of households. This yields an enormous footprint of construction that will take place in the residential sector. Three scenarios have been assumed to determine this footprint—a person occupies either 8 sqm or 10 sqm or 12 sqm in a house. This results in around 133 million sqm (at 8 sqm per capita), 167 million sqm (at 10 sqm per capita) and 200 million sqm (at 12 sqm per capita) of residential area that will need to be constructed by 2034. Projections for other years are shown in *Graph 2: Residential area footprint projections*. Strategies are needed to minimize the materials, and embodied and operational energy impact of this construction.

The affordability and resource efficiency connect: Co-benefits of appropriate planning and design of affordable housing are numerous. If planned and designed well, affordable housing can uplift quality of life and also enable social mobility among the lower income households. However, badly planned and designed affordable housing may lead to creation of fixed assets with low economic value, which are practically fruitless for the government. Ghost towns located at the peripheral areas of the city or underlit and faulty structures due to uninformed design and substandard materials are a good example of this phenomenon.

Graph 2: Residential area footprint projections (sqm)



Source: CSE estimation based on Samagra Kutumba Survey 2014

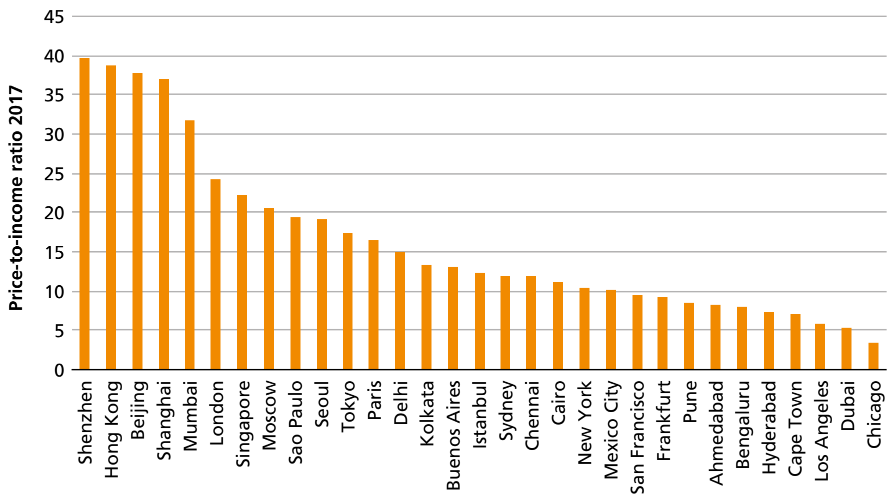
UN Habitat recognizes this is a major issue in developing nations faced with the challenge of high housing shortages. At a time when state governments are heavily investing in the sector, measures are needed to ensure appropriate planning and design of affordable housing (see *Box 1: UN housing framework includes seven principles for affordable housing*).

BOX 1: UN HOUSING FRAMEWORK INCLUDES SEVEN PRINCIPLES FOR AFFORDABLE HOUSING

1. Security of tenure: housing is not adequate if its occupants do not have a degree of tenure security which guarantees **legal protection against forced evictions, harassment, and other threats**.
2. Availability of services, materials, facilities, and infrastructure: housing is not adequate if its occupants do not have **safe drinking water, adequate sanitation, energy for cooking, heating, lighting, food storage, or refuse disposal**.
3. Affordability: housing is not adequate if its **cost threatens or compromises** the occupants' enjoyment of other human rights.
4. Habitability: housing is not adequate if it does not guarantee physical safety or provide adequate space, as well as **protection against the cold, damp, heat, rain, wind, other threats to health, and structural hazards**.
5. Accessibility: housing is not adequate if the **specific needs of disadvantaged** and marginalized groups are not taken into account.
6. Location: housing is not adequate if it is cut off from **employment opportunities, health-care services, schools, childcare centres, and other social facilities**, or if located in polluted or dangerous areas.
7. Cultural adequacy: housing is not adequate if it does not respect and take into account the **expression of cultural identity**.

Housing affordability gap: What still fails to catch attention is the financial implication of inappropriately planned and designed affordable housing for the beneficiaries. Housing affordability gap is widest in the large urban centres of India. According to IDFC Institute, price-to-income ratio (median house price divided by the annual median household disposable income) in Mumbai, Delhi, Kolkata, and other metropolitan cities is higher than those of developed cities like Chicago and Los Angeles (see *Graph 3: Price-to-income ratio in cities across the world*).[1] This calls for a study from the perspective of beneficiaries in order to find ways to reduce incidental costs as a result of poor planning and design.

Graph 3: Price-to-income ratio in cities across the world



Source: IDFC Institute 2018

Several factors play a role in effective affordable housing. CSE has conducted an investigation in Telangana to understand these factors ranging from the location of the site in the city context, access to public transport, school, health facilities, and common environmental services at site level. All these factors in turn affect energy consumption. Energy is consumed in buildings due to household operations, at site due to common services, and in travel. The more effectively and efficiently affordable housing is planned and designed the lesser will be its resource footprint and the financial costs associated with it. This connection needs to be explicitly captured especially in the times of a changing 'normal' when it is more important for habitats to perform functionally and effectively. Several projects spread across different districts were visited and analyzed for these aspects.

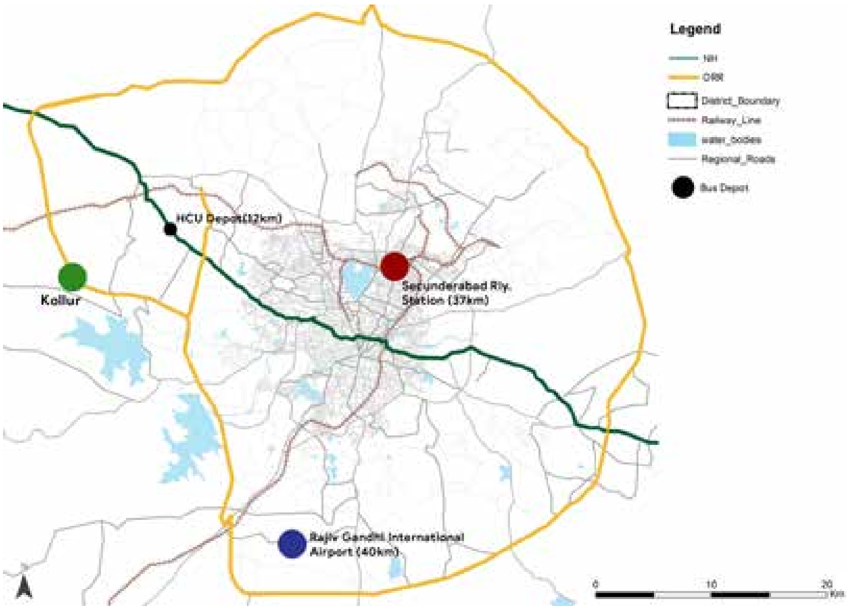
Sites visited for assessment in Telangana

To carry out this assessment, CSE visited a number of 2BHK scheme projects across six districts and two climate zones Telangana. A few of the visited sites are described below.

Kollur II

Kollur II is the largest site of all the 2BHK scheme projects. With 124 acres of site area and 15,660 dwelling units, it is an ambitious township project that is being implemented by GHMC. It falls under Rangareddy district, in a

Map of Kollur II



Site summary

Site Summary	
Plot Area	501810.2 sq.m. , 124 acres
Dwelling Units:	15,660
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	117
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility

Interior Wall	Exterior Wall
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

Site Is Located On South West Part Of Hyderabad

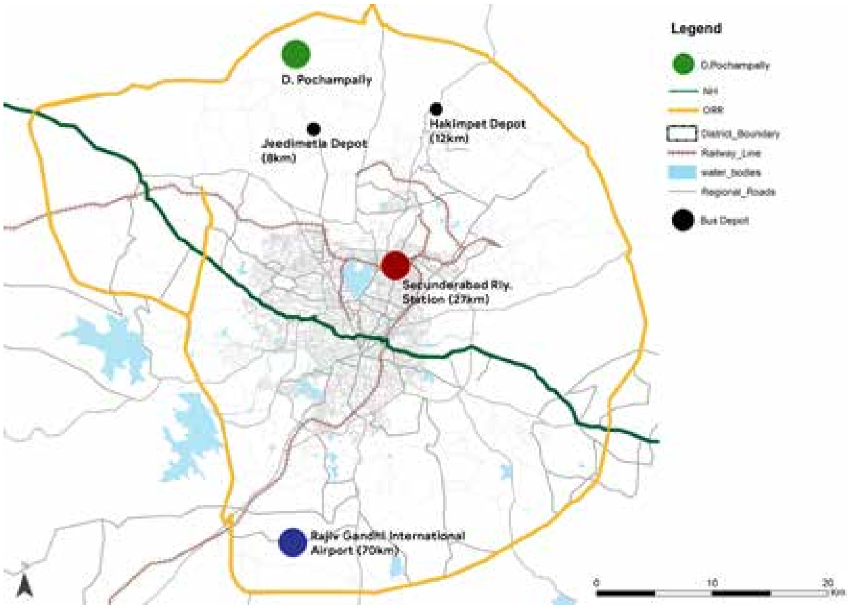
Floors	Location	Climatic Zone	Wall Material	Env. Services
G+9/10/11	Hyderabad, Telangana	Composite	Concrete-fly ash blocks	1 STP & RWH with rechargeable pits

composite climate zone, and is located adjacent to the outer ring road (ORR). Due to the massive size of the project, the design was entrusted to the School of Planning and Architecture at Jawaharlal Nehru Architecture and Fine Arts University in Hyderabad. The project comprises of four different types of building blocks, namely—'L' Block, Linear Block, 'U' Block and 'O' Block with height varying from G+9 to G+10 and G+11. Each dwelling unit has an area of 52 sqm comprising two bedrooms, living area, kitchen, two toilets, and one utility space. It is developed with a conventional RCC frame structure with fly ash bricks as the walling material. It has a STP of nine MLD capacity spread across 1.63 acres for on-site treatment of wastewater. Rain water harvesting pits have been provided for ground water recharge.

D Pochampally

D Pochampally is located to the north of Hyderabad city and falls under Medchal Malkajgiri district. It has a site area of seven acres with 1,260 dwelling units. Each building has 10 floors (G+9). The construction material used for all 15 blocks is concrete fly ash bricks. There is one STP on the site, the treated water from which will be used for horticulture purposes in the near future. There are around 10 rainwater recharge pits of 2mx2mx2m each.

Map of D Pochampally



Site summary

Site Summary	
Plot Area	28328 sq.m. ,7 acres
Dwelling Units:	1260
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	15
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility

Interior Wall	Exterior Wall
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

Site Lies in North Near Hyderabad

Floors
G+9

Location
Hyderabad, Telangana

Climatic Zone
Composite

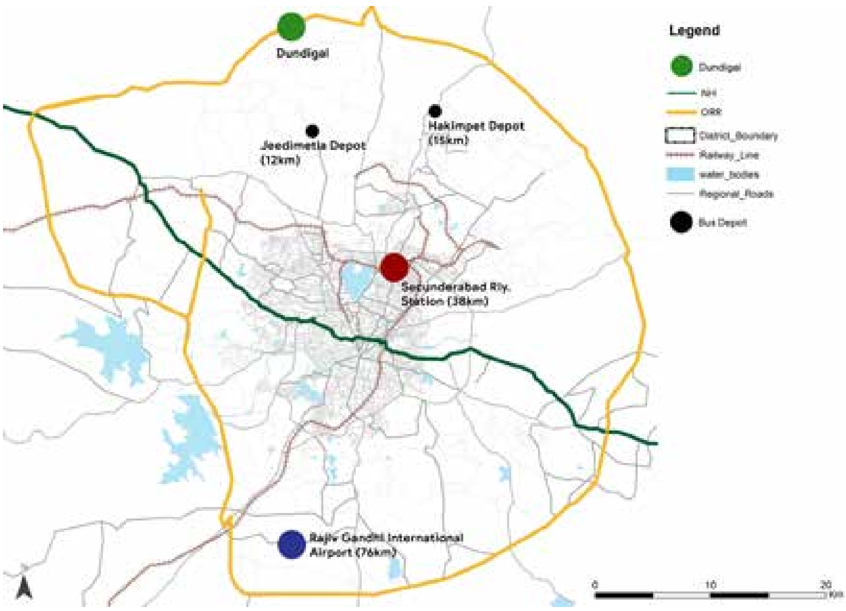
Wall Material
Fly ash bricks

Env. Services
1 STP &10 RWH with rechargeable pits

Dundigal

Dundigal is also located in the Medchal Malkajgiri district of Telangana to the north of Hyderabad city. The site has an area of 19.25 acres with 3,996 dwelling units. Height of the buildings is G+9 (stilt+9) floors each. This project being implemented by GHMC uses different materials and construction technologies. Monolithic concrete using aluminium formwork, pre-cast concrete, AAC blocks, and concrete blocks have been used at this site.

Map of Dundigal



Site summary

Site Summary	
Plot Area	77917.18 sq. m. , 19.25 acres
Dwelling Units:	3996
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	32
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility
Interior Wall	**Exterior Wall**
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Cement, Sand, Aggregate, Burnt clay bricks
Construction	Framed RCC

Site is located on the outskirts of Hyderabad towards north

Floors	Location	Climatic Zone	Wall Material
S+9	Hyderabad, Telangana	Composite	Monolithic concrete, Pre cast concrete, AAC blocks, Concrete blocks

Ambedkar Nagar

Ambedkar Nagar is an in-situ slum rehabilitation project in Warangal city in the Warangal Urban district. The project is being implemented by the Roads and Building Department of the Telangana state government. The site falls under composite climate zone and has an area of 6.8 acres with 592 dwelling units. The height of the buildings is 4 floors (G+3). The construction material used for 37 building blocks is burnt clay bricks and AAC blocks. The site has an STP of 300 KLD capacity that uses moving bed biofilm reactor technology. The treated wastewater will be used for horticulture.

Map of Ambedkar Nagar

Site summary

Site Summary	
Plot Area	27660.66 sq.m.,6.8acres
Dwelling Units:	592
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	37
Spaces	2 Bedrooms, Living, Kitchen,2 Toilets, Utility
Interior Wall	**Exterior Wall**
12mm plaster + 100/115mm + 12mm plaster	12mm plaster + 200/230mm + 12mm plaster
Key materials used	Burnt clay bricks, AAC blocks
Construction	Framed RCC

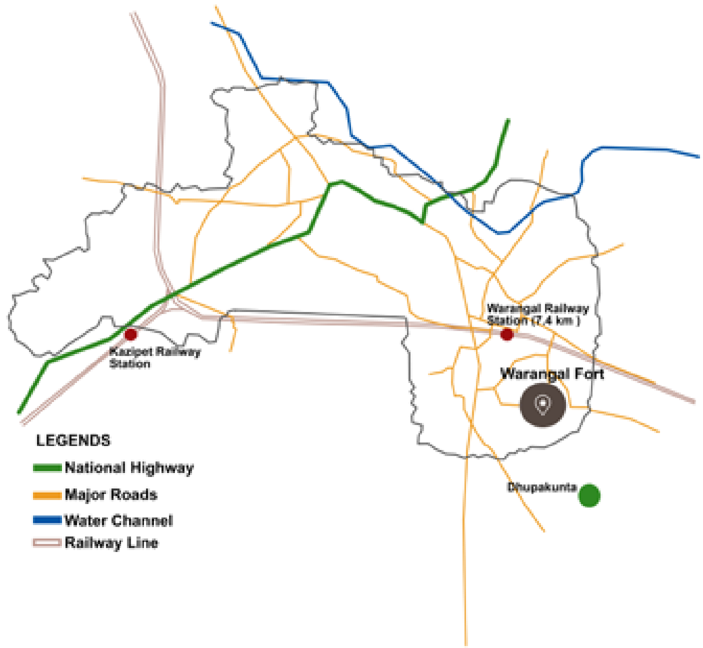
Site is located in south west part of Hanamkonda city in Warangal

Floors	Location	Climatic Zone	Wall Material	Env. Services
G+3	Hanamkonda, Telangana	Composite	Burnt clay bricks & AAC blocks	1 STP of 300 KLD & treated water is used for gardening

Dhupakunta

Dhupakunta is located at the outskirts of Warangal city near the Warangal fort. It is being developed on Nagar Panchayat land. The site has an area of 23.5 acres with 1,548 dwelling units. Every building has 4 floors (G+3). The construction material used for the 129 blocks is concrete blocks.

Map of Dhupakunta



Site summary

Site Summary	
Plot Area	95457,23.5 acres
Dwelling Units:	1548
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	129
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility

Interior Wall	Exterior Wall
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

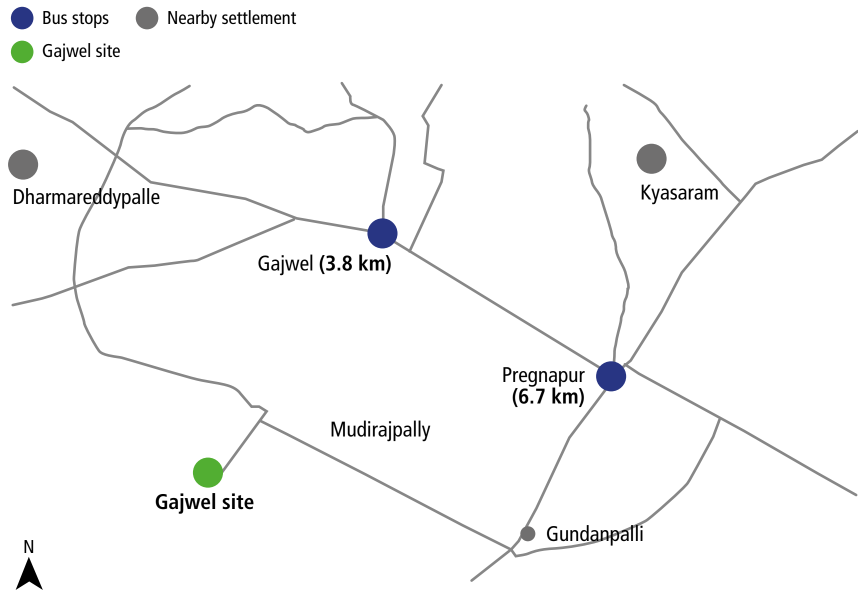
Site Lies In the South near Warangal Fort

Floors G+3	**Location** Warangal, Telangana	**Climatic Zone** Composite	**Wall Material** Concrete-fly ash blocks

Gajwel

Gajwel is located near Gajwel village in the Siddipet district of Telangana. It falls under composite climate zone and the site has a plot area of 64 acres with 1,250 dwelling units. Every building block has 2 floors (G+1). The walling material used for 150 building blocks is concrete fly ash blocks.

Map of Gajwel



Site summary

Site Summary	
Plot Area	258999sq. m. , 64 acres
Dwelling Units:	1250
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	150
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility
Interior Wall	**Exterior Wall**
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

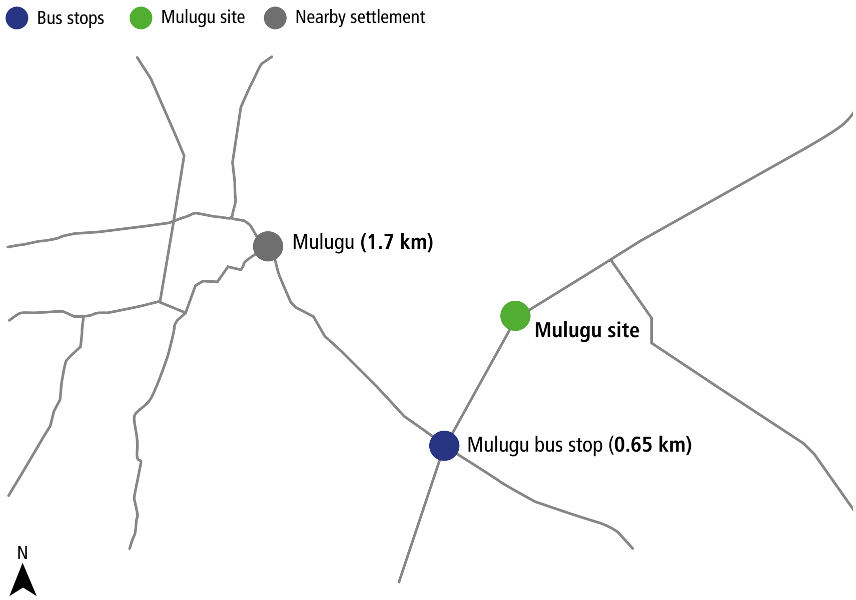
Site Is Located Near Gajwel Village in Siddipet District

Floors	**Location**	**Climatic Zone**	**Wall Material**
G+1	Siddipet, Telangana	Composite	Concrete -fly ash blocks

Mulugu

Mulugu is located at the southern tip of Siddipet district of Telangana. The site has an area of 8.6 acres with 94 dwelling units. Every building has two floors (G+1).The construction material used for the 188 blocks on the site is concrete fly ash blocks.

Map of Mulugu



Site summary

Site Summary	
Plot Area	34803 sq. m. , 8.6 acres
Dwelling Units:	188
Area of each dwelling unit	560sq. Ft. – 52sq. m.
No. of blocks	94
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility

Interior Wall	Exterior Wall
4” Fly ash + 12mm plaster both side	6” Fly ash + 12 mm plaster both side
Key materials used	Fly ash, Cement, Gypsum

Site Is Located In North east of Hyderabad

Floors	Location	Climatic Zone	Wall Material
G+1	Mulugu, Telangana	Composite	Concrete-fly ash blocks

YSR Nagar

YSR Nagar project is located outside the city of Khammam, towards the eastern side of the Khammam district. Falling under warm-humid climate zone, the site has a plot area of 2.69 acres with 240 dwelling units. Every building has 3 floors (G+2).The construction material used for the 10 blocks on the site is concrete fly ash blocks.

Map of YSR Nagar

Site summary

Site Summary	
Plot Area	10886.04sq. m. , 2.69acres
Dwelling Units:	240
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	10
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility
Interior Wall	**Exterior Wall**
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

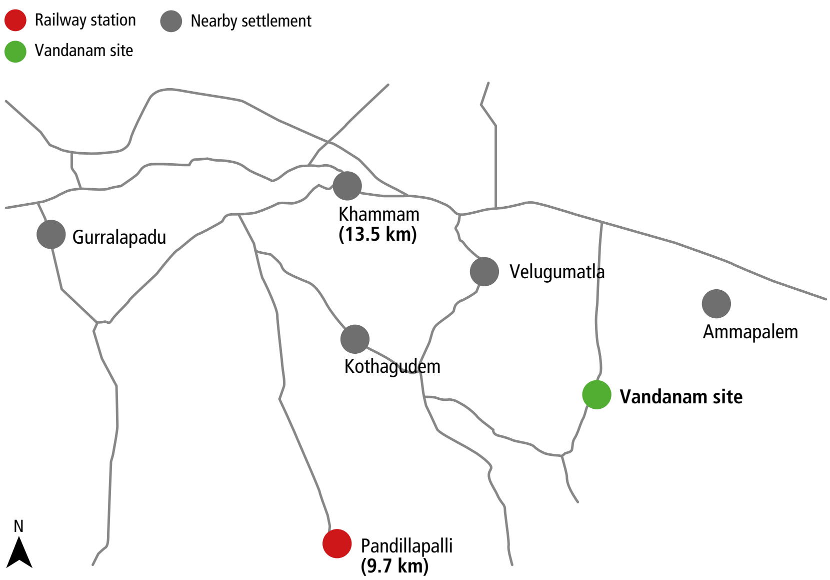
The site is located outside the city, towards the eastern side of Khammam

Floors	Location	Climatic Zone	Wall Material	Env. Services
G+2	Khammam, Telangana	Warm & Humid	Concrete-fly ash blocks	Site has 10 septic tanks & 1 soak pit

Vandanam

Vandanam is located in a rural setting near Khammam city in Khammam district of Telangana. The site has an area of 2.69 acres with 50–60 dwelling units. These units are independent houses with a plinth area of 52 sqm and only the ground floor. The construction material used for walling is concrete fly ash blocks.

Map of Vandanam



Site summary

Site Summary	
Plot Area	12990.41sq.m. , 3.21acres
Dwelling Units:	50-60
Area of each dwelling unit	560sq. Ft. – 52sq. m.
No. of blocks	50-60
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility

Interior Wall	Exterior Wall
12mm plaster + 150mm + 12mm plaster	12mm plaster + 200mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

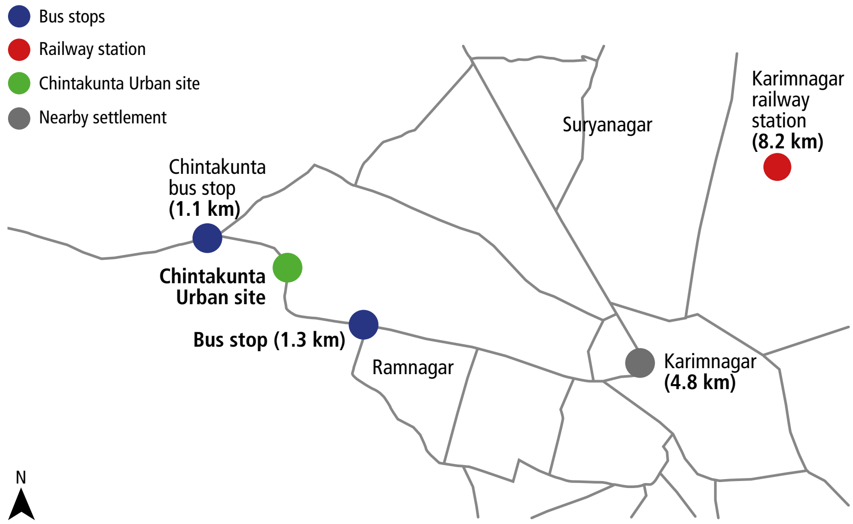
Site Is Located in Rural setting in Vandanam near Khammam

Floors	Location	Climatic Zone	Wall Material
Ground Floor	Khammam, Telangana	Warm & Humid	Concrete-fly ash blocks

Chintakunta

Chintakunta is located on the outskirts of Karimnagar city in the Karimnagar district of Telangana. Falling under composite climate zone, the site has an area of 6.73 acres with 1,194 dwelling units. Every building has six floors (G+5). The construction material used for the 16 blocks is fly ash blocks.

Map of Chintakunta



Site summary

Site Summary	
Plot Area	272775.27 sq. m. ,6.73 acres
Dwelling Units:	1194
Area of each dwelling unit	560 sq.ft. (incl. common areas) 52 sq.m.
No. of blocks	16
Spaces	2 Bedrooms, Living, Kitchen, 2 Toilets, Utility
Interior Wall	**Exterior Wall**
12mm plaster + 100mm + 12mm plaster	12mm plaster + 150mm + 12mm plaster
Key materials used	Fly ash, Cement
Construction	Framed RCC

Site Is Located in The Outskirts Of Karimnagar

Floors	Location	Climatic Zone	Wall Material	Env. Services
G+5	Karimnagar, Telangana	Composite	Fly ash bricks	No STP currently but has water recharge pits

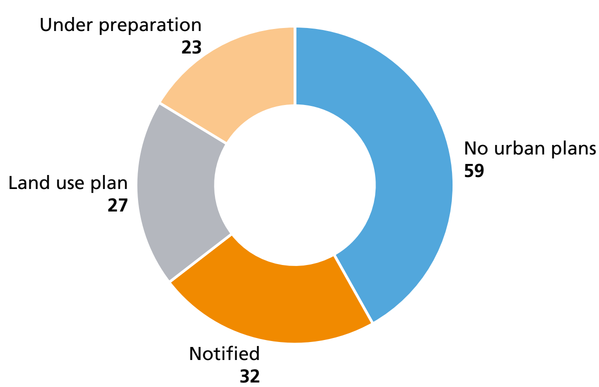
Section 2: Locational characteristics and city master plans

Location of affordable housing determines the distance, volume, and cost of travel. This includes trips to workplaces, markets, schools, health care units, and other social and physical infrastructure. If not located strategically, new affordable housing will increase the cost burden for beneficiaries linked with these trips. Telangana is constructing affordable housing heavily to contribute to India's aim to provide houses for everyone by 2022. This housing stock needs to be planned to cater to the accessibility requirements of the beneficiaries.

Planning for affordable housing and the linked accessibility needs are captured in master or development plans for cities. In fact, PMAY has a mandatory condition to earmark appropriate land for affordable housing in the city master plan in order to avail support under the scheme. CSE looked at how the master plans for these cities are aligned.

There are 141 ULBs in Telangana. Of these, 32 have a notified master plan (see *Graph 4: Status of master plans in Telangana*). Around 27 ULBs have prepared land use plans and 23 ULBs are preparing their master plans. The remaining 59 ULBs do not have any urban plan in place or in the pipeline. The government of Telangana initiated a 'Telangana Municipal Development Project' to target preparation of master plans for ULBs and make their geo-spatial database. This project is a great opportunity to integrate locational requisites for affordable housing in the master plans.

Graph 4: Status of master plans in Telangana



Source: Telangana Socio-Economic Outlook 2020

Hyderabad, Warangal, Karimnagar, Nizamabad, and Khammam are five large urban centres of Telangana. While Hyderabad has several updated master plans in force within the Hyderabad Metropolitan Region, the master plans of the remaining four cities are in the process of updation. The fact that these cities are working on updating their master plans provides a lot of opportunity to integrate the several locational parameters with affordable housing and strategically plan for it (see *Table 1: Master plan status of cities in Telangana*).

Table 1: Master plan status of cities in Telangana

City	Master plan status
Hyderabad	Metropolitan Development Plan 2031 for Hyderabad Metropolitan Region
Warangal	Warangal Master Plan 1971 (Master Plan 2041 for Kakatiya Urban Development Authority is awaiting notification)
Karimnagar	Karimnagar Municipality Master Plan and Zoning Regulations 1983
Nizamabad	Master plan of Nizamabad 1974
Khammam	Khammam Municipality General Town Planning Scheme (Master Plan) 1987

Proliferation of slums in cities is a phenomenon closely linked with urbanization. The urban form attracts people from rural areas as it grows. In absence of adequate financial resources and access to decent housing, this population finds itself squatting in the marginal areas of that urban form and highly dependent on the centrality offered by these areas in terms of services and infrastructure. The government of Telangana recognizes this dependence and is rehabilitating slums in-situ across the state under its 2BHK scheme. For instance, out of about 124 slum sites spread in Hyderabad and Rangareddy districts under HMDA, 83 are being rehabilitated in-situ and 41 on vacant land due to site constraints according to the online geo-spatial database of the 2BHK scheme—Telangana State Remote Sensing Applications Centre.

The larger strategy for affordable housing in Telangana, as observed in the master plans of other major cities, is to reserve plots or dwelling units or land for the economically weaker sections and lower income groups in town planning schemes or group housing schemes. The reservation for EWS and LIG ranges from five per cent to 25 per cent. Telangana's two-pronged approach of addressing the livability of slum dwellers by rehabilitating them in-situ as well as ensuring affordable housing through zoning regulations has helped guide and shape the future urban agenda for comfort and livability.

The recognition due to which Telangana government is rehabilitating slums in-situ under 2BHK scheme needs to be mainstreamed and culminate into appropriate zoning for affordable housing in master plans. Other cities have started innovating to strategically plan for affordable housing keeping the locational characteristics in mind. They have started zoning for affordable housing which is integrated with public transport. Similar instruments are needed in the cities of Telangana for identification of appropriate location of affordable housing.

Proximity analysis for self-sufficient neighbourhoods

Any planned development requires certain infrastructure that plays a foundational role for livability and well being in an urban setting. This infrastructure includes public transport, schools, health care facilities, and local market for daily necessities. Neighbourhood planning principles guide that this infrastructure must be in close proximity to or a part of any upcoming development for it to function as a complete living ecosystem. In absence of important social and physical infrastructure in close proximity, there is a severe implication for beneficiaries such as increased distances and travel costs. A planning regime that increases travel also steers away from the energy efficiency trajectories of the country.

Taking cognizance of this, Telangana's 2BHK scheme comes with the provision of mixed-use development in some of the projects in Hyderabad. These projects promote the concept of self-sufficient neighbourhoods. For instance, the Kollur II project is planned as a township that has everything a beneficiary would need for better livability. It is equipped with commercial areas, health care facility, primary school, community centre, religious buildings, and other social and physical infrastructure within the site.

In other areas where it has not been possible to incorporate essential infrastructure within the site, the 2BHK scheme provides for external development to connect to the central infrastructure. In this approach, it is expected that support services and essential infrastructure will take some time to come to the level as it is in the city centre after the beneficiaries will occupy the houses. A survey of 22 2BHK scheme relocation sites in Greater Hyderabad area reveals that 10 sites have a bus stop within a 400 m distance. Access to secondary schools is available for 12 sites, while each site has one school within three km as guided by the URDPFI Guidelines 2016. Under the COVID-19 pandemic, when people are locked inside their houses and have significantly reduced accessibility to all services, including essentials, self-sufficiency of affordable housing in terms of good access to services and infrastructure becomes important. Guidelines like URDPFI must be adhered to (see *Table 2: URDPFI Guidelines for access to basic services*).

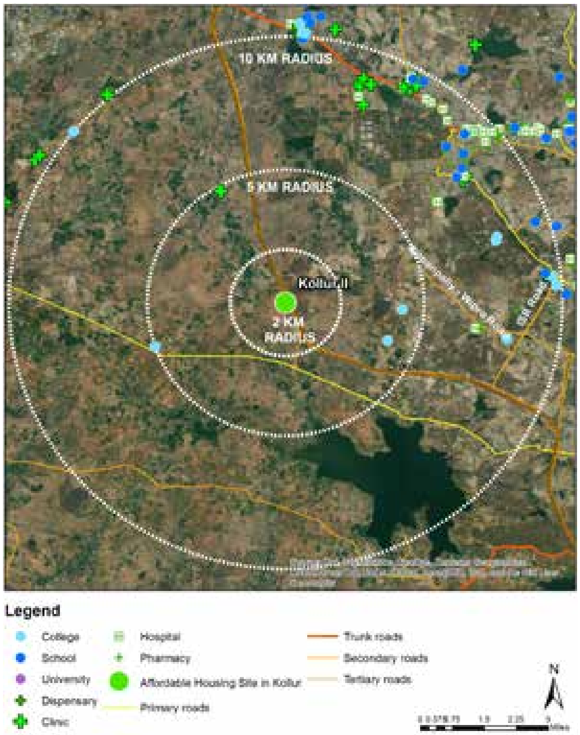
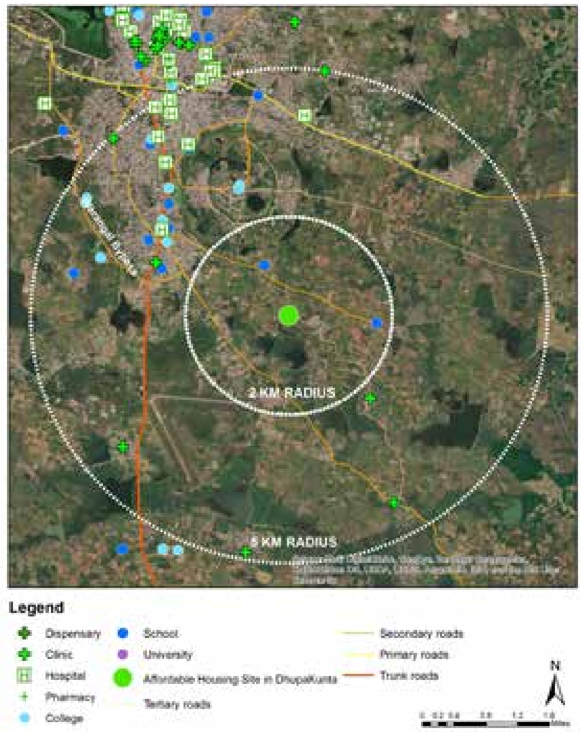
Table 2: URDPFI Guidelines for access to basic services

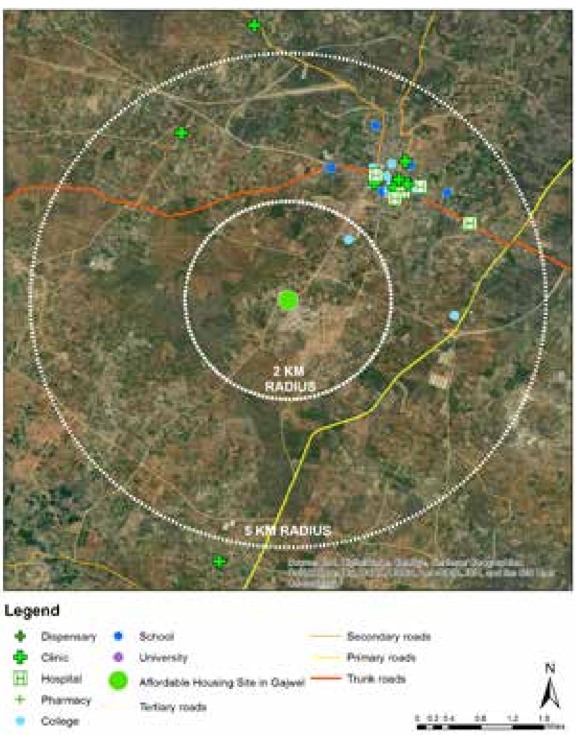
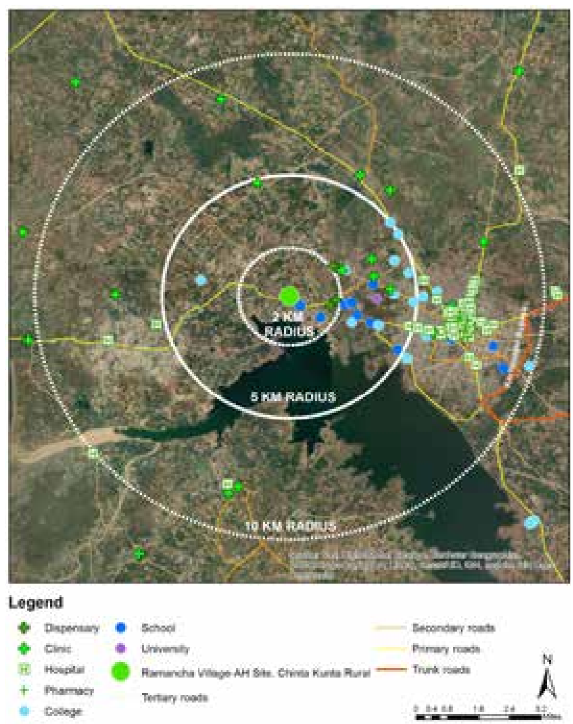
Site	No. of bus stops within 400m	No. of primary schools within one km	No. of healthcare facilities within two km	No. of secondary schools within three km
Kollur	0	0	0	0
Narsingi	1	0	1	0
Hafeezpet	0	0	3	7
Munganoor	0	0	0	2
Bairagiguda	0	0	1	0
Pochampally	0	0	1	1
Nallagandla	4	1	4	5
Batasingram	2	0	1	0
Chandrayanagutta Bandlaguda	0	0	3	0
Muraharipally	2	0	0	0
Chaithanyanagar	10	0	6	2
Rampally	0	0	0	0
Ahmedguda	0	0	0	0
Bahadurpally	1	0	5	2
Ibrahimpatnam Banjara Colony	0	0	0	2
Baghhayathnagar	3	2	7	4
Kaithalapur	0	0	2	1
Mailardevpally	1	0	0	0
Uppal	0	0	1	2
Budvel	0	0	2	0
MansoorabadSaroornagar/Bandaraviryal	2	0	8	1
Gajularamaram	1	1	2	1

Source: CSE investigation

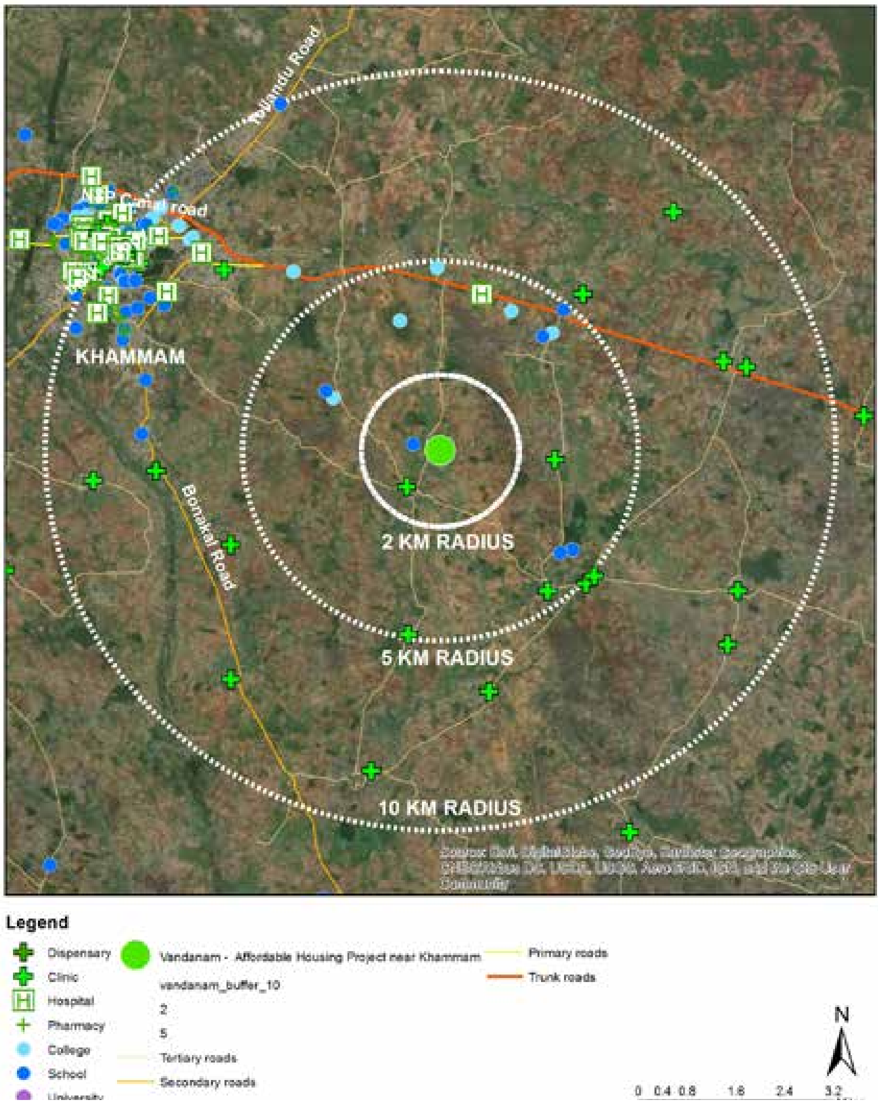
To expand the understanding on access to primary social and physical infrastructure, sites in different districts were assessed. Almost all the sites reveal that the surrounding development will take some time to have adequate essential service infrastructure like markets, health care facilities, primary schools, etc. within a two km radius of these locations. This aspect needs explicit integration with affordable housing schemes for self-sufficiency and improved accessibility for the beneficiary (see *Map 2: A-E: Proximity analysis for housing sites in selected districts*).

Map 2: Proximity analysis for housing sites in selected districts

A. Proximity analysis for Kollur II in Rangareddy district	*B. Proximity analysis for Dhupakunta in Khammam Urban district*
	

C. Proximity analysis for Gajwel in Siddipet district	*D. Proximity analysis for Ramancha in Karimnagar district*
	

E. Proximity analysis for Vandanam in Khammam district



Section 3: Access to services

Water and wastewater paradigm of affordable housing: Urban areas including GHMC have periodically faced water supply shortages during peak summers. The government of Telangana has launched Mission Bhagiratha to deal with this. This water conservation and infrastructure project involves establishment of water supply chain—from sourcing water from surface water bodies to treating it and supplying it to every household via a tapped connection. Further, the state has taken measures such as mandating rainwater harvesting in plots with areas more than 300 m^2, and above 6m^3 storage for every 100 m^2 of rooftop space. A 10 per cent rebate on property tax is also offered to install rainwater harvesting structures, according to the State Building Rules, 2012. The 2BHK scheme projects have provided for rainwater harvesting pits for groundwater recharge.

2BHK scheme's projects in urban areas (GHMC and other municipalities) have also setup on-site wastewater treatment using conventional sewage treatment plants. A few projects (like the one at Ambedkar Nagar, Warangal) have started experimenting with new and alternative technologies such as moving bed biofilm reactor technology for sewage treatment. With such experiences from the 2BHK scheme, the state has a great opportunity to standardize water conservation measures by mandating rainwater harvesting, on-site wastewater treatment, and reuse to reduce dependence on potable water for other needs. These water conservation methods prove to be cost-effective in the longer run, especially with the use of nature-based solutions.

Image 1: Moving bed biofilm reactor technology based sewage treatment plant at Ambedkar Nagar, Warangal

Managing solid waste in affordable housing: The 2BHK scheme places a need for an organized system for scientific collection, transportation, treatment, and disposal of substantial volumes of solid waste every day. Solid Waste Management Rules, 2016, mandate three-way segregation and the EIA guidelines encourage on-site treatment of organic waste using natural techniques. Cities are making several efforts to mainstream these provisions for the general public. For instance, GHMC distributed 44 lakh bins to segregate dry and wet waste in households to encourage segregation. A strong policy framework guides and ensures better implementation. In this view, municipal bodies must adopt the rules and increase public awareness on them including the endless opportunities of sustainable solid waste management. A calculation reveals that on-site treatment of organic waste using non-mechanized methods requires less than five per cent of unpaved or green space and a minuscule amount of the site area. Financial requirement is only towards payment of daily wages to manual labourers to ensure segregation of waste and look after composting. Such provisions must be mainstreamed and addressed in site layouts for affordable housing, in order to comply with the provisions of EIA guidelines, especially in larger projects.

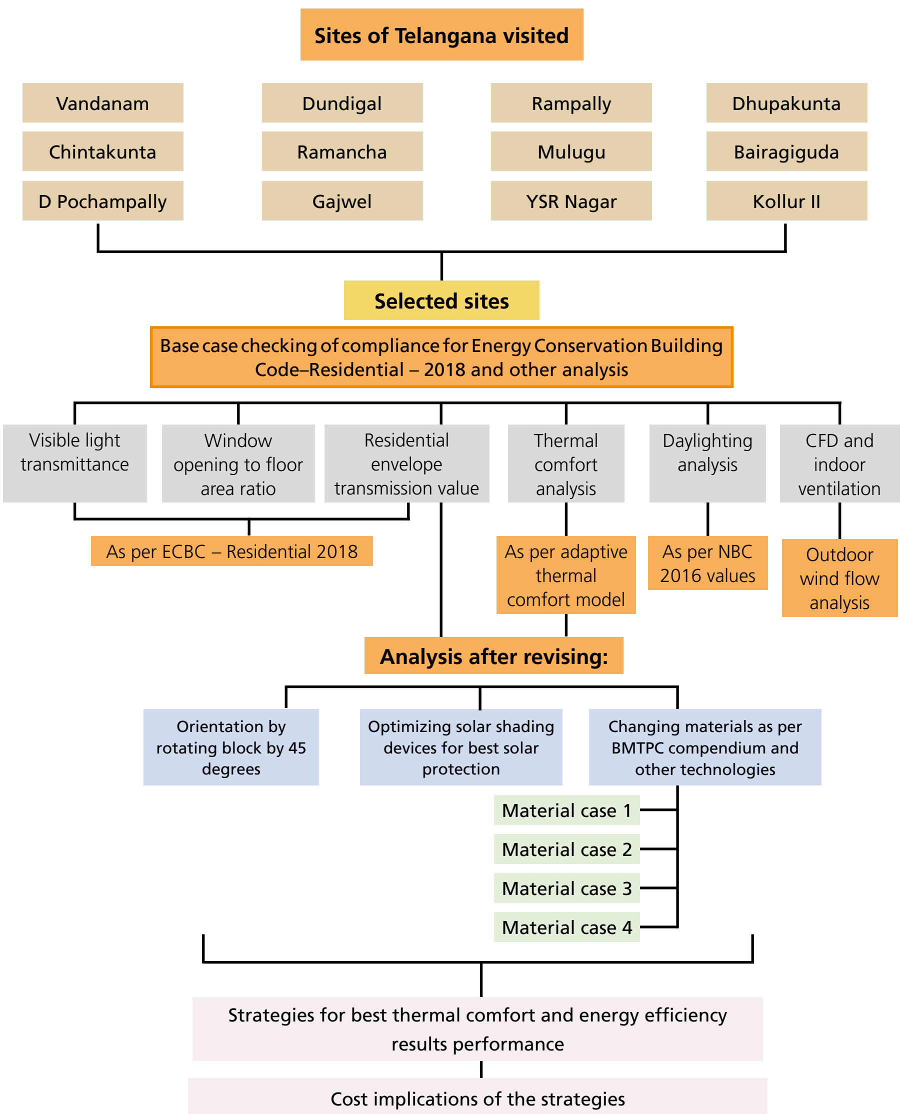
Linking renewable energy with affordable housing: Telangana Solar Policy, 2015 provides many incentives on taxes and duties vis-à-vis solar power. Residential Rooftop Solar Policy, 2018 provides 30 per cent subsidy from Ministry of New and Renewable Energy and 30 per cent from the state government. State Building Rules also provide a 10 per cent rebate on property tax on use of solar water heaters and solar-powered street lighting. EIA guidelines mandate five per cent of connected load from renewable energy. Many states have mandated the use of rooftop PV systems under their affordable housing schemes, especially where government provides land. With all 2BHK scheme projects being executed on government land and with substantial rooftop space, Telangana can harness the potential of its solar rich geography. Further, Renewable Energy Service Companies (RESCO) are offering competitive prices including establishment, operation, and maintenance costs for solar power plants. Latest auctions conducted by Solar Energy Council of India saw solar power tariffs settle between Rs 2.44 and Rs 6.20 per unit, which is lower than conventional power tariff. On-site solar rooftop power generation has tremendous scope in Telangana.

Operations and maintenance: According to the 2BHK scheme guidelines, O&M of common infrastructure and utilities such as water supply system, sewage treatment plants, and lighting in common areas is to be conducted by the beneficiaries. This includes contribution of costs. Also, O&M costs will peak after a few years when the infrastructure will require intensive investments. For instance, an STP requires recapitalization in about 20 years and a diesel generator in 10 years. To cater to this, GHMC has provided commercial areas in their projects to facilitate some of the recurring O&M costs through commercial rent for beneficiaries. Now when the beneficiaries will be occupying 2BHK houses, experience on their operations, related costs and maintenance efforts will have to be documented with a view to enrich future housing schemes.

Section 4: Designing for thermal comfort

Thermal comfort and energy efficiency: simulation analysis

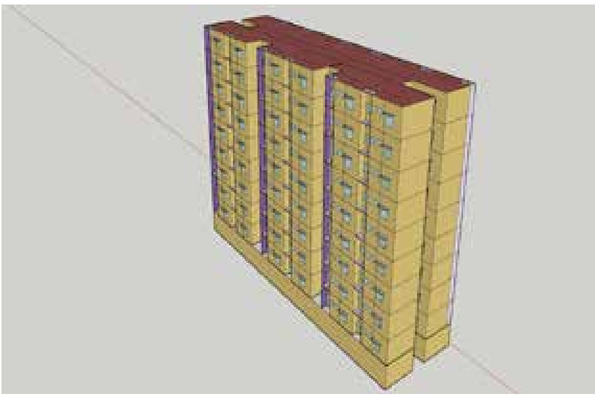
CSE has simulated more sites for a deeper understanding of the performance of layouts, design, and materials being used in 2BHK schemes. Sites located in Telangana's two climate zones—composite and warm-humid—and with different typologies were visited for selection. For composite climate zone, design and material of D Pochampally (simulated earlier in a pilot study), Kollur II (high-rise typology) and Gajwel (G+1) were simulated. For warm-humid climate zone, YSR Nagar (G+2) was chosen.

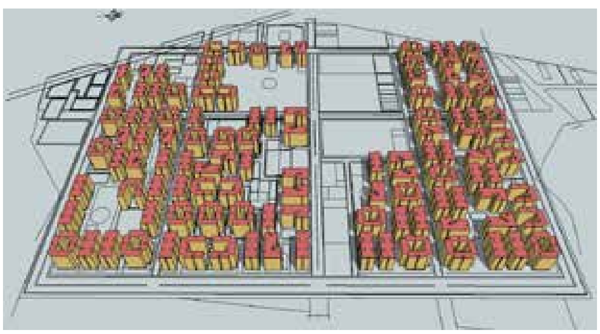


CSE checked all these sites for their compliance to Eco Niwas Samhita 2018 or ECBC-R. Kollur II (Linear and 'O' block) and Gajwel were simulated for thermal comfort. All blocks of Kollur II were simulated for daylighting. Kollur II, being the largest site of around 125 acres, was simulated for computational flow dynamics to understand natural ventilation across the site. The thermal comfort and daylighting analysis have been carried out based on NBC 2016.

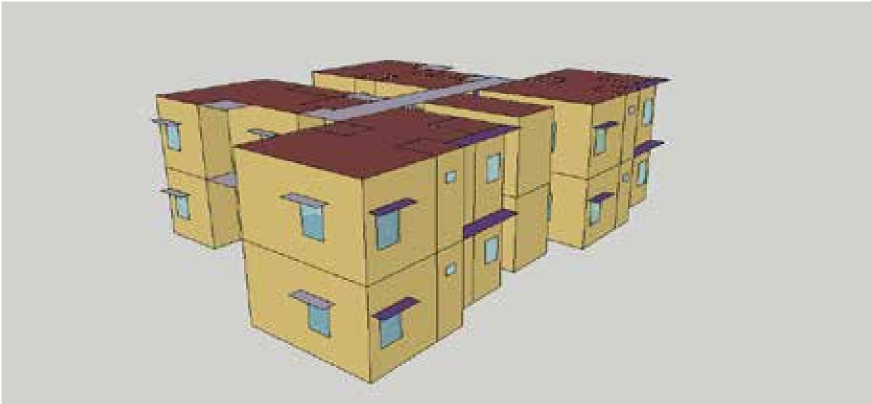
The results of thermal comfort simulation and RETV as per ECBC-R were then reviewed by rotating the building blocks by 45 degrees. Impact of solar shading devices and alternative materials promoted by Building Materials and Technology Promotion Council were also understood. This analysis yielded directions for thermal comfort and energy efficiency strategies that need to be adopted by the government in the affordable housing sector. There is cost implication of these strategies due to better layouts, designs, and choice of materials. This implication is also analyzed to inform government supported affordable housing construction. This combined adoption has become important to achieve the national goal of providing thermal comfort for all and to fulfil energy efficiency objectives.

Typical block and 3D views in D Pochampally



Kollur II site plan, typical blocks and 3D view	
	
	Kollur II Linear block
	
Kollur II 'O' block	
	
	

Typical block in Gajwel



Typical floor plan and blocks in YSR Nagar

Compliance of the 2BHK scheme sites to ECBC-R

The government of India recognizes that majority of construction will take place in the residential sector. To curb the impact of energy consumption of residential buildings, Bureau of Energy Efficiency launched Eco Niwas Samhita or ECBC-R with the aim of setting performance standards for building envelope to limit heat gains or losses. Heat gain or loss through the building envelope takes place due to its orientation, extent of opaque and non-opaque building components, and surfaces like doors, windows, projections (*chajjas*), and walling materials, and their characteristics like ability to shade, insulate, and ventilate. ECBC-R provides performance criteria specific to different climate zones.

This assessment checks the identified sites—D Pochampally, Gajwel, YSR Nagar, and four blocks of Kollur II—on three parameters:

i) WFRop that indicates the potential of using natural wind for ventilation in the building. It is the ratio of total openable area of all the windows to the total carpet area of dwelling units.

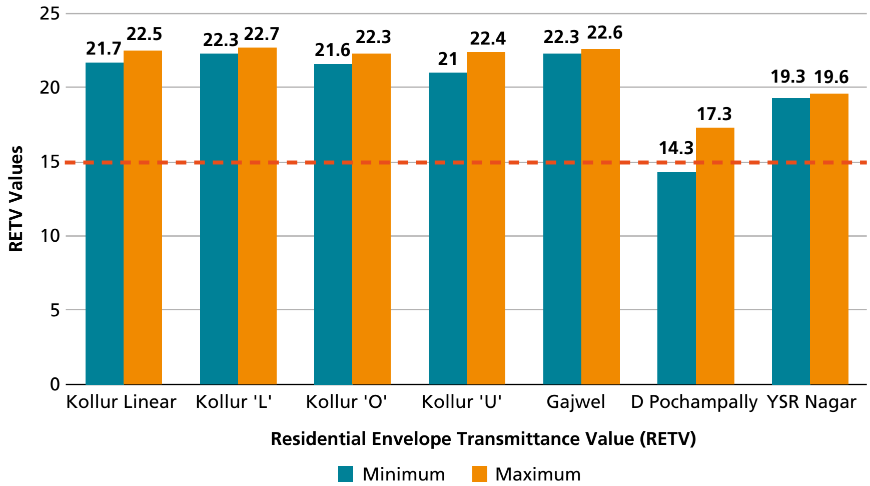
ii) VLT that indicates the potential of using daylight in the building. It is applicable as per the Window to Wall Ratio of the building.

iii) RETV that indicates the thermal performance of a building envelope (except roof). It is the net heat gain rate through the building envelope of dwelling units divided by total area of building envelope. A lower RETV indicates lower heat gains through the building envelope. The maximum RETV for composite, temperate, hot-dry, and warm-humid climate zones has been kept at 15 W/m^2 in ECBC-R. It takes into account heat conduction through opaque building envelope components, heat conduction through non-opaque building envelope components, and solar radiation through non-opaque building envelope components.

Results of the RETV analysis

For this simulation analysis, the housing blocks were rotated by 45 degrees to get the maximum and minimum RETV for eight cardinal directions. Telangana has much opportunity to work towards achieving requisite RETV. To be compliant, the RETV must be within 15 W/m^2 for both composite and warm-humid zones. Among the sites, D Pochampally adheres to the code with RETV at 14.3 W/m^2 when the block is oriented with its longer facade facing the north-south direction. This lays emphasis on the orientation of the buildings. Since the choice of walling material plays a crucial role in RETV, the compliant values of D Pochampally can also be attributed to better materials.

Graph 5: Maximum and minimum RETV for identified sites when oriented in different directions

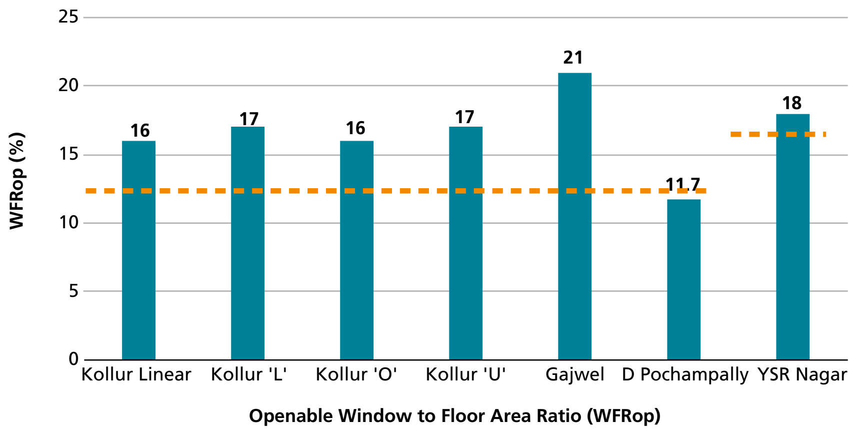


Source: CSE analysis

Results of the WFRop analysis

The minimum value of WFRop for a building to be compliant with ECBC-R in composite climate zone is 12.5 per cent and in warm-humid climate is 16.66 per cent. All the blocks analyzed were found to be compliant, except D Pochampally (see *Graph 6: Openable window to floor area ratio in identified sites*). The WFRop value of 11.7 per cent in D Pochampally can be improved with minor corrections to make it compliant.

Graph 6: Openable window to floor area ratio in identified sites

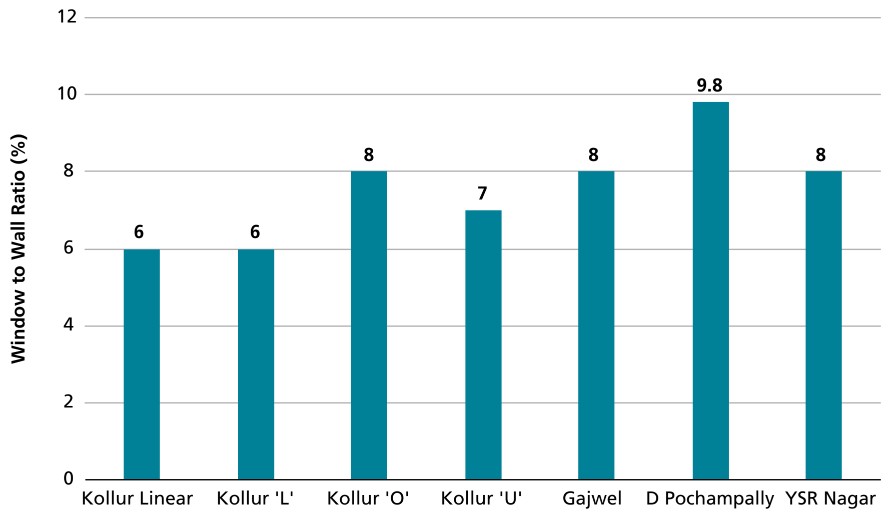


Source: CSE analysis

Results of the VLT analysis

The visible light transmittance or VLT is a function of window to wall area ratio. WWR in the identified sites was calculated and found ranging from six per cent in Kollur II Linear and 'L' blocks to 9.8 per cent in D Pochampally (see *Graph 7: Window to wall ratio in identified sites*).

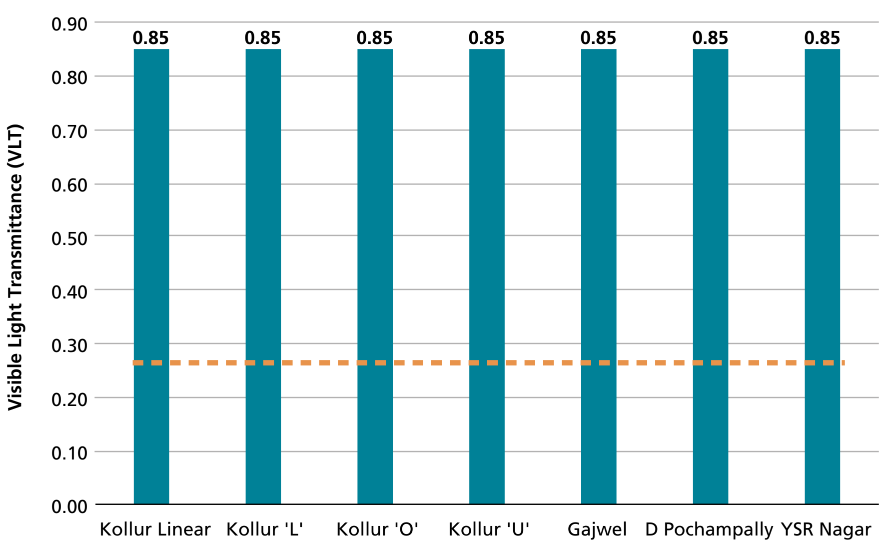
Graph 7: Window to wall ratio in identified sites



Source: CSE analysis

Based on the WWR values, the VLT results for the identified sites fell within the threshold compliance limit set by ECBC-R (see *Graph 8: VLT values in identified sites*).

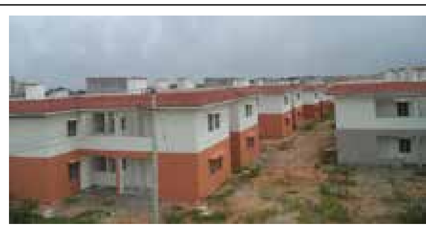
Graph 8: VLT values in identified sites



Source: CSE analysis

While most of the sites are adhering to WWR, VLT, and WFRop thresholds, there is opportunity to work towards and improve the results in the sites for RETV (see *Table 3: Summary of ECBC-R results for all sites*).

Table 3: Summary of ECBC-R results for all sites

Parameter	Value achieved	Value needed for compliance	Compliance achieved	
D Pochampally				
WFRop	11.70%	≥ 12.5%	No	
WWR	0.10	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	14.3–17.3	≤ 15	Adheres to the standard in N–S orientation	
Kollur II Linear Block				
WFRop	16.00%	≥ 12.5%	Yes	
WWR	0.06	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	21.7–22.5	≤ 15	No	
Kollur II 'L' Block				
WFRop	17.00%	≥ 12.5%	Yes	
WWR	0.06	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	21.7–22.5	≤ 15	No	
Kollur II 'O' Block				
WFRop	16.00%	≥ 12.5%	Yes	
WWR	0.08	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	21.6-22.3	≤ 15	No	
Kollur II 'U' Block				
WFRop	17.00%	≥ 12.5%	Yes	
WWR	0.07	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	21–22.4	≤ 15	No	
Gajwel				
WFRop	21.00%	≥ 12.5%	Yes	
WWR	0.08	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	22.3–22.6	≤ 15	No	
YSR Nagar				
WFRop	21.00%	≥ 16.66%	Yes	
WWR	0.08	≤ 0.7	Yes	
VLT	0.85	≥ 0.27	Yes	
RETV	19.3–19.6	≤ 15	No	

Daylighting analysis of the 2BHK scheme for energy efficiency

This study has simulated the Linear, 'L', 'O' and 'U' blocks of the Kollur II site to understand daylight penetration into the structures. This analysis was focused at dense and high-rise typology since low-rise typologies generally perform well due to lesser mutual shading among the building blocks. The lowest habitable floor, middle floor, and top floor were simulated to get a wider idea of daylight ingress into the dwelling units. Two scenarios were simulated—one has no other building in the vicinity to obstruct its daylight, while the other considers building around the subject structure that may affect the amount of daylight it gets.

The simulation uses daylight factor requirement as given in NBC 2016. It assumes a uniform sky condition with 8,000 lux outside. The compliant area will be the part of the floor achieving a minimum illumination of 50 lux (0.625% daylight factor) on work plane height (800mm from finished floor level) in bedrooms and living rooms, and illumination of 200 lux (2.5% daylight factor) in kitchens. Areas receiving illumination less than required daylight factor are considered underlit. NBC 2016 also recommends that a project should achieve minimum 25 per cent area receiving the required daylight factor.

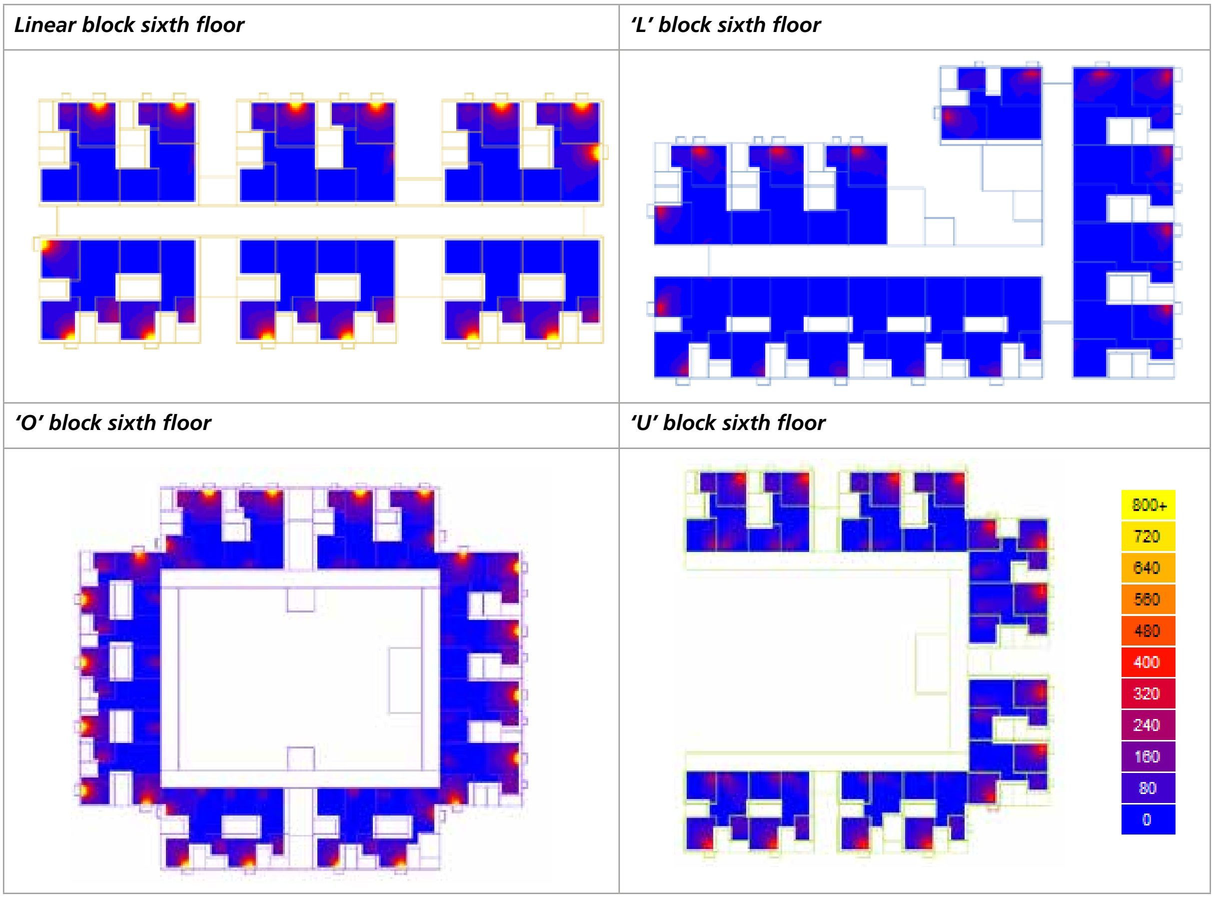
Ecotect software is used for developing building daylight models while Radiance is used for simulation of the models. A range of parameters contributes to the final level or amount of daylight we receive in a building. The reflectance of light from wall, floor and ceiling do count. The level of daylight passing through the glass of a window contributes. Daylight is usually measured at a fixed level of say a table or working plane in a room. The sky condition contributes as well as it can range from overcast to clear sky. Considering these factors, following simulation logics were considered:

- Wall reflectance :50%
- Floor reflectance :30%
- Ceiling reflectance :80%
- Glass visual light transmittance :85%
- Sky condition :Uniform (at 8,000 lux)
- Working plane height :800 mm

Results of the daylighting simulation of blocks in isolation

Different block types result in substantial variation in daylight ingress in Kollur II. Simulation of the middle floor or the sixth floor of the four different block types in Kollur II showed 'U' block with the highest daylight ingress and linear block with the lowest (see *Figure 1: Daylight ingress in the middle floors of blocks in Kollur II*).

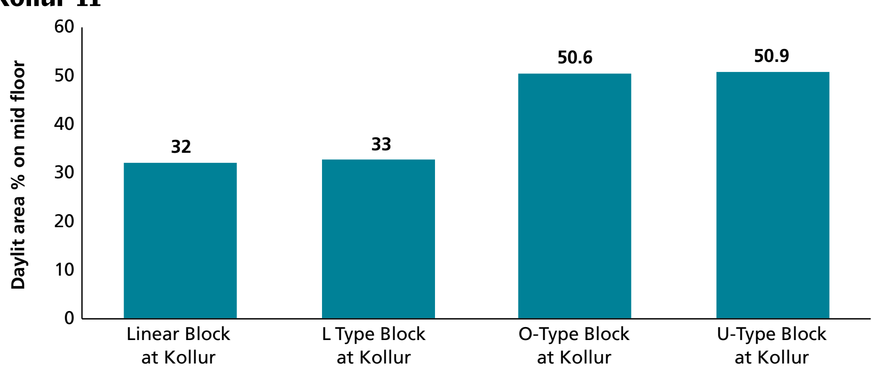
Figure 1: Daylight ingress in the middle floors of blocks in Kollur II



Source: CSE Analysis

With respect to spatial coverage of daylight, all block-types at the site were found compliant to the NBC 2016 threshold of 25 per cent. Linear blocks received daylight in 32 per cent of the total floor area; 'L' shaped blocks received daylight in 33 per cent of the floor area; 'O' block received daylight in 50.6 per cent and 'U' block daylight in 50.9 per cent of their respective total floor areas. The 'O' and 'U' blocks perform better than the 'L' and Linear blocks as they also receive daylight from the courtyard side of the block (see *Graph 9: Percentage of daylit area in the middle floors of blocks in Kollur II*).

Graph 9: Percentage of daylit area in the middle floors of blocks in Kollur II



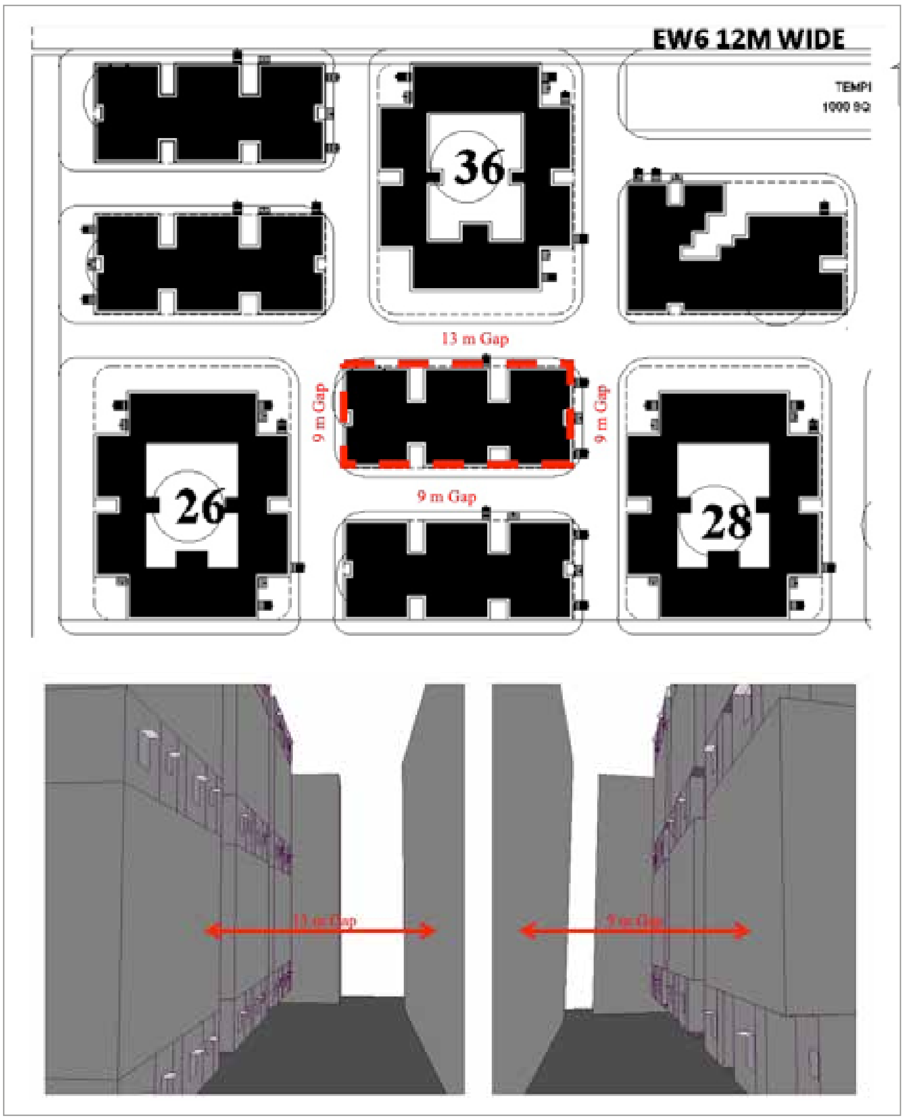
Source: CSE analysis

Results of the daylighting simulation of blocks in site conditions

The four block types of Kollur II were simulated with adjacent buildings obstructing their daylight ingress to replicate the ground situation according to the layout plan. Interestingly, daylight ingress varies substantially when simulated with actual sites conditions.

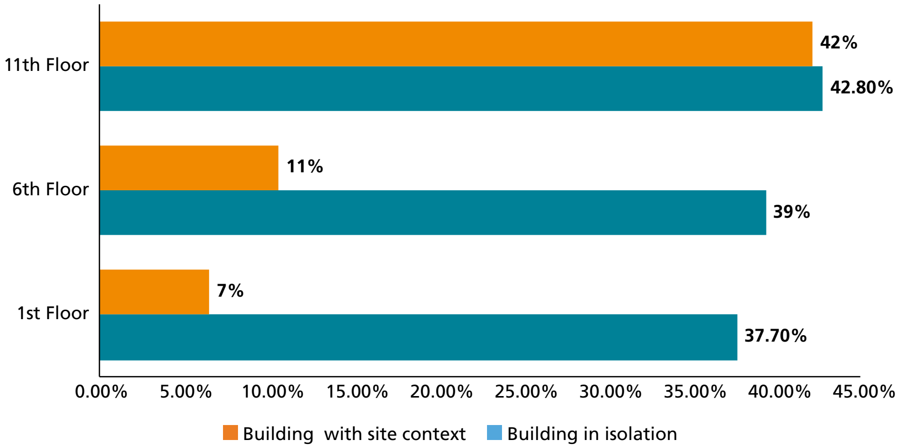
The Linear block of Kollur II has 'O' block and another Linear block adjacent to it (see *Figure 2: Kollur II Linear block in its actual site condition*). Due to these buildings, the first floor shows an enormous drop in the amount of daylight it receives, from 37.7 per cent to only seven per cent (see *Graph 10: Comparison of daylight ingress levels for Linear block*). The sixth floor shows a variation from 39 per cent to 11 per cent from building in isolation to on-site simulation. The top floor does not show much variation.

Figure 2: Kollur II Linear block in its actual site condition



Source: CSE analysis

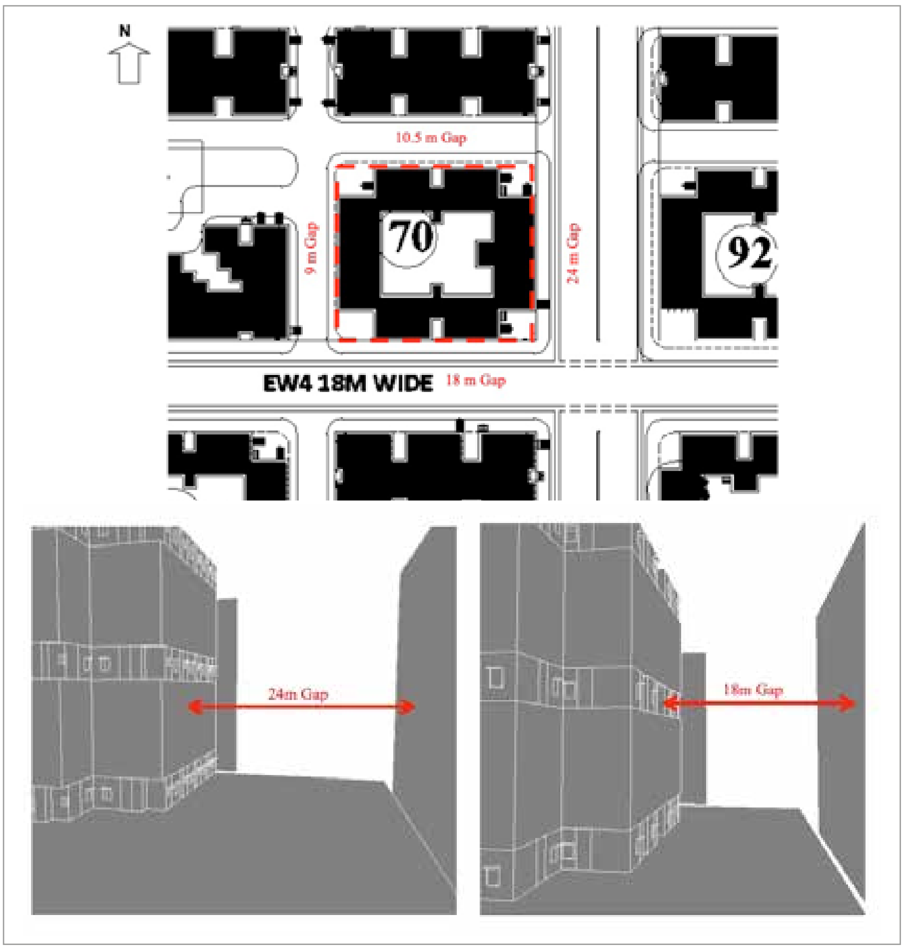
Graph 10: Comparison of daylight ingress levels for Linear block



Source: CSE analysis

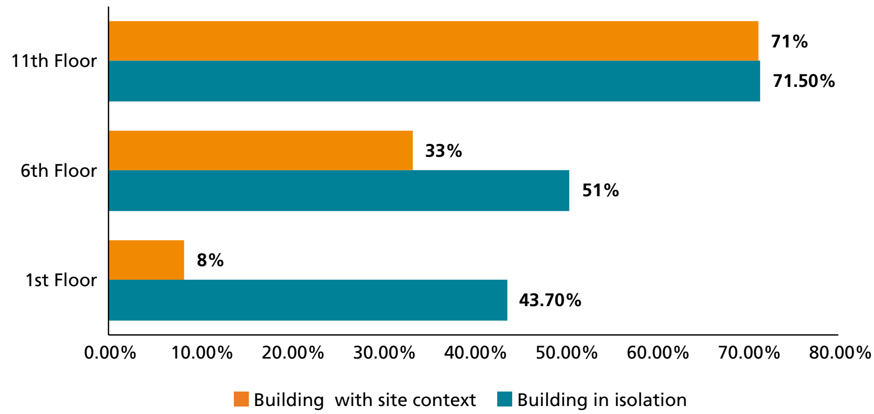
Similarly, the 'O' block shows maximum daylight drop on the first floor from 43.7 per cent to eight per cent (see *Graph 11: Comparison of daylight ingress levels for 'O' block*). On the sixth floor, it loses a third of its daylight amount when simulated in site context.

Figure 3: Kollur II 'O' block in its actual site condition



Source: CSE analysis

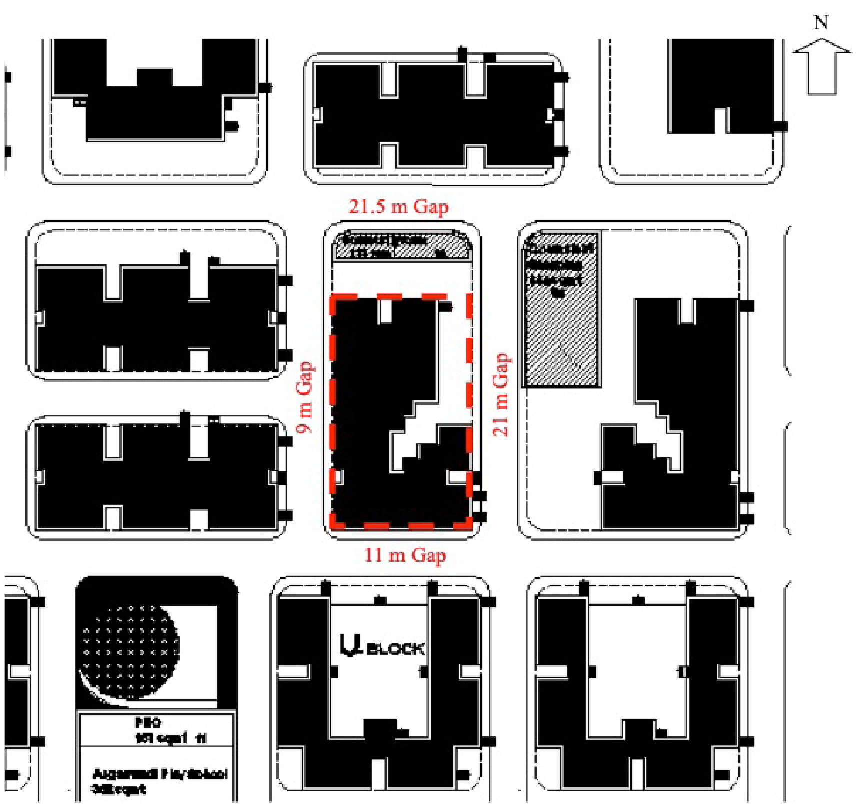
Graph 11: Comparison of daylight ingress levels for 'O' block



Source: CSE analysis

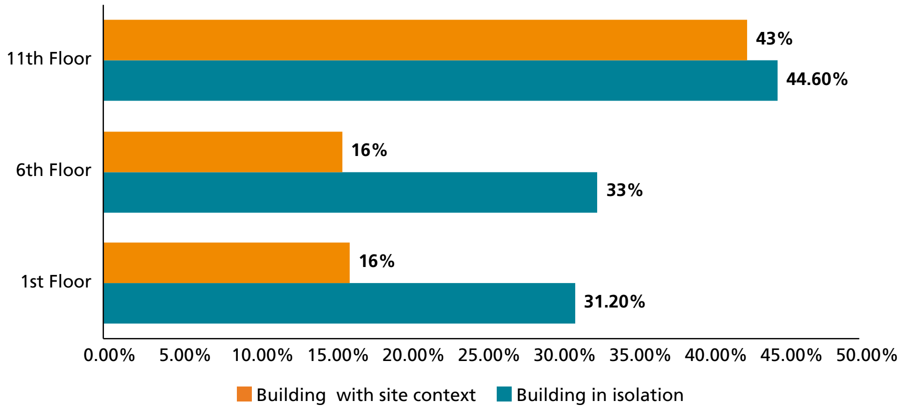
The 'L' block and 'U' block show nearly equal drops on the first floor and sixth floor when simulated with on-ground site conditions (see *Graph 12: Comparison of daylight ingress levels for 'L' block* and *Graph 13: Comparison of daylight ingress levels for Kollur II 'U' block*). In the 'L' block, the amount of daylight reduces to half when the buildings are mutually shading each other as per the layout plan.

Figure 4: Kollur II 'L' block in its actual site condition



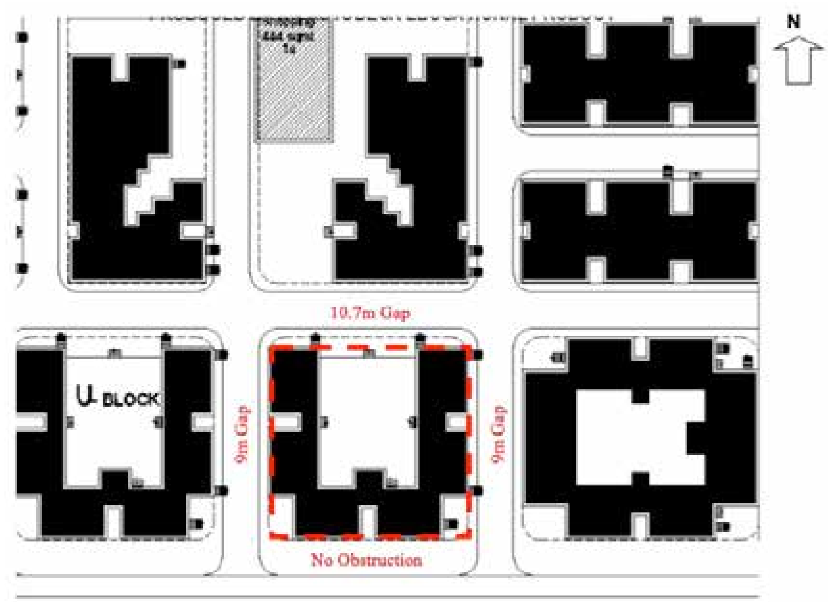
Source: CSE analysis

Graph 12: Comparison of daylight ingress levels for 'L' block



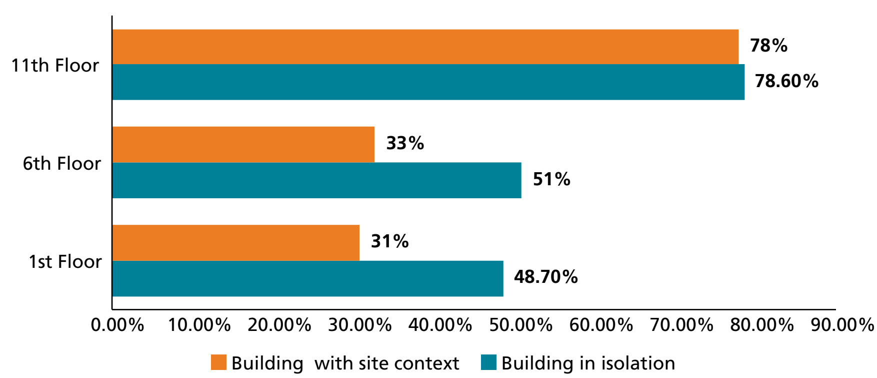
Source: CSE analysis

Figure 5: Kollur II 'U' block in its actual site condition



Source: CSE analysis

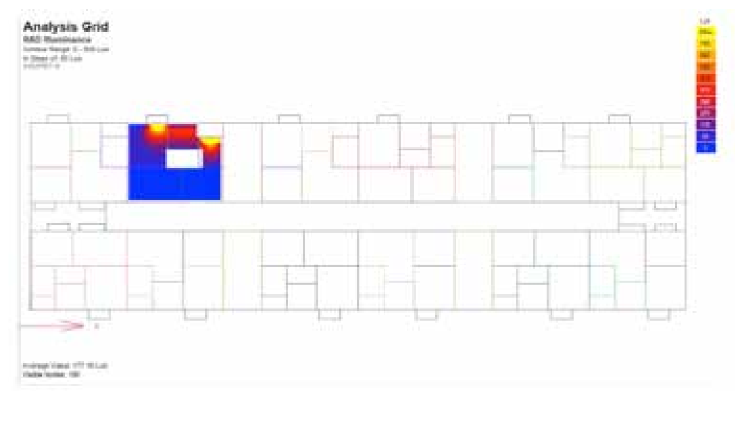
Graph 13: Comparison of daylight ingress levels for Kollur II 'U' block



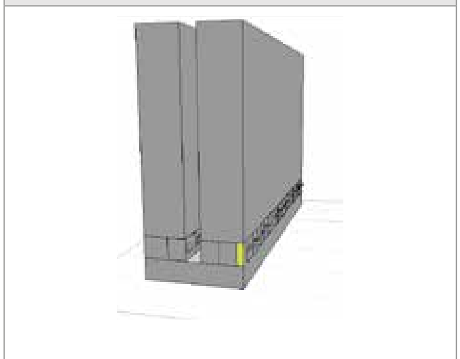
Source: CSE analysis

The lower floors in all the blocks were found to be non-compliant with NBC 2016, minimum 25 per cent daylit area, except the 'U' block. While all the cases are compliant on the top floors, only 'O' and 'U' blocks are compliant in the middle floors. The 'O' and 'U' blocks performed better than the Linear and 'L' blocks overall. This can be attributed to the form of these blocks. Since it has a central courtyard, the interior of 'O' block remains relatively unaffected by the shadows of other buildings.

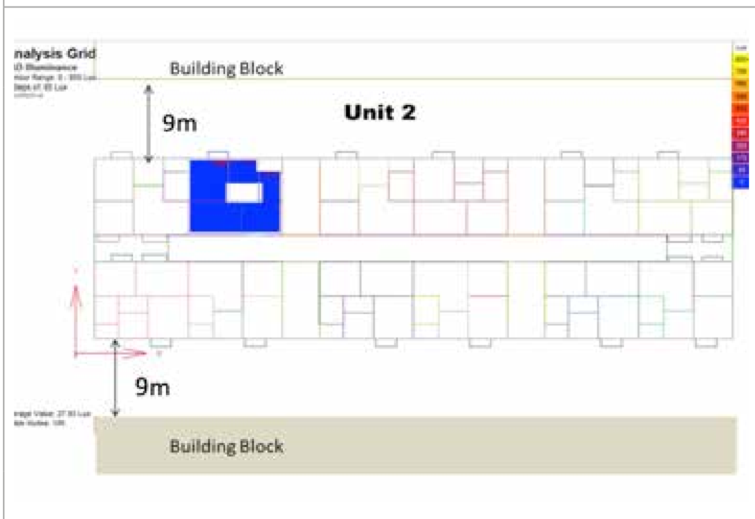
Figure 6: Comparison of daylight ingress levels for D Pochampally



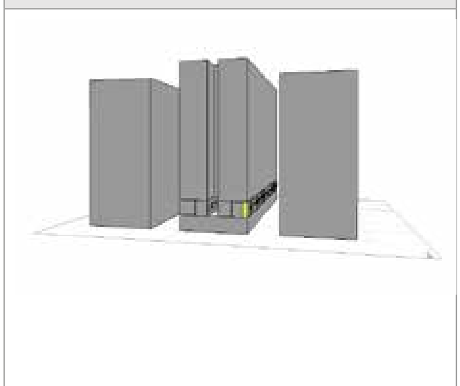
Scenario 1: Building simulated in isolation



Daylit area—47%



Scenario 2: Building simulated with site context



Daylit area—15%

Source: CSE analysis

Figure 7: Typical block at D Pochampally in its actual site condition

Source: CSE analysis

These results are consistent with other sites also. For instance, buildings in D Pochampally when simulated in isolation resulted in 47 per cent of the dwelling unit area receiving daylight. This coverage reduced to 15 per cent when simulated with adjacent blocks as laid out in the site plan. This finding gives a clear understanding on the performance of block-types in isolation vs. with adjacent blocks mutually shading them.

Is VLT a good indicator for daylighting in buildings?

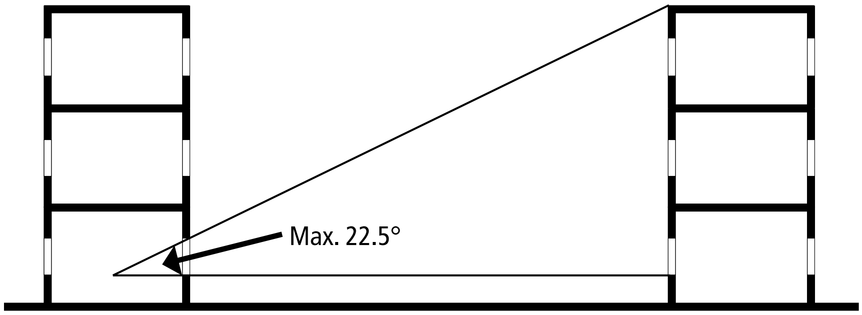
After analyzing the subject sites for daylighting performance as per ECBC-R and analyzing simulation models based on NBC 2016 guidelines, it is clear that the results are not consistent when checked for a block in isolation and when checked for a block in the on-ground context. There is a drop of 17 to 34 per cent in the first floor when simulated with site conditions. Further, the layout plans are providing daylight to very less area of the lower floors—31.2 per cent to 48.7 per cent even when the buildings are simulated in isolation. Interestingly, all the blocks otherwise adhere to ECBC-R for daylight performance, while spatial coverage of daylight penetration does not capture even half of the dwelling units. This coverage reduces by 7–31 per cent for the lower floors when simulated with surrounding buildings. The distance between the buildings becomes a crucial parameter for ideal daylight penetration.

ECBC-R relies on VLT as an indicator for daylight ingress in buildings. The results of this assessment suggest that VLT (calculated for an individual block) may not be defining the level of daylight as received by the occupant of the building. For instance, there is a drop of 17 to 34 per cent drop in day lighting on the first floor when simulated with site conditions, while all the blocks otherwise adhere to ECBC-R for daylight performance. Daylighting area coverage reduces by 7-31 per cent for the lower floors when simulated with surrounding buildings.

Therefore, ECBC-R's reliance on VLT may be conveying the performance of the 'hardware' and not the level of services (of daylighting) that the beneficiary is actually receiving. This learning is crucial for the states who are aiming towards excellence—beyond compliance to the ECBC-R—or even improving the codes for better performance. In order to achieve this, states will require to work on the affordable housing layouts and designs to provide better daylighting to the beneficiary in order to reduce energy consumption in buildings and avoidable financial implications for the beneficiary. The distance between the buildings becomes a crucial parameter for ideal daylight penetration.

According to CPWD's integrated green design manual, the distance between the buildings for ideal daylight penetration should be such that the lowest floor windows of a building should subtend a maximum angle of 22.5 degrees with the top of the of the adjacent building (see *Figure 8: Guideline for ideal daylight penetration*). Since this gap could be quite wide and may have limitations with ground coverage on the site, a closer placement is suggested.

Figure 8: Guideline for ideal daylight penetration



Source: Integrated Green Design, 2013

Wind flow analysis of the 2BHK scheme for ventilation strategies

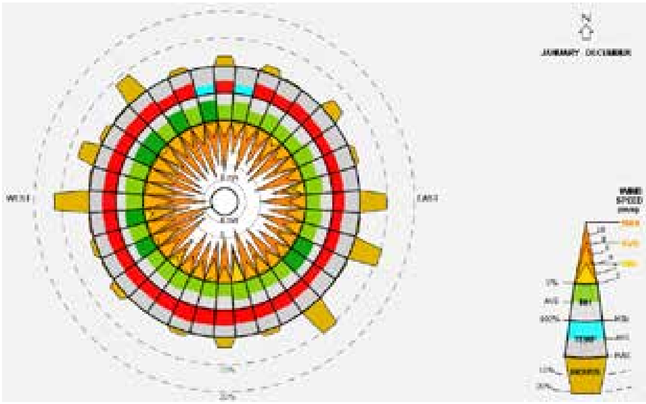
Most 2BHK scheme projects in Hyderabad region are high-rise developments. Due to limitations of land availability in major cities and urban agglomerations, the typology for affordable housing has shifting towards high-rise development. As the number of high-rise buildings increase, wind flow in that urban geography and its surroundings gets disturbed. Very often, wind is locked out of the ambient area around the buildings. This gradually contributes to altering of the micro-climate in and around the high-rise building clusters by depriving it of natural wind or sometimes exposing it to excessive natural wind.

This issue of disrupted natural ventilation due to high-rise buildings has caught attention of countries across the world. In response, they have either come up or are working towards coming up with ventilation strategies. For instance, the city of London has drawn Wind Microclimate Guidelines which asks for several studies as part of new development proposals. It asks for certain performance criteria to ensure quality and usability of outdoor areas primarily with regard to comfort and safety. India has a great opportunity to investigate and identify ventilation strategies while it has yet to develop majority of its infrastructure, especially mass housing.

CFD simulation helps understand wind flow in a given environment. CSE simulated the largest 2BHK scheme project—Kollur II—to understand the impact of wind flow on the high-rise buildings being constructed. This analysis has been done using IES-VE Macroflo software for outdoor wind flow around the building. Climatic data for predominant wind direction and wind speed are used in the CFD analysis for the entire site of Kollur II and also the individual building blocks.

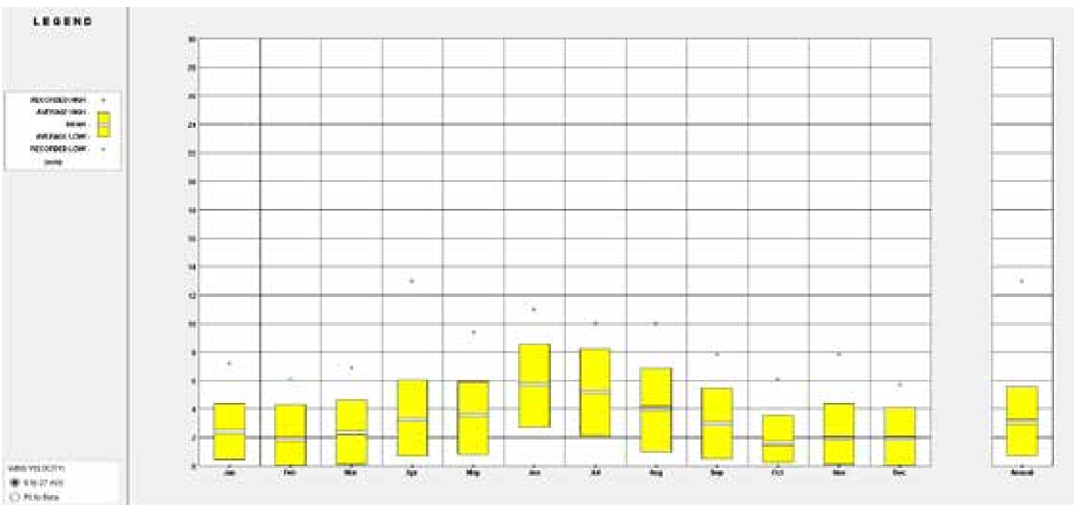
Hyderabad has predominant wind directions as west, east, and south east. The wind rose diagram created using the weather file for Hyderabad is shown in *Figure 9: Wind rose diagram for Hyderabad*. The annual average wind speed in Hyderabad is approximately 2.5 m/s (see *Figure 10: Annual average wind speed in Hyderabad*).

Figure 9: Wind rose diagram for Hyderabad



Source: Hyderabad weather file

Figure 10: Annual average wind speed in Hyderabad



Source: Hyderabad weather file

To understand the impact of indoor ventilation in each dwelling unit and how it may contribute to thermal comfort, an indoor CFD analysis has also been conducted. Since this analysis is dependent on climate, it is done considering all windows are 100 per cent openable and will remain open at all times. This will give the full potential of natural ventilation in the design.

High wind velocities due to 'tunnel effect'

The impact of clustering of blocks on the site is shown in *Figure 11: Impact of clustering on wind flow across the site of Kollur II*. When the wind is flowing from the west and perpendicular to the buildings, several cases of venturi effect or tunnel effect were found on the site. In these cases, the wind Velocity was higher but only outside, without any of it getting into the buildings.

Wind speed in these 'tunnels' reaches up to 3.5 m/s. These high wind velocities can dissuade occupants from opening their windows even when the weather is

Figure 11: Impact of clustering on wind flow across the site of Kollur II

favourable. Therefore, this elevated wind velocity is unable to provide comfort and can rather damage the windows if they are the side hung type. The facades facing these high wind zones also become affected.

Stagger buildings to negate the tunnel effect

The tunnel effect reduces when buildings are placed in a staggered manner (see *Figure 12: Staggering mitigates the tunnel effect*). On staggering, the wind shadows (low or least velocity zones) do not fall on the adjacent building and instead occupy the void between the buildings.

CFD analysis for wind flow at intermediate floor (fifth floor) and from south-east direction reveals that the amount of wind shadow area i.e. the area with very low wind velocity (less than 0.5 m/s), is significantly less than when the wind was hitting perpendicular to the building (see *Figure 13: Wind flow from south-east direction*). The spread of wind across the site is better than it was when flowing from the west. This streamlining of wind flow completely cancels out the tunnel effect as well.

Figure 12: Staggering mitigates the tunnel effect

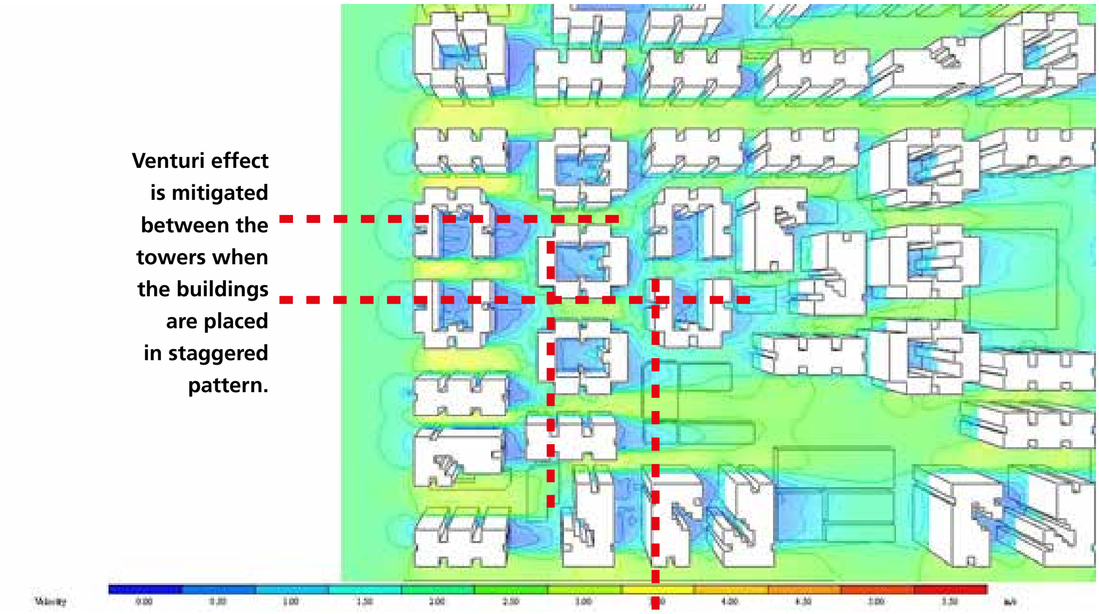
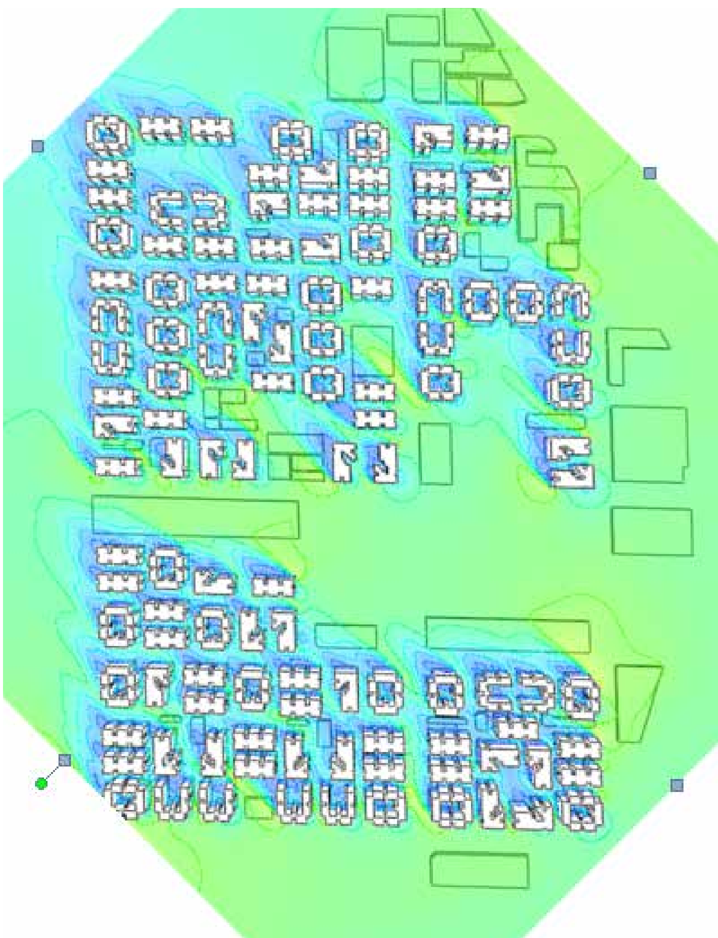


Figure 13: Wind flow from south-east direction

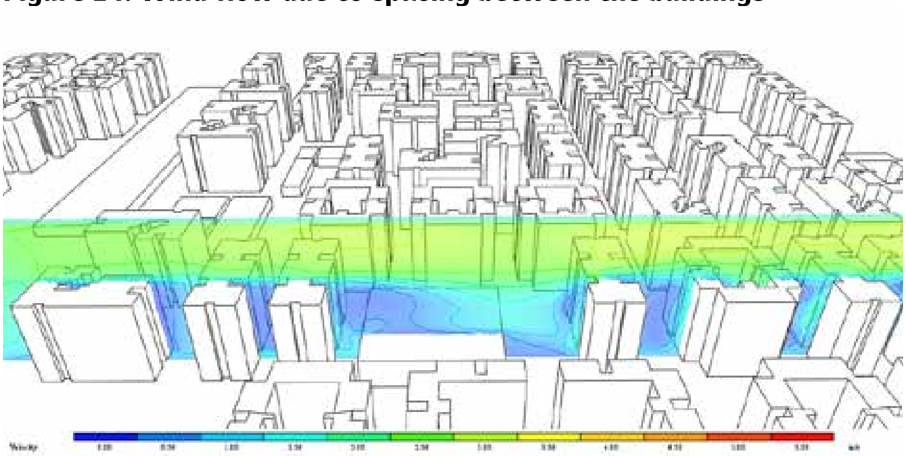


Source: CSE analysis

Wind flow improves with adequate spacing between the buildings

As the space between the buildings increases, the wind velocity also increases for the next buildings in the windward direction as shown in Figure 14.

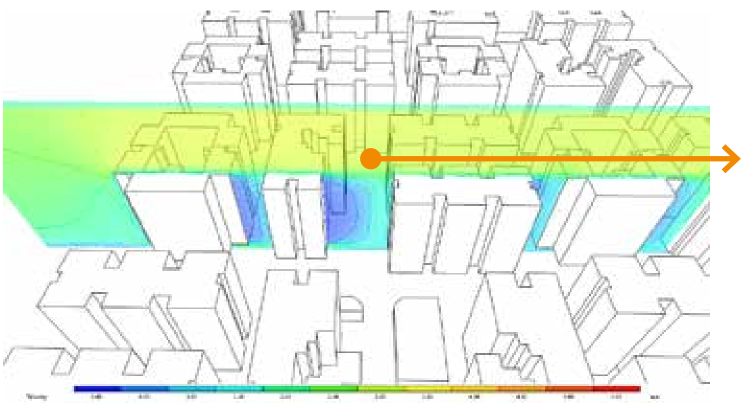
Figure 14: Wind flow due to spacing between the buildings



Wind flow is better in mid-rise developments

A case with mid-rise development (G+6) with the same site plan of Kollur II was simulated for wind flow. A significant decrease in wind shadow areas was observed as compared to high-rise development (see *Figure 15: Impact of height on wind flow between buildings in Kollur II*).

Figure 15: Impact of height on wind flow between buildings in Kollur II

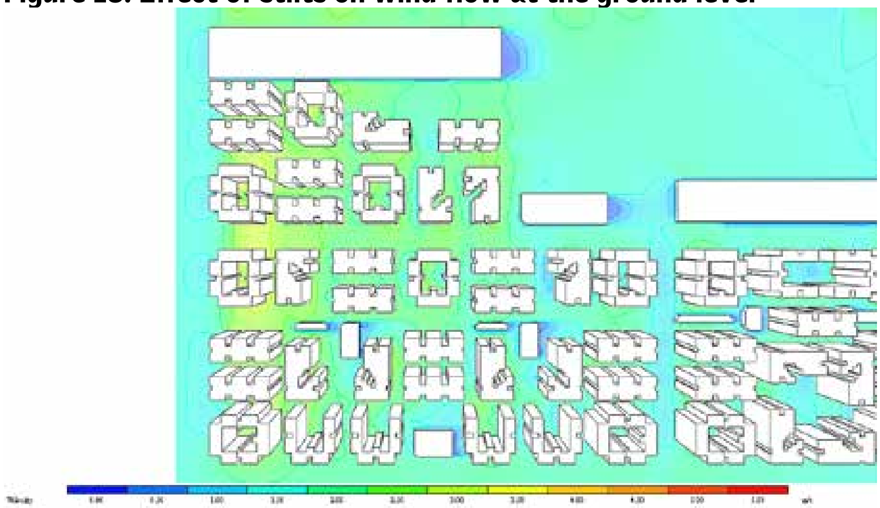


Source: CSE analysis

Stilts increase wind flow at the ground level

CFD analysis at ground levels to see the impact of stilts on wind flow reveals that the wind velocity increases due to stilts and can be attributed to the tunnel effect at ground level alone. This shows that stilted floors can contribute in dissipation of heat absorbed by the paved surfaces and improve pedestrian thermal comfort. Wind shadows were found to be the least in this case (see *Figure 16: Effect of stilts on wind flow at the ground level*).

Figure 16: Effect of stilts on wind flow at the ground level



Source: CSE analysis

Indoor ventilation analysis

To understand the impact of wind on indoor ventilation, annual ventilation flow rates of entire dwelling units facing different directions on lowest floor, intermediate floor, and top floor were calculated. This includes correlation of air changes per hour (ACH) or the indoor ventilation rate to outside wind speed for the intermediate floor. For this, the windows to the outside are modelled considering that they are shielded from free-flowing wind. The windows were considered open for enhancing thermal comfort and wind comfort with following conditions:

a. Outdoor temperature is higher than 18°C AND
b. Indoor temperature is more than 22°C AND
c. Indoor temperature is higher than outdoor temperature AND
d. Indoor ventilation rate is limited to only 10 ACH (optional)

West facing dwelling units of Kollur II's Linear and 'O' Block were simulated with these conditions. This resulted in multiple scenarios involving different floors, different ACH, and different types of windows (fully openable hinged windows and 50 per cent openable sliding windows) (see *Table 4: Indoor ventilation results for Linear block's west facing units*). The analysis revealed that ventilation rate may drop to below two ACH for up to 25 per cent of the year. On the other hand, ventilation rate can increase and go above 50 ACH when the windows are fully open. ACH below two is almost negligible and above 10 is too windy to be suitable for thermal comfort. Beyond 10 ACH, there is also a risk of windows getting damaged due to fluttering which will discourage inhabitants from opening them.

Table 4: Indoor ventilation results for Linear block's west facing units

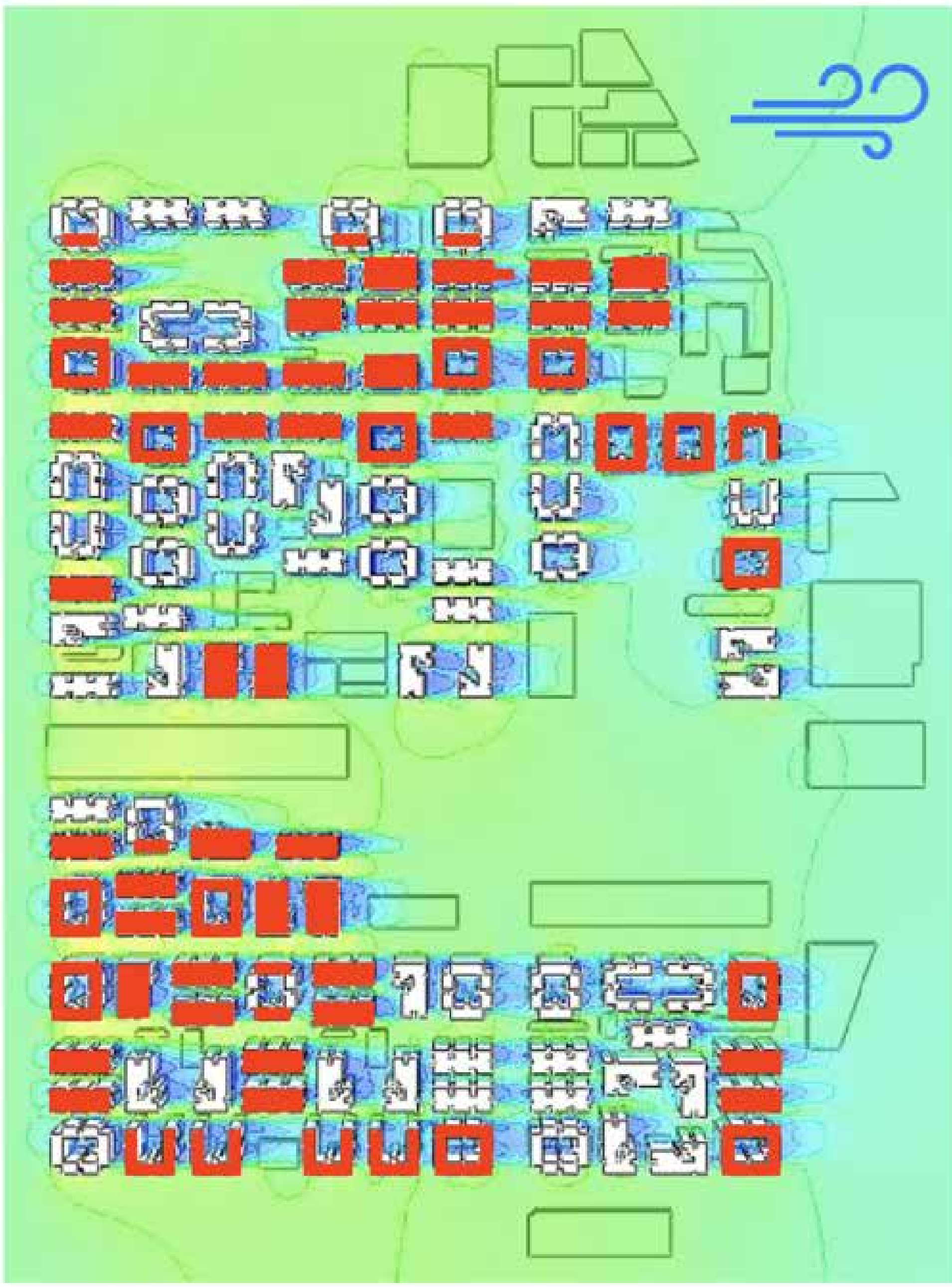
Linear block west DU	Average ACH	Period <2 ACH	Period >10 ACH
Lower floor full open windows	38.8	0.0%	62.3%
Lower floor full windows open with thermal comfort conditions	21.3	26.8%	54.4%
Lower floor full windows open with thermal comfort conditions & 10 ACH limit	6.8	26.8%	0.0%
Lower floor sliding windows open with 50% area & thermal comfort conditions	11.2	26.5%	42.4%
Lower floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	6.0	26.5%	0.0%
Middle floor full open windows	42.7	0.0%	84.3%
Middle floor full windows open with thermal comfort conditions	26.2	19.8%	62.3%
Middle floor full windows open with thermal comfort conditions & 10 ACH limit	7.6	19.8%	0.0%
Middle floor sliding windows open with 50% area & thermal comfort conditions	14.0	18.0%	51.5%
Middle floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	6.9	18.0%	0.0%
Top floor full open windows	48.3	0.0%	85.9%
Top floor full windows open with thermal comfort conditions	31.3	16.1%	67.5%
Top floor full windows open with thermal comfort conditions & 10 ACH limit	8.0	16.1%	0.0%
Top floor sliding windows open with 50% area & thermal comfort conditions	16.6	14.2%	55.9%
Top floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	7.4	14.2%	0.0%

Table 5: Indoor ventilation results for 'O' block's west facing units

'O' type block west DU	Average ACH	Period <2 ACH	Period >10 ACH
Lower floor full open windows	46.4	0.0%	88.1%
Lower floor full windows open with thermal comfort conditions	24.5	25.0%	57.6%
Lower floor full windows open with thermal comfort conditions & 10 ACH limit	7.1	24.8%	0.0%
Lower floor sliding windows open with 50% area & thermal comfort conditions	12.9	24.6%	47.1%
Lower floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	6.4	24.5%	0.0%
Middle floor full open windows	51.1	0.0%	88.5%
Middle floor full windows open with thermal comfort conditions	27.4	23.3%	59.8%
Middle floor full windows open with thermal comfort conditions & 10 ACH limit	7.3	22.2%	0.0%
Middle floor sliding windows open with 50% area & thermal comfort conditions	14.5	22.5%	50.7%
Middle floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	6.7	21.9%	0.0%
Top floor full open windows	57.7	0.0%	90.4%
Top floor full windows open with thermal comfort conditions	36.3	14.8%	70.9%
Top floor full windows open with thermal comfort conditions & 10 ACH limit	8.2	14.8%	0.0%
Top floor sliding windows open with 50% area & thermal comfort conditions	19.1	13.4%	61.9%
Top floor sliding windows open with 50% area & thermal comfort conditions & 10 ACH limit	7.7	13.4%	0.0%

This analysis revealed that about 40 per cent of the blocks in the site are receiving adequate ventilation. Rest of the blocks would have required some intervention in the layout as they are either under ventilated or are facing extremely windy conditions (see *Figure 17: Blocks affected by low and extremely high wind flow*). Natural ventilation is required in buildings to lower indoor temperatures and dissipate any indoor air pollution. Too low a ventilation rate will result in stagnation of indoor air and will push the beneficiary to switch to mechanical means of ventilation and cooling. If the ventilation rate is on the higher side, it may cause damage to the windows, increasing capital cost and posing a threat to human safety.

Figure 17: Blocks affected by low and extremely high wind flow



Source: CSE analysis

It is now clear that air movement is affected by the form, height, distances between the blocks, clustering, and placement of the blocks on the site. Blocks must be staggered or oriented with respect to the streets in a way that the favourable wind direction hits the buildings diagonally rather than in a perpendicular fashion (see *Figure 18: Wind behaviour due to staggering of buildings*). This reduces wind shadow area and tunnel effect. Therefore, studying the predominant wind direction in detail and determining the appropriate typology of blocks, along with their clustering and layout, is an exercise that should be taken up during the planning stage. In absence of this exercise at Kollur II, about 40 per cent of the blocks in the site are receiving appropriate ventilation which is neither under ventilated or facing extremely windy conditions. States can increase this percentage by working on and regulating layouts. Adequate natural ventilation lowers indoor temperatures and dissipates any indoor air pollution. Too low a ventilation rate will increase reliance on mechanical means of ventilation and cooling.

Generally, in mass housing, if the impact of wind flow is not understood and addressed at planning and design stage, reparative measures will need to be taken up at the cost of the beneficiary. With several incentives for affordable housing construction under government schemes such as extra floor area ratio/floor space index, the typology for affordable housing is shifting towards high rise development in major cities. Ventilation strategies need to be sought in that case to negate the effects of high-rise development on micro climate. Analysis such as CFD simulation helps in understanding the impact of wind and its crucial role for thermal comfort, energy efficiency, and health and safety.

WFRop as an indicator of indoor ventilation in buildings

CFD analysis has revealed that air movement is affected by the form, height, distances between blocks, and clustering and placement of blocks on the site. It will be inadequate to evaluate a building on only one or two of the factors. WFRop is an indicator for ventilation in buildings as per ECBC-R. It evaluates ventilation in a building based on the ratio of openable area of windows and the floor area of the dwelling unit. This method evaluates a building for ventilation in isolation. There is opportunity for states to improve upon this indicator for ventilation when they adopt ECBC-R.

Thermal comfort analysis for the 2BHK scheme

This assessment has simulated three sites of 2BHK scheme with different typologies for thermal comfort. The assessment used the adaptive thermal comfort model of NBC 2016 and whole building energy and thermal simulation approach. The analysis has helped in the calculation of EPI for a typical building and also in estimating indoor comfort conditions achieved in the dwelling units.

Different orientations were tested by rotating the design by 45 degrees (east–west), 90 degrees (north-east–south-west), and 135 degrees (north–south). The performance of these orientations is further understood by evaluating and

Figure 18: Wind behaviour due to staggering of buildings

Source: CSE analysis

comparing annual hours of discomfort due to overheating. The units with the least amount of annual overheating are considered to be better performing. The discomfort due to under heating, i.e. when the operative temperature goes below the thermal comfort limit, is not considered because that can be addressed by heavier clothing. Whereas, the overheating hours, i.e. operative temperature above the thermal comfort limit, cannot be addressed by adjusting clothing and will require energy intensive solutions like air conditioning or evaporative cooling technologies.

The simulation is done using Sketchup for preparing the building shell while OpenStudio is used for inserting various building parameters like construction materials, operation and occupancy schedules, internal lighting and equipment loads, natural ventilation logic, etc. OpenStudio has further used Energy Plus as thermal simulation engine for the calculation of indoor thermal comfort in dwelling units.

Following parameters are considered in the building simulation model:
Building envelope : As per the respective design case
Interior lighting load : 5 W/m^2
Interior equipment load : 10 W/m^2
No. of occupants per DU : 4
Thermal comfort system : Natural ventilation
Thermal comfort range : Following operative temperature (as per Indian Adaptive Thermal Comfort Model for Naturally Ventilated Spaces)

Climate	Natural ventilation	Evaporative cooling (mixed mode)	Air conditioned (mixed mode)
Hyderabad	22 °C–32 °C	20.4 °C–30.3 °C	20.4 °C–30.3 °C

Logic used for natural ventilation dictates that windows are open:
a. When the outside temperature is above 18 °C
b. At evening and night time between 7 PM to 7 AM
c. Until the rate of air change is equal to or below 10 ACH

CSE also simulated the different materials and construction technologies promoted by BMTPC to understand their impact on thermal comfort. Their thermal transmittance or U-value is given in Table 6. To compare the performance of these materials, the average, minimum, and maximum values of annual thermal comfort achieved in different dwelling units are calculated.

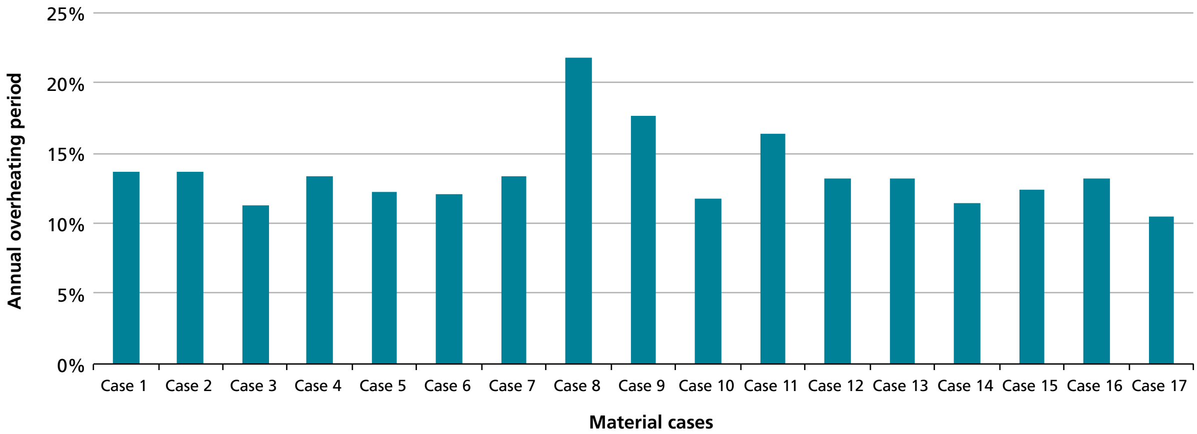
Table 6: Thermal transmittance value of different materials and construction technologies

Sr. no.	Description of construction technology	U-Value W/m^2K
1	Case 1: Monolithic concrete	3.4
2	Case 2: Modular tunnel form	3.4
3	Case 3: Insulating concrete form	0.3
4	Case 4: Plaswall panel	2.7
5	Case 5: Plasmolite	1.3
6	Case 6: EMMEDUE	0.5
7	Case 7: GFRG	1.559
8	Case 8: Waffle crete	5.0
9	Case 9: Precast large concrete panel	3.8
10	Case 10: 150mm AAC blocks	0.9
11	Case 11: Hollow concrete wall	2.5
12	Case 12: CSEB	2.5
13	Case 13: Burnt clay bricks	2.1
14	Case 14: 250mm AAC blocks	0.54
15	Case 15: 150mm RCC + 100mm AAC	1.03
16	Case 16: 150mm flyash bricks	1.5
17	Case 17: 250mm AAC + 0.45 SHGC glass	0.54

Source: Compiled from various sources

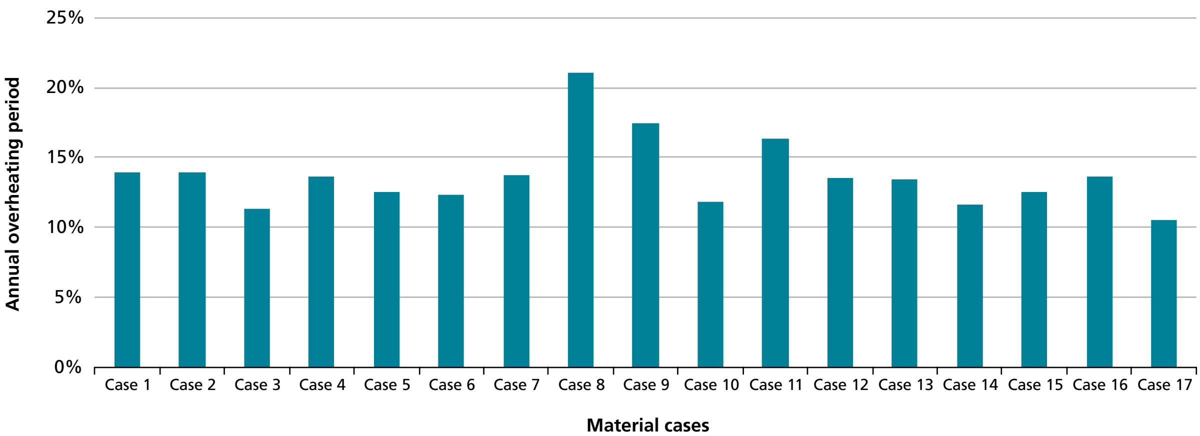
The overheated hours or the period for which the dwelling units will not be thermally comfortable due to excessive heat have been simulated for the Kollur II Linear block, Kollur II 'O' block, and Gajwel. These hours have been calculated for different materials. The annual overheating period for Kollur II Linear block ranges from 10.6 per cent to 21.8 per cent of the year. For Kollur II 'O' block, the annual overheating period ranged from 10.6 per cent to 21.2 per cent of the year. Low-rise typology of Gajwel resulted in annual overheating from 10.8 per cent to 24 per cent of the year. Materials as in cases 3, 5, 6, 10, 14, 15, and 17 performed consistently well for thermal comfort in the three sites. These are the cases involving insulation and mainly AAC blocks. Cases 8, 9, and 11 performed the worst by exceeding overheating hours by 15 per cent.

Graph 14: Annual overheating period for Kollur II Linear block



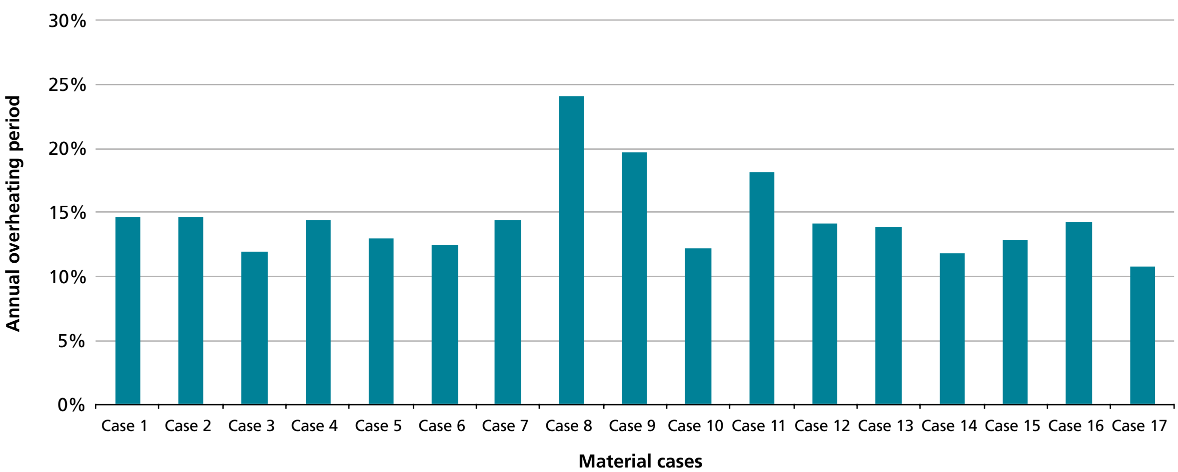
Source: CSE analysis

Graph 15: Annual overheating period for Kollur II 'O' block



Source: CSE analysis

Graph 16: Annual overheating period for Gajwel



Source: CSE analysis

RETV as an indicator of thermal comfort

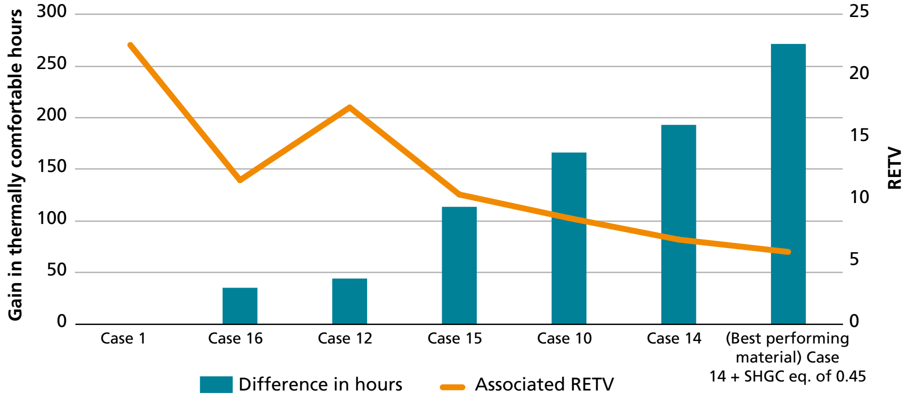
ECBC-R relies on RETV as an indicator of thermal comfort in buildings. To see how consistent RETV is with thermal comfort simulation results, CSE compared the analysis of two different materials from the design case—concrete blocks and the best performing material. According to the results, RETV showed a proportionate relationship with thermal comfort (in terms of reduction in overheating hours from the base case), but only in cases involving insulation.

The relationship between RETV and thermal comfort showed inconsistency with Case 12, that is Compressed Stabilized Earthen Blocks (CSEB). CSEB outperformed fly-ash bricks in thermal comfort simulation despite having a U-value more than fly-ash bricks (Case 16) resulting in higher RETV. Similarly, a combination of 150 mm RCC and 100 mm AAC on the inside of the walling assembly (Case 15) performed better than fly ash bricks (Case 16) by a huge margin, even when their U-values are very similar—1.3 and 1.5 W/m^2K respectively.

These results show that when states are ratifying ECBC-R they can innovate and identify indicators that take into consideration the thermal transmittance as well as thermal mas properties of the materials. The analysis provides evidence that RETV's reliance on U-value may not always deliver better thermal comfort. CSEB is delivering better thermal comfort because it has higher thermal mass than fly ash bricks.

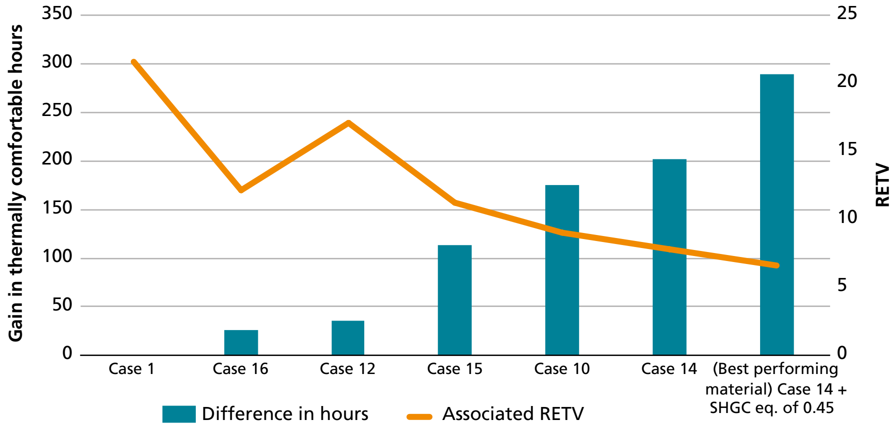
Walling assemblies combining materials with high thermal mass and insulation can result in better thermal comfort and thus need to be explored. Indian Standard SP:41 (S&T) (about performance of walling) states that time taken to transfer heat through a wall increases by up to three times when the insulation is placed on the outside of the regular masonry external wall compared to when it is placed on the inside of the same wall. This means the sequence of the layers of materials makes a difference in the thermal comfort of an occupant, although U-value does not change. This finding is very important for states such as Telangana who are exploring new and alternative walling assemblies. When such states adopt ECBC-R, they have potential to address time taken by a walling to transfer heat from the outside to the inside of the wall in addition to RETV.

Graph 17: Comparison of RETV and gain in thermal comfort hours for Kollur II Linear block



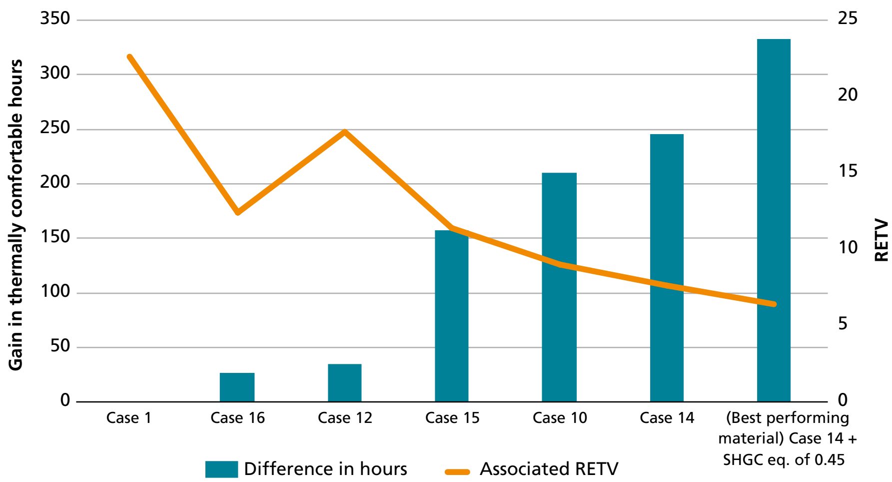
Source: CSE analysis

Graph 18: Comparison of thermal comfort simulation and RETV results for Kollur II 'O' block



Source: CSE analysis

Graph 19: Comparison of thermal comfort simulation and RETV results for Gajwel

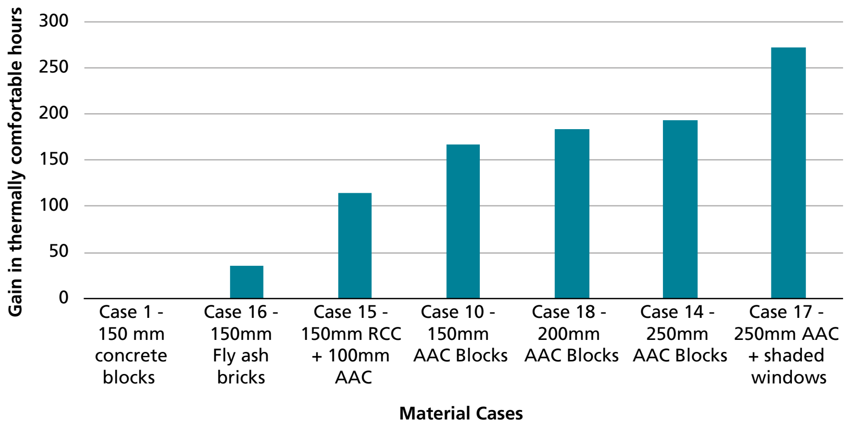


Source: CSE analysis

Impact of materials on thermal comfort

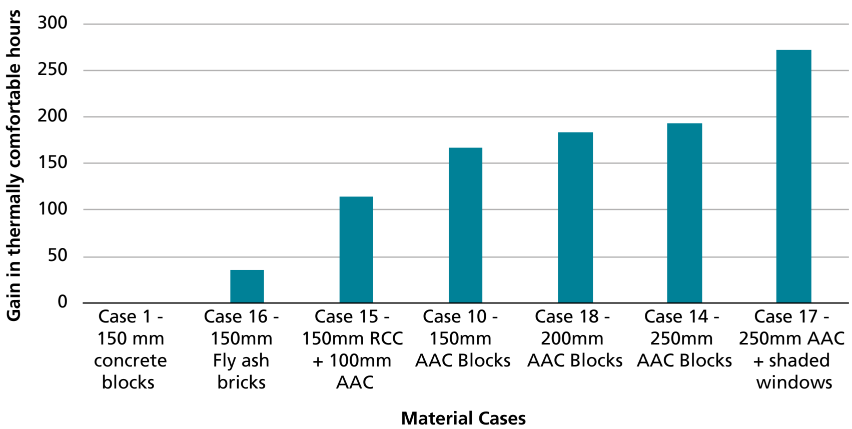
To further the understanding on materials, CSE evaluated the gain in thermal comfort hours due to a change in materials only. The 2BHK scheme sites are primarily using concrete blocks (Case 1), followed by fly ash bricks (Case 16), as walling materials. However, a few projects have also used AAC blocks (Case 10). The results showed that the walling assembly with a combination of insulation and shading devices (Case 17) delivered the best thermal comfort in all the three types of blocks evaluated. This case has the potential to provide about 272 to 333 annual thermal comfort hours above the case widely used in Telangana's 2BHK scheme as of 2020. Future projects can go for combination assemblies to maximize annual thermal comfort hours.

Graph 20: Gain in annual thermal comfort hours due to materials in Kollur II Linear block



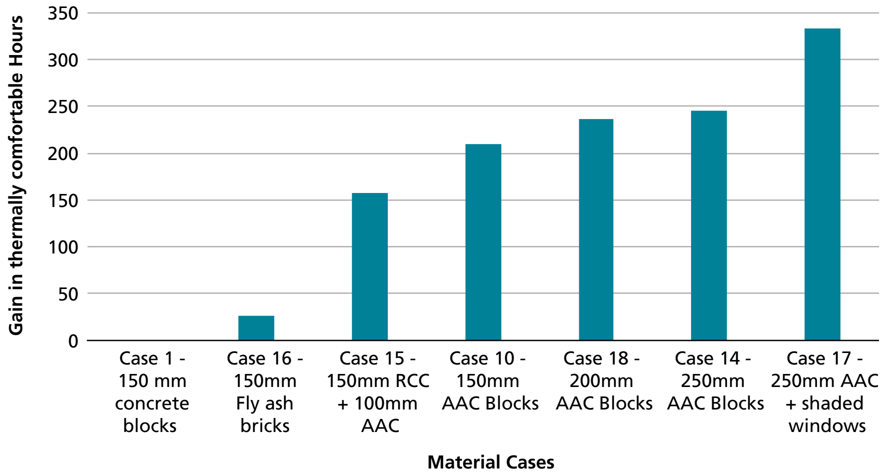
Source: CSE analysis

Graph 21: Gain in annual thermal comfort hours due to materials in Kollur II 'O' block



Source: CSE analysis

Graph 22: Gain in annual thermal comfort hours due to materials in Gajwel



Source: CSE analysis

Fly ash bricks (Case 16) and various thicknesses of AAC blocks (Cases 10, 18, 14) provide more annual thermal comfort hours when compared with the base case of concrete fly ash bricks used widely in Telangana. A combination of 100 mm AAC along with 150 mm monolithic concrete blocks (Case 15) increases about 114 to 158 thermal comfort hours in the building. This case also provides the advantage of faster construction. Alternatively, combinations like monolithic concrete in the interior load bearing walls and insulating materials such as AAC in the exterior wall can be used for mass housing. These will have the advantage of faster construction (due to poured concrete used for load bearing walls) as well as enhanced thermal comfort hours due to AAC blocks as exterior walls.

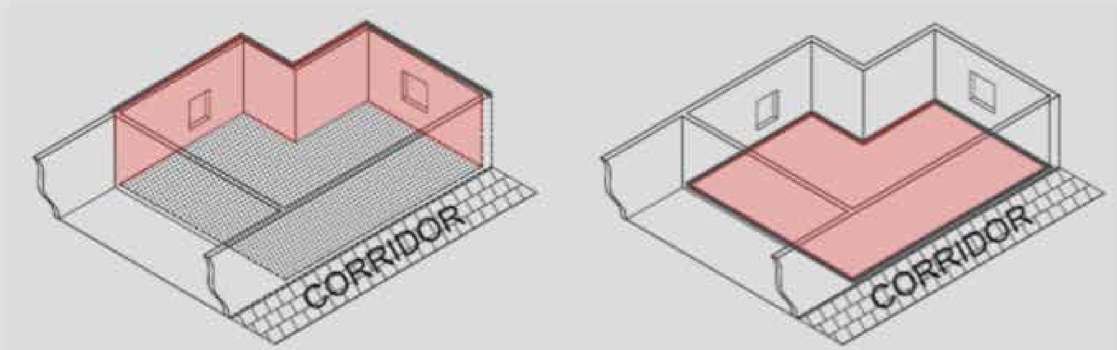
This analysis also highlights the limitations of insulation properties of walling materials. As the thickness of AAC in exterior walls increases from 150 mm to 200 mm, the gain in thermal comfort hours is between 17.52 to 26.28 hours. But increasing the AAC wall thickness from 200 mm to 250 mm yields a gain of just 8 to 9 thermal comfort hours. This highlights that insulation properties of a walling material can contribute towards thermal comfort only to some extent. Beyond a certain thickness of insulation material, gain in thermal comfort hours stops rising in proportion.

Impact of building envelope on thermal comfort

Building geometry plays a role in the amount of heat ingress that takes place through the building envelope. It is safe to say there is a proportional relationship between the amount of building surfaces exposed to the exterior and heat gain into the dwelling unit. The ratio of total envelope area to the carpet area can provide a picture of the heat gain into the unit and its effect on thermal performance. The envelope factor is capable of capturing the efficiency of the building envelope geometry for all designs. On a scale of 0.5 to 2.0, the more the envelope factor is towards the former value, the better the envelope performance will be (see *Figure 19: Envelope factor for different 2BHK scheme projects in Telangana*).

Figure 19: Envelope factor for different 2BHK scheme projects in Telangana

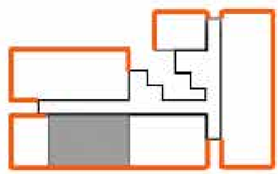
Envelope factor: Envelope area (not roof) / Carpet area of DU



Envelope area of dwelling units (walls towards corridor, shafts or common walls are excluded)

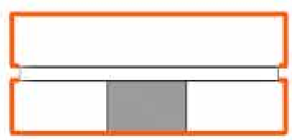
Carpet area of dwelling units (partition walls are included)

Case studies and their envelope factor



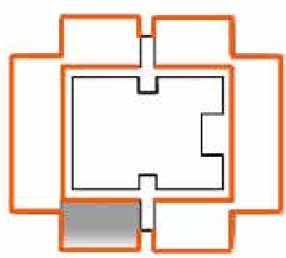
Envelope Factor: 1.05

L TYPE BLOCK



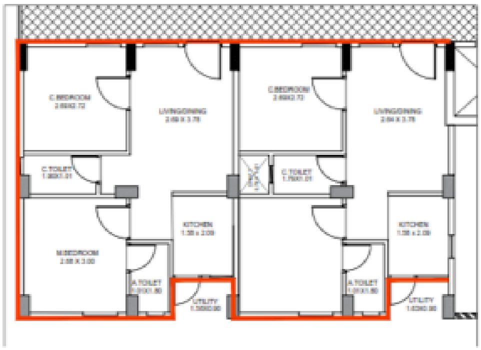
Envelope Factor: 1.10

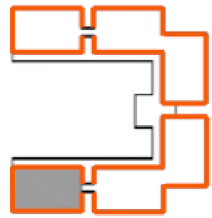
LENEAR TYPE BLOCK



Envelope Factor: 1.43

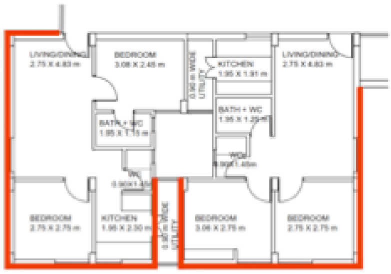
O TYPE BLOCK

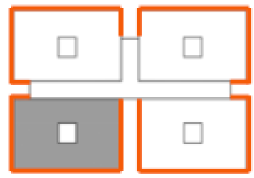




Envelope Factor: 1.56

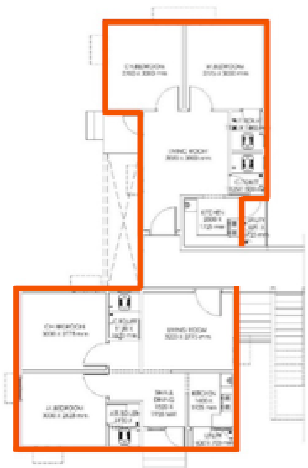
U TYPE BLOCK

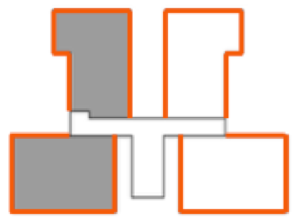




Envelope Factor: 1.30

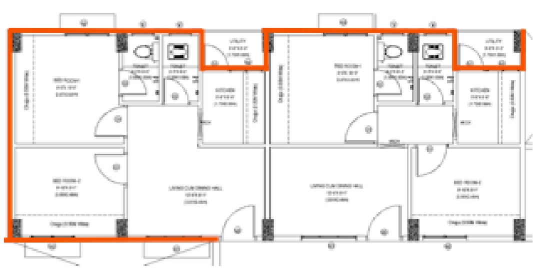
Y S R NAGAR

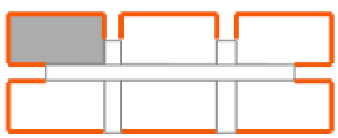




Envelope Factor: 1.93

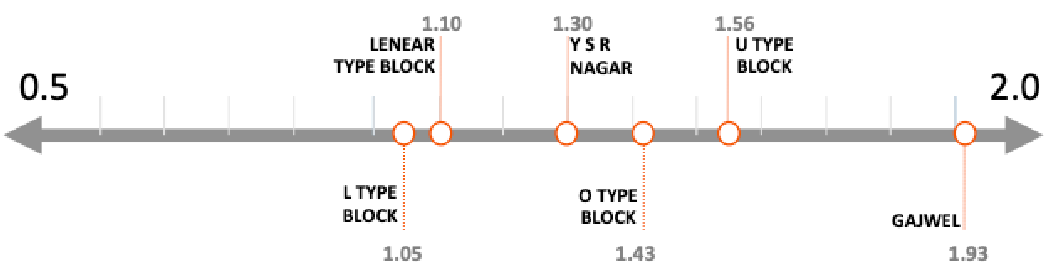
GAJWEL





Envelope Factor: 0.86

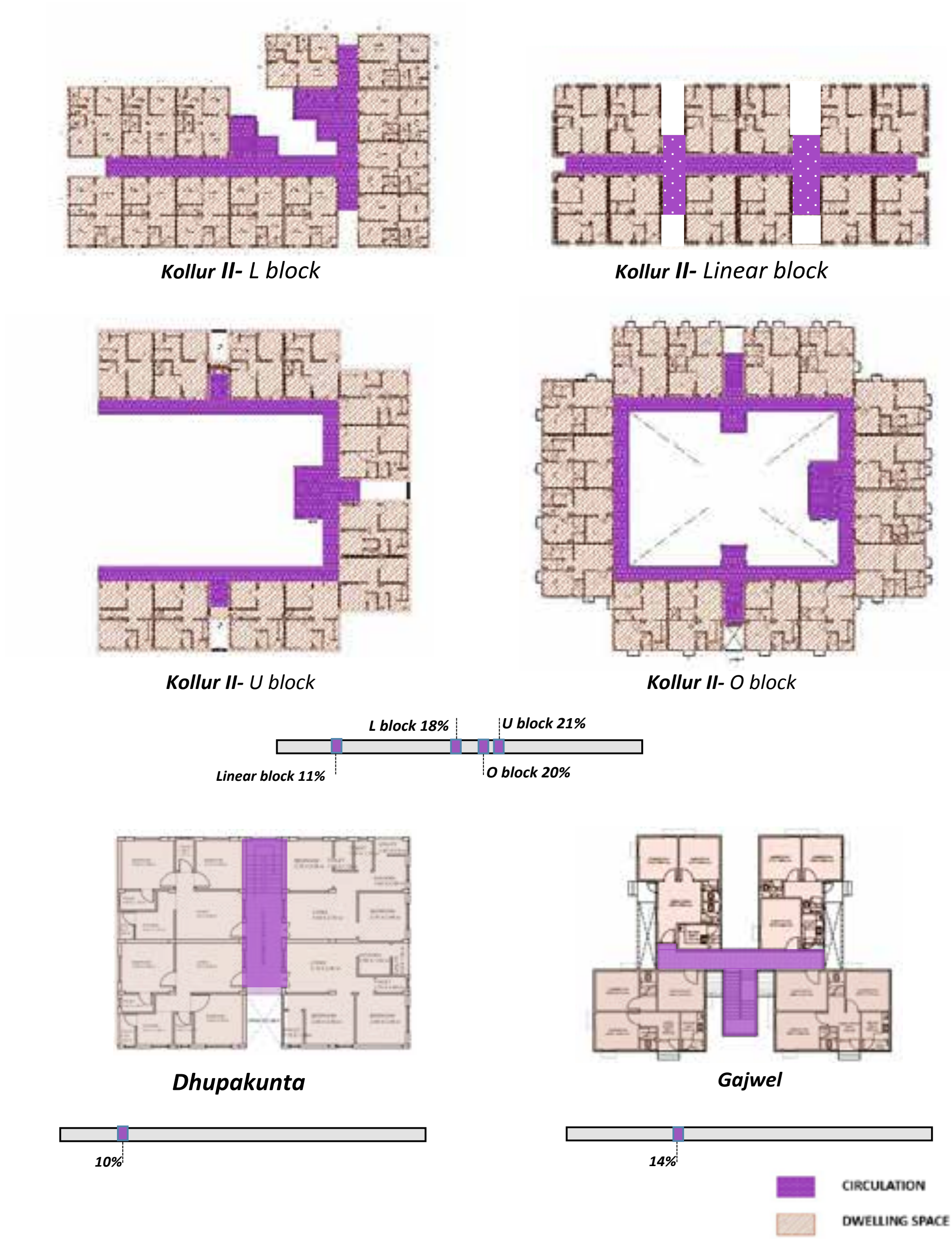
CHITAKUNTA



BOX 2: CIRCULATION EFFICIENCY AS AN INDICATOR OF EFFICIENT SPACE UTILIZATION

The 2BHK scheme in Telangana has adopted a fixed template of dwelling units with 560 sqft or 52 sqm of built up area. However, different sites are using different typologies of blocks. The efficiency of the design of a block can be determined from how the common spaces such as corridors, lifts, and staircases are designed. To understand this variation, CSE analyzed the floor plans of different building blocks with a view to find how much space goes into the elements of circulation. Blocks involving double loading of corridors performed well. Kollur II 'O', 'U', and 'L' blocks had around 18–21 per cent of the floor plan—the highest of all blocks evaluated—going into circulation. More space going into circulation implies scope for improvement.

CIRCULATION EFFICIENCY



A positive correlation was found between envelope factor and thermal comfort. Envelope factor and percentage of overheated hours were calculated for Kollur II Linear block, Kollur II 'O' block, and Gajwel, keeping the same material specifications in all cases. Gajwel that is exposed to the exterior on almost three sides results in highest envelope factor (1.92) and percentage of over heated hours (14.6 per cent) among the three cases (see *Table 7: Envelope factor, heat gain factor and percentage of overheated hours in Kollur II Linear block, 'O' block and Gajwel).*

Table 7: Envelope factor, heat gain factor and percentage of overheated hours in Kollur II Linear block, 'O' block and Gajwel

Project	Carpet area	Envelope area	Envelope factor	Overheated hours with same material (%)
Kollur II Linear	4,471	4,926.6	1.10	13.7
Kollur II 'O' type block	5,856	8,388.5	1.43	13.9
Gajwel	303.6	582.96	1.92	14.6

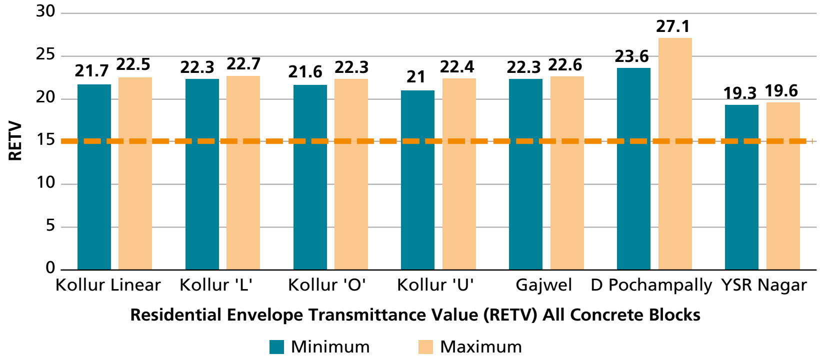
Source: CSE analysis

Impact of building orientation on thermal comfort

In order to understand and quantify the impact of orientation in 2BHK scheme projects in Telangana, a RETV comparison of all the sites was done while keeping the material constant. Since concrete blocks are being used in

2BHK scheme projects widely, the first scenario uses them to see the impact of orientation. While in all cases the RETV remained above the compliance threshold of 15 W/m^2, D Pochampally showed the most variation between the worst and best orientation of about 3.5 W/m^2 (see *Graph 23: RETV with concrete blocks as the constant material*).

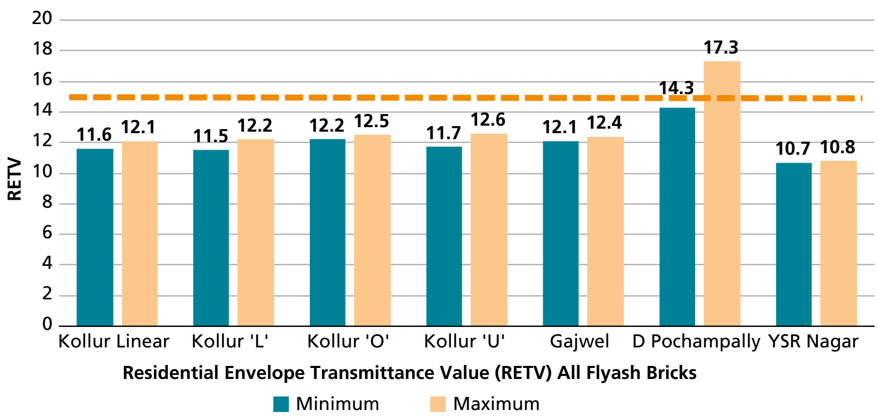
Graph 23: RETV with concrete blocks as the constant material



Source: CSE analysis

On keeping the constant material as fly ash bricks, almost all projects start complying to the RETV requirement of 15 W/m^2 as per ECBC-R (see *Graph 24: RETV with fly ash bricks as the constant material*). This improvement in fact shows a major impact of materials on thermal comfort and energy efficiency. Change of materials from concrete blocks to fly ash bricks gives an improvement of approximately 9 W/m^2 in all projects. While D Pochampally shows the most variation in RETV between the best and worst case—of about 3 W/m^2—with this material as well, YSR Nagar does not show much variation in both the cases. This means orientation plays a greater role in RETV performance of D Pochampally as compared to other projects.

Graph 24: RETV with fly ash bricks as the constant material

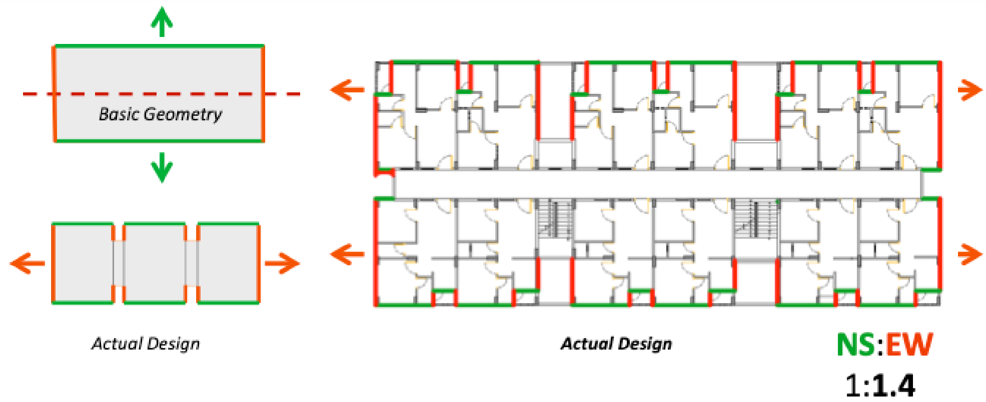


Source: CSE analysis

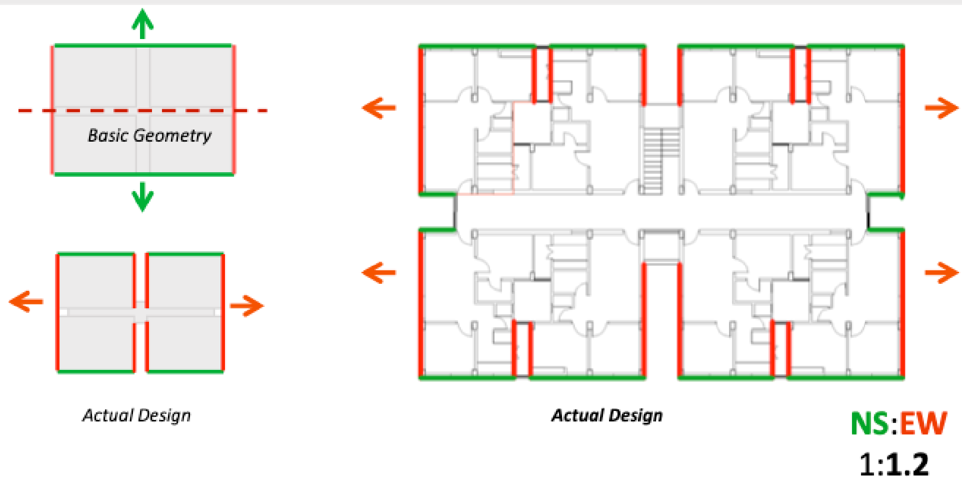
To see why other projects and blocks did not show much impact of orientation on RETV, CSE checked the form of the blocks in each project. In a first look, both YSR Nagar and Kollur II Linear blocks appear rectangular in shape. But on a closer look, the indentations in the design negate the potential benefit of a better orientation by effectively exposing the net surfaces to a worse orientation.

This building form analysis revealed that surface exposure ratio i.e. the ratio of building surface areas facing north–south to east–west directions has a role to play in energy and thermal performance of buildings. The Kollur II Linear block and YSR Nagar project had effective surface area facing E–W direction even when the block was oriented to face N–S directions at length. Their surface exposure ratios (NS:EW) were found to be 1:1.5 and 1:1.2 respectively. This result explains the low variation in RETV with the worst and best orientation for both the sites.

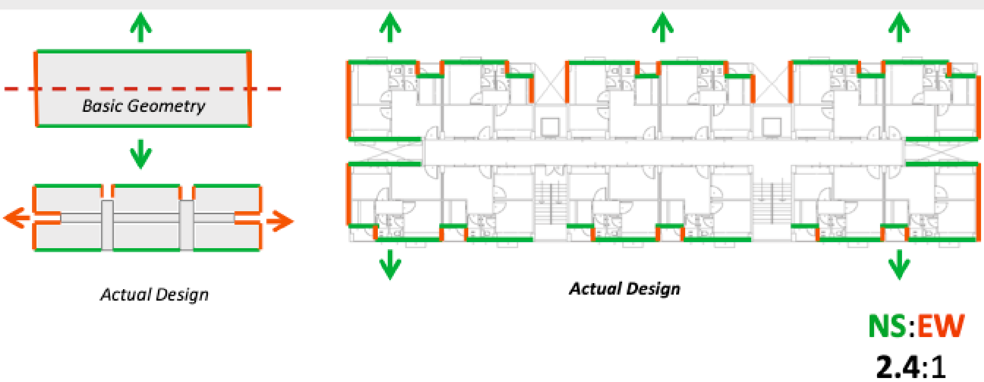
KOLLUR II



YSR NAGAR



D POCHAMPALLY



D Pochampally is able to improve its RETV by orienting majority of its surface area towards N–S directions. Its NS:EW ratio of 2.4:1 is estimated to gain 1.5 per cent more thermal comfort hours annually as compared to E–W orientation. This gain translates to over 131.4 hours, which demonstrates the potential to improve thermal performance of buildings by better orientation and form.

Combined impact of orientation and materials on thermal comfort

It is shown in a previous section that materials have a clear impact on thermal comfort. CSE checked the extent of improvement in thermal comfort with the current designs of 2BHK scheme projects in Telangana if appropriate materials are combined with appropriate orientation. As discussed earlier, surface exposure ratio has a role to play in the performance of orientation for thermal comfort. This was included as a criterion in the estimation of gain in thermal comfort hours. This estimation was carried out for different material cases to see the combined impact of surface exposure ratio, orientation, and materials on thermal comfort.

The results build a strong case for internalizing the benefit offered by orientation, for thermal comfort (see *Table 8: Impact of orientation, surface exposure ratio and materials on thermal comfort in Kollur II Linear block*; *Table 9: Impact of orientation, surface exposure ratio and materials on thermal comfort in Kollur II 'O' block*; and *Table 10: Impact of orientation, surface exposure ratio and materials on thermal comfort in Gajwel block*). The gain in annual thermal comfort hours in Kollur II Linear block is estimated to range from 165 to 403 hours, Kollur II 'O' block from 158 to 420 hours, and Gajwel block from 158 to 464 hours.

Table 8: Impact of orientation, surface exposure ratio, and materials on thermal comfort in Kollur II Linear block

Kollur Linear block	Gain in annual thermal comfort hours due to materials	Estimated gain in annual thermal comfort hours due to the combined effect of surface exposure ratio, orientation, and materials
Case 1	0	0
Case 16	35.04	166.44
Case 15	113.88	245.28
Case 10	166.44	297.84
Case 18	183.96	315.36
Case 14	192.72	324.12
Case 17	271.56	402.96

Source: CSE analysis

Table 9: Impact of orientation, surface exposure ratio, and materials on thermal comfort in Kollur II 'O' block

Kollur II 'O' block	Gain in annual thermal comfort hours due to materials	Estimated gain in thermal comfort hours due to the combined effect of exposure ratio, orientation, and materials
Case 1	0	0
Case 16	26.28	157.68
Case 15	113.88	245.28
Case 10	175.2	306.6
Case 18	192.72	324.12
Case 14	201.48	332.88
Case 17	289.08	420.48

Source: CSE analysis

Table 10: Impact of orientation, surface exposure ratio, and materials on thermal comfort in Gajwel block

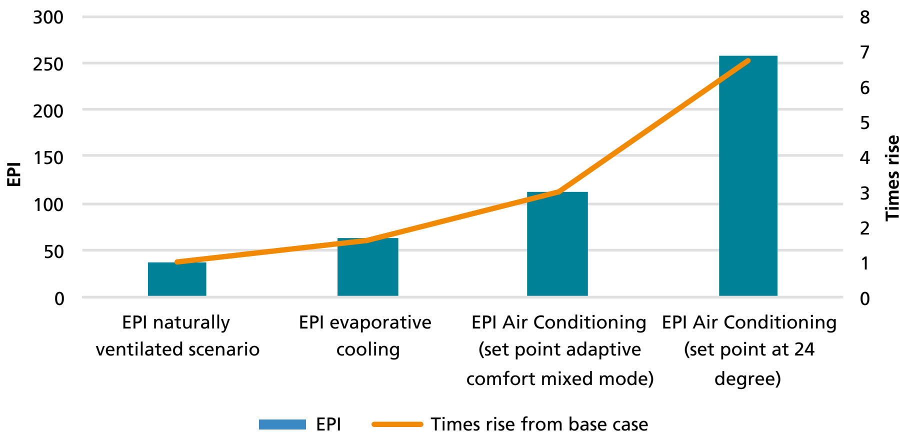
Gajwel block	Gain in annual thermal comfort hours due to materials	Estimated gain in thermal comfort hours due to the combined effect of exposure ratio, orientation, and materials
Case 1	0	0
Case 16	26.28	157.68
Case 15	157.68	289.08
Case 10	210.24	341.64
Case 18	236.52	367.92
Case 14	245.28	376.68
Case 17	332.88	464.28

Source: CSE analysis

CSE analyzed the impact of worst orientation and material choice in mass housing to give a value to the risk faced by the government towards elevated energy consumption in houses when designs and walling materials are unrelated to the native climate. EPI was calculated for Kollur II Linear and 'O' blocks for a combination of E–W (or worst) orientation and concrete blocks as walling material. Cooling scenarios were simulated for the hours of thermal discomfort in a year. The scenarios include natural ventilation, evaporative cooling, air-conditioning in a mixed mode building, and air-conditioning with 24 °C set point temperature.

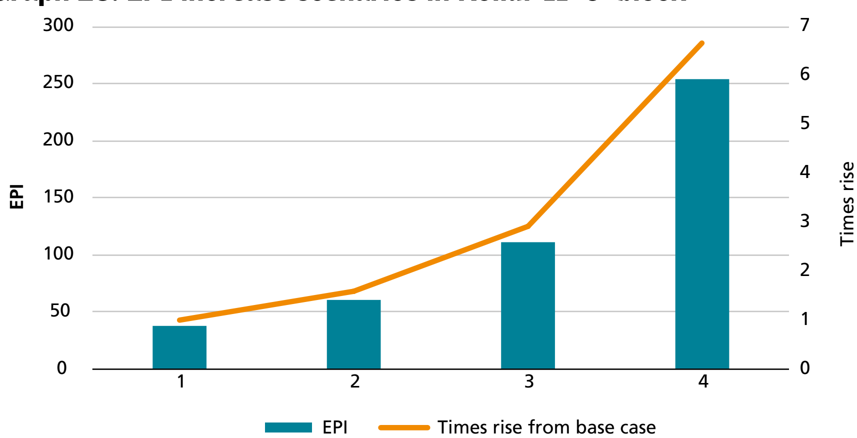
In both of Kollur II's Linear and 'O' blocks, EPI jumps to a little less than twice when evaporative cooling methods such as desert coolers are used in the dwelling units in hours of thermal discomfort (see *Graph 25: EPI increase scenarios in Kollur II Linear block* and *Graph 26: EPI increase scenarios in Kollur II 'O' block*). It expands almost threefold when air conditioning is used by the occupants at a 30.3°C set point as per the adaptive thermal comfort model of NBC 2016.

Graph 25: EPI increase scenarios in Kollur II Linear block



Source: CSE analysis

Graph 26: EPI increase scenarios in Kollur II 'O' block



Source: CSE analysis

Considering an AC set point temperature of 24 °C as promoted by BEE, the climb in EPI (in kWh/m^2/year) is steep—to 256.3 for Kollur II Linear block and 253.4 for Kollur II 'O' block from 38 and 38.1 respectively in a naturally ventilated scenario. This is an EPI jump of about seven times and can be considered the worst scenario that must be avoided. Solutions are needed to ensure that households do not reach this scenario.

These results show a mere glimpse of the damage the transition to mechanical cooling systems will deal on the energy consumption trajectory of India. While these scenarios present a conservative picture, the jump in energy consumption will actually be higher than these values. This is because the moment a user switches to mechanical means of cooling, it gets more and more difficult to rationalize and minimize the cooling consumption with time. This can be attributed to sticky human behaviour. Therefore, efforts must be made to prolong this transition to energy-intensive cooling methods.

Crucial steps to curb the energy threat from poor designs and uninformed material choices

The EPI of roughly 38 kWh/m^2/year for a naturally ventilated scenario in both the blocks simulated is theoretically a threshold that our regulatory frameworks such as state energy policies must strive to achieve because the drive towards less energy intensive space cooling is practically irreversible. Our regulatory frameworks need to harness the potential of good layouts, designs, and materials that enable the beneficiary to keep away from mechanical cooling systems for a longer time.

As discussed in previous sections, N–S orientation along with a higher NS:EW surface exposure ratio are simple criteria that can reduce annual hours of thermal discomfort substantially. Additionally, adherence to these criteria hardly bears any financial implication. These do not require any simulation studies and can be calculated easily. The government can easily incorporate these as guidelines for construction of mass housing or in their building bylaws.

Walling materials can further reduce the annual hours of thermal discomfort once the potential of good orientation is exhausted. Materials with high thermal mass or materials with insulation properties or a combination of both are options to enable this reduction. Thermal comfort increases even further when shading devices are combined with the walling material in the building envelope according to the simulation results. These interventions, however, will incur a cost since materials with insulation properties are slightly more expensive than conventional materials.

An investigation into the cost of walling materials in Telangana revealed that the incremental increase in cost of using fly ash and AAC blocks range between Rs 15–20 per square foot and Rs 78–130 square foot respectively. Combined with alternative walling technologies for fast-paced construction such as precast concrete system, monolithic concrete construction using aluminium or plastic formwork and monolithic concrete system using modular tunnel formwork, the additional cost comes to around Rs 200–400, Rs 200–300, and Rs 200–250 per square foot respectively. Therefore, enhanced composition of massing and insulation with the right proposition of shading may work at an additional cost of Rs 500–600 per square foot over conventional construction. If used appropriately and in the right order, the walling assemblies will keep up the construction pace while enhancing thermal comfort. However, this will first of all need regulatory interventions and guidance.

The government of India is providing financial support to the developers to strike financial feasibility in affordable housing projects. The elevated cost of material and design interventions can be catered to from this support. Currently, there is no performance criteria linked to this financial support. A strategy that ties together performance criteria and the release of fiscal support can shape an effective mechanism to regulate thermal as well as environmental performance in mass housing. Since Telangana has a documentation of 2BHK projects and their performance, it has opportunity to spearhead and address this in its housing scheme and other regulatory frameworks.

For instance, EIA Form 1 seeks information from the project proponent on use of materials in the project. There is opportunity to ingrate this segment with materials that have a good thermal performance. This will not only contribute to the objectives of ICAP but also strengthen environmental regulation. Completion certificate can be linked with usage of better performing materials. Urban local bodies can monitor and ensure that these materials are used. If compliance is not found, any government support to the project, for instance in the form of extra FAR/FSI/TDR, will need to be surrendered or a corresponding monetary penalty can be imposed. This will enable stringent implementation of green performance in mass housing.

Thermal comfort gains can also be achieved from interventions in layouts. Orientation of buildings, with respect to the predominant wind direction, their clustering, form, height, etc., also contributes to indoor as well as outdoor thermal comfort or micro-climate at the site. There is a common understanding that height of the building and width of the abutting road need to be planned in tandem. This relationship can be exemplified from several building bylaws such as G.O. M.s. No. 168 for Hyderabad, wherein height of the building is suggested in correspondence to the width of the abutting road. This relationship is important for ventilation and daylighting as both are affected by spacing between the buildings. CFD simulations showed that about 40 per cent of the Kollur II site is receiving neither poor ventilation (below 2 ACH) nor extremely windy conditions (10 ACH). Ventilation performance is better in mid-rise developments. To improve ventilation in high rise buildings, solutions like stilts or providing an empty floor in the middle of the building for purging can be planned. But for this, appropriate analysis at the planning stage is a must.

Way forward

Covid-19 will have a significant bearing on many definitions and associated provisions which were an integral part of the urban space. Thermal comfort (adaptability of structures that promote passive cooling and limit use of active cooling), inclusive planning, and decentralized services will require more focussed approach in the planning of habitat from here onwards.

While buildings will have to be designed from the perspective of thermal comfort, health, livability, and safety, performance of neighbourhoods in terms of access to essential services and infrastructure related to management of wastewater, solid waste, and mobility services will require special attention.

The Government of India is providing financial support to developers for affordable housing projects. Currently, there is no performance criteria linked to this financial support. A strategy that ties together performance criteria and the release of fiscal support can shape an effective mechanism to regulate thermal as well as environmental performance in mass housing. Telangana, with this documentation of its 2BHK scheme projects and evaluation of their performance, has opportunity to spearhead and address this strategy in its housing scheme and other regulatory frameworks. This will draw a learning curve for the rest of the country.

For instance, EIA requires information from the project proponents on use of materials in the project. Performance criteria can be linked to materials used. Approval and completion certificates can also be linked with usage of better performing materials and walling assembly approaches. Urban local bodies can monitor and ensure that these materials are used. If compliance is not found, any government support to the project, for instance in the form of extra floor area ratio (FAR), floor space index (FSI), or transferable development rights (TDR), will need to be surrendered, or a corresponding monetary penalty can be imposed. This will enable stringent implementation of green performance in mass housing.

Similarly, thermal comfort gains need more explicit link with layouts. Orientation of buildings with respect to the predominant wind direction, their clustering, form, height, etc. contribute to indoor as well as outdoor thermal comfort or micro-climate at the site. In view of this, some priority steps are needed immediately.

Telangana paves the path for green recovery in post-COVID housing: ECBC-R is a code for buildings that evaluates the energy performance inside a building based on the physical features of that building. This analysis has revealed that ECBC-R evaluates thermal performance of the building envelope through RETV. Expressed in W/m^2, RETV evaluates and indicates the performance of the building envelope in terms of heat ingress per unit area of the envelope. If a site has different types of blocks, one block may perform well in terms of RETV, while another may not. Even with an averaged out RETV complying to the thresholds given in the code, beneficiaries living in the blocks with higher RETV will have to live in thermally uncomfortable dwellings and face higher operational costs due to mechanical cooling. Further, simulation analysis shows that a building that performs in adherence to RETV may not deliver on thermal comfort for a certain period of the year. Based on a building-scale evaluation, the objective of ECBC-R to regulate heat gain in residential buildings by RETV is weakened by not addressing layout and the site context. Similar issues were observed with VLT, used to evaluate daylighting, and WFRop used as an indicator for ventilation in buildings as per ECBC-R. WFRop evaluates ventilation in a building based on the ratio of openable area of windows and the floor area of the dwelling unit, which is again an isolated assessment. Computational flow dynamics (CFD) analysis has revealed that the air movement is affected by form, height, distances between buildings, clustering, and placement of the blocks on the site. It will be inadequate to evaluate a building on only one or two of the factors. Telangana has an opportunity to improve upon these issues when it ratifies ECBC-R and demonstrate achieving excellence in energy performance to the rest of the states of India.

State housing guidelines need to factor in the role of thermal mass in thermal comfort: This study has compared RETV and thermal comfort simulation analysis to check their consistency. RETV showed a proportionate relationship with thermal comfort (in terms of improvement in overheating hours from the base case) in cases involving insulation. It particularly showed inconsistency with a case involving CSEB. CSEB performance was better with fly ash bricks, in spite of having a higher U-value that results in higher RETV. Similarly, a combination of 150 mm RCC and 100 mm AAC on the inside of the walling assembly performed better than fly ash bricks by a huge margin, even when their U-values are very similar. These results show that RETV's reliance on U-value may not always deliver better thermal comfort. Thermal mass properties of the materials substantially improve thermal comfort and must be addressed either during adoption of ECBC-R or via state housing guidelines to enable thermally comfortable housing.

Evaluate daylighting performance in a site context to incorporate the impact of layout: Daylight simulation showed that the percentage of daylit area varies substantially for a unit when it is simulated in isolation as compared to when it is simulated with site conditions. Daylit area in a block at 38 per cent when in isolation can drop to a meagre seven per cent in the lower floors when observed in the real ground situation as planned. Even in the middle floors (sixth floor), daylit area in most cases that were simulated could not reach the compliance threshold of 25 per cent as given by NBC 2016. Blocks with a central courtyard performed relatively better. Surprisingly, all these cases showed a very good compliance to VLT that is promoted as an indicator for daylight ingress under ECBC-R. Simulation results suggest that VLT, which is calculated for an individual block, may not be an adequate indicator for daylight performance. Therefore, Telangana may need to work on a more effective performance indicator to deliver affordable housing layouts and designs that provide better daylighting to the beneficiary. This is important as artificial lighting is substantially responsible for energy consumption in buildings and will have financial implications for the beneficiary that could be completely avoided with better designs. Therefore, it is important to assess daylighting in a site context wherein buildings are mutually shading each other for a better understanding of energy implications of artificial lighting.

Ventilation analysis in high-rise mass housing is a must: A simulation analysis of the largest 2BHK scheme project in Telangana reveals that about 40 per cent of the blocks in the site are neither under ventilated nor are facing extremely windy conditions. Too low a ventilation rate results in stagnation of indoor air and pushes the beneficiary to switch to mechanical means of ventilation and cooling. If the ventilation rate is on the higher side, it may cause damage to the windows due to fluttering, therefore, increasing capital cost and posing a threat to human safety. Natural ventilation is required in the buildings to lower indoor temperatures and dissipate any indoor air pollution. Therefore, studying the predominant wind direction in detail and determining the appropriate typology of blocks, along with their clustering and layout, is an exercise that should be taken up during the planning stage. Based on that, future high-rise housing in Telangana can be planned for either wind calming or wind enhancing measures such as leaving an empty floor in the middle of the building.

With several incentives for affordable housing construction under government schemes, such as extra FAR/FSI, the typology for affordable housing is shifting towards high rise development in major cities. Ventilation strategies need to be sought in that case to negate the adversities of high-rise development on micro climate. CFD simulations reveal that these adversities are much lesser in mid-rise developments. Such analysis can help in understanding the impact of wind and its crucial role for thermal comfort, energy efficiency, and health and safety. The CFD analysis for Kollur II has made it clear that the air movement is affected by the form, height, distance between buildings, clustering, and placement of the blocks on the site. Blocks must be staggered or oriented with respect to the streets in a way that the favourable wind direction hits the buildings diagonally rather than in a perpendicular fashion. This reduces wind shadow area and the tunnel effect. There is a common understanding that height of the building and width of the abutting road need to be planned in tandem. This relationship can be exemplified from several building bylaws such as G.O. M.s. No. 168 for Hyderabad, wherein height of the building is suggested in correspondence to the width of the abutting road. This relationship is important for ventilation and daylighting as both are affected by spacing between the buildings and therefore need to be addressed effectively.

Telangana can achieve substantial thermal comfort gains just by working on orientation and building envelope: The simulations have shown that north–south orientation along with a higher NS:EW surface exposure ratio can reduce annual hours of thermal discomfort substantially—around 132 hours. Similarly, *envelope factor*—the ratio of total envelope area to the carpet area—is an effective indicator to evaluate the efficiency of the building envelope for heat gain. It has shown a positive correlation with the number of overheated hours in a building. The higher the envelope factor, the more inefficiently it tends to perform with respect to thermal comfort. Just looking at these two factors translates to a lot of energy savings for a household that otherwise would have required mechanical cooling measures. The state government can easily incorporate these criteria as guidelines for construction of mass housing or in their building bylaws as they hardly bear any financial implication and do not require any simulation studies.

Need focus on materials to ensure thermal comfort for all: Walling materials offer to reduce the annual hours of thermal discomfort once the potential of good orientation is exhausted. Telangana is widely using 150 mm concrete blocks in the 2BHK scheme projects. Materials with better insulation properties such as AAC blocks have resulted in a gain ranging from 193 to 245 annual thermal comfort hours with 250 mm thick walling. To internalize the associated energy savings, Telangana can provide for or even prioritize thermal comfort by materials, especially insulation. For an affordable mass housing context, strategies such as using a combination of 100 mm AAC along with 150 mm monolithic concrete walling, which has enabled a gain of 114 to 158 annual thermal comfort hours, can be used. This case provides the advantage of faster construction as well. Alternatively, monolithic concrete can be used in the interior load bearing walls while AAC blocks can be used in the exterior wall. This combination will still have the advantage of fast-paced construction (due to poured concrete used for load bearing walls) but more annual thermal comfort hours due to AAC blocks in the exterior walls. Thermal comfort increases even further when shading devices are combined with the walling material in the building envelope according to the simulation results. Further, similar strategies can improve thermal performance when the layouts have been planned and the building envelope has been designed wrongly or there are other site limitations and there is no scope to change them. In such cases, strategies such as increasing insulation in exterior walls will help in ensuring thermal comfort. These interventions however will incur a cost since materials with insulation properties are more expensive than the conventional materials. The government will need to support that additional cost for the benefit of the household who will occupy these dwelling units.

Telangana can spearhead and develop fiscal strategies and instruments of accountability to minimize cost of improving thermal comfort: A sound fiscal strategy is needed to support the incremental cost from new construction technologies, material, and thermal comfort approaches. This is needed in favour of the beneficiary so that operational cost burden linked with under-performing structures can be minimized. Currently, the government of India is providing a support package to developers in the form of incentives such as extra FAR/FSI/TDR and tax holidays. A number of incentives are already available to the developer. Linking these with performance regulations is necessary. Currently, EIA Form 1 seeks information from the project proponent on use of materials in the project. There is opportunity to integrate this segment with materials that have a good thermal performance. Completion certificate can be linked with usage of better performing materials. Urban local bodies can monitor and ensure that these materials are used. If compliance is not found, any government support to the project like extra FAR/FSI/TDR availed will need to be surrendered or a corresponding monetary penalty can be imposed. This will enable stringent implementation of green performance in mass housing. Existing regulatory frameworks such as building bylaws and PPP models or procurement guidelines for affordable housing need to incorporate similar performance indicators and instil healthy competition among developers based on green performance of affordable housing.

Invest in architectural design and layouts of affordable housing: Design and approvals currently account for only one per cent of the cost of government affordable housing projects in Telangana, whereas the cost is nearly twice in the private sector. Although the state government of Telangana has fixed the layout for a dwelling unit, the private sector—developers, architects, and engineers—involved may not have a direction or a guideline to follow for the layout and design of the structures. This lack of direction has resulted in layouts and designs that will place a cost burden on the beneficiary and impact their quality of life. This burden is completely avoidable with guided designs and layouts. Simulation analysis such as computational flow dynamics for ventilation, building energy simulation for thermal comfort, and daylighting simulation for visual comfort and energy efficiency have become essential due to several goals placed by India for thermal comfort, energy security, resource sufficiency or circularity, emission reduction, and, most importantly, reducing vulnerability and uplifting livability of the poor under Sustainable Development Goals (SDG) 11.

Telangana addresses livability of the poor and urban form but needs instruments to ensure appropriate location of future affordable housing: The government of Telangana recognizes the dependence of the poor on the city's infrastructure through a two-pronged approach. Under one approach, it is rehabilitating beneficiaries living in the slums in-situ and promoting mixed use development in some of the high-density projects in Hyderabad. In the other approach, it includes reservation for EWS and LIG in any residential scheme. In order to ensure that all future housing schemes in the state follow the current path, mechanisms that ensure identification of suitable locations for affordable housing and access to social and physical infrastructure can be integrated with master plans and zoning regulations. PMAY guidelines make it mandatory to earmark these locations in master plans. But this is an area of intervention for the state government. As Telangana is updating the master plans for its major urban centres, these plans can be reinforced with criteria that identify and enable strategically planned affordable housing primarily by linking it with the public transport network. Effective criteria for master plans, in favour of beneficiaries, are developed based on socio-economic and spatial studies that can inform an affordable housing strategy for the city. Other key requisites regarding location of affordable housing are given in CSE's publication—*Beyond the Four Walls of PMAY*.

Augment building bylaws for encouraging environmental services in affordable housing: Telangana is converging several of its initiatives on resource conservation and efficiency with the 2BHK scheme; such as with Mission Bhagiratha and Swachh Bharat Mission. The 2BHK scheme has also shown the other states the way for sustainable brownfield and greenfield development by working on existing site enhancements and new provisioning for environmental services like wastewater treatment, safe water supply and sanitation and conservation practices. For a resource-efficient and post-COVID housing, other initiatives such as Telangana solar rooftop policy, ECBC-R, EIA guidelines, etc. can be mandated or integrated with the housing scheme. Building bylaws are important regulatory tools that bind to deliver on set requirements. Telangana's building bylaws scribed in G.O. Ms. 168 offer 10 per cent property tax rebate on installation of solar heating or lighting, rainwater harvesting, and wastewater recycling. These measures not only enable sustainability, but also improve access to basic services for the beneficiary; aside from being cost-effective in the long term. Other states have mandated many of these measures by augmenting their building bylaws with requirements such as meeting five per cent of connected load by solar rooftop energy. Now is a great opportunity for Telangana to weave the provisions and incentives under various policies together and standardize them to enable low-impact affordable housing construction.

Expand knowledge base on climate-appropriate design, materials, and associated tools and techniques: There is a need for recognizing and learning new tools and techniques to deliver affordable housing in line with India's thermal comfort, resource efficiency, and sustainability goals. These tools such as simulation software and analysis should be made part of academic curricula of the architecture, planning, and engineering courses. Academia needs to be familiarized with these analyses and their importance given the several challenges and objectives of the country. The construction industry, comprising of both government bodies like CPWD, NBCC, etc. and private developers, also needs to do the same. Developer associations like CREDAI need to be particularly engaged and trained on the subject to make them ready to receive and deliver on the requirements for thermal comfort, resource efficiency, and sustainability. Much depends on human behaviour when it comes to thermal comfort and associated space cooling consumption. Awareness programmes are needed for the civil society to create a demand for thermal comfort and enable contribution towards the ICAP objectives from the bottom-up as well.

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Investigation into the government's mass housing schemes in Telangana has revealed that there is great opportunity to take the state's tremendous efforts to provide shelter to the poorup a notch and build a learning curve for the otherstates. Location of housing, adoption of environmental services, climate-appropriate design, and choice of materials are all intervention areas which can improve thermal comfort and livability of housing and also lower the linked energy consumption, while meeting the goals of India Cooling Action Plan (ICAP). In a COVID-19 pandemic-ridden world, these intervention areas have become very important and must be addressed by strengthening the existing regulatory systems.

The Centre for Science and Environment (CSE) has prepared the first part of the guidelines to inform how, with concerted efforts, the ongoing housing regime can be worked on to improve thermal comfort, livability, and the resource footprint of yet-to-be-built housing.

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