Building Policies for a Better World

A POLICY STRATEGY FOR DECARBONIZING THE BUILDING SECTOR

Project Report • January 2021

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ABOUT GBPN

The Global Buildings Performance Network (GBPN) is a globally organised and regionally focusednetwork whose mission is to advance best practice policies that can significantly reduce energy consumption and associated carbon dioxide emissions from buildings.

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Authors

Rajan Rawal, CEPT University
Yash Shukla, CEPT University
Priyanka Bhanushali, CEPT Research and Development Foundation, CEPT University
Arjun Desai, CEPT Research and Development Foundation, CEPT University
Sneha Asrani, CEPT Research and Development Foundation, CEPT University

Reviewers:
Dr. Peter Graham, GBPN
Jeswynn Yogaratnam, GBPN
Gautam Nagar, GBPN

Designers:
Mona Galsar, CEPT Research and Development Foundation, CEPT University

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LIST OF ACRONYMS

AEEE	Alliance for an Energy Efficient Economy
BEE	Bureau of Energy Efficiency
ECBC	Energy Conservation Building Code
ECBC- R	Energy Conservation Building Code – Residential (now known as ECO-Niwas Samitha 2018)
GBPN	Global Building Performance Network
GHG	Green House Gas
kWh	Kilowatt - Hour
PMAY- U	Pradhan Mantri Awas Yojana (Urban)
SDC	Swiss Agency for Development and Cooperation
AAC	Autoclaved aerated Concrete
AEEE	Alliance for an Energy Efficient Economy
AHP	Affordable Housing in Partnership
AMC	Ahmedabad Municipal Corporation
BIS	Bureau of Indian Standards
BLC	Beneficiary Led Construction
BMTPC	Building Materials and Technology Promotion Council
CAD	Computer Aided Drawing
CARBSE	Centre for Research in Building Science and Energy
CEA	Central Electricity Authority
CLSS	Credit Linked Subsidy Scheme
CNA	Central Nodal Agency
CPWD	Central Public Works Department
CSMC	Central Sanctioning and Monitoring Committee
DHP	Demonstration Housing Project
DUs	Dwelling Units
EPI	Energy Performance Index
EPS	Expanded Polystyrene
EWS	Economically Weaker Section
GDP	Gross Domestic Product
GFRG	Glass Fibre Reinforced Gypsum Panel
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
HUDCO	Housing and Urban Development Corporation Limited
IHSDP	Integrated Housing and Slum Development Programme
ISSR	In-Situ Slum Redevelopment
LIG	Lower Income Group
LGSFS	Light Gauge Framed Steel Structure
MEP	Mechanical, Electrical and Plumbing
MCC	Monolithic Concrete Construction
MIG	Middle Income Group
MoHUA	Ministry of Housing and Urban Affairs, Government of India

MoUD	Ministry of Urban Development
MRV	Measuring, Reporting and Verification
NBC	National Building Code of India
NIUA	National Institute of Urban Affairs
PAC	Performance Appraisal Certificate
PMAY-U	Pradhan Mantri Awas Yojna- Urban
PPP	Public Private Partnership
RAY	Rajiv Awas Yojna
RCC	Reinforced Concrete Cement
RETV	Residential Envelope Transmittance Value
RFP	Request for Proposal
SDA	State Development Authority
SDC	Swiss Agency for Development and Cooperation
SLNA	State Level Nodal Agency
TCPO	Town and Country Planning Organisation
TSM	Technology Sub-Mission
ULB	Urban Local Body
URDPFI	Urban and Regional Development Plans Formulation and Implementation Guidelines
N-S	North – South orientation
E-W	East – West orientation
NE-SW	Northeast – Southwest orientation
NW-SE	Northwest – Southeast orientation

NOMENCLATURE

°C	Temperature in degree Celsius
EPI	Energy Performance Index (($kWh/m^2/year$)
MtCO2e	Metric tons of carbon dioxide equivalent
RH	Relative Humidity (%)
RETV	Residential Envelope Transmittance Value (W/m^2)
TWh	Terawatt-hour
U_{roof}	U-value or Thermal transmittance value of roof (W/m^2 K)
U_{wall}	U-value or Thermal transmittance value of wall (W/m^2 K)
VLT	Visible Light Transmission (%)
Wf_{op}	Window to Floor-area of Openings
WFR	Window to Floor-area Ratio

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CHAPTER 1: INTRODUCTION

Rapid urbanisation, coupled with rising income levels and a demand for a better lifestyle, has collectively led to a substantial rise in buildings' construction over the last decade. It is expected that the residential sector floor area will increase from 15.3 billion sq.m in 2017 to 21.9 billion sq.m in the next 10 years[1]. To provide for her citizens' need for shelter and reduce the shortage thereof, India has launched various housing policies and missions. In 2005, Jawaharlal Nehru National Urban Renewal Mission (JNNURM) was launched to support modification in land-related laws, property tax system and the abolition of Urban Land Ceiling and Regulation Act (ULCRA). Rajiv Awas Yojna (RAY) in 2011 was launched with a focus on slum redevelopment in association with private players. It provided the developers with incentives such as an increase in Floor Space Index (FSI)/Floor Area Ratio (FAR), lease and tenure rights, single-window clearance, better access to credit, master plan amendments, etc. In 2015, 'Housing for All (HFA) by 2022' mission, also called Pradhan Mantri Awas Yojana (PMAY), was launched to focus on the actual ground delivery of affordable houses.Against the 18.78 million housing demand, the PMAY-Urban had initially proposed 20 million units by 2022, which has been recently revised to 12 million[2].

India is currently involved in building extensive infrastructure, be it buildings, roads etc. But, along with the necessary infrastructure, the services that furnish it, thereby rendering it useful, i.e., electrical energy, water, etc. need to be prioritised. Electrical energy consumption in residential buildings accounts for 24% of the total energy consumption[3]. Projections show that this energy consumption will nearly become two-folds from 255TWh in 2017 to 532TWh in 2027 and the residential sector is expected to become the largest consumer of electricity in the country[4].

Residential buildings constructed under PMAY are expected to last beyond four to six decades. Now, more than ever, not only is there a need to optimise the electrical energy, which will only be consumed by buildings in their operation phase, but also their embodied energy. Embodied energy is the energy consumed throughout a building's lifespan, involving extraction, manufacturing, and transportation of building materials.Thus, the upcomingresidential building floor space, especially the affordable housing section, would need to be designed and developed prioritising optimum use of resources for their economic opportunity limits them. This would entail considering occupant comfort, which is oftenoverlooked. Designing spaces/buildings catering to occupants' thermal comfort needs, and studying them, would provide us withscientific methods that could regulate the thermal performance, energy use, costs, and associated carbon emissions over these buildings' lifetime. These methods, when implemented rigorously, via a policy framework, would help India in building sustainable infrastructure, which would be optimum and efficient for the present as well as the future.To develop such an efficient data-driven framework, it becomes very important to study the relevant baseline datasets to understand the potential opportunities for interventions through policies and training.

The project "A Policy Strategy for Decarbonizing the Buildings Sector" by Global Building Performance Network (GBPN) aims to guide the state governments in India to adopt appropriate sustainable building policies and energy codes to meet the nation's climate action commitments of a 33-35% reduction in carbon emissions intensity/Gross Domestic Product (GDP). This report is a product of Phase 1of this project,which aims to meet the GBPN's intent to develop a policy implementation pipeline; that walks regional jurisdictions through policy planning, adoption and implementation, by 2020 in India. In the Indian context, the

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[1]Kachhawa, S., Singh, M. & Kumar, S. Decoding India's residential building stock characteristics to enable effective energy efficiency policies and programs. in Eceee Summer Study Proceedings 2019-June, 1289–1294 (European Council for an Energy Efficient Economy, 2019)
[2]MoHUA. (2017) . http://pib.nic.in/newsite/PrintRelease.aspx?relid=173805
[3]CEA. (2018). All India Electricity Statistics
[4]CEA. (2017). Nineteenth Electric Power Survey of India

diverse range of local conditions such as various climatic zones, local governing bodies, regulatory methods, vernacular building design adaptations, demographics, and trending construction technologies decide the success or failure of any building policy. A comprehensive study of such conditions regarding the thermal performances of housing projects and imposed or proposed building code feasibility is missing. This report aims to make Energy Conservation Building Code for Residential Buildings (ECBC-R) compliance suitable for application in such local conditions of the Indian housing sector and facilitate pilot projects at the city level for ensuring its scalability to the national by-laws.

About Phase 1

This project's activities were bifurcated into two phases, which would ensure jurisdictions effectively adopt appropriate sustainable building policies and energy codes, that achieve and exceed their climate action commitments. Figure 1 elaborates the action plan of the project along with the timeline.

Phase 1 of this project was dedicated to building administrative capacity, which would be necessary to formulate a robust compliance mechanism of ECBC-R.[5]

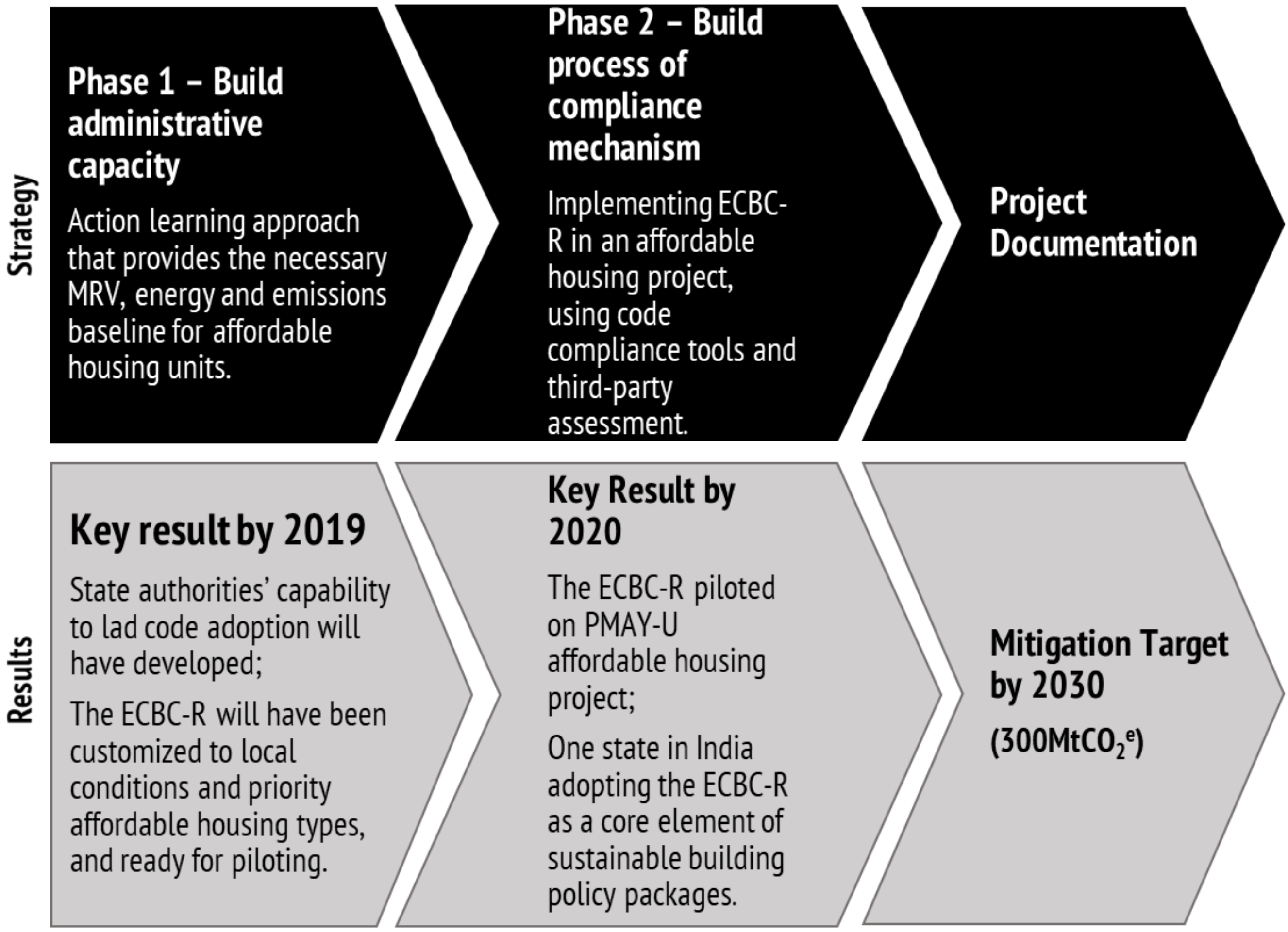


Figure 1: Action plan of the project

[5]MoHUPA. (2016). Housing for All (Urban) Scheme Guidelines

Aims and objectives

The broader goal of Phase 1, was divided into the activities, which were further subdivided into tasks, as shown in Figure 2.

As a first step, the appropriate state-city-local authorities, and the relevant stakeholders were identified and sensitised. After that, PMAY-U projects across the country were mapped, and relevant information about their status, building construction techniques and materials involved, available design drawings etc. were gathered. The Phase 1 activities culminated with establishing the impact of implementing ECBC-R on energy consumption and thermal comfort, at the Urban Local Body (ULB) level.

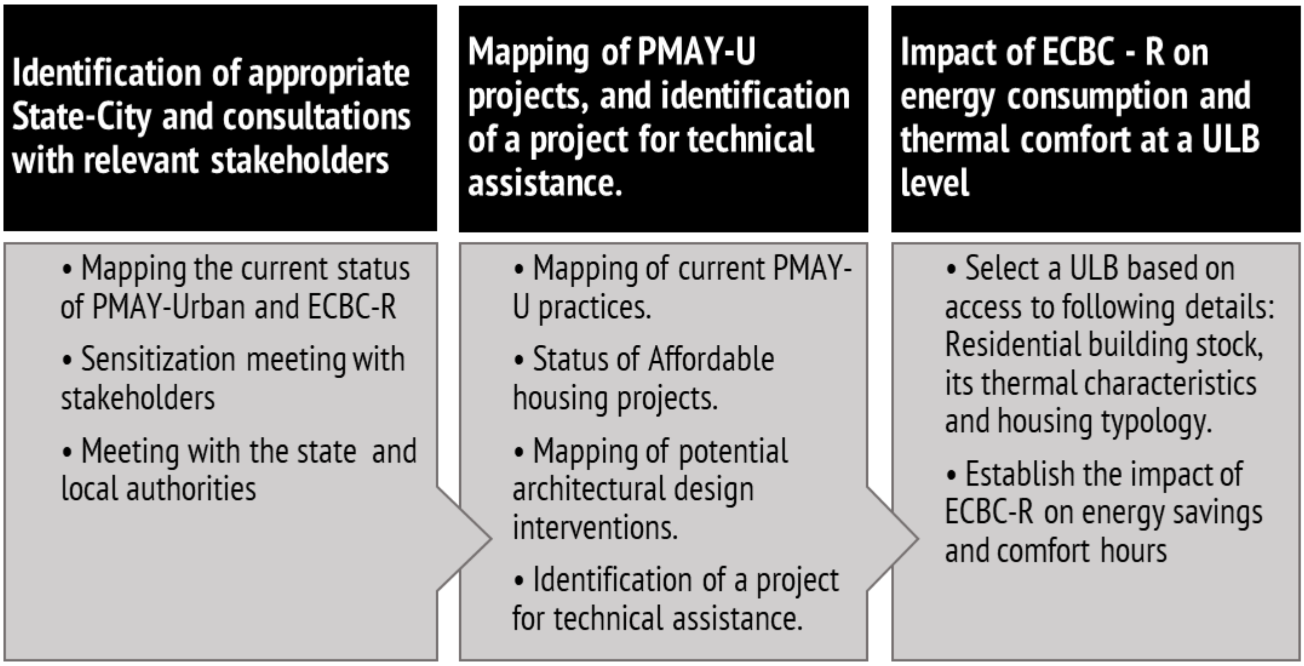


Figure 2: Activities executed under Phase 1.

CHAPTER 2: METHODOLOGY

As a first step, information about PMAY projects, being constructed in various states, in different climate zones, across the country (Figure 3) was collected, and a dataset was prepared. This database was then used to develop a comparative study between the building characteristics and the building envelope performance aspects. The following subsections detail the process of data collection for Phase 1, which included mapping PMAY projects, their sampling, and a comparative analysis between design factors, local conditions, and RETV factors of the selected samples.

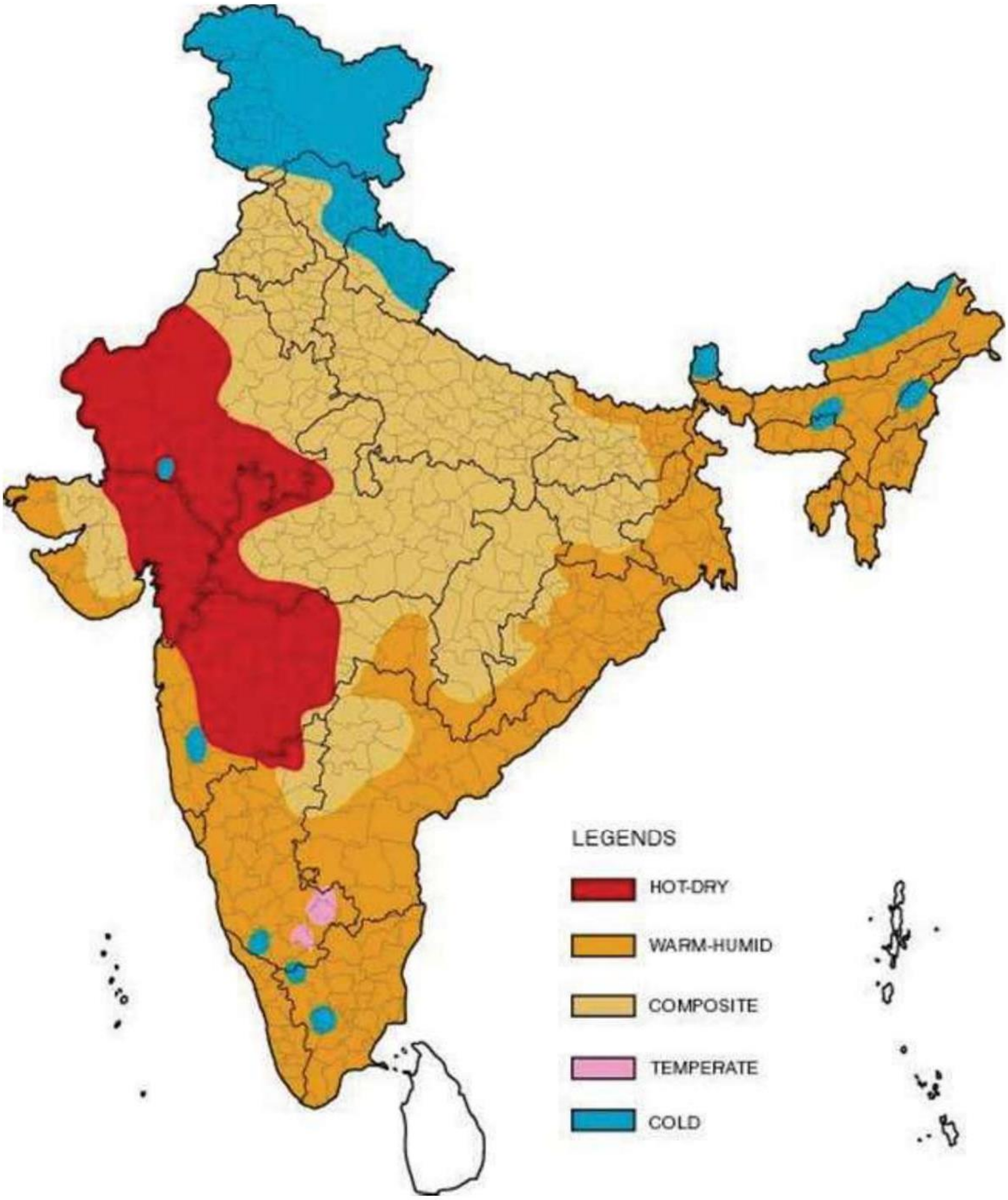


Figure 3: Climate Zone map of India (Source: BEE, ECBC document)

Table 1: Criteria for climate classification of India (SP 7: NBCI 2005)

Sr No.	Climate Zone	Mean Monthly Maximum Temperatures (°C)	Relative Humidity (%)
1	Hot and Dry	>30	<55
2	Warm and Humid	>30	>55
		>25	>75
3	Composite	This applies when six months or more do not fall within any of the above categories	
4	Temperate	25-30	<75
5	Cold	<25	All Values

Selection of case studies

Data about the buildings being constructed under PMAY-U was collected from varied secondary data sources and web portals[6], and the following details were gathered in a tabulated format:

1. Project status
2. Geographical location and climate zone (as categorised in Figure 3, and Table 1)
3. Specification of building materials
4. Design drawings
5. PMAY-U vertical under which the project is being constructed

For this exercise, projects from only two PMAY-U verticals, namely – Affording housing in Partnership (AHP), and In-Situ Slum Rehabilitation (ISSR), were considered. Some exceptional projects under RAY, IHSDP, DHP, and AHP-PPP offering a potential case for comparison of RETV performances were also considered. At the end of this process, nearly 80 PMAY-U housing schemes across various ULBs in the country were identified.

Sampling of projects

After the initial data collection and project selection, the selected sites were sampled, leading to a consolidated database of 30 projects. The sampling was done to formulate a database that provided a greater scope of analysing and understanding the buildings' varying thermal performance across different building typologies and climate zones.

The list of selected projects can be referred to in Annexure A. The three major criteria set for sampling the PMAY-U projects were as follows:

1. **Status of the project:** This was considered to understand the change in the choice of building materials over time. This assisted in providing implementable interventions based on the remaining construction scope when necessary. Details and classification of each sampled project's status, as mentioned below, can be found in Annexure
    a. Completed and already occupied,
    b. Ongoing construction, and
    c. Proposed or under planning

[6]MoHUA, & CSMC. (n.d.). PMAY (U) - CSMC Minutes. Retrieved February 24, 2020, from https://pmay-urban.gov.in/minutes

2. **Construction technology used:** While aiming to construct such a massive volume of residential floor space within a limited timeframe, new construction technologies which focus on construction speed, while maintaining the strength requirements were deemed critical. The sampled projects had various building construction material and technologies, as shown in Figure 4, such as the conventional brick and Concrete, and new practices propagated by Building Material and Technology Promotion Council (BMTPC). The different construction technologies identified can be found in Table 2[7,8,9,10,11,12,13,14,15] and Figure 6. Distribution of projects based on construction technology can be found in Figure 4, and the detailed classification of the same can be found in Annexure A.

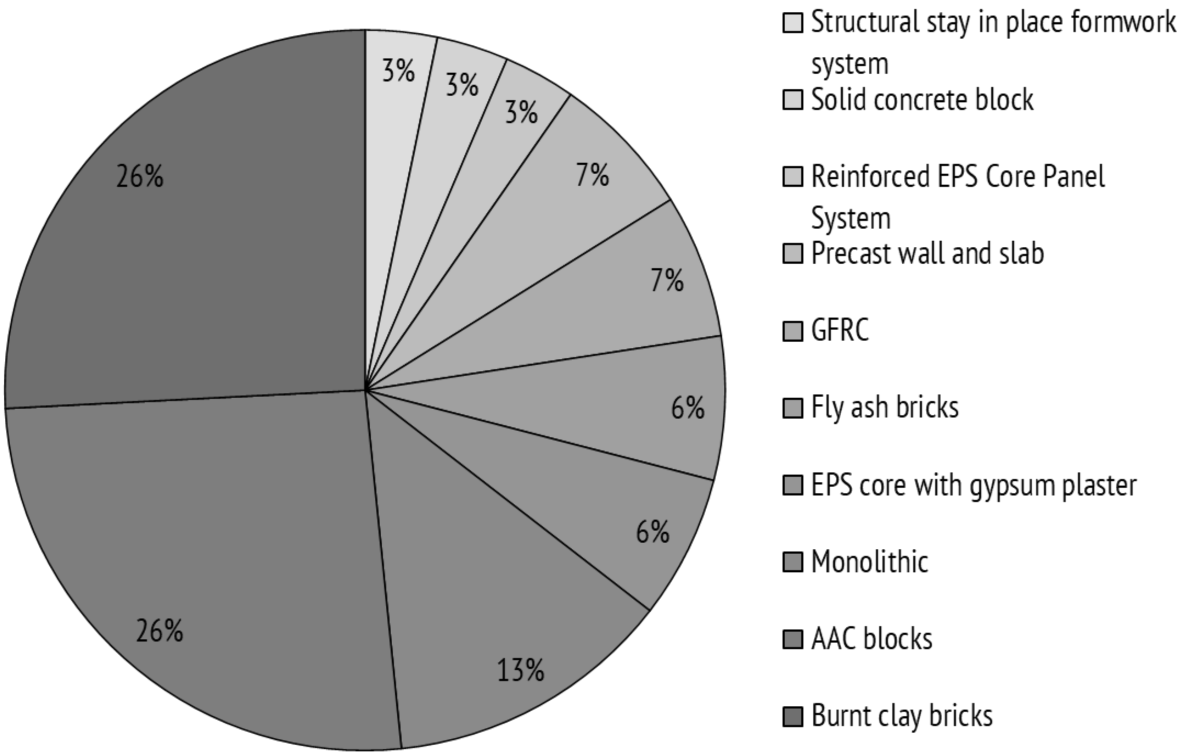


Figure 4: Distribution of sampled projects based on construction technology

3. **Availability of necessary drawings:** The selected projects' drawings were obtained from various secondary sources and, digitised to *.dwg files with accurate spatial dimensions. These drawings provided input data of dimensions for window area, total wall surface area and height of each dwelling unit for calculating the Residential Envelope Transmission Value (RETV).

[7]BMTPC. (n.d.-a). Brick masonry walls. Retrieved April 1, 2020, from http://bmtpc.org/topics.aspx?mid=356&Mid1=360
[8]BMTPC. (n.d.-b). Techno Feasibility Report on Concrete Hollow and Solid Block.
[9]BMTPC. (n.d.-c). Technology profile of monolithic construction system using aluminium formwork, by Building Materials & Technology Promotion Council, Ministry of Housing & Urban Poverty Alleviation, Government of India, New Delhi.
[10]BMTPC. (2011). GFRG Panel PAC BMTPC. Retrieved from http://www.bmtpc.org/DataFiles/CMS/file/PDF_Files/22_GFRG-Panel-RCF.pdf
[11]BMTPC. (2015a). Compendium of Prospective Emerging Technologies for Mass Housing, First Edition.
[12]BMTPC. (2015b). Reinforced EPS Core Panel System. Retrieved from http://bmtpc.org/DataFiles/CMS/file/PDF_Files/34_PAC-EPS.pdf
[13]BMTPC. (2018a). BMTPC EPS core panel - YouTube. Retrieved from https://www.youtube.com/watch?v=4pvXDLAZzmo
[14]BMTPC. (2018b). Structural Stay-in-Place Formwork (Coffor) System PAC BMTPC. Retrieved from: Retrieved from http://bmtpc.org/DataFiles/CMS/file/PDF_Files/50_PAC_Coffor.pdf
[15]BMTPC. (2019). PAC document OF Precast Construction Technology PAC No.: 1046-S/2019

4. **Climate zone:** After all the above criteria were met, it was ensured that there was at least one project from each climate zone in the sampled database. The various climate zones in India and their differentiating characteristics can be found in Figure 3 and Table 1, respectively. The distribution of projects concerning climate zones can be found in Figure 5.

Table 2: Identified construction technologies for PMAY housing projects

Sr No.	Construction technology
I. Formwork Systems:	
(a) Engineered formwork systems	
1	Monolithic Concrete Construction System using Aluminium, Plastic-Aluminium or Composite formwork
2	Modular Tunnel Formwork system
(b) Engineered formwork systems	
3	Sismo Building Technology
4	Insulating Concrete Forms
5	Monolithic Insulated Concrete System
6	Structural Stay-in-place formwork system (Coffor)
7	Lost-in-place formwork system- Plaswall Panel system
8	Plasmolite Wall Panels
II. Precast Sandwich Panel Systems	
(a) EPS based Systems	
9	Advanced Building System – Emmedue
10	Rapid Panels
11	Reinforced EPS Core Panel System
12	QuickBuild 3D Panels
13	Concrewall Panel System
(b) Others	
14	Glass Fibre Reinforced Gypsum Panel System
15	Prefabricated Fibre Reinforced Sandwich Panels
16	Rising EPS (Beads) Cement Panels
III. Light Gauge Steel Structural Systems	
17	Light Gauge Steel Framed Structure (LGSFS)
18	Light Gauge Steel Framed Structure with Infill Concrete Panel Technology
IV. Steel Structural Systems	
19	Factory Made Fast Track Modular Building System
20	Speedfloor System
V. Precast Concrete Construction Systems	
21	SRPL Building System
22	Precast Large Concrete Panel System
23	Industrialised 3-S System using Precast RCC Columns, Beams & Cellular light weight concrete Precast RCC Slabs
24	Walltec Hollow-core Concrete Panel

Sr No.	Construction technology
Other construction technologies in practice	
25	Conventional Brick masonry
26	Solid Concrete blocks masonry
27	Hollow concrete block masonry
28	AAC blocks masonry
29	Fly-Ash brick masonry
30	Fly-Ash hollow bricks masonry

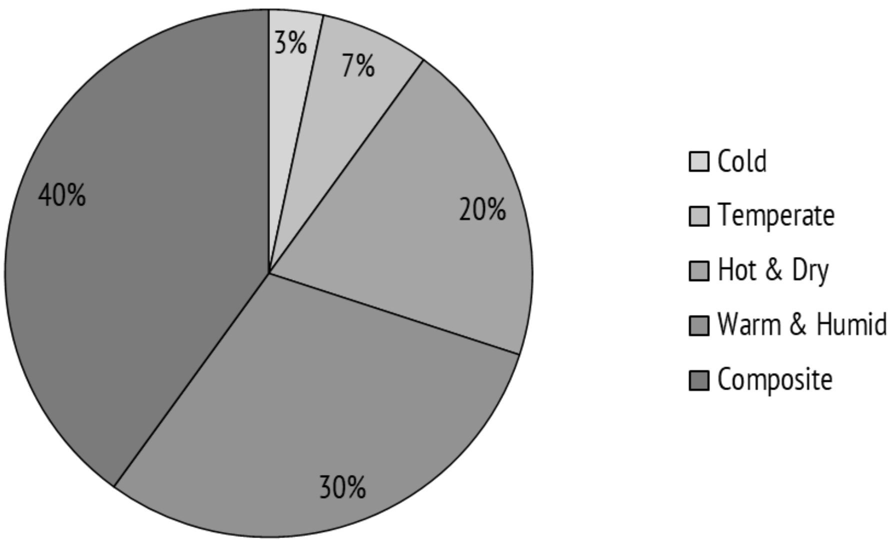


Figure 5: Distribution of sampled projects based on climate zones

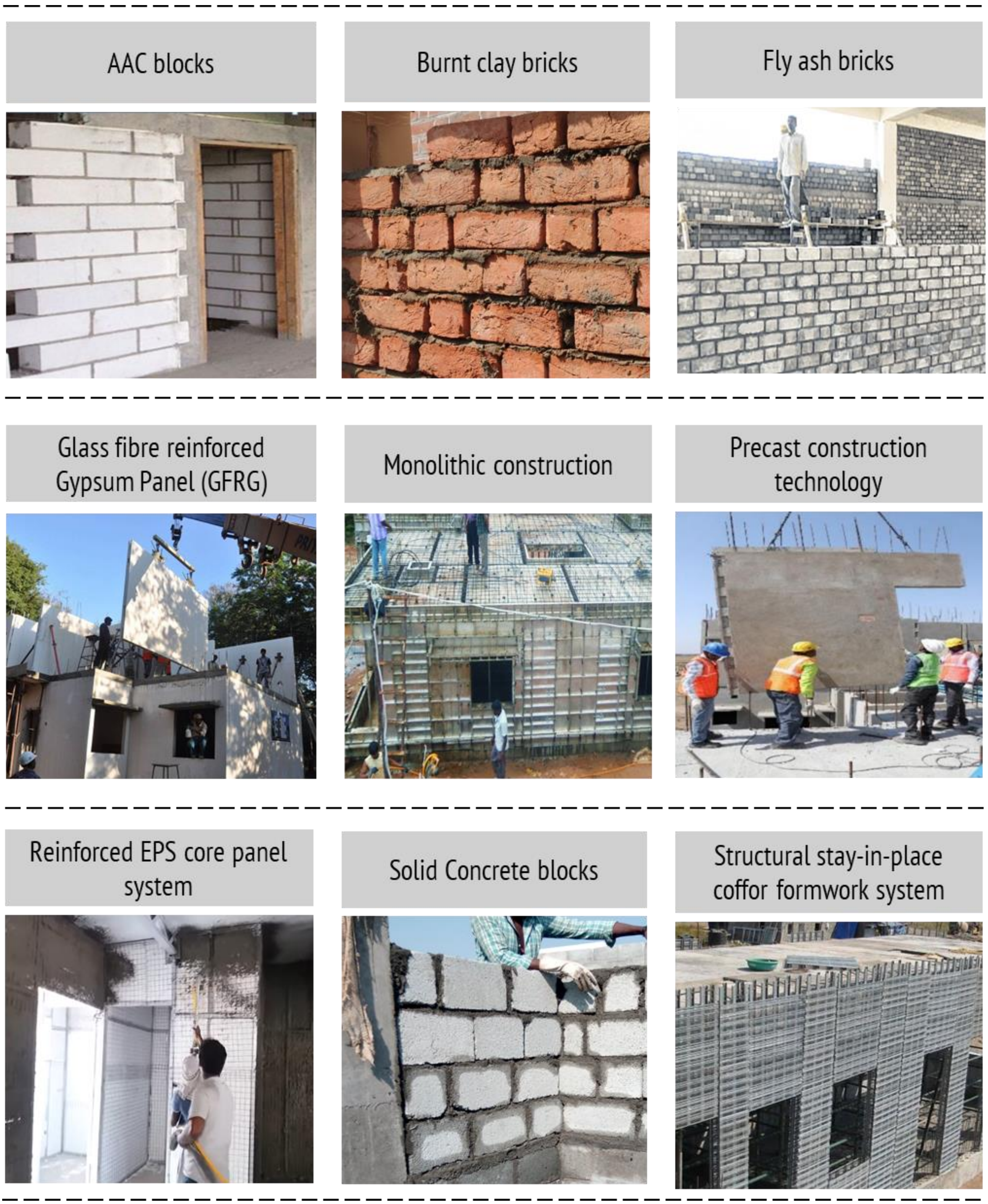


Figure 6: Construction technologies of sampled projects[7,8,9,10,11,12,13,14,15]

CHAPTER 3: CALCULATION AND ANALYSIS

Calculation of Residential Envelope Transmittance Value (RETV)

Residential Envelope Transmission Value (RETV), for each sampled project, was calculated to numerically quantify how the building envelope would perform in terms of heat transfer. The RETV calculations were conducted using the Energy Conservation Building Code-Residential (ECBC-R) Compliance check tool. This tool has been designed to provide the project proponent complete virtual assistance for evaluating the code compliance of the proposed residential building design. Construction details of various building envelope elements such as walls, roofs, windows, ventilators & doors were provided as inputs in specified forms. The compliance tool then calculated the parameters mentioned in Table 3 and checked whether the calculated values complied with the baseline values. The database of RETV for each of the 30 projects can be referred to in Annexure A.

Table 3: Climate Zone wise compliance values for ECBC-R parameters

Climate zone	Minimum WFR_{op} (%)	U_{roof} (W/m^2 K)	RETV (W/m^2)
Composite	12.5	1.2	15
Hot & Dry	10	1.2	15
Warm & Humid	16.66	1.2	15
Temperate	12.5	1.2	15
Cold	8.33	1.2	1.8

Analysis and interpretation of results

The following subsection presents the comparison and analysis of the calculated RETV and its relationship with building design parameters. Major input parameters of PMAY-U buildings were climatic zone, the building's orientation, PMAY component/verticals, wall construction technologies, roof construction technology, fenestration design, and overall building design. Major aspects of output parameters from RETV calculation were window-to-floor area ratio (WFR), U-values of the wall construction technologies (U_{wall}), and U-value of the roof construction technology (U_{roof}). Various graphs explaining these relationships are presented below from, Figure 7 to Figure 15.

Figure 7 shows the range of RETV across different climate zones. The RETV range reveals that most of the projects from the hot and dry climate zone employed various walling materials. Figure 8 shows that the number of non-compliant projects was less in the warm-humid climate zone with cities like Mumbai, Pune, etc. This was mainly because most of these projects were on PPP basis and were either ongoing or in their proposal stage. In the composite climate zone, there was a higher proportion of non-compliant projects, but the mean of the calculated RETV was the highest amongst all climate zones, as observed from Figure 8 and Figure 7 respectively. This could be because of the prevelant use of varied building construction technologies and materials in specific regions/climate zones. This signifies greater opportunities for incorporating and implementing design and material-construction interventions for these projects.

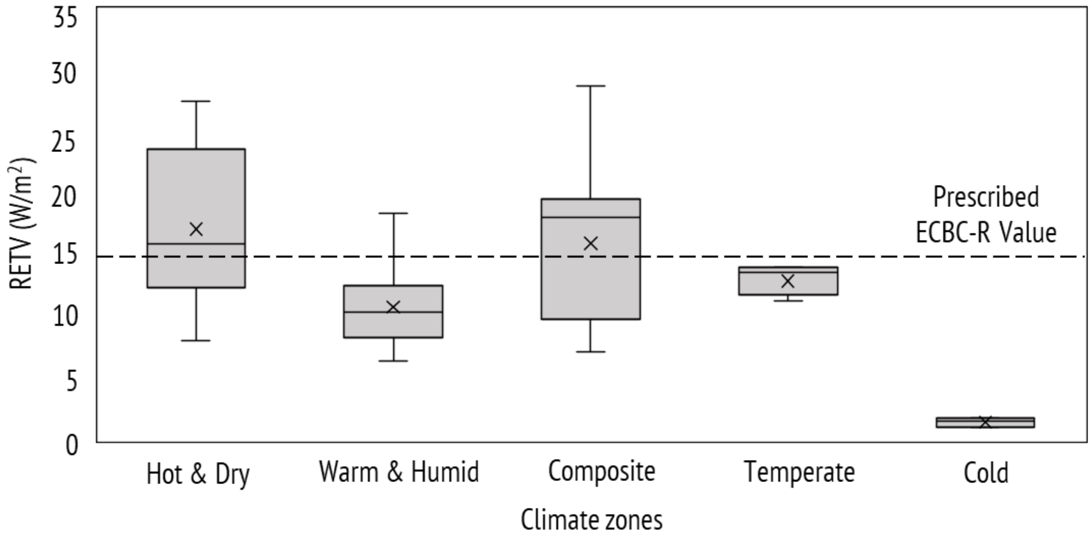


Figure 7: Range of RETV across different climate zones

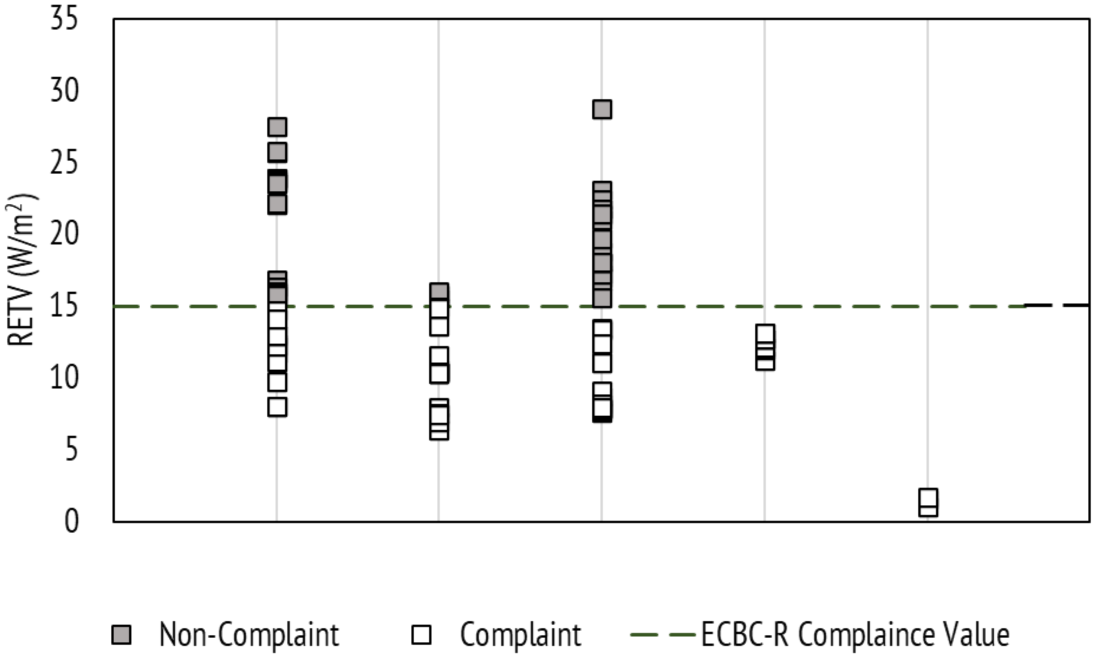


Figure 8: RETV of PMAY-U projects from different climate zones

The sampled projects interestingly, at times, consisted of more than one building block having the same or different orientation, spatial configuration, design, and construction material. Thus, the RETV for each building block, comprising all the sampled projects (No. 1 to 30) was calculated, plotted, and categorised as per their orientation. This was done to find any possible relationship of the RETV with orientation, i.e., to understand whether and how the orientation of a building would affect the RETV. Figure 9 shows that majority (77%) of buildings oriented N-S (i.e. their longer side would be facing North-South) were compliant with ECBC-R, followed by the buildings (61%) oriented E-W (i.e. their longer side would be facing east-west). Simultaneously, the majority of buildings with NE-SW (56%) and NW-SE (65%) orientations were found to be non-compliant with the ECBC-R prescribed value. This is enough to establish that as a rule of thumb, N-S or E-W orientation would be a better option than other orientation, but not as a fact. Then again, RETV is more a function of latitude of the project location than the orientation, suggesting projects/cases would need to be deigned to consider all the permutations and combinations of design features/inputs towards the orientation, to optimise the building's performance.

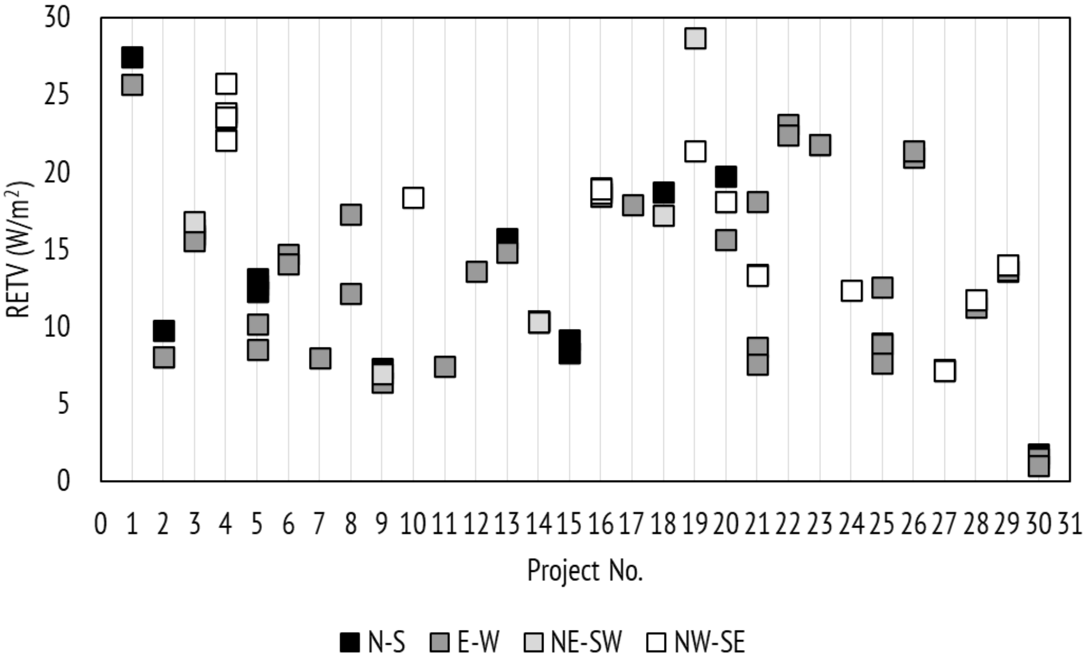


Figure 9: Orientation of the housing block and their RETV

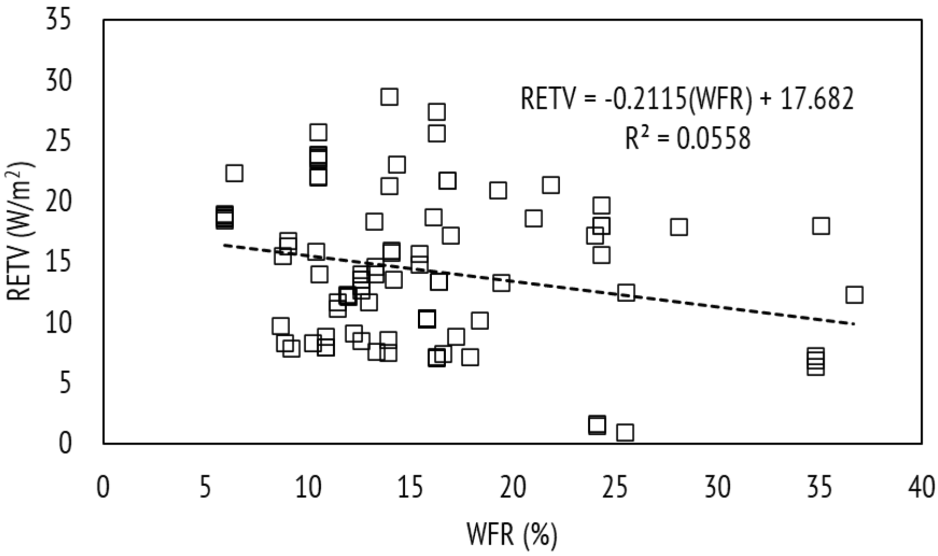


Figure 10: RETV to WFR (Window to Floor-area Ratio)

The second input parameter investigated for its impact on RETV was the Window to Floor ratio (WFR). In Figure 10, an inverse linear relationship can be observed between RETV and WFR, but the relationship is not statistically strong (R^2 = 0.056). This led to further plotting the WFR of all projects per their climate zone, and categorising them as compliant or non-compliant, as seen in Figure 11. It was interesting to note that most building projects were found to be compliant with the ECBC-R WFR values. Even though WFR is an important parameter that would need to be compliant with the ECBC-R prescribed WFR, its corelation with RETV was not strong, indicating probably a more significant role of design factors other than WFR.

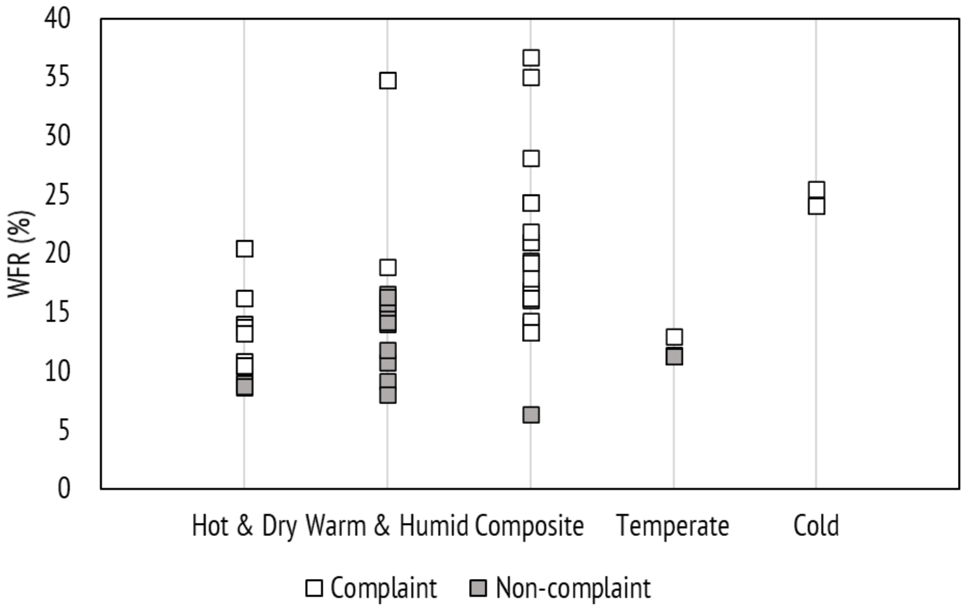


Figure 11: Climate Zone and WFR (Window to Floor-area Ratio)

Though U_{roof} values are not considered in the RETV calculations, it can be observed in Figure 12 that most of the projects whatsoever did not comply with the ECBC-R U_{roof} benchmark. The roof's surface would conduct and radiate heat inwards towards the buildings through the ceiling, thus leading to a rise in surface temperatures and the occupant's discomfort. By providing additional layers of insulation or reflective materials, the heat transfer can be reduced to a great degree, if not stopped; this would prove to be the easiest way to reflect direct radiation from the buildings' top surfaces. Thus making a strong case for the roof construction guidelines to be included in the codes.

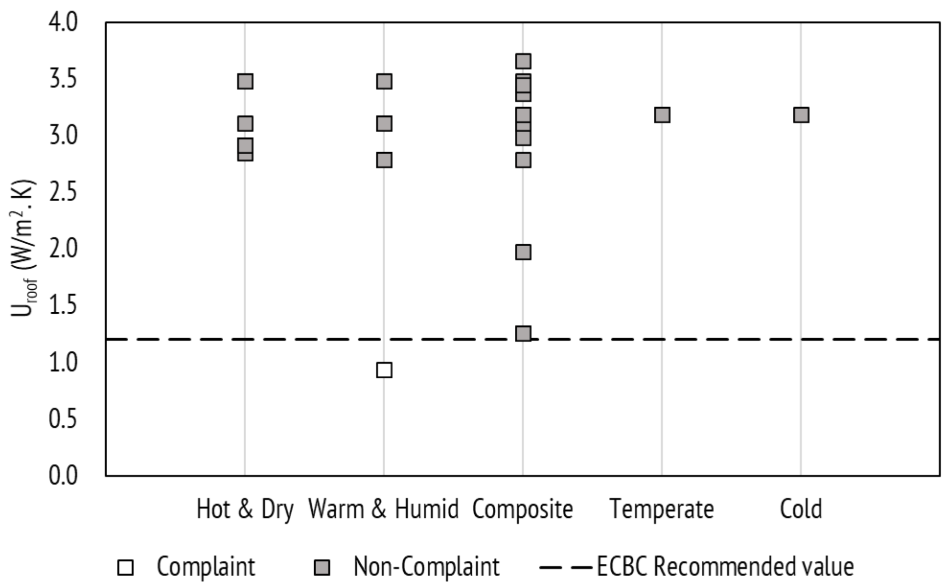


Figure 12: U_{roof} for all projects across different climate zones

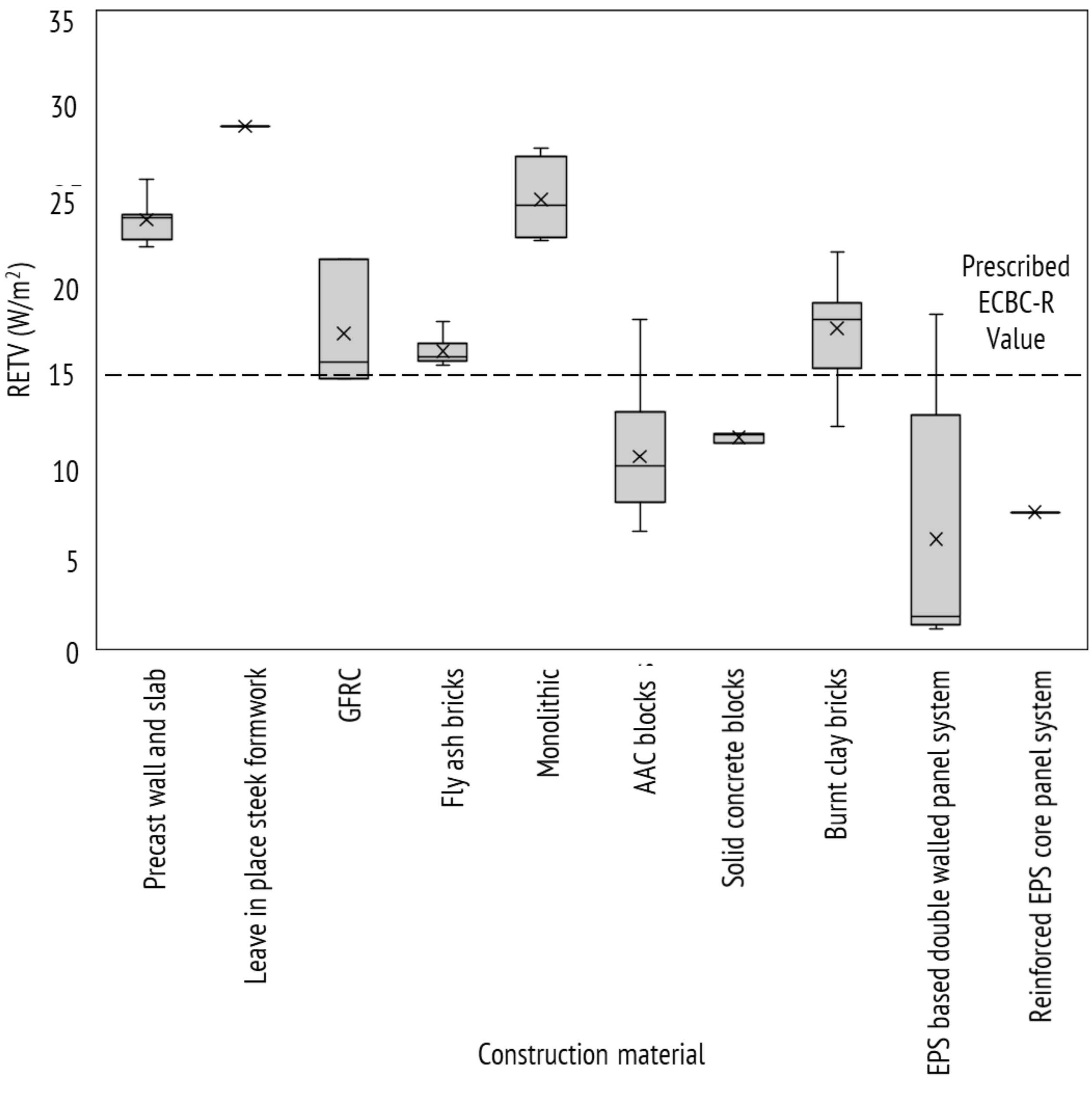


Figure 13: RETV - Wall construction technologies

To understand whether and how different construction technologies and materials impacted RETV and thereby the building envelope's performance, the calculated RETV were plotted against the respective construction material/technology as seen in Figure 13. The following observations could be made from Figure 13:

1. Monolithic construction, which performed the worst in the RETV scenario, was the most widely used construction method, only because of its ease and speed of construction.
2. AAC blocks performed reasonably well in the RETV scenario and are currently replacing conventional brick construction. However, their performance was correlated to the building orientation, thus, strengthening the need for a holistic design approach optimising the building's performance.
3. Fly-ash and precast RCC construction had no chance of performing better regardless of orientation and climate zone.
4. Burnt clay bricks demonstrated potential only when designed carefully considering the orientation.

5. EPS based double core panel system showed promising results for the cases that needed retrofitting, like design interventions. Similar was the Reinforced EPS core panel; only it was more implementable from the cost point of view.
6. GFRC panels were employed as an experiment in the chosen samples in composite and warm and humid climate zones. Thus, they might not offer a good performance in a hot and dry climate looking at the range of its present RETV performance.
7. Leave-in-place coffor formwork system did not offer good performance.
8. Solid concrete blocks offered near-threshold performance in the temperate climate.

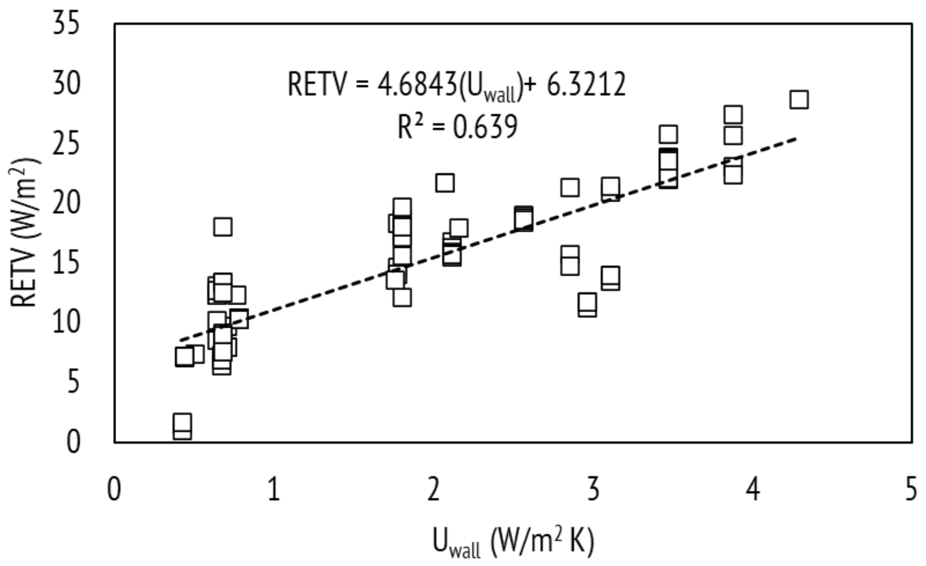


Figure 14: RETV trends concerningU-values of different walling materials

Figure 13 quantified that certain building construction materials performed better regardless of climate zone or other design input parameters. Thus, to scientifically establish the relationship between RETV and building construction material, the U_{wall} (U value of the building material –a measure of the materials intrinsic heat transfer performance) was plotted against the corresponding RETV. Figure 14 establishes a linear relationship between the building's walling material and RETV performance. Thus, the higher the material's U value, the worse the building's performance would be. This reinforces that concept of a holistic design approach, choosing the best-suited design parameters to optimise the buildings' performance and occupant comfort.

After understanding the impact of various design input parameters on RETV, an effort was made to understand whether or how the RETV, and subsequently the building performance, varied under different PMAY-U verticals. From Figure 15, the following observations can be made:

1. AHP projects rarely exceeded the RETV threshold.
2. As most PPP projects employed monolithic RCC or precast RCC based construction, the RETV ranged above the prescribed value.
3. RAY projects being constructed in the temperate climate zone were selected owing to the fact that PMAY-U was still in the process of adoption. These projects employed conventional brick construction, showing ECBC-R compliant results.

4. All Demonstration Housing Projects- DHP were experimental projects under PMAY-U by Building Materials and Technology Promotion Council (BMTPC), each deployed in a different climate zone. The results show that the promoted wall construction methods or products do not necessarily perform better regarding RETV.
5. As ISSR projects have policy and practical benefits for both developers and the government, code-compliance and cost-effectiveness were easy to achieve compared to other PMAY verticals.

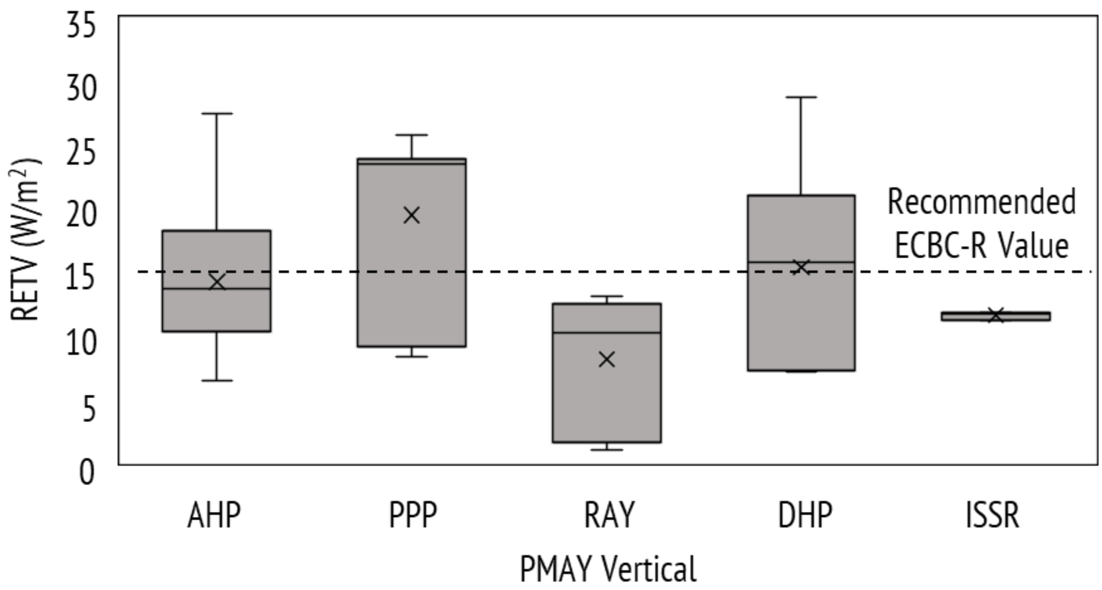


Figure 15: RETV across various PMAY-U verticals

Impact of ECBC-R on Energy Consumption and Thermal Comfort at a ULB Level

After the initial analysis, to understand the larger picture of the benefits achieved by implementing the code, the following study was undertaken. This study would further act as a case-study for ECBC-R implementation at other ULBs and SDAs since it provides quantifiable evidence for the benefits from ECBC-R.

1. Selecting a ULB that had necessary baseline data to measure energy savings and comfort hours:
   The extent/scale of impact that could be brought about by implementation and compliance of ECBC-R was quantified by examining available floor space within a city. Ahmedabad Municipal Corporation (AMC), a ULB based in Ahmedabad, was selected due to the required data's (found in Annexure B) availability. Based on the previous work done by AEEE on residential building stock modelling and the future floor space projections, residential building stock, its thermal characteristics and nature of housing typology were assessed. The selected case study was in its preliminary planning stage and was supported by the ULB's interest to self-retrofit for ECBC-R compliance.

2. Establishing the impact of ECBC-R on energy savings and comfort hour by simulating the code conditions to imply the need to scale up the code compliance:
   As a first step, the RETV of the selected case study was calculated, with the current (actual) design features of the project as input parameters. Furtheron, the walling material was varied (as mentioned in Table 5), and RETV for each of those cases was calculated, and the results compared. The energy simulations for one dwelling unit of the selected case study were carried out using DesignBuilder V5, an energy modelling software. The energy simulation results were then multiplied with the available floor space within the city of Ahmedabad, to obtain the values of energy savings and the comfort hours for the whole city. The list of studies undertaken to understand the impact of ECBC-R

on the energy savings and comfort hours is mentioned below; detailed inputs and their results are represented in Table 4 and Table 5, and from Figure 16 to Figure 20.

a) RETV assessment of the ULB driven project selected for ECBC-R impact assessment
b) Impact of various construction technologies on RETV for a ULB Driven project
c) Energy consumption and savings comparison for different wall construction assemblies
d) CO_2 released at ULB level
e) Savings in CO_2 equivalent while in operation
f) Number of comfortable hours for each wall construction for a project

Table 4: RETV assessment of the ULB driven project selected for ECBC-R impact assessment

Project vertical	Construction material	Orientation	Wf_{op}	VLT (%)	U_{roof} (W/m^2 K)	RETV (W/m^2)	U_{wall} (W/m^2 K)
AHP	Bricks	N-S	**13.38**	**85**	**2.98**	**18.55**	2.155
		E-W	**13.65**	**85**	**2.9**	**17.28**	2.155
		N-S	**13.65**	**85**	**1.98**	**18.1**	2.155
ECBC-R Benchmark		-	10	-	1.2	15	-

Table 5: Comparative study of impact of various construction technologies on RETV values in the case of the selected ULB driven project for ECBC-R assessment

Sr. No.	Wall Assembly	U value	RETV
A	Cement plaster (12 mm), Fly ash brick (230 mm), Cement plaster (6 mm)	2.155	**18.55**
B	Cement plaster (12 mm), AAC blocks (150 mm), Cement plaster (6 mm)	0.99	**12.23**
C	Rat trap bond wall	1.673	**15.94**
D	Light Gauge framed steel structure with EPS	1.188	**13.30**
E	Light Gauge framed steel structure with PPGI Sheet	1.629	**15.70**
F	Reinforced EPS core Panel system	0.907	**11.78**
G	Glass fibre reinforced Gypsum Panel -Unfilled	1.559	**15.32**
H	Glass fibre reinforced Gypsum Panel -with RCC & non-structural filling	1.715	**16.17**
I	Glass fibre reinforced Gypsum Panel -with partial RCC filling	1.534	**15.18**
J	Brick Wall	1.67	**15.92**
K	Structural stay-in-place formwork system (Coffor) – Insulated panel	NA	-

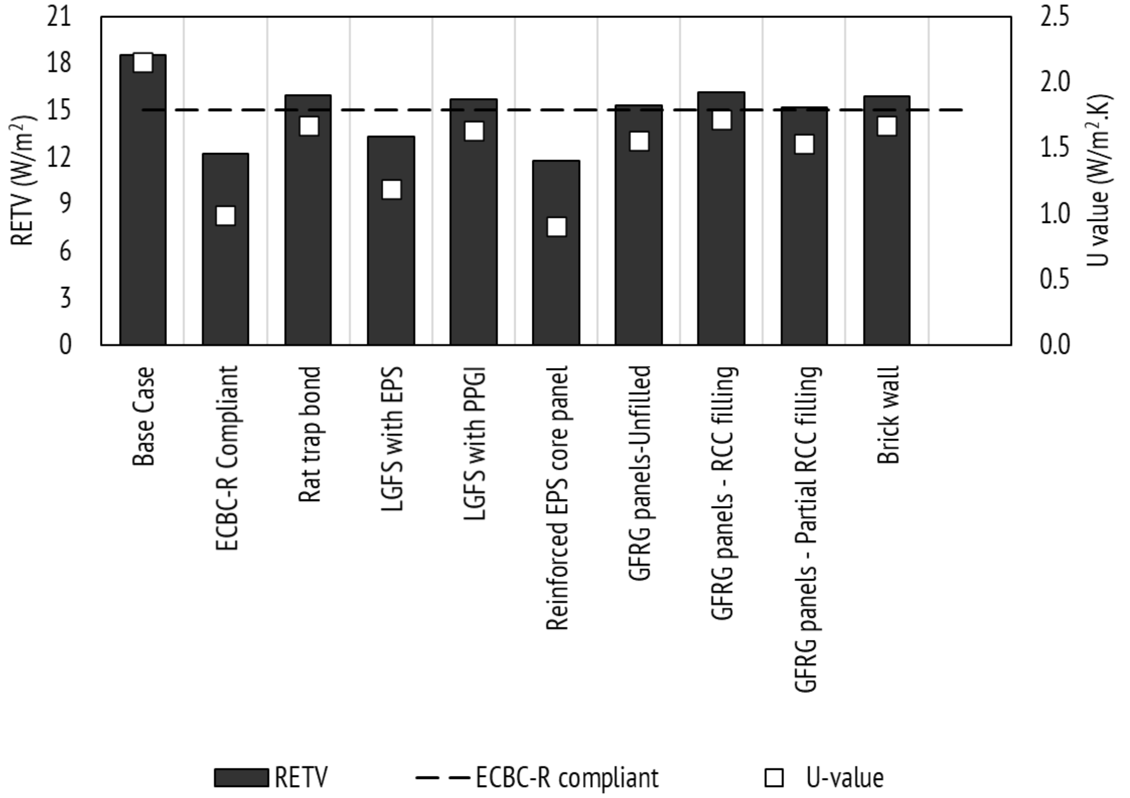


Figure 16: Impact of various construction technologies on RETV for a ULB Driven project

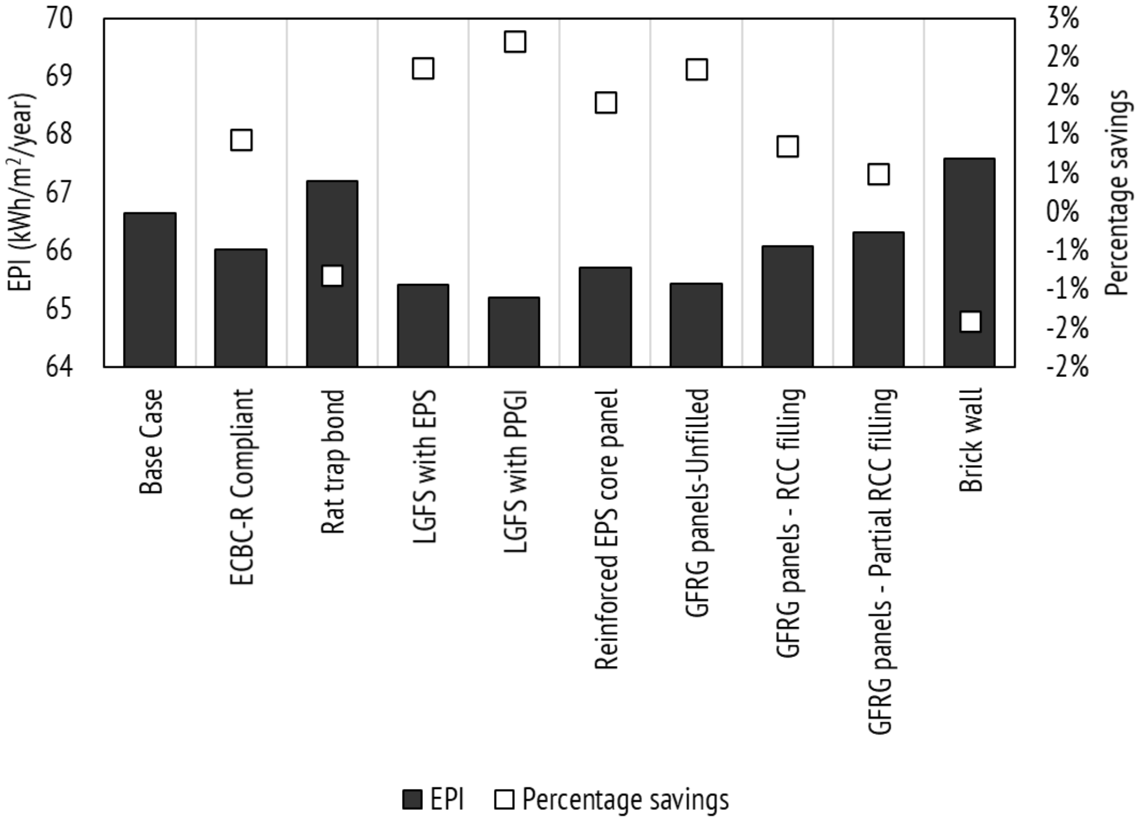


Figure 17: Energy consumption and savings comparison for different wall construction assemblies

The results, as shown in Figure 16, were plotted after calculating the project's base case RETV and the RETV calculated by varying the walling material. The Energy Performance Index (EPI) and the percentage energy savings, for the base case and other cases were plotted subsequently as shown in Figure 17. The aim was to understand how a change in walling material, basically a change in U value, would impact the overall building performance in heat transfer and energy. It can be observed that conventional brick wall construction, although through a rat-trap bond masonry, did not help make a building ECBC-R compliant (Figure 16). Wall constructions with EPS insulation provided the desired reduction in EPI, rendering a higher percentage of energy savings.

To integrate the efforts in making building construction sustainable embodied energy would need to be reduced. It can be quantified by understanding the CO_2 released throughout the building's life cycle. Thus, the equivalent CO_2 released, and the potential savings in CO_2 during the building's lifecycle across all cases was plotted, as seen in Figure 18 and Figure 19 respectively. The results in Figure 18 show how insulated wall construction offered a possibility of a reduction in MtCO2e release at ULB level, which were further reinforced by the results in Figure 19.

Building a comfortable building is a predecessor to sustainability so the building's energy (embodied and electrical) efficiency, and how comfortable it is for the occupants to live in matters. Thus, to understand the impact changing the walling material would have on occupant comfort, the comfortable hours for all cases were plotted against respective walling materials, as shown in Figure 20. It is interesting to note that the results show congruence with the results in Figure 18: having insulated walls would help reduce the building's carbon footprint and increase the occupant comfort.

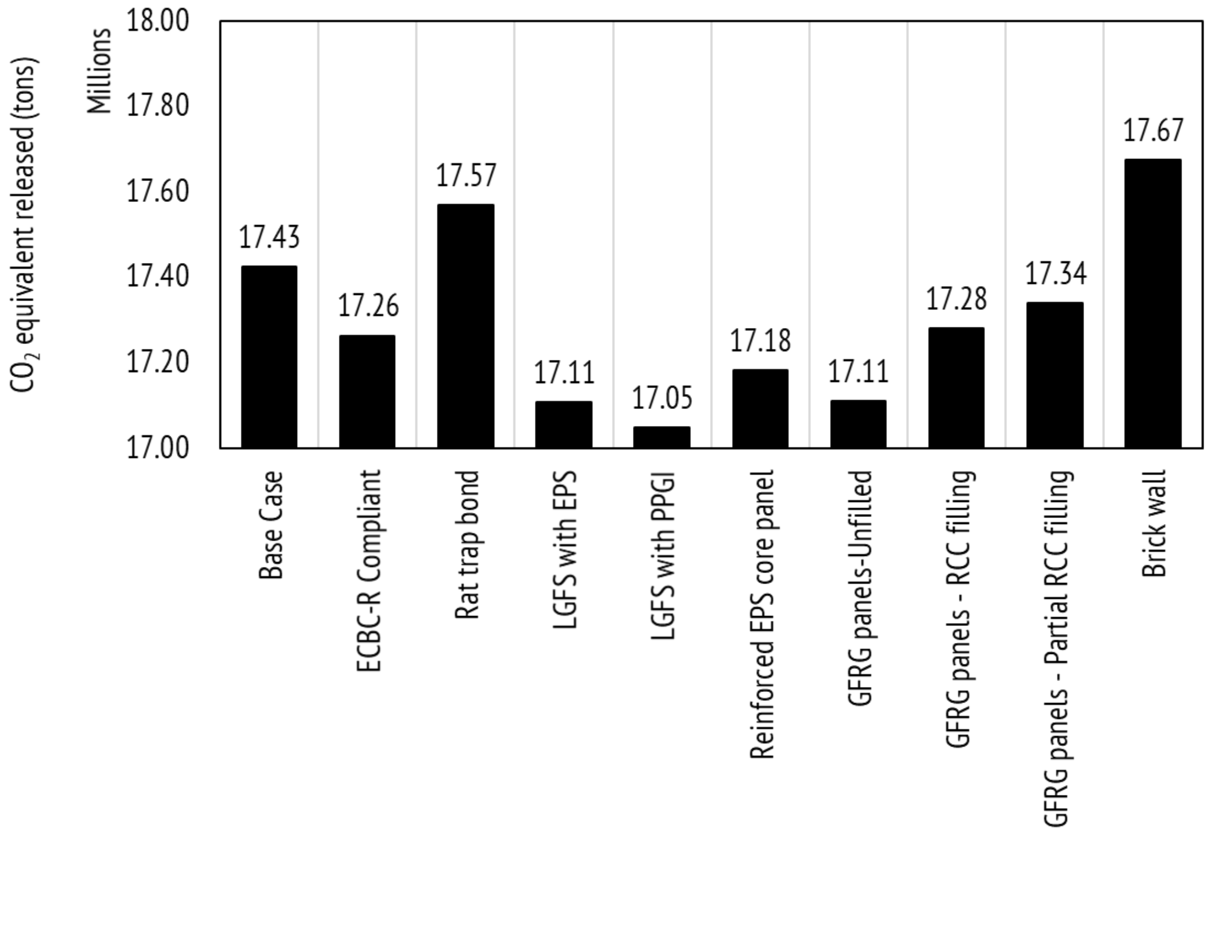


Figure 18: CO_2 equivalent released at ULB level

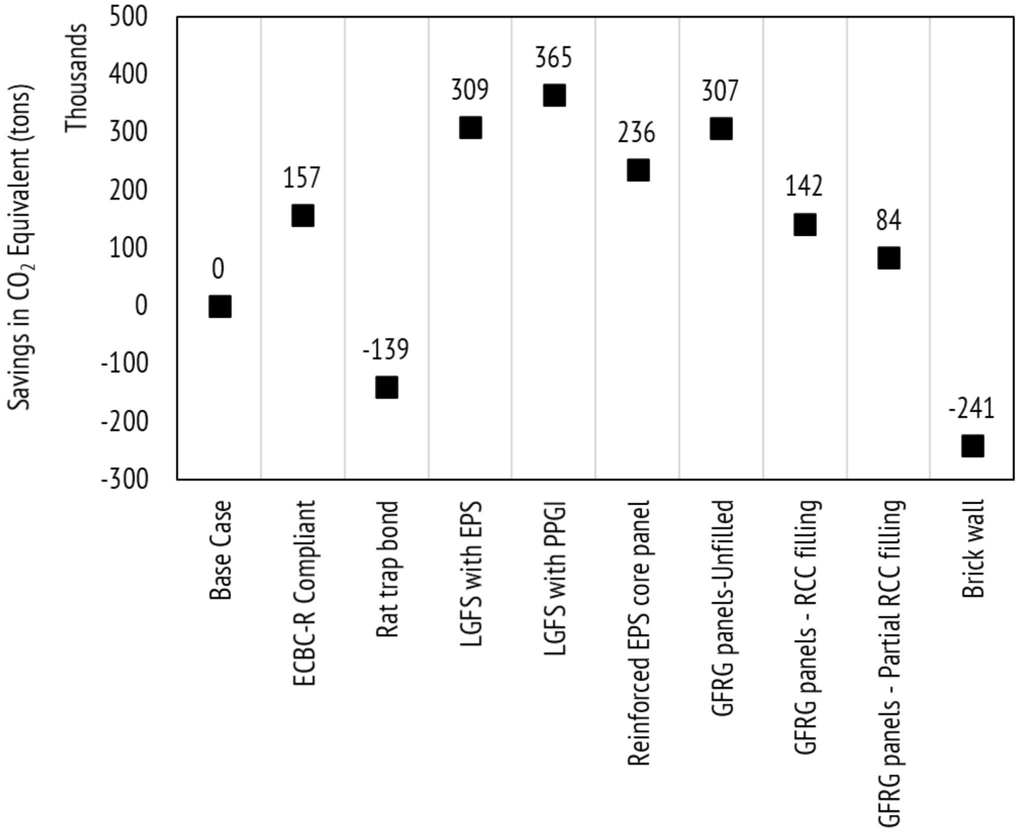


Figure 19: Savings in CO_2equivalent while in operation

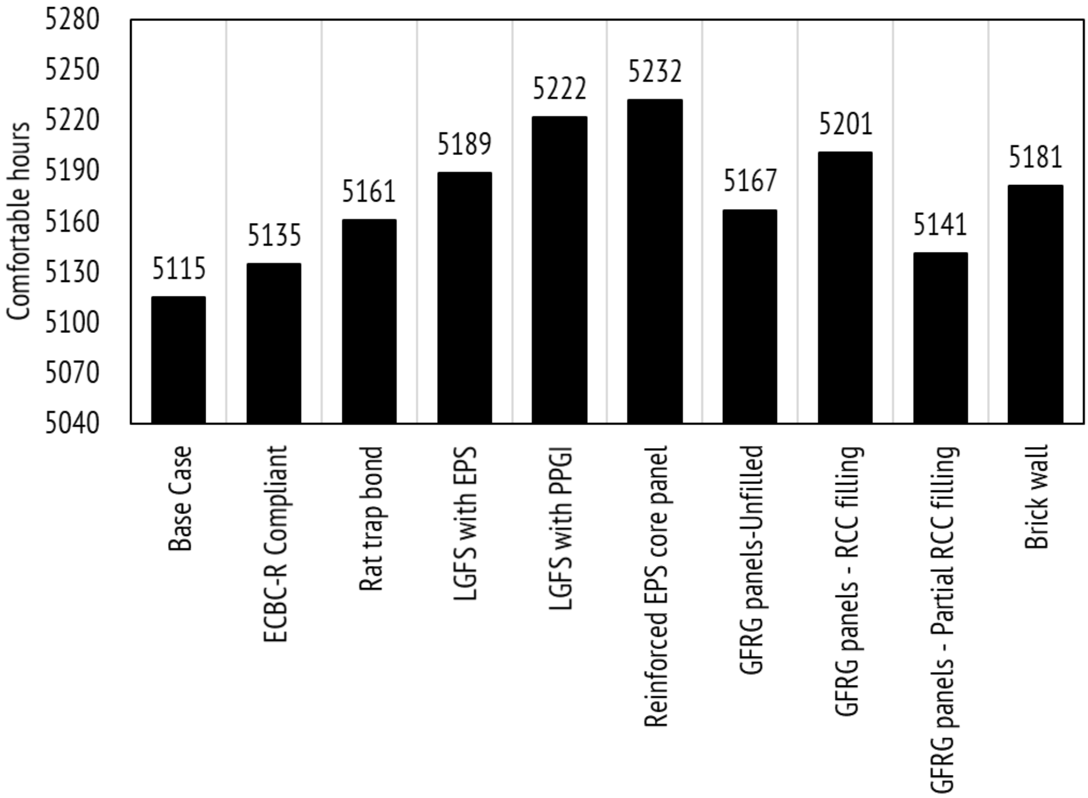


Figure 20: Number of comfortable hours for each wall construction for a project

3. Identification of a pilot PMAY-U project for technical assistance to map gaps in the practical implementation of ECBC-R and exemplify easy scalability suitable to local conditions:

A project for technical assistance, through a mediatory organisation, was identified and made compliant with ECBC-R through technical assistance. This activity aimed to collate the sampled project's details such as necessary proejct information, project's collaboration with the ULB, and project's collaboration with various stakeholders, for the training program. Table 6 provides more details on the same.

Table 6: Details of the project selected for technical assistance

Aspects	Information
ULB	AMC - Ahmedabad Municipal Corporation
Climate Zone	Hot and Dry
City, State	Ahmedabad, Gujarat
NGO associated for implementation and capacity building	MHT- Mahila Housing SEWA Trust, Ahmedabad
Status of the activity	Informative presentations regarding the complete project have been discussed with the ULB and 2 projects under construction have been finalised. Round-table meetings have been fixed with all the stakeholders i.e., private builders, ULB, NGO volunteers, and CARBSE; Basic cost analysis of construction interventions has been done. Overview of the protocol of distribution of the responsibilities has been discussed.
Selected Projects	1. Chanaji Project, Ahmedabad (ISSR) 2. Radha Raman Project, Ahmedabad (ISSR) 3. Odhav Project, Ahmedabad (AHP)

CHAPTER 4: RESULTS AND CONCLUSIONS

This project aimed to quantify the potential of a paradigm shift towards sustainability by incorporating a strict policy and code compliance framework. Bureau of Energy Efficiency launched the Energy Conservation Building Code for Residential Buildings (ECBC-R) in 2018 as the first step to climate-conscious, sustainable building construction. This movement's timing is more than appropriate, given the large volume of residential building floor space still being under construction or yet to be constructed. Building sustainability and efficiently would only become a norm, if (when) it is accessible at a reasonable cost, to all income groups. Thus, focusing on affordable housing being constructed under the PMAY-U, served as a starting point.

Various (80) PMAY-U projects spanning across the nation, falling under various climate zones were gathered and formulated into a dataset. Out of these only 30 projects were sampled and further considered for calculation and analysis. The RETV of these sampled projects was calculated and the influence of various design input parameters on RETV was evaluated. Furthermore, the impact a small variation like changing the walling material would have on overall building performance, in terms of heat transfer, energy efficiency, carbon footprint, and occupant comfort, was also studied. This involved narrowing down a case study and demonstrating the results, which could be scaled up to the ULB level.

For the non-compliant PMAY-U buildings which were already under construction or constructed, it was seen that impractical building orientation, and not focusing on optimising all design input parameters simultaneously was the primary factor responsible for non-compliance. Introducing guidelines and policies addressing building retrofitting costs and payback period would serve as an excellent opportunity for market creation of ECBC-R. For the non-compliant PMAY-U projects which were still at the proposal stage, the relevant regulatory bodies could be collaborated with, to launch them as ECBC-R pilot projects with the required technical assistance. They could also be marketed using this goodwill, creating demand for code compliance. A comparative database of U-value of walls, their embodied energy, lifespan, maintenance performance and cost analysis would bring clarity in compliance measures. ECBC-R, when supported by this dataset, would have the maximum potential of its implementation like a preferred design guide rather than an enforced rule. Other housing schemes such as RAY, IHSDP etc. portrayed a need of awareness and training regarding the ECBC-R.

This study called for and reinforced the need for taking more scientific, and data-informed decisions when constructing buildings rather than replicating design input parameters amongst projects. By choosing a walling material suitable for the respective climate zone, varying the design input parameters such as WFR, sizing and material of windows and doors, and the roofing material to optimise the building's performance holistically.

The observations from studying the code compliance effectiveness in India's diverse local conditions suggested ECBE-R to be the most relevant code that can be developed for enforcement. Here, the target groups involved the governing bodies, policy makers, and private stakeholders, including architects, MEP consultants, energy consultants, developers, manufacturers, and end-users.

The action-learning approach adopted in the study has created collaborative platforms among the stakeholders. This has further strengthened the administrative capacity to carry out policy development and implementation activities. At the ULB level, a strong foundation of code adoption has been established due to a structured collaboration with stakeholders backed by reasonable quantity and quality of data, and a focused analysis.

ANNEXURE A

The relevant details of all selected projects with regards to RETV calculation can be found in Table 7.

Table 7: details of selected projects

Climate zone	Project ID	Construction material	Orientation	WFR_{op}	VLT (%)	U_{roof} ($W/m^2 K$)	RETV (W/m^2)
Hot & Dry	HD_1	Monolithic	N-S	**16.29**	85	**2.85**	**27.5**
			E-W	**16.29**	85	**2.85**	**25.7**
	HD_2	AAC blocks	E-W	**10.85**	85	**2.92**	**8.04**
			N-S	**8.66**	85	**2.92**	**9.8**
			E-W	**10.85**	85	**2.92**	**8.04**
	HD_3	Fly ash bricks	NE-SW	**9.01**	85	**2.92**	**16.79**
			E-W	**9.01**	85	**2.92**	**16.34**
			E-W	**14.06**	85	**2.92**	**16**
			E-W	**10.39**	85	**2.92**	**15.9**
			E-W	**8.77**	85	**2.92**	**15.57**
			N-S	**14.06**	85	**2.92**	**15.8**
	HD_4	Precast (Wall and Slab) technology proposed with Hollow core slabs for walls	NW-SE	**10.48**	85	**3.48**	**23.88**
			NW-SE	**10.48**	85	**3.48**	**23.88**
			NE-SW	**10.48**	85	**3.48**	**23.75**
			NW-SE	**10.48**	85	**3.48**	**22.08**
			NW-SE	**10.48**	85	**3.48**	**25.8**
			NE-SW	**10.48**	85	**3.48**	**22.15**
			NW-SE	**10.48**	85	**3.48**	**23.58**
			NW-SE	**10.48**	85	**3.48**	**23.57**

Climate zone	Project ID	Construction material	Orientation	WFR_{op}	VLT (%)	U_{roof} (W/m^2 K)	RETV (W/m^2)
	HD_5	AAC blocks	N-S	**11.93**	85	**2.92**	**12.33**
			N-S	**11.93**	85	**2.92**	**12.34**
			E-W	**18.4**	85	**2.92**	**10.21**
			E-W	**12.57**	85	**2.92**	**8.58**
			N-S	**12.58**	85	**2.92**	**13.1**
			N-S	**12.58**	85	**2.92**	**12.72**
	HD_6	Bricks	E-W	**13.26**	85	**3.11**	**14.68**
			E-W	**13.26**	85	**11**	**14.08**
Warm & Humid	WH_1	AAC blocks	E-W	**9.18**	85	**2.79**	**7.98**
	WH_2	Bricks	E-W	**24**	85	**3.48**	**17.27**
			E-W	**11.94**	85	**3.48**	**12.17**
	WH_3	AAC blocks	E-W	**34.78**	85	**2.79**	**6.43**
			N-S	**34.78**	85	**2.79**	**7.33**
			NE-SW	**34.78**	85	**2.79**	**6.97**
	WH_4	Bricks	SE-NW	**13.25**	85	**2.73**	**18.4**
	WH_5	Reinforced EPS Core Panel System	E-W	**16.6**	85	**2.79**	**7.46**
	WH_6	Bricks	E-W	**14.19**	85	**2.79**	**13.63**
	WH_7	GFRC	N-S	**15.45**	85	**2.79**	**15.75**
			E-W	**15.45**	85	**2.79**	**14.82**
	WH_8	Precast (Wall and Slab) technology proposed with	NE-SW	**15.78**	85	**3.11**	**10.43**
			N-S	**15.78**	85	**3.11**	**10.34**

Climate zone	Project ID	Construction material	Orientation	WFR_{op}	VLT (%)	U_{roof} (W/m^2 K)	RETV (W/m^2)
		Hollow core slabs for walls	NE-SW	**15.78**	85	**3.11**	**10.42**
			N-S	**15.78**	85	**3.11**	**10.4**
			NE-SW	**15.78**	85	**3.11**	**10.42**
			N-S	**15.78**	85	**3.11**	**10.39**
			NE-SW	**15.78**	85	**3.11**	**10.33**
			N-S	**15.78**	85	**3.11**	**10.34**
	WH_9	AAC blocks	N-S	**10.23**	85	**2.87**	**8.37**
			N-S	**8.88**	85	**2.87**	**8.37**
			N-S	**12.23**	85	**2.87**	**9.18**
Composite	COM_1	Bricks	NW-SE	**5.92**	85	**2.79**	**18.66**
			NW-SE	**5.92**	85	**2.79**	**18.91**
			NE-SW	**5.92**	85	**2.79**	**19.04**
			NE-SW	**5.92**	85	**2.79**	**18.81**
			NE-SW	**5.92**	85	**2.79**	**18.47**
			NE-SW	**21**	85	**2.79**	**18.67**
	COM_2	Fly ash bricks	E-W	**28.12**	85	**3.19**	**17.95**
	COM_3	Bricks	N-S	**16.11**	85	**3.48**	**18.77**
			NE-SW	**16.94**	85	**3.48**	**17.22**
	COM_4	Structural Stay in Place Formwork System	NE-SW	**13.96**	85	**3.66**	**28.74**
			NW-SE	**13.94**	85	**3.66**	**29.01**
	COM_5	Bricks	E-W	**24.35**	85	**3.37**	**15.63**
			N-S	**24.35**	85	**3.37**	**19.74**

Climate zone	Project ID	Construction material	Orientation	WFR_{op}	VLT (%)	U_{roof} (W/m^2 K)	RETV (W/m^2)
			NE-SW	**24.35**	85	**3.37**	**18.1**
			NW-SE	**24.35**	85	**3.37**	**18.1**
	COM_6	AAC blocks	E-W	**13.89**	85	**1.26**	**8.66**
			E-W	**13.89**	85	**1.26**	**7.62**
			E-W	**70.09**	85	**1.26**	**28.89**
			SE-NW	**19.43**	85	**1.26**	**13.32**
			E-W	**16.37**	85	**1.26**	**13.43**
			E-W	**16.37**	85	**1.26**	**13.42**
	COM_7	Solid concrete block	E-W	**57.33**	85	**2.98**	**20.78**
			E-W	**6.41**	85	**2.98**	**17.88**
	COM_8	Bricks	E-W	**16.78**	85	**1.98**	**21.8**
			E-W	**16.78**	85	**1.98**	**21.79**
	COM_9	AAC blocks	SE-NW	**36.68**	85	**3.45**	**12.41**
	COM_10	AAC blocks	E-W	**17.24**	85	**3.11**	**8.92**
			N-S	**10.87**	85	**3.11**	**8.95**
			E-W	**25.56**	85	**3.11**	**12.56**
			E-W	**13.32**	85	**3.11**	**7.66**
	COM_11	Monolithic	E-W	**19.28**	85	**3.11**	**21.01**
			E-W	**21.87**	85	**3.11**	**21.43**
	COM_12	Stay in Place EPS based double walled panel System	NW-SE	**16.28**	85	**3.19**	**7.22**
			NW-SE	**16.28**	85	**3.19**	**7.17**
			NE-SW	**17.92**	85	**3.19**	**7.21**

Climate zone	Project ID	Construction material	Orientation	WFR_{op}	VLT (%)	U_{roof} ($W/m^2 K$)	RETV (W/m^2)
			NE-SW	**16.28**	85	**3.19**	**7.27**
Temperate	T_1	Solid concrete block	E-W	**11.42**	85	3.19	**11.26**
			N-S	**11.42**	85	3.19	**11.75**
			NW-SE	**12.99**	85	3.19	**11.79**
	T_2	Monolithic	E-W	**12.61**	85	3.19	**13.66**
			N-S	**12.61**	85	3.19	**13.58**
			NW-SE	**10.55**	85	3.19	**14.04**
			NE-SW	**12.61**	85	3.19	**14.04**
Cold	C_1	Stay in Place EPS based double walled panel System	E-W	**24.11**	85	**3.19**	**1.514**
			E-W	**25.5**	85	**3.19**	**1.016**
			N-S	**24.11**	85	**3.19**	**1.751**

ANNEXURE B

The relevant details of the ULB driven project can be found in Table 8. Figure 21 andFigure 22 show the site and building floor plans for the same.

Table 8: Project information of the selected ULB driven project to apply ECBC-R

Project Information	
Project Name	Proposed PMAY EWS Houses atT.P.109 (Muthiya, Bilasiya, Hanspura) on F.P. 119
Location	Ahmedabad, Gujarat
Climate	Hot and Dry
PMAY component	AHP
SLNA	Ahmedabad Municipal Corporation
Status of the project	Preliminary planning stage
Walling Construction Technology	Fly-Ash brick masonry with internal and external cement plaster
Roof Construction	For block A and B, China mosaic tile (4 mm), Concrete laid to slope (50 mm), RCC slab (150 mm), Internal plaster (6 mm) with U_{roof} = 2.899W/m^2 K. For Block C, China mosaic tile (4 mm), Concrete laid to slope (50 mm), PUF (40 mm), Cement screed (10 mm), RCC slab (150 mm), Internal plaster (6 mm), of which the U_{roof} = 0.477W/m^2 K.
Carpet Area	28 sqm
Housing Typology	P+14 Apartments
Total no. of Dwelling Units	Type A block: 16 units x 21 blocks x 14 floors = 4704 DUs, Type B block: 12 units x 4 blocks x 14 floors = 672 DUs, Total DUs = 5376 DUs

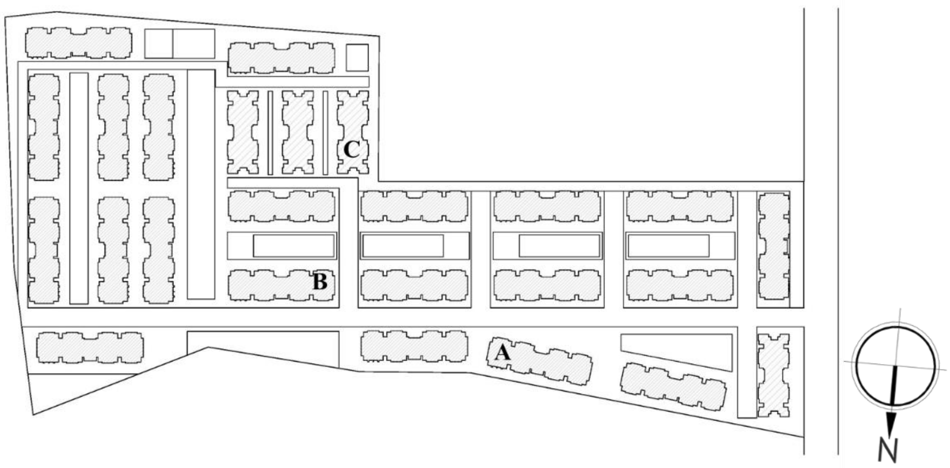
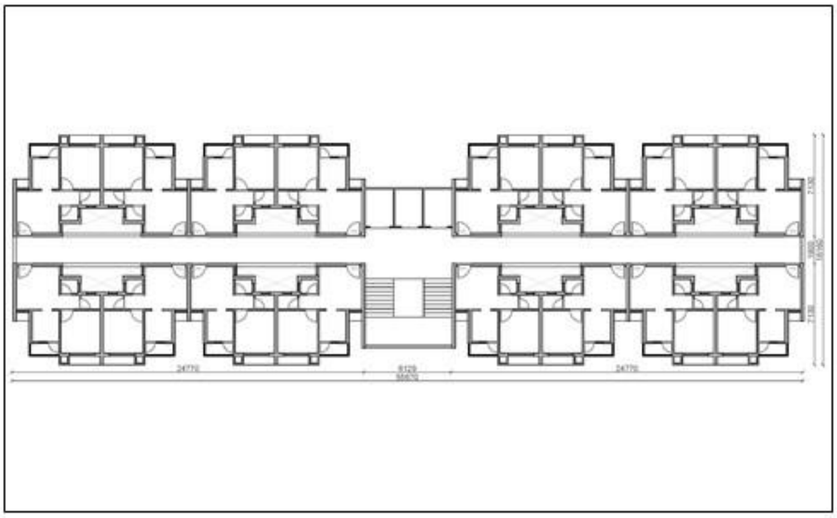
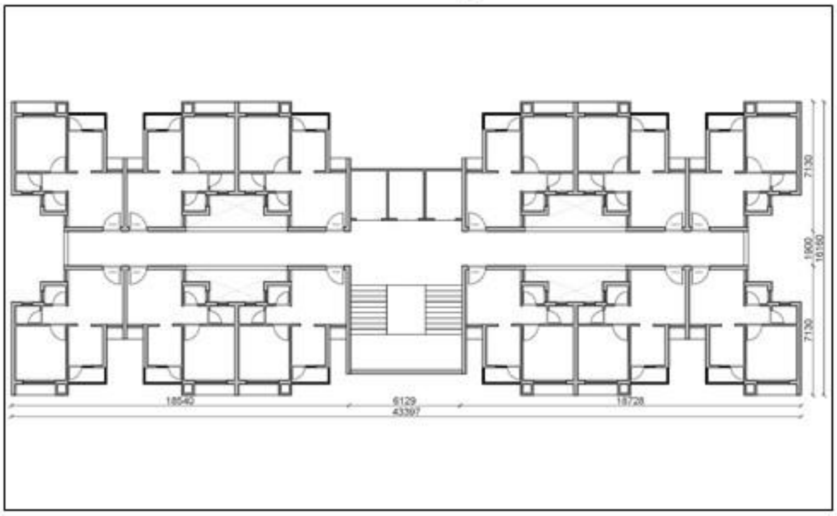


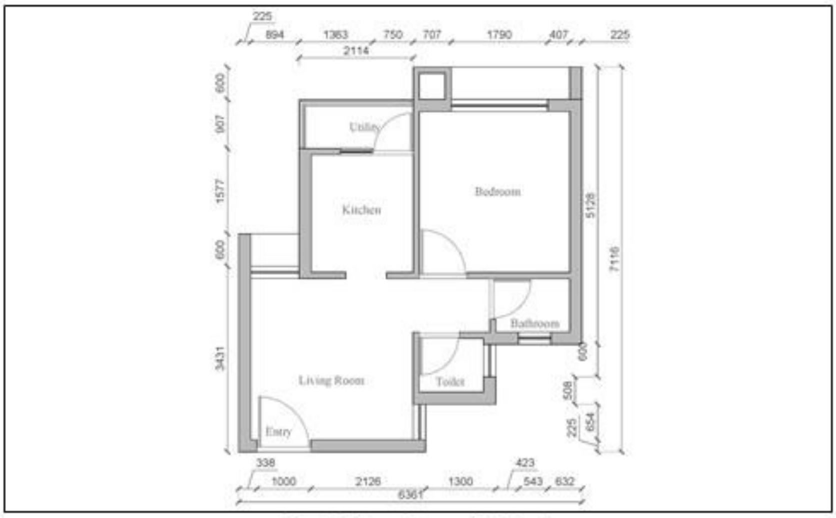
Figure 21: Site Plan of Proposed PMAY EWS Houses atT.P.109 (Muthiya, Bilasiya, Hanspura) on F.P. 119



Floor Plan –Type A



Floor Plan- Type B



Unit Plan- Area: 27.2m²

Drawings of the case: Proposed PMAY EWS Houses atT.P.109 (Muthiya, Bilasiya, Hanspura) on F.P. 119

Figure 22: Floor plans and unit plan of the case: Proposed PMAY EWS Houses atT.P.109 (Muthiya, Bilasiya, Hanspura) on F.P. 119

Global Buildings Performance Network

Building Policies for a Better World

GBPN
Global Buildings Performance Network

24, avenue Hoche
75008 Paris
France

info@gbpn.org

www.gbpn.org
@GBPNetwork

About GBPN The Global Buildings Performance Network (GBPN) is a globally organised and regionally focused network whose mission is to advance best practice policies that can significantly reduce energy consumption and associated CO_2 emissions from buildings.