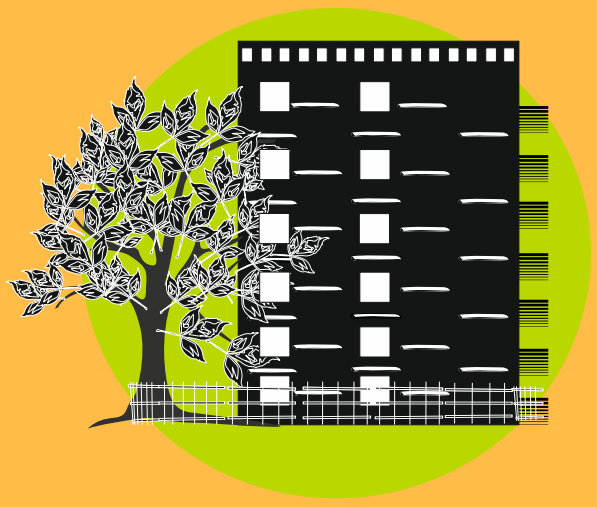

HOUSING SIZE & TYPOLOGY STUDY

Development of Thermal Comfort Action Plan 2050 and Thermal Comfort Performance based Design Standard cum Guidelines for Affordable Housing in India. [REF: 8338 0638]

Environmental Design Solutions Private Limited

Wuppertal Institute for Climate, Environment and Energy GmbH

Hunnarshala Foundation for Building Technology and Innovations

Quality Control Log

Date	Version	Revision Description	Prepared by	Approved by
Nov 24, 2021	0		Piyush	Gurneet
January 31, 2022	1	Updated a section on cost information and revised		

Disclaimer

This report is prepared by Consortium of Environmental Design Solutions Private Limited [EDS], Wuppertal Institute for Climate, Environment and Energy GmbH and Hunnarshala Foundation for Building Technology and Innovation (referred to as Consortium Partners from here on) for the Ministry of Housing Affairs (MoHUA) and the Deutsche Gesellschaft fur Internationale Zusammenarbeit (GIZ) GmbH. This report is part of the *"Development of Thermal Comfort Action Plan 2050 and Thermal Comfort Performance based Design Standard cum Guidelines for Affordable Housing in India. [REF: 8338 0638]"* project under the *Climate Smart Buildings Program* funded by GIZ India.

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Contents

Abbreviations

AAC	Aerated Autoclaved Concrete
AHP	Affordable Housing in Partnership
ARHC	Affordable Rental Housing Complex
BLC-N / BLC-E	Beneficiary-led construction or enhancement
BHK	Bedroom-Hall-Kitchen
CLC	Cellular Lightweight Concrete
CLSS	Credit Linked Subsidy Scheme
CSEB	Compressed and Stabilized Earth Block
EMI	Equated Monthly Instalment
ENS	Eco Niwas Samhita
EPS	Expanded Polystyrene
EWS	Economically Weaker Section
FALG	Fly-ash Lime Gypsum
GFRC	Glass fiber reinforced concrete
GFRG	Glass Fiber Reinforced Gypsum
GI	Galvanized Iron
GRIHA	Green Rating for Integrated Habitat Assessment
LGSF	Light Gauge Sheet Framed Structures
LIG	Low-Income Group
MoHUA	Ministry of Housing and Urban Affairs
MIG	Middle-Income Group
NBC	National Building Code
PMAY(U)	Pradhan Mantri Awas Yojana (Urban)
PMV	Predictive Mean Vote
RCC	Reinforced Cement Concrete
SC	Shading Coefficient
SIP	Structural Insulated Panel
VLT	Visual Light Transmittance
WFR	Window to Floor area Ratio
WWR	Window Wall Ratio

1 Expected outcomes

This report outlines the current affordable housing stock and typologies based on research and collected data. The purpose of characterizing affordable housing is to draw representative characteristics of existing Affordable Housing stock. These characteristics will serve as reference buildings. Thermal comfort enhancements will be applied to these reference buildings as envelope improvements, passive design principles, etc. These improvements will be synthesized into design requirements and incorporated as the Thermal Comfort performance-based Design Standard.

Following are the key outcomes expected from this report:

1) Affordable Housing typologies
2) Typical design features and construction materials
3) Range of design features and materials used in constructing affordable housing
4) Passive design features for affordable housing
5) Range of affordable housing cost

2 Establishing affordable housing characteristics

Building geometry, Envelope characteristics, Occupancy and Equipment schedules, and Cost are key affordable housing characteristics that are crucial to the development of Reference Buildings. This information is being collated from information available in the public domain such as, PMAY(U) (Schemes, Lighthouse Projects, Demonstration Projects, PMAY Model Designs, etc.), Census data, Policy papers, Case Studies and existing projects. Analysis and outcomes of secondary research are outlined in the following sub-sections.

2.1 Review of PMAY(U) policies

The existing PMAY-U schemes outline key attributes of affordable housing development that are eligible for financial incentives. Primary attributes include area and nature of development. These attributes are derived from definitions of affordable housing outlined by Task Force on *'Affordable Housing for All'*.

The Task Force has outlined the following conditions to define affordable housing:

a) Affordable housing for Economically Weaker Section (EWS)/ Lower Income Group (LIG) categories of households: A unit with a carpet area between 300-600 ft^2 (i.e. ~28 – 56 m^2) with,
    i. cost not exceeding four times the household gross annual income, and,
    ii. Equated Monthly Instalment (EMI)/rent not exceeding 30 percent of the household's gross monthly income.
b) Affordable housing for Middle Income Group (MIG) category of households: A unit with a carpet area not exceeding 1,200 ft^2 (111.5 m^2) with,
    i. the cost not exceeding five times the household gross annual income, and
    ii. EMI/rent not exceeding 40 percent of the household's gross monthly income.
c) the size of the household as five members.

With specific emphasis on PMAY(U) program, the following section reviews the various schemes of the program and how these translate into affordable housing Scope for the standard.

The PMAY(U) mission has four schemes, In-situ Slum Redevelopment (ISSR), Credit-linked subsidy scheme (CLSS), Affordable housing in Partnership (AHP) and Beneficiary-led construction (BLC). Very recently, i.e. in July 2020, the union cabinet extended the Pradhan Mantri Awas Yojana (Urban) to include Affordable Rental Housing Complexes (ARHCs). These schemes outline financial incentives for prospective homeowners, developers and planning/implementing authorities of state/UTs. These schemes shape not only the design of the development, but

also the demand for affordable housing. A brief description of these policies and the developments they support are outlined below.

a) **In-situ slum redevelopment (ISSR):** Using land as resource, the scheme provides houses to eligible slum dwellers by redeveloping the existing slums on public/ private land. Under this scheme, a grant of 1 lakh per house is provided by the central government to the planning and implementing authorities of the states/UTs.
b) **Credit-linked subsidy scheme (CLSS):** under this scheme, institutional credit is provided to EWS, LIG and MIG households for purchase of homes with interest subsidy credited upfront to the borrower's account through primary lending institutions (PLIs), effectively reducing housing loan and equated monthly instalments (EMI)
c) **Affordable housing in Partnership (AHP)**: provides financial assistance to private developers to boost private participation in affordable housing projects; central assistance is provided at the rate of 1.5 lakh per EWS house in private projects where at least 35 per cent of the houses are constructed for the EWS category.
d) **Beneficiary-led construction or enhancement (BLC):** this scheme involves central assistance of 1.5 lakh per family for new construction or extension of existing houses for the EWS/ LIG.
e) **Affordable Rental Housing Complex Scheme:** Beneficiaries for ARHCs are urban migrants/ poor from EWS/ LIG categories. ARHCs will be a mix of single/double bedroom Dwelling Units and Dormitory of 4/6 beds including all common facilities which will be exclusively used for rental housing for a minimum period of 25 years (ARHCs for Urban Migrants/Poor, MoHUA).

While not explicitly defined, these schemes also indicate the nature of development. Schemes such as ISSR, AHP and ARHC are essentially meant for multi-family dwelling units and can drive mass-scale housing developments. On the other hand, BLC scheme is meant for single family homes only. This is critical in developing reference building typologies for the standard.

Figure 1 and Table 1 illustrate the applicability of PMAY schemes and definition of affordable housing to building and development typologies.

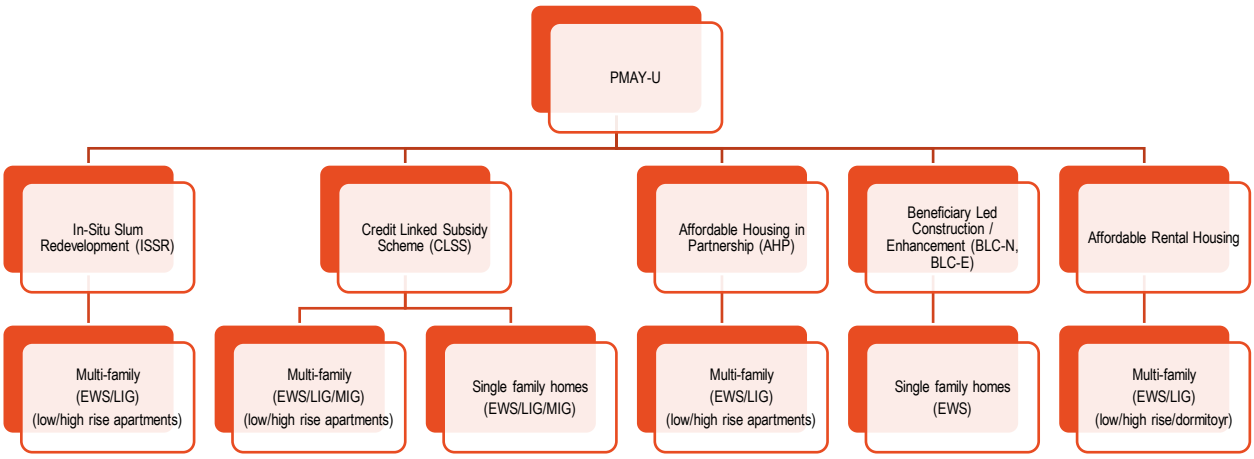


Figure 1 The PMAY-U schemes can be mapped to the typology of Dwelling Units and the nature of development

Table 1 Matrix mapping PMAY-U Schemes to dwelling unit characteristics

PMAY-U Schemes	ISSR	CLSS	AHP	BLC-N, BLC-E	ARHC
Dwelling Unit (DU) Size (Carpet Area)					
EWS	Up to 30 sqm	Up to 30 sqm	21-27 sqm	Up to 30 sqm	Up to 30 sqm
LIG	Up to 60 sqm	Up to 60 sqm	-	NA	Up to 60 sqm
LIG-A	-	-	28-40 sq m	NA	NA
LIG-B	-	-	41-60 sq m	NA	NA
MIG-1	Up to 160 sqm	Up to 160 sqm	NA	NA	NA
MIG-2	Up to 200 sq m	Up to 200 sq m	NA	NA	NA
Dormitory	NA	NA	NA	NA	
Economic Criteria (Annual Household Income)					
EWS	Up to 3 lakhs				
LIG	Between 3-6 lakhs			NA	
MIG – 1	Between 6- 12 lakhs		NA	NA	NA
MIG - 2	Between 12-18 lakhs		NA	NA	NA
Affordable Housing Project			Projects using at least 60 percent of the FAR/ FSI for dwelling units of carpet Area not more than 60 sqm.		At least 40 DUs must be constructed. Maximum of 1/3rd DUs may be 2 Bedroom units.
Dwelling Characteristics					
Min. No. of DU			250		40
EWS	Low-rise (G+3), High-rise, typically 1 BHK			Single- Family	Multi-family (1BHK)
LIG	Low-rise (G+3), High-rise, typically 2 BHK			NA	Multi-family (2BHK)
MIG	Low-rise (G+3), High-rise, typically 2.5 BHK		NA	NA	NA

*NA = Not Applicable

2.2 Review of Census data

Census includes information on housing and characteristics. This information can be filtered to reveal characteristics of urban housing. Further, markers such as number of dwelling units can reveal additional information. This section identifies relevant information from census data. Census outcomes will form a backdrop to other collected data and serve as a validation.

Census in India is conducted in two phases; Houselisting and Housing Census followed by the Population Enumeration. The Houselisting and Housing Census forms a backdrop to the Population Enumeration exercise. For Census 2011, the Houselisting and Housing Census was conducted in the period between April – September 2010. The objective of Houselisting and Housing Census is to collect data on characteristics of the house, available amenities and assets owned by home. Some of the physical characteristics of homes that the census identifies and that are relevant to this study are:

1. Condition of home ('Pucca', 'Kutcha')
2. Pre-dominant materials of construction (Floor, Wall and Roof)
3. Use type (9 attributes including residential, residential and other uses, vacant, etc.)

4. Number of dwelling rooms
5. Main source of lighting

Census defines a dwelling room as "any room with walls, a doorway and a roof having width and length enough for a person to sleep in, i.e., a length of not less than 2 metres, a breadth of at least 1.5 metres and a height of 2 metres.". Dwelling room includes living room, bedroom, dining room, drawing room, study room, servant's room and other habitable rooms that satisfy the physical dimensions outlined in the definition. It is noted that kitchen, bathroom, latrine, store-room, passageway and verandah are not considered as dwelling rooms (Census of India, 2011). As per Census data, between 1991 and 2011 approximately two-thirds of dwellings were one and two room establishments. In the decade ending 2011 the one and two room dwellings shrunk from 70% to 63% and in the same period the three-room units witnessed a marginal growth from 15% to 18%. In line with area caps outlined by policies in the previous sections, the one and two rooms dwelling units make up for EWS and LIG typologies of the Affordable housing segment. As per statistics on housing, 96% of shortage is in the EWS and LIG category (Census of India, 2011).

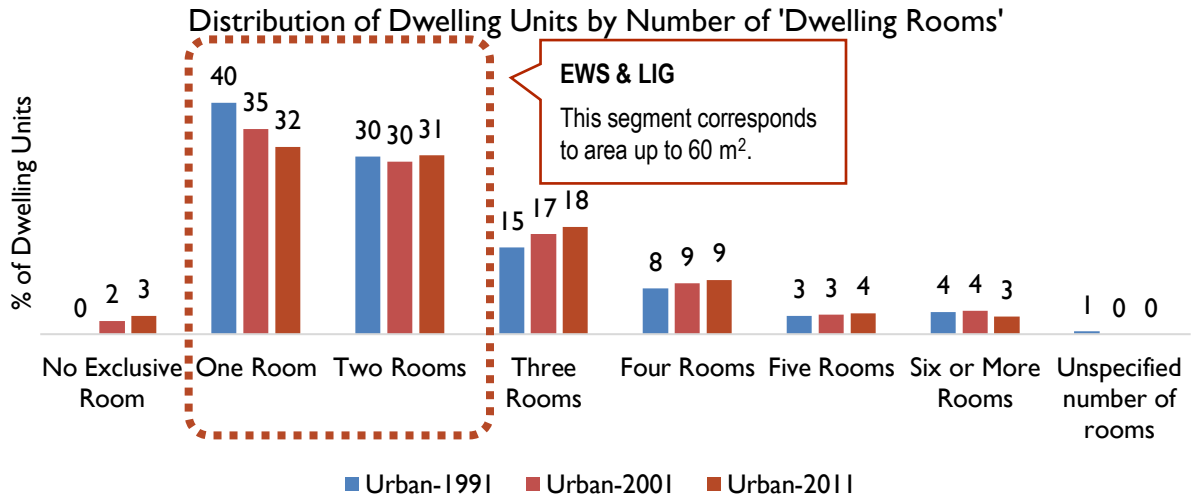


Figure 2 81% housing stock corresponds to Affordable Housing (as of 2011). Source: Distribution of households by size of dwelling units (occupied), Census 2011

The census identifies materials for homes and, based on wall and roof materials the census classifies dwellings as 'Kutcha' or 'Pucca'. Table 2 outlines the materials enumerated in the census forms. For a building to be considered 'Pucca' construction the census specifies materials for both walls and roofs. These materials have been annotated with (P) in Table 3. Buildings where wall and/or roof are predominantly made of materials such as unburnt bricks, bamboos, mud, grass, reeds, thatch, plastic/ polythene, loosely packed stone, etc., are treated as 'Kutcha' buildings. For the purpose of characterization for affordable housing, only the characteristics of 'Pucca' building are relevant.

Table 2 Materials enumerated in the Census for floor, wall and roof.

Floor	Wall	Material
Mud	Grass/thatch/bamboo etc.	Grass/thatch/bamboo/wood/mud etc.
Wood/Bamboo	Plastic/polythene	Plastic/polythene
Burnt Brick	Mud/unburnt Brick	Hand-made tiles
Stone	Wood	Machine-made tiles (P)
Cement	Stone not packed with mortar (P)	Burnt brick (P)
Mosaic/Floor Tiles	Stone packed with mortar	Stone (P)

Any other	G.I./metal/asbestos sheets (P)	Slate (P)
	Burnt brick (P)	G.I./metal/asbestos sheets (P)
	Concrete (P)	Concrete (P)
	Any other	Any other
Note: (P) indicates materials that are acceptable as 'Pucca' Construction. Although not included in the enumeration, cement bricks for walls and, Cement tiles and Cement Bricks for roof also qualify as materials for 'Pucca' house.		

Based on census data, a distribution of wall and roof materials of occupied houses indicates that almost 3/4th of the homes are constructed with burnt bricks and approximately half the homes had a concrete slab for roof. Figure 3 outlines the distribution of materials by housing stock.

Figure 3 Households by predominant material of wall and roof from census of occupied houses, Census 2011

2.3 Review of publications

Extensive secondary research has been performed to identify typical envelope characteristics, traditional design practices and exemplary design measures. Data sources include policy organizations, government agencies, research publications and market assessment studies. A literature review of publications has been presented in following sub-sections.

Representative building characteristics of low-cost housing for thermal comfort assessment studies.

Prasad et al., developed a methodology to establish thermal comfort for housing development in India. The study establishes a prototype that is an aggregate of housing building practices in New Delhi for a Middle-Income Group (MIG) household. The prototype is a cluster with 4 dwelling units on each floor. The construction practices and adopted materials are defined as follows:

- Non-load bearing 8-inch-thick brick wall supported with RCC framework. 1,440 kg/m3 is the density of bricks and thermal resistance of R-2.5 [0.44 (m^2.K)/W].
- Roof construction 4-inch-thick concrete slab with ½ inch of waterproofing (bituminous felt) and finished with 3-inch of clay tiles held with 1:3 cement mortar.
- Floor slab is 4-inch-thick concrete finished with 1-inch thick terrazzo.

- Windows are single plane glass fitted in 1 inch metal frame. Center of glass U-value is 5.11 W/(m^2.K), emissivity 0.84 and Shading Coefficient (SC) of 1.
- Window to wall ratio of 10%.
- Windows have horizontal shading 1 feet (0.3 m) deep and no vertical shades.

The study goes on to simulate various passive measures against the defined baseline to enhance thermal comfort. The study establishes an annual Root Mean Square (RMS) Predicted Mean Vote (PMV) of 2.93 for the baseline case and demonstrates improvement to 0.98 through design interventions and inclusion of evaporative cooling (Prasad & Jones, 2001).

Traditional construction practices in India for identifying representative building characteristics in low-cost housing

Tam compares the construction cost of traditional and low-cost housing methods from case studies in India. The paper identifies traditional practices for foundation, walling materials, structure (columns and beams), roof, flooring, paint and finish. The research identifies the following as typical construction materials:

- Sub-floor with 1:4:8 volumetric concrete mix over compacted soil.
- 9-inch-thick burnt brick masonry with cement plaster for outer walls,
- Roof and floor slabs are 6-inch-thick Reinforced Cement Concrete (RCC) slabs
- The wall surface is prepared with putty, primer and finished with paint.

There is no mention of window material for traditional construction methods. Low-cost construction technologies include timber frame windows, rat-trap bond (without finish) for wall, filler slab for roofs and terracotta tiles or cement flooring with colored oxides for floor. The research concludes that low cost technologies can offset more than 20% costs compared to traditional construction methods (Tam, 2011).

Baseline building parameters for Affordable Housing and alternative materials in context of urban centers: Delhi (Composite) and Mumbai (Warm-humid)

A study conducted for the Trust Fund for Environmentally and Socially Sustainable Development (TFESD), to address Climate Change with low-cost Green Housing, identifies technically viable and socially acceptable 'green alternatives', including passive measures. The technical viability of measures is based on first cost, embodied energy, operational energy, and cost of scalability and replicability. For the purpose of quantification of embodied energy and operational energy savings, a baseline case was developed for simulation studies for Delhi (Composite Climatic Zone) and Mumbai (Warm and Humid Climatic Zone). The baseline for this study has been based on housing developments in and around Delhi (Bawana, Narela, Baprola, Bhogarh, and Omicron). The study indicates that the baseline is an aggregate of typical practices in low-income development in terms of; the size of the development, unit size, semi-urban location, building materials vocabulary and number of floors.

Table 3 Baseline building parameters. Source: (EDS, Worldwide, & IIEC, 2011)

Parameter	Value
Number of floors	3 (G+2)
Floor-to-floor height	3m
Number of units in block	4 (1 BHK units of 35 m^2 each)
Built-up area of each floor	161 m^2
External wall area	208 m^2
Total window area	17.28 m^2
Window sizes	2mX1.2m, 0.9mX1.2m and 0.6 mX0.6m
m	15.12 m_2 (size 0.9 m x 2.1 m)

Table 4 Baseline building material properties. Source: (EDS et al., 2011)

Material	U-value
Brick wall with plaster on both sides	2.8 W/m^2.°C
Floor, concrete slab	3.5 W/m^2.°C
Glazing, single, clear	5.0 W/m^2.°C

Table 5 Baseline building internal gains assumptions. Source: (EDS et al., 2011)

Internal Gains	Value
Infiltration	2 Air Changes per Hour (ACH)
Lighting	5 W/m^2 (3 CFLs)
Equipment	10 W/m^2 (1 Refrigerator, 1 TV, 2 Ceiling Fans, 1 Evaporative Cooler)
Occupancy	4 (Husband, wife & 2 Children)

Figure 4 Industrial workers' housing at Bawana by Delhi State Industrial Development Corporation (DSIDC) (Architect: Adlakha Associates) has been used as representative construction for analyses.

In addition, the study also outlines alternative materials, technologies and practices in Table 6 that led to enhanced comfort and energy savings in operation (EDS et al., 2011).

Table 6 Alternative materials/practices that can improve thermal comfort performance. Source: (EDS et al., 2011)

Wall Materials/Practices	Roof Materials/Practices	Door & Window Frame Materials/Practices
Compressed Stabilized Earth Block (CSEB), Fly-ash brick, Structural Insulated Panel (SIP), Aerated Autoclaved Concrete (AAC) block, Cellular Lightweight Concrete (CLC) block.	Reflective roof tiles, Filler slab, Insulated roof.	RCC door frames and lintels Wood/plastic composites

Typical and alternative building materials in social housing in India.

Mainstreaming Sustainable Social Housing in India Project (MaS-SHIP) explores the challenge of social housing provision in India, response by state governments and learnings from case studies. As part of this project, common building materials and typologies for low-income housing have been identified. The report states that majority of low-

income housing uses conventional construction practices such as RCC framed construction. The report recognizes G+3 developments with a cluster of 4 dwelling units as the most common typology. In addition, report outlines typical materials and construction practices. These have been outlined in Table 7 (Herda et al., 2017).

Table 7 Typical material and construction practices in low-income housing. Source: (Herda et al., 2017)

Building Element	Specifications
Structure	Low-rise: Load bearing construction with strip footing and RCC plinth beam. High-rise: RCC frame structure as per codal provisions for seismic design, using M20 strength concrete.
Building envelope	230/250mm thick burnt clay brick masonry in cement-sand mortar (1:6) 150-200 mm thick concrete block masonry in cement mortar (1:6) Fly ash bricks have become a feasible alternative to burnt clay bricks in locations where fly ash availability as raw material is in the range of 100km.
Flooring	Ceramic/ vitrified tiles OR Locally available (pre polished) stone tiles 20-30mm thick over Plain Cement Concrete floor.
Openings	Pressed steel door-window frames (125mmx65mm double rebate or 100mmx50mm single rebate) Solid Core Flush doors 30mm thick or PVC shutter for internal door 6mm thick float glass for glazed parts, 450mm wide RCC sunshades for windows
Finishes	Cement-Sand Plaster 20mm thick (external), 15mm thick (internal) White cement-based putty Cement Paint external and internal or white-wash internal

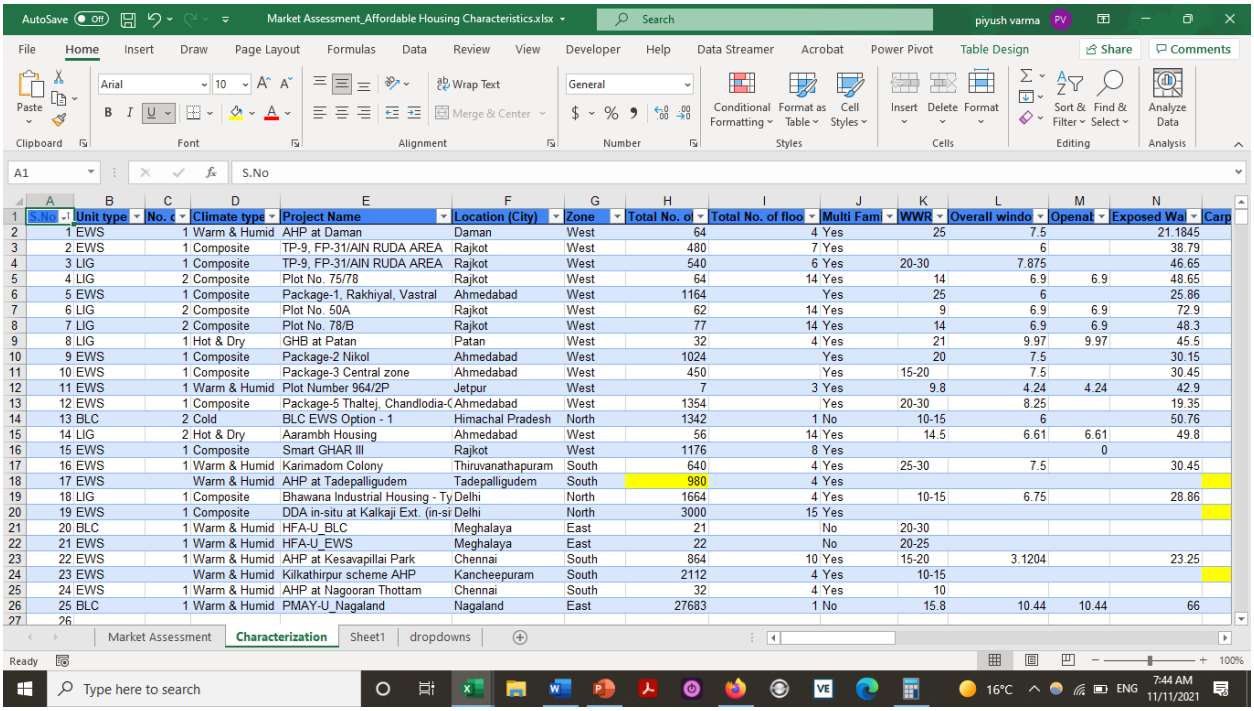
The MaS-SHIP project also identifies alternative building materials and systems. Table 8 outlines at alternative building materials and systems.

Table 8 Alternative Building Materials/ Systems. Source: (Herda et al., 2017)

Wall	Roof	Door/Window
Rat-trap bond walls in burnt clay bricks	Filler slab roof	Natural Fibre Composite door shutters
Fly ash bricks	Precast brick panel roof	Precast RCC door-window frames
Concrete blocks	Precast Plank Joist roof	
Stone filler blocks	Jack Arch roof	
EPS panels	EPS panels	
Glass fiber reinforced concrete (GFRC)	Glass fiber reinforced concrete (GFRC)	
AAC blocks		
Monolithic concrete technology		

2.4 Compilation of project data and case studies

An extensive study of Affordable Housing projects available in the public domain has been conducted. This includes the Light House Projects, Demonstration Housing Projects, Housing projects executed by various State Housing boards and projects by private developers. The data looks at EWS and LIG categories. The typologies included in the dataset include single-family units and multi-family that are low- and high-rise. The data set represents information from over 40 projects indicative of approximately 30,000 dwelling units from 4 climate types (Cold, Composite, Hot-dry and Warm-humid). The data looks at key metrics including area of dwelling units, number of rooms, window to floor area and exposed wall area to floor area ratios. These metrics can be identified based on climate and typology.



S.No	Unit type	No. c	Climate type	Project Name	Location (City)	Zone	Total No. of	Total No. of floo	Multi Fami	WWR	Overall windo	Openat	Exposed Wa	Carp
1	EWS	1	Warm & Humid	AHP at Daman	Daman	West	64	4	Yes	25	7.5		21.1845	
2	EWS	1	Composite	TP-9, FP-31/AIN RUDA AREA	Rajkot	West	480	7	Yes		6		38.79	
3	LIG	1	Composite	TP-9, FP-31/AIN RUDA AREA	Rajkot	West	540	6	Yes	20-30	7.875		46.65	
4	LIG	2	Composite	Plot No. 75/78	Rajkot	West	64	14	Yes	14	6.9	6.9	48.65	
5	EWS	1	Composite	Package-1, Rakhiyal, Vastral	Ahmedabad	West	1164		Yes	25	6		25.86	
6	LIG	2	Composite	Plot No. 50A	Rajkot	West	62	14	Yes	9	6.9	6.9	72.9	
7	LIG	2	Composite	Plot No. 78/B	Rajkot	West	77	14	Yes	14	6.9	6.9	48.3	
8	LIG	1	Hot & Dry	GHB at Patan	Patan	West	32	4	Yes	21	9.97	9.97	45.5	
9	EWS	1	Composite	Package-2 Nikol	Ahmedabad	West	1024		Yes	20	7.5		30.15	
10	EWS	1	Composite	Package-3 Central zone	Ahmedabad	West	450		Yes	15-20	7.5		30.45	
11	EWS	1	Warm & Humid	Plot Number 964/2P	Jetpur	West	7	3	Yes	9.8	4.24	4.24	42.9	
12	EWS	1	Composite	Package-5 Thaltej, Chandlodia-(	Ahmedabad	West	1354		Yes	20-30	8.25		19.35	
13	BLC	2	Cold	BLC EWS Option - 1	Himachal Pradesh	North	1342	1	No	10-15	6		50.76	
14	LIG	2	Hot & Dry	Aarambh Housing	Ahmedabad	West	56	14	Yes	14.5	6.61	6.61	49.8	
15	EWS	1	Composite	Smart GHAR III	Rajkot	West	1176	8	Yes			0		
16	EWS	1	Warm & Humid	Karimadom Colony	Thiruvanathapuram	South	640	4	Yes	25-30	7.5		30.45	
17	EWS		Warm & Humid	AHP at Tadepalligudem	Tadepalligudem	South	980	4	Yes					
18	LIG	1	Composite	Bhawana Industrial Housing - Ty	Delhi	North	1664	4	Yes	10-15	6.75		28.86	
19	EWS	1	Composite	DDA in-situ at Kalkaji Ext. (in-si	Delhi	North	3000	15	Yes					
20	BLC	1	Warm & Humid	HFA-U_BLC	Meghalaya	East	21		No	20-30				
21	EWS	1	Warm & Humid	HFA-U_EWS	Meghalaya	East	22		No	20-25				
22	EWS	1	Warm & Humid	AHP at Kesavapillai Park	Chennai	South	864	10	Yes	15-20	3.1204		23.25	
23	EWS		Warm & Humid	Kilkathirpur scheme AHP	Kancheepuram	South	2112	4	Yes	10-15				
24	EWS	1	Warm & Humid	AHP at Nagooran Thottam	Chennai	South	32	4	Yes	10				
25	BLC	1	Warm & Humid	PMAY-U_Nagaland	Nagaland	East	27683	1	No	15.8	10.44	10.44	66	
26														

Figure 5 Data compilation of Affordable Housing Projects

The data analysis reveals the following characteristics.

1. The following construction materials by building elements are prevalent.
    a. Wall construction material: Burnt bricks, AAC block and Monolithic Concrete
    b. Roof construction is RCC
    c. Single Glazing 6 mm in Aluminum Frame
2. Building Geometry
    a. Window to wall ratio:
        i. EWS: 10-30%
        ii. LIG: 20-25%
    b. Wall Area (exposed) to floor area ratio
        i. EWS: 1.0
        ii. LIG: 1.3

Other than a few isolated cases in the cold climate, there are no climatic/geographic variations in construction. Additionally, key metrics defining building geometry (WWR, WFR and Exposed Wall area to floor area ratio) for EWS and LIG are similar. The analysis is ongoing and is expected to be updated.

Case examples of in-situ and relocation housing for slum dwellers across11 cities in India

Society for the Promotion of Area Resource Centres (SPARC) conducted surveys and field studies in 11 cities spanning 9 states to document Basic Services for Urban Poor (BSUP) under the Jawaharlal Nehru National Urban Renewal Mission (JNNURM) scheme. This program identifies in-situ and relocation housing for slum dwellers. The report explores the gaps in implementation and best practices in successful projects elsewhere. The extensive field studies and data compilation indicates that of the approximately 1.70 lac Dwelling Units sanctioned from 2006 onwards until the preparation of this report (2012), less than a quarter of Dwelling Units were completed and less than half of them were occupied. The report investigates challenges that are leading to limited uptake of these homes

(SPARC, 2012). A review of 10 such projects spread across India, indicates that 9 of these developments are low - rise (G+3) and only one is mid-rise (Stilt + 7). The mid-rise development is in the metropolitan city of Pune. The analysis of this report indicates that low-rise development has been the most common across tier 1 and lower tier cities, while in dense urban agglomerations mid/high-rise developments have been adopted as well. Findings from the report indicate that these projects had limited participation from developers as these were not seen as profitable ventures. In most cases, the developers who did take up these projects provided construction of sub-standard quality. Among these projects, there have been several instances of contractors leaving jobs in between due to lack of finances. It may be concluded that amidst lack of financing, limited infrastructure and constrained capacity to deliver, low-rise constructions will remain to be of significant interest. It is noteworthy that the information contained in the report reflects the 2000-2010 decade and urbanization has been on the rise since then. Refer Table 9 for images and details of case examples.

Table 9 Majority of In-situ and Re-location housing examples have been constructed as low-rise development in the first decade of the 21st century. Source: (SPARC, 2012)

Case examples of In-situ and Re-location Housing Developed under the Basic Services for Urban Poor (BSUP) sub-mission of Jawaharlal Nehru National Urban Renewal Mission (JNNURM) scheme	
	
Location: Asansol, West Bengal Project: In-situ and Relocation Housing, Shrinagar Colony Implementing Agency: Asansol Municipal Corporation (AMC) Typology: G+3 Number of Units: 288 Cost/DU: 1,32,000 (As/DPR, actual data not available) Completion Year: 2009	Location: Durgapur, West Bengal Project: In-situ Redevelopment, Sanatorit, Cmeri Basti, Durgapur Implementing Agency: Durgapur Municipal Corporation (DMC) Typology: G+1 Number of units: 400 Cost/DU: 1,32,000 (As/DPR, actual data not available) Completion Year: 2010
	
Location: Bhopal, Madhya Pradesh Project: In-situ Redevelopment, Kalpana Nagar, Near Indrapuri	Location: Bhopal, Madhya Pradesh Project: In-situ Redevelopment and Relocation Housing, Shabri Nagar

Implementing Agency: Bhopal Municipal Corporation (BMC) Typology: G+3 Number of Units: 212 Cost/DU: 1,50,000 Completion Year: 2012 Area: 223 ft^2	Implementing Agency: Bhopal Municipal Corporation (BMC) Typology: G+3 Number of Units: 512 Cost/DU: 1,15,000 Completion Year: 2011
 	
Location: Bhubaneswar, Odisha Project: In-site Relocation at Gadakan, Damana and Chandrashekharpur Implementing Agency: Bhubaneswar Development Authority (BDA) Typology: G+3 (6 blocks, 32 units per block) Number of Units: 192 Cost/DU: 3,25,000 Completion Year: 2013 (Expected at the time of report publication) Area: 36.5 m^2	Location: Patna, Bihar Project: In-situ project at Sharifaganj Phase III, Patna Implementing Agency: Housing and Urban Development Corporation (HUDCO) Typology: G+3 Number of Units: 208 Cost/DU: 1,55,000 Completion Year: No data available
	

	
Location: Patna, Bihar Project: In-situ project at Isopur Nahar, Phulwari Sharif Phase I, Patna Implementing Agency: Housing and Urban Development Corporation (HUDCO) Typology: G+3 Number of Units: 192 Cost/DU: 2,42,000 Completion Year: 2011	Location: Pune, Maharashtra Project: Relocation housing at Warje, Pune Implementing Agency: Pune Municipal Corporation (PMC) Typology: Stilt+7 Number of Units: 2,576 (1,344 DUs for relocation) Cost/DU: 4,25,000 Completion Year: No data Units do not include a balcony. MIG and HIG units have also been constructed.
	
Location: Vishakhapatnam, Andhra Pradesh Project: Relocation housing at Madhurwada I, Kommadi (Package II DPR) Implementing Agency: Greater Vishakhapatnam Municipal Corporation (GVMC) Typology: G+3 Number of Units: 960 Cost/DU: 1,92,000 Completion Year: No data	Location: Vishakhapatnam, Andhra Pradesh Project: In-situ Redevelopment in East Point Colony (Package I DPR) Implementing Agency: Greater Vishakhapatnam Municipal Corporation (GVMC) Typology: G+3 Number of Units: 32 Cost/DU: 1,65,000 Completion Year: No data

Case studies of exemplary housing projects across India's climate zones

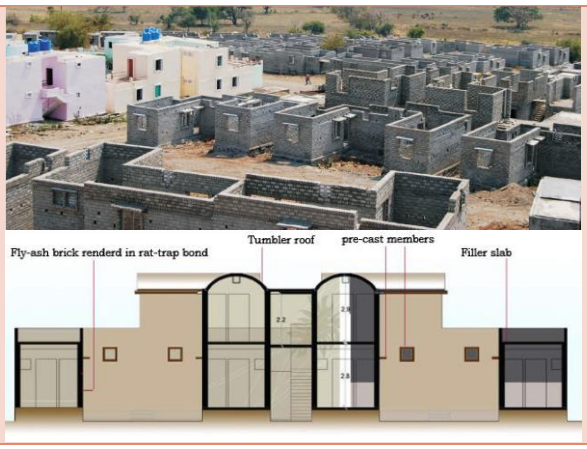
Case studies of housing projects with innovative and exemplary design practices have been compiled from several sources. These identify passive strategies and innovative materials that may be utilized for enhancing thermal comfort performance. These case studies also identify climate specific strategies.

Table 10 Salient features of Passively Designed Thermally Comfortable Housing Projects across climate zones

Case Examples: Materials, Technologies and Design Practices that enhance Thermal Comfort Performance	
	
Project Name: T-Zed Homes **Location | Climate:** Bengaluru, Temperate **Typology:** Multi-family, 2BHK (120 m^2), 3 BHK (250 m^2) **Conditioning Status:** Air-conditioned **Passive Features:** # Low rise (15 m) – limited to height of existing trees # Designed for daylight. Total lighting load across the season at daytime is nearly 0. # Shaded East-West facade **Wall:** Concrete Blockwork containing Flyash, soil stabilized blocks and mortar on exterior and interior surfaces containing granite dust, no external paint application **Floor:** Natural stone finish **Roof:** Filler slabs (using recycled railway sleeper bits) **Glazing:** Shutters of non-forest timber like rubber wood. Source:	**Project Name:** Malhar Footprints (Good Earth) **Location | Climate:** Bengaluru, Temperate **Typology:** Multi-family, 3 BHK (213 m^2) **Conditioning Status:** Non-Air-conditioned. **Passive Features:** # Reduced hard paving, Mud concrete for paved surfaces # Surface to Volume ratio ranging between 0.26 to 0.43 # WWR of 18% to 25% # Shaded Verandah # Skylights over stairwell, # Courtyards integrated for daylighting and ventilation **Wall:** CSEB & random rubble masonry **Floor:** Local clay tiles, athangudi and vitrified tiles **Roof:** RCC Roof slab ventilated and shaded with GI sheet. **Glazing:** Single glazing, shaded with RCC and Mangalore tile roof overhang. **Source:**
	

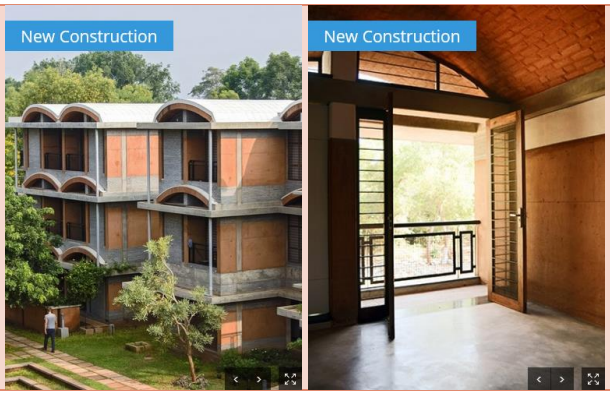
Project Name: Realization Community **Location | Climate:** Tamil Nadu, Warm-Humid **Typology:** Multi-family, 1& 2 BHK **Conditioning Status:** Non-Air-conditioned **Passive Features:** # Double height spaces for stack effect cooling # Staggered floor plan # Earth cooling tunnels # Hygrothermal cooling **Wall:** Compressed Stabilized Earth Blocks (CSEB) with lime stabilized earth plaster **Floor:** Vaulted floor systems having cavities and ventilators **Roof:** CSEB vaulted roofing with insulation **Glazing:** Single Glazed, recessed windows or with overhangs **Source:** Tropical Buildings	**Project Name:** Humility **Location | Climate:** Tamil Nadu, Warm-Humid **Typology:** Multi-family, 2 BHK (131 m^2), 3 BHK (170 m^2), **Conditioning Status:** Non-Air-conditioned **Passive Features:** # Naturally ventilated low height structures. # Floor to ceiling openings on North and South façade for cross ventilation and daylighting # Vegetation to shade East and West walls **Wall:** Flyash bricks with Lime cement finish **Floor:** Vitrified tiles **Roof:** Styrofoam insulation and reflective tile finish **Glazing:** Anodised Aluminium for windows and sliding doors **Source:** Topical Buildings
	
Project Name: Slum Rehabilitation **Location | Climate:** Bhuj, Hot-dry **Typology:** Incremental Row house, 2 BHK (21 - 35m^2) **Conditioning Status:** Non-Air-conditioned **Passive Features:** # Oriented facing South and South-West for ventilation **Wall:** Light coloured **Roof:** Sloping roof with insulation layer, and Flat roof made of shallow domes using earth blocks **Source:** NAREDCO	**Project Name:** Smart Ghar III **Location | Climate:** Rajkot, Hot-dry **Typology:** Multi-family, 1 BHK (34 m^2), Stilt + 7 **Conditioning Status:** Non-Air-conditioned **Passive Features:** # Cavity wall (South façade) # Common shaft for mechanically assisted ventilation # Insulated (40mm Polyurethane foam insulation) and roof finished with china mosaic. # Casement windows with external movable shades **Wall:** 230mm AAC blocks, South façade cavity wall **Roof:** Insulated (40mm Polyurethane foam insulation) and roof finished with china mosaic. **Source:** BEEP

Project Name: Demonstration Housing Project
Location | Climate: Rae Bareli, U.P., Composite
Typology: Multi-family, 1 BHK (34 m2), G+1
Conditioning Status: Non-Air-conditioned
Passive Features:
Rat-trap bond wall and filler slab.
Shaded windows
High ceiling for top floor
Wall: Burnt Clay bricks in Rat Trap Bond, Exposed finish with pointing and water-proofing cement paint.
Roof: Reinforced Brick Concrete Slab for ground floor roof, Filler slab with Earthen Pots for slope roofing, Mangalore tile cladding on sloping roof.
Floor: IPS flooring
Door/Window: Pre cast RCC door frames, Steel window frames and glazed shutters.
Source: Special Issue – Voices from Slums, Nirman Sarika, BMTPC (Vol.3, Issue 3, July – September 2014)



Project Name: Integrated Housing and Slum Development Programme (IHSDP) Phase II at Lonar
Location | Climate: Lonar, Maharashtra, Hot-dry
Typology: Multi-family, 1 BHK (25 m^2), G+1
Conditioning Status: Non-Air-conditioned
Passive Features:
Filler slab, tumbler roofing and rat-trap to improve insulating properties of the envelope.
Cluster planned around courtyards to improve natural ventilation potential.
Wall: 230 mm Rat trap bond using Flyash Bricks and 15mm plaster on both faces.
Roof: Tumbler roofing, that is burnt clay conical tumblers are placed in the arch on the roof.
Source: TERI/HUDCO

Project Name: GERES
Location | Climate: Leh, Cold
Typology: Single-family, 1 BHK (34 m2), G+1
Conditioning Status: Non-Air-conditioned
Passive Features:
Solarium facing South to trap heat during day.
Double wall with insulation on North, East and West



Project Name: Humanscapes Habitat
Location | Climate: Auroville, Puducherry, Warm-Humid
Typology: Single-family, 1 BHK (34 m2), G+1
Conditioning Status: Non-Air-conditioned
Passive Features:
Light shelf for daylight.

# Insulated floor and roof **Wall:** Outer wall made of rammed earth or mud/cement bricks. Inside wall made of mud/cement brick. **Roof:** Structural system made of wood with a layer of insulation and finished with mud. False roof on the inside filled with natural materials (dried vegetation) and saw dust. **Source:** TERI/HUDCO	# Takes advantage of land and sea breeze for natural ventilation # Shaded windows # High ceiling to aid ventilation. Designed for adaptive comfort **Wall:** Poured Earth Concrete (PEC) wall and Waste Cuddapah stone wall **Roof:** Brick vaults. **Flooring:** Natural stone flooring, Indian Patent Stone (IPS) **Source:** Construction21 International

3 Performance of materials and construction practices

In addition to outlining the alternatives and materials, establishing their performance is essential to the development of the standard. Review of performance characteristics will also facilitate shortlisting viable materials/techniques for enhancing thermal comfort. A preliminary review of data available in the public domain has been conducted to outline performance of walling materials and construction assemblies.

A study conducted by GKSPL and CRDF evaluated the thermophysical properties of commonly used building products. Samples for Fired clay brick, Fly ash brick, Solid concrete brick, Solid concrete block, Calcium silicate block, Autoclaved aerated concrete block (AAC), Cellular light weight concrete block (CLC) and Compressed stabilized earth block (CSEB) have been collected for measuring Thermal conductivity, Specific Heat, Dry Density and Water Absorption. Products from across India have been sampled and tested. The study establishes a correlation between thermal conductivity and bulk density for fired and non-fired walling material. Finally, RETV is calculated on a standard design using uniform thickness of 200mm with 15mm thick plaster on both sides for each tested walling unit. The analysis is performed for Rajkot (Composite climate) (Rawal et al., 2020). The thermal performance of materials as RETV is outlined in Figure 6.

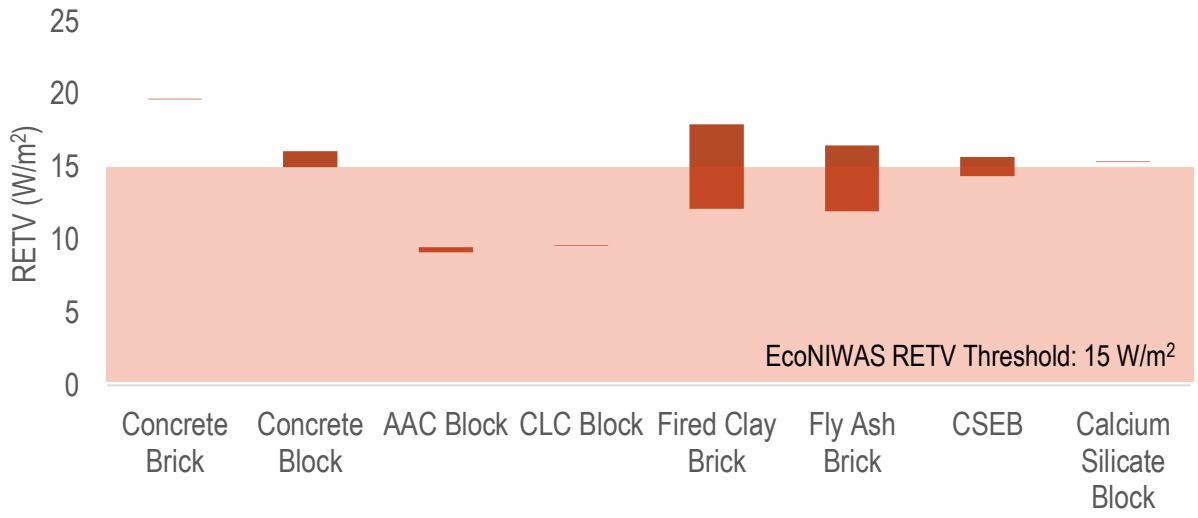


Figure 6 Building materials' RETV performance analyzed for a standard design in Composite climate

The study by GKSPL and CRDF also evaluates construction technologies that are being promoted to support the Affordable Housing boom for thermal performance. The study tested wall assemblies using the Guarded Hot Box as

per ASTM C 1363. The assemblies include low cost masonry techniques (Standard brick wall and Rat-trap bond wall) and 7 other walling technologies certified by the BMTPC (Rawal et al., 2020).

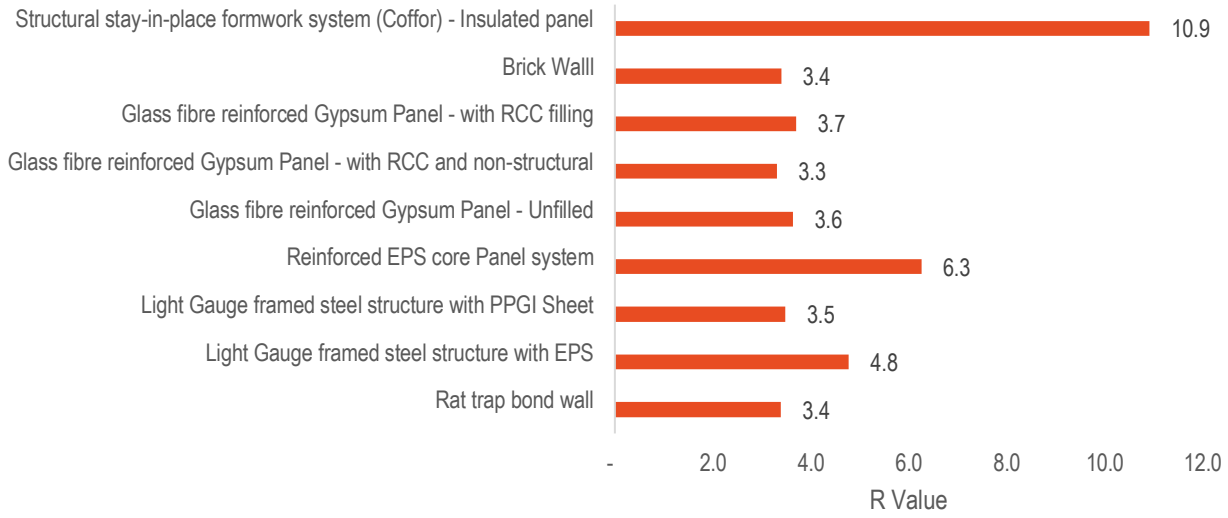


Figure 7 Thermal performance of Wall Construction Technologies

4 Cost of developing affordable housing

This section outlines the range of cost of affordable housing. It looks at data available in the public domain.

"Affordable" as a concept is relative and dependent on an individual's financial capability, city of consideration, demand-supply dynamics and real estate prices, which makes the definition of "affordable housing" very subjective. Various socio-economic factors such as household income, location, price, size of dwelling units, employment opportunities, government incentives, etc. play a key role in defining affordable housing. Generally, affordable housing is targeted towards a particular section of society which has an income equivalent or lowers than the median income.

The cost of affordable housing varies drastically even between the different metro cities, which can be observed in the below attached table. To summarize the below data available, the cost range of affordable housing in most of the cities is more or less the same, alike Mumbai and Kolkata, which stands out, in terms of being the costliest and cheapest, respectively.

Table 11: Cost of affordable housing in metro cities

S.No.	City	Cost
1.	National Capital Region	INR 2,400/- to INR 3,500/- per ft². Source
2.	Hyderabad	INR 2,800/- to INR 4,000/- per ft² Source
3.	Ahmedabad	INR 1,700/- to INR 3,100/- per ft² Source
4.	Kochi	INR 2,500/- to INR 3,000/- per ft² Source
5.	Kolkata	INR 600/- to INR 1,900/- per ft² Source
6.	Chennai	INR 2,500/- to INR 3,500/- per ft² Source
7.	Bengaluru	INR 2,900/- to INR 4,000/- per ft² Source
8.	Mumbai	INR 6,100/- per ft² Source

Table 12: Cost of affordable housing in non-metro cities

S.No.	City	Cost
1.	Nagpur	INR 2,000/- to INR 2,400/- per ft^2 *Source*
2.	Jaipur	INR 1,260/- per ft^2 *Source*
3.	Siliguri	INR 450/- to INR 620/- per ft^2 *Source*
4.	Bhopal	INR 1,400/- to INR 2,000/- per ft^2 *Source*
5.	Raipur	INR 900/- to INR 1,400/- per ft^2 *Source*

In addition to the above information, cost information has been compiled for more than 50 Affordable Housing Projects across India. These projects are spread across Metro and Non-metro cities. It must be borne in mind that the data presented for these reflects data from for a period spanning 2 decades. Figure 8 indicates correlation of cost versus area and the distribution of unit cost across metro and non-metro cities. The analysis indicates that the cost per unit area Non-metros ranges between 850 to 2,600, while for Metros it is considerably higher at 1,750 to 3,200.

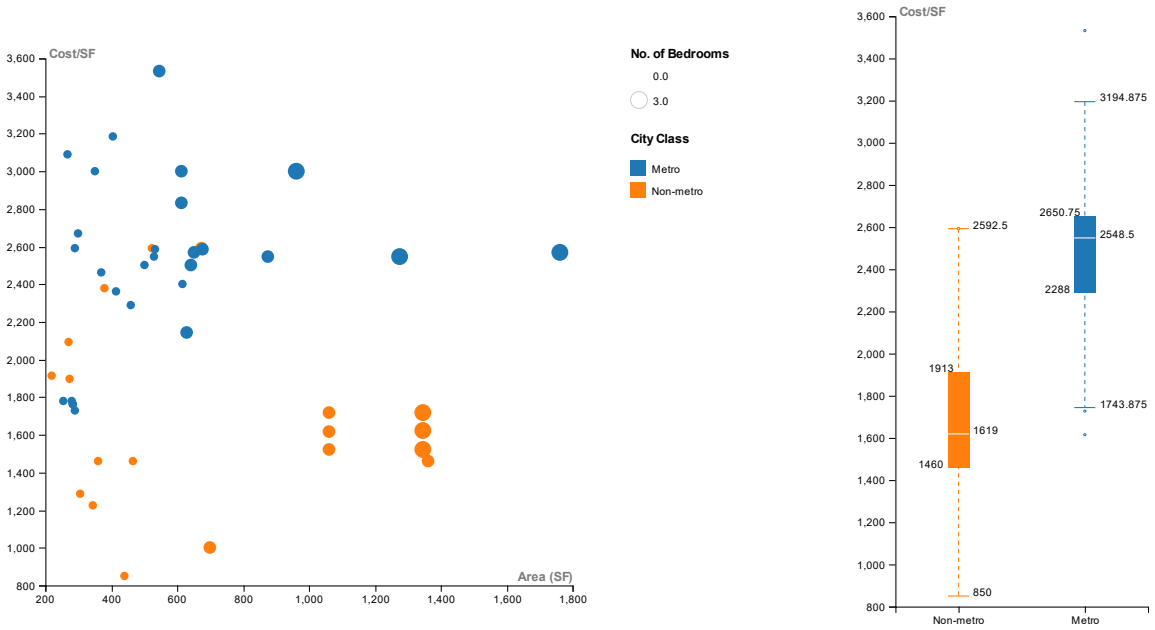


Figure 8 Cost information segregated by urbanization for a sample of projects indicates that the prices in Non-metros are significantly lower than cost for Metros.

As far as the Light House Projects (LHPs) are concerned, the typical cost of a single LHP unit having carpet area of 370 ft^2 of carpet area, is estimated at 12.59 lakhs which is around INR. 3,400/- per ft^2 of carpet area. The Indian Government is expected to provide a subsidy of INR 7.83 lakhs to the buyer. The LHPs with alternate systems cost 10-15% higher initially, but across the life of the building these prices are expected to be lower. During the life span of a building, the financial payback will exceed the additional initial cost of using alternate systems. And broader benefits, such as reductions in greenhouse gases (GHGs) and other pollutants have large positive impacts on surrounding communities and on the planet (Tandon 2021).

In contrast to the information above, cost information outlined for the sample of 50 projects, indicates that largely government housing is more economical than their private counterparts for the end user. However, it is important to note that the costs reflected for government housing includes subsidized rates which is not reflective of the actual cost. Further, the dataset does not include cost information for Light House Projects and Demonstration Housing Projects.

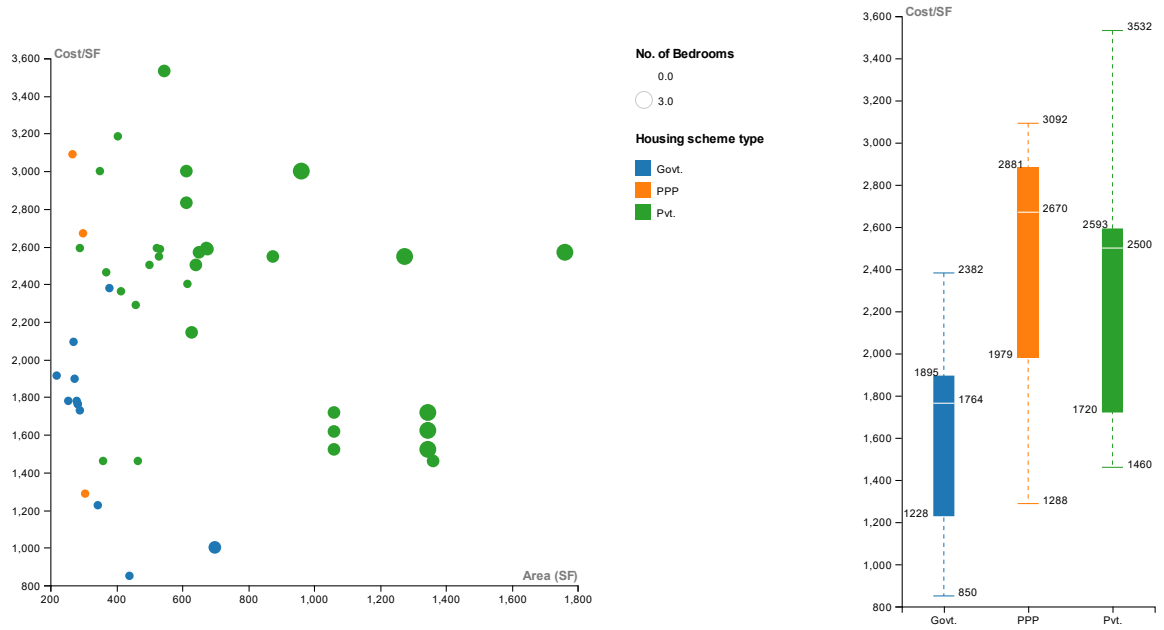


Figure 9 Cost information segregated by developing authority for a sample of projects indicates that government sponsored housing is more affordable compared to private housing.

5 Outcomes

The review of housing policies, census data, research and publications, case studies and data on existing projects have facilitated assessment of existing affordable housing stock to draw out reference building characteristics. The analysis outlines typologies, building geometry, typical construction and traditional construction practices. The review also identifies alternative materials, technologies and techniques which will serve as boundary conditions for development of thermal comfort standard. Finally, case studies outline passive design principles for enhancing thermal comfort performance. The following sub-sections describe these outcomes.

Typologies

The typologies have been synthesized from policies and existing building practices. These typologies are primarily characterized by nature of development and area. Figure 10 outlines the typology map and Figure 11 presents building geometry for different typologies from PMAY(U) model homes.

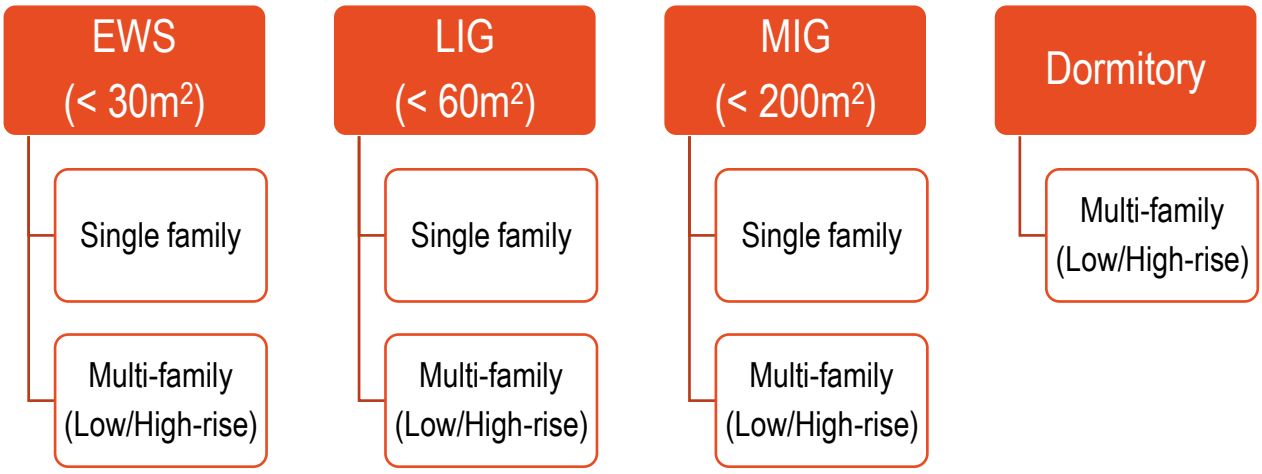


Figure 10 Affordable housing typology map

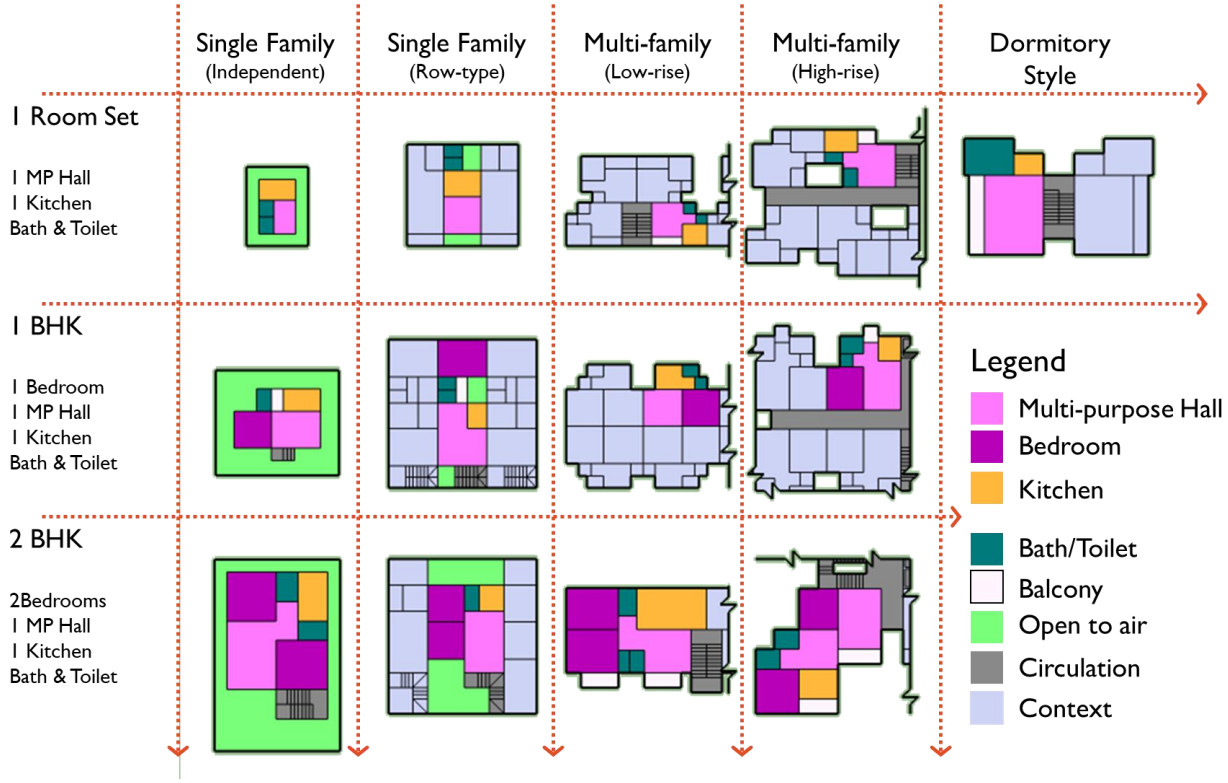


Figure 11 Review of PMAY-U schemes outlined typical geometries for, EWS, LIG, MIG and Dormitory style homes.

Envelope Characteristics – Typical

Analyses of case-studies, research, publications and existing projects reveals typical construction materials. Research of existing projects, largely implemented under various central/state programs in the last 2 decades indicate similar characteristics (design and materials) with little or no variation across climates. There are slight variations among multi-story apartments and single-story dwelling units owing to structural requirements. Typical housing characteristics have been presented in Table 13.

Table 13 Typical construction assemblies that characterize for affordable housing in India.

	Single Family	Multi-family
Structure	Load bearing construction with strip footing and RCC plinth beam. Stone, where readily available.	RCC frame structure as per codal provisions for seismic design, using M20 strength concrete.
Envelope	230/250mm thick burnt clay brick masonry in cement-sand mortar (1:6) 150-200 mm thick concrete block masonry in cement mortar (1:6) Fly Ash bricks are a feasible alternative.	
Flooring	Ceramic/ vitrified tiles Locally available (pre polished) stone tiles 20-30mm thick Plain Cement Concrete floor	
Openings	Wooden shutters on wooden frame. Pressed steel door-window frames (125mmx65mm double rebate or 100mmx50mm single rebate)	Pressed steel door-window frames (125mmx65mm double rebate or 100mmx50mm single rebate)
Finishes	Cement-Sand Plaster 20mm thick (external), 15mm thick (internal) White cement-based putty Cement Paint external and internal or White wash internal	

Alternative Construction Materials and Technologies

Review of existing projects and research in materials technology led to the identification of several construction materials, techniques and technologies. Some of these have been compiled in Table 14.

Table 14 Alternative materials and technologies

Alternative Wall Materials	
• Aerated Autoclaved Concrete (AAC) block • Clay Fly Ash Burnt Bricks • Concrete Brick/Block (Hollow/Solid) • Corrugated Sheet (G.I./metal/asbestos/bamboo mat) • Cellular Lightweight Concrete (CLC) block. • Compressed Stabilized Earth Block (CSEB) • Ferrocement Panel • Fly-ash brick	• Fly-ash Lime Gypsum (FALG) brick • Hemp blocks (Hemp or Agri-waste with lime binder) • Marble Slurry Bricks • Rice Husk Block • Stone • Stone filler blocks • Structural Insulated Panel (SIP)
Alternative Wall Technologies/Techniques	
• Cavity wall • Cement Plaster on Bamboo Split • Compressed Earth/ Fly-ash Lime, Sand and Gypsum Composite Interlocking blocks • Expanded Polystyrene Core Panel System • Exterior Insulation and Finishing System • Factory Made Fast Track Modular System • Fibre reinforced cement sheets on either side of light weight concrete core (Aerocon Panels) • Glass Fiber Reinforced Gypsum (GFRG) Panel Building System	• Light Gauge Sheet Framed Structures (LGSF) System • Monolithic Concrete Construction System using aluminum/plastic-aluminum formwork • Monolithic Construction with Structural Stay-In-Place CR Steel Specially Designed Formwork System (Coffor) • Poured Earth Concrete • Rat-trap bond • Stay in place EPS double walled panel system
Alternative Roof Materials	
• Brick • Concrete (Cast in-situ, Pre-cast, Pre Stressed) • Corrugated Sheet (G.I./metal/asbestos/bamboo mat)	• Ferrocement • Micro concrete • Stone
Alternative Roof Technologies/Techniques	
• Cellular light weight concrete slabs • Ferrocement Roofing Channel • Filler slab roof • Glass Fiber Reinforced Gypsum (GFRG) panel building system • Jack Arch roof • Light Gauge Sheet Framed Structures (LGSF) system	• Madras roofing technique • Micro concrete roofing tiles • Precast brick panel roof • Precast concrete panels • Precast plank joist roof • Precast solid slab • Prestressed concrete ribbed/cored slabs
Door and Window Frames	
• Ferrocement frames • Pressed steel door and window frames • Natural Fibre Composite door shutters	• UPVC Window frames • Wood/plastic composites

• RCC door frames and lintels	

Passive measures in the Indian Context

Review of Case Studies and existing rating systems (GRIHA and SVAGRIHA) led to a comprehensive list of passive design strategies and low-energy comfort systems, mapped to India's 5 climatic zones. These measures can potentially enhance thermal comfort. These have been outlined in Table 15.

Table 15 Passive design measures and their applicability in India's 5 Climate Zones. Source: GRIHA-AH v1 and SVAGRIHA v2.2

Measures	Composite	Cold	Warm-Humid	Temperate	Hot - Dry
Building Orientation					
Buffer spaces on east & west facades					
Ventilators					
Earth berms					
Thermal Mass					
Cross Ventilation					
Green Roof / Terrace Gardens					
Cool Roofs, High-reflective paint surfaces					
Geothermal cooling/heating					
Solar Chimney/Wind Tower					
Courtyards					
Light colored external surfaces					
Passive Evaporative Cooling Structures					
Reduced solar access					
Cavity walls					
Roof insulation					
Light shelves					
Trombe Walls					
Solarium					
Heat capturing wall panels					
Sun spaces					
Solar wall					
Solar heat collector-based ventilation/ thermal system					
Direct solar gain in rooms					
In-direct solar gain					

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