Mainstreaming thermal comfort for all and resource efficiency in affordable housing

Status review of PMAY-U mission
to understand barriers and drivers

May 2018

SHAKTI SUSTAINABLE ENERGY FOUNDATION

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Contents

List of figures

List of tables

List of abbreviations

AHP	Affordable Housing in Partnership
AIPs	Annual Implementation Plans
AMRUT	Atal Mission for Rejuvenation and Urban Transformation
BEE	Bureau of Energy Efficiency
BLC	Beneficiary-Led Construction
BMTPC	Building Materials and Technology Promotion Council
BSUP	Basic Services for the Urban Poor
BUA	Built-up Area
CEA	Central Electricity Authority of India
CLSS	Credit Linked Subsidy Scheme
CLTC	City Level Technical Cell
CNAs	Central Nodal Agencies
CPR	Centre for Policy Research
CSMC	Central Sanctioning and Monitoring Committee
DPRs	Detailed Project Reports
DUs	Dwelling Units
ECBC	Energy Conservation Building Code
ECBC-R	Energy Conservation Building Code for Residential
EWS	Economically Weaker Section
FAR	Floor Area Ratio
FSI	Floor Space Index
GDCR	General Control Regulation
GoI	Government of India
GRIHA	Green Rating for Integrated Habitat Assessment
HFA	Housing for All
HFAPoA	Housing for All Plan of Action
HUDCO	Housing and Urban Development Corporation
HVAC	Heating, Ventilation and Air-conditioning
IGBC	Indian Green Building Council
IHSDP	Integrated Housing and Slum Development Programme
ISHUP	Interest Subsidy Scheme for Housing the Urban Poor
ISSR	“In situ” Slum Redevelopment
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
LIG	Lower Income Group
MIG	Middle Income Group
MoA	Memorandum of Agreement
MoHUA	Ministry of Housing and Urban Affairs
MoHUPA	Ministry of Housing and Urban Poverty Alleviation
MoUD	Ministry of Urban Development
NBC	National Building Code
NHB	National Housing Bank
NIUA	National Institute of Urban Affairs
NSDP	National Slum Development Programme
NSS	National Sample Survey
PMAY	Pradhan Mantri Awas Yojana
PMAY-G	Pradhan Mantri Awas Yojana (Gramin)

PMAY-R	Pradhan Mantri Awas Yojana (Rural)
PMAY-U	Pradhan Mantri Awas Yojana (Urban)
PPP	Public Private Partnership
RAY	Rajiv Awas Yojana
RUDA	Rajkot Urban Development Authority
SHGC	Solar Heat Gain Coefficient
SLAC	State Level Appraisal Committee
SLNA	State Level Nodal Agency
SLSMC	State Level Sanctioning and Monitoring Committee
SLTC	State Level Technical Cell
SRI	Solar Reflective Index
TCPO	Town and Country Panning Organisation
TDR	Transferable Development Rights
TPQMA	Third Party Quality Monitoring Agency
TWh	Terawatt hours
ULBs	Urban Local Bodies
URDPFI	Urban Regional Development Plans Formulation and Implementation
UTs	Union Territories
VAMBAY	Valmiki Ambedkar Awas Yojana
VLT	Visual Light Transmittance
WWR	Window to Wall Ratio

1. Introduction

Pradhan Mantri Awas Yojana (PMAY), Government of India's flagship program aims to provide affordable housing to urban and rural poor. Launched in 2015, the PMAY - U (urban) is targeting to build approximately 12 million dwelling units by 2022. Each dwelling unit is around 30 - 60 sq m in area (depending on the category such as economically weaker section (EWS) or low income group housing (LIG)). As a result, the expected addition to the building footprint by 2022 will be at least 360 million sq m. This is equivalent to 25% of the existing commercial building footprint (AEEE, 2017).

The focus of the Mission is to build fast and deliver units at an affordable price within the specified period. Housing that is built as part of PMAY will last 40-60 years and decisions taken today will have an impact on the level of comfort that these dwellings provide to its occupants and the energy use, costs and associated carbon emissions over the lifetime of the building. Building design, materials and construction all have an impact on how much additional (operational) energy is needed to reach comfort levels in the buildings. Additionally, a large amount of energy is embedded in the extraction, manufacture/ processing of building materials and the construction process itself, which adds to the overall energy required to build and operate these dwellings.

Residential sector is responsible for 22% of the current electricity use and is expected to lead the electricity demand representing 39% of the total electricity demand by 2047. In absolute terms, this would mean a ten-fold increase - from 175 TWh in 2012 to 1840 TWh by 2047 (NITI Aayog, 2015). While current affordable housing units have low electricity consumption, with rising incomes and comfort aspirations, energy use and associated costs in these houses is expected to rise. Large-scale construction of affordable housing provides an opportunity to evaluate, demonstrate and build housing that also focuses on providing thermal comfort hence, minimising future energy and resource use, in line with India's climate change targets.

There are numerous challenges to achieving this vision. Affordable housing provision is a multi-layered social issue comprising primarily of the right to basic services, livelihood, housing and mobility for the urban poor.

Housing has two primary costs - the cost of land and the cost of construction. To ensure that housing is accessible to the poor, 'affordability in terms of the cost of the dwelling unit' takes prime importance. Unless supported by measures to subsidise or provide suitable land parcels, land availability and its price determine the location and the cost, and hence a number of other related factors. Housing projects have suffered from improper selection of land, either due to high costs, lack of availability of land within the city or lack of employment opportunities and basic infrastructure and services around the chosen site. As a result, significant number of affordable housing projects remains vacant, with the beneficiaries refusing to occupy houses allocated to them.

There are multiple other challenges in the entire ecosystem. There is a lack of participation from organised real estate companies due to low profit margins. Developers also cite lack of suitable finance options and lengthy approval processes as key barriers, amongst others. For the implementing agencies, lack of coordination among development norms and multiple central and state level policies as well as capacity constraints present challenges in delivering affordable housing projects (Deloitte, 2016). As a result, neither the government, nor the private sector has been able to build affordable housing at a scale that is required to meet the demand.

Within this context, mainstreaming energy efficiency and optimisation in this segment of housing to provide thermal comfort is likely to be seen as an additional challenge - the issue of additional cost and compliances for energy efficient design and construction. However, business as usual construction will lead to locking in a large amount of inefficient housing stock, while also impacting the costs of running and maintaining these inefficient houses. Building thermally comfortable housing is also important from a resilience perspective. Urban poor are most vulnerable to climate change impacts such as increased temperature and urban heat island effects due to their lack of access to proper housing and common services. Building climate resilient housing will reduce these vulnerabilities from both a health and energy perspective (ACCCRN, 2013).

With support from Shakti Sustainable Energy Foundation (SSEF), AEEE has carried out this scoping study to identify potential opportunities as well as research and data gaps, for mainstreaming thermal comfort and energy optimization in affordable housing.

The study's objective is to assess the mission targets (building stock analysis) to understand the type of housing being built and highlight the energy impact (embodied and operational) of building design and construction within affordable housing segment. This is a first step towards understanding the energy impacts and pathway consequences of affordable housing construction under the PMAY-Urban mission.

1.1. Project scope and limitations

The project scope includes:

1. Estimation and analysis of affordable housing stock to be built under PMAY-U mission (2015-2022)
2. Highlighting operational and embodied energy impact due to building design and construction in affordable housing as established through existing research
3. Discussing possible approaches for embedding these in the Mission implementation and identifying gaps in research and institutional processes.
4. Evaluation of the key policy options/ rating programs

The Mission has four different components addressing both supply and demand side issues.

1. "In situ" Slum Redevelopment (ISSR) and Affordable Housing in Partnership (AHP) address housing supply by facilitating construction of EWS housing by the government or through private partnership.
2. Credit Linked Subsidy Scheme (CLSS) and Subsidy for Beneficiary-Led Construction (BLC), are demand side interventions for eligible beneficiaries that provide access to subsidized credit or direct monetary assistance for either buying or constructing/upgrading self-build housing respectively.

Since the housing delivery mechanism and type of monetary assistance varies across these four components, different set of recommendations are required to mainstream energy optimisation and user comfort, especially, as a large number of dwelling units are likely to be self-built/ standalone houses under the BLC component.

The scope of this study hence is limited to multi-family housing by the organised construction sector as part of the ISSR, AHP and CLSS components by the government, through private partnership and by real estate developers' builders.

1.2. Project Methodology

The project methodology includes:

1. Collation of information from key regulations relevant to the affordable housing sector, PMAY-U mission requirements and governance and implementation processes.
2. Detailed analysis of government and other available datasets for assessing the affordable housing stock progress under the PMAY-U mission.
3. Comprehensive literature review of existing research in energy efficiency strategies for affordable housing.
4. Select one-on-one expert stakeholder consultation to inform the literature review gaps (where possible) and understand their perspective on potential levers to mainstream energy optimisation and thermal comfort in affordable housing.

1.3. Expected outcome

The long-term outcome of the report is to minimise the current and future impacts of energy use from affordable housing through mainstreaming thermal comfort and resource efficiency (in building materials) within the PMAY-U Mission.

2. Affordable Housing and PMAY Mission

The following sections look at what constitutes as affordable housing in India, including how parameters and key regulations have evolved upto the PMAY mission.

1.4. Affordable Housing: Definitions and criteria

There are multiple definitions for affordable housing and affordable housing projects. In essence, affordable housing is broadly defined as that which is adequate in quality and location and does not cost so much that it prohibits its occupants in meeting other basic living costs or threatens their enjoyment of basic human rights (UN-Habitat, 2011).

In the Indian context, affordable housing refers largely to *low cost housing* built for economically weaker sections (EWS) or lower income group (LIG) and has a specified built up area in relation to the income parameters that define EWS and LIG.

In 2012, the **report by the Task Force on Promoting Affordable Housing** set up by the erstwhile Ministry of Housing and Urban Poverty Alleviation (MoHUPA) defined affordable housing as individual dwelling units with a carpet area not exceeding 60 sq m and preferably within the price range of five times the annual income of the household as notified. It could be either as a single unit or part of a building complex with multiple dwelling units. Further, affordable housing projects required at least 60% of the floor area ratio (FAR)/ floor space index (FSI) to consist of dwelling units with a maximum carpet area of 60sq m, and either 15% of the total FAR/ FSI or 35% of the total number of dwelling units to be reserved for EWS category.

Additionally, state governments could consider an increase of up to a maximum of 25% on the recommended household income levels, supported with adequate justification, for cities and urban agglomeration with population exceeding a million inhabitants (MoHUPA, 2012c). Table 1 shows the EWS and LIG definition.

Table 1: Definition of EWS, LIG and MIG (MoHUPA, 2012c)

	Income	Carpet Area
EWS	up to INR1,00,000 (monthly INR 8,000)	21-27 sq m
LIG – A (Lower Income Group)	up to INR 2,00,000 (monthly between INR 8000 - 16,000)	28-40 sq m
LIG – B (Upper Lower Income Group)		41-60 sq m

The **Jawaharlal Nehru National Urban Renewal Mission** (JNNURM) mission directorate in 2012, extended affordable housing beyond EWS and LIG to middle income group (MIG) housing, both in terms of built up area as well as the price range reflected as paying capacity, in terms of rent or housing loan repayments (MoHUPA, 2012a).

Table 2: Definition EWS, LIG and MIG (MoHUPA, 2012a)

	Size	EMI or Rent
EWS	Minimum of 300 sq ft super built-up area Minimum of 269 sq ft (25sq m) carpet area	Not exceeding 30-40% of gross monthly income of buyer
LIG	Minimum of 500 sq ft super built-up area Maximum of 517 sq ft (48 sq m) carpet area	
MIG	600-1200 sq ft super built-up area maximum of 861 sq ft (80sq m) carpet area	

The **Model State Affordable Housing Policy draft (2013)** defines *affordability* in the context of house prices as 3-4 times of the household annual income. In case a subsidy is offered by the state or central government, the policy allows the affordable price range to be redefined to be a maximum of 5 times the annual household income. The subsidy is applicable only for individual dwelling units of carpet area of upto 60 sq m. The definition of affordable housing projects was also retained as per the task force report (MoHUPA, 2013).

In 2014, the revised **Urban Regional Development Plans Formulation & Implementation (URDPFI) guidelines (2014),** further focussed on the affordability aspect stating that the cost of the housing should be affordable to the disposable income of LIG, EWS and the poor, where the cost of a house has two major components - land and construction of houses (MoUD, 2015).

Affordability, hence, is a directly linked to the buying capacity in terms of income and cost of housing provision, which remains the central narrative in affordable housing policies and projects. Over time and with subsequent policies addressing the need for affordable housing, these definitions of EWS, LIG have evolved, and most recently, have been extended to include MIG as well. Multiple affordable housing definitions have been adopted at the Centre and State level, reflecting different standards/norms of size, and income criteria and sale price of dwelling units.

1.5. India's Affordable housing shortage

Housing shortage in India has been a key challenge for a long time and in spite of various initiatives by the government, affordable housing continues to fall short of the expected demand.

The report by the **Technical Group on Urban Housing Shortage 2012-17** estimated existing shortages of 18.78 million residential units in urban areas and 43.67 million units in rural areas. The report analyses Census and National Sample Survey (NSS) data to understand current housing conditions that are either inadequate or require up-gradation as well as mapping the demand based on income categorisation. Housing for EWS and LIG currently account for 95 percent of urban housing shortage in the country (Table 3). Approximately 80% of the housing shortage consists of households living in severely congested conditions requiring new houses (MoHUPA , 2012b).

Table 3: Urban housing shortage (MoHUPA , 2012b)

Category	Shortage (in million)	Percentage in Total
EWS	10.55	56.18
LIG	7.41	39.44
MIG	0.82	4.38
Total	18.78	100.00

Table 4: Housing shortage congestion (MoHUPA , 2012b)

Household type	Severe congestion	Congestion
Households living in non-serviceable katcha	0.99	0.99
Households living in obsolescent houses	2.27	2.27
Households living in congested houses requiring new houses	14.89	14.99
Households in homeless condition	0.53	0.53
Total	18.68	18.78

Note: Households living in ≤ 300 sq ft of house with one or more married couples not having a separate room counts under severe congestion; whereas, congestion is calculated for all households irrespective of the house size.

Several policies and missions have been launched to provide for appropriate affordable housing, the most recent of which is the PMAY-U mission. Against the 18.78 million housing demand, the PMAY-U had initially proposed construction of 20 million units by 2022. It has been recently revised to 12 million (MoHUA, 2017a).

1.6. Pradhan Mantri Awas Yojana (PMAY)

PMAY was launched in 2015 by the central government with two distinct components for urban and rural housing with an objective to provide affordable housing for all by 2022. As per the mission scheme guidelines (MoHUPA, 2016), the PMAY-U consists of following four sub components.

1. **"In situ" Slum Redevelopment (ISSR):** This is a supply side intervention for redevelopment of slums by the government or through private partnership. Under ISSR, there are two sub components:
    a. *Slum rehabilitation component* provides housing along with basic civic infrastructure to eligible slum dwellers,

b. *Free sale component* provides developers flexibility of selling the units to cross subsidize the project.

2. **Credit Linked Subsidy Scheme (CLSS):** This is a demand side intervention providing credit linked subsidy on housing loans through financial institutions. EWS, LIG & MIG can avail the subsidy for new or incremental housing.
3. **Affordable Housing in Partnership (AHP):** This supply side component focuses on providing houses for EWS category. States/UTs either through its agencies or in partnership with private sector, can plan following types of affordable housing projects:
   a. Independent affordable housing project
   b. Housing projects where 35% of the houses are constructed for EWS category
4. **Subsidy for Beneficiary-Led Construction (BLC):** This is another demand side intervention focusing on providing fixed monetary assistance to eligible EWS beneficiaries to either construct new houses or renovate existing houses.

The mission supports construction of houses up to 30 sq m of carpet area with basic civic infrastructure like water, sanitation, sewerage, road, electricity etc. The minimum size of houses constructed under the mission should conform to the standards provided in National Building Code (NBC). As per the mission, only citizens currently residing in slums can avail benefits under the ISSR component, whereas citizens from non-slum areas are eligible for the other three components of the mission. An EWS household can claim assistance under any component of the mission, whereas LIG and MIG can claim assistance under CLSS component.

Table 5 provides information on EWS, LIG and MIG income bands and sanctioned carpet area as per PMAY mission. The income criterion was revised upwards to INR 3 lakhs for EWS from the earlier criteria at 1 lakh. The mission provides flexibility to States/UTs to redefine the annual income criteria/ carpet area as per local conditions in consultation with the Centre and for choosing the best options amongst the four components of the mission. The mission also request States/ UTs to converge various other government missions/ schemes targeting urban poor with PMAY-U for effective implementation.

Table 5: Definition of EWS, LIG and MIG per PMAY mission (MoHUPA, 2016)

	Income	Sanctioned Carpet Area
EWS	up to INR3,00,000	upto 30 sq m
LIG	between INR 3,00,001 - 6,00,000	upto 60 sq m
MIG I*	Between INR 6,00,001 - 12,00,000	Upto 120 sq m (upgraded from 90sq m)
MIG II*	between INR 12,00,001 - 18,00,000	Upto 150 sq m (upgraded from 120sq m)

A Technology Sub-Mission is also set up under the mission to promote faster and quality construction of houses by adoption of modern, innovative and green technologies, and building materials. Further, the sub-mission also facilitates preparation and adoption of building plans / layout designs for various climatic zones. It also assists States/ Cities in deploying disaster resistant and environment friendly technologies. To support the sub-mission, a technical cell has been set-up in the Building Materials and Technology Promotion Council (BMTPC). As of now, BMTPC has recommended 16 new emerging technologies to facilitate speed, safety and sustainability in the construction which are categorised under following heads: Formwork Systems, Precast Sandwich Panel Systems, Light Gauge Steel Structural Systems, Steel Structural Systems and Precast Concrete Construction Systems. The recommended project scale and skillset required is also highlighted to understand the applicability of these technologies. (BMTPC, 2017) .

1.7. Energy impact of affordable housing construction

The construction of affordable housing has been driven by the need to provide housing and basic services at minimal cost. This has manifested at multiple levels and drives decision making in terms of where houses are located, the selection of construction materials and technologies which are either low cost and/or reduce construction time, in order to limit the total cost of the project.

Since the market has not addressed this segment of housing, the gap between the demand for affordable housing and its supply has been increasing and subsequent government policies and missions have even larger targets to meet. PMAY-U Mission is targeting to meet this shortfall of 12 million houses within a short span of time till 2022. According to Dr. Kundu (2016), the bottom 30% of the urban households cannot afford more than 1200 INR per month house instalment. The loan amount and maintenance are to be taken into consideration during planning and construction phase.

With each dwelling unit size varying from 30 - 60 sq m, the additional building footprint in urban area by 2022 will be at least 360 million sq m. The energy impact and subsequent carbon emissions of this significant amount of housing construction has not been adequately evaluated.

The housing sector lies at the intersection of the government's plan to meet both its sustainable development goals (SDG 7- Affordable and Clean Energy; SDG 11- Sustainable and Clean Cities) as well as climate change mitigation goals.

It is imperative that this growth follows a low carbon development pathway and avoids the long term lock-in of inefficient, high energy consuming residential buildings.

3. Regulatory instruments and implementation process

To mainstream energy optimisation and thermal comfort within the PMAY mission, this section maps various stakeholders, their roles and regulatory instruments.

1.8. Estimating Demand and Implementation: The role of Centre, State and Local government

The erstwhile Ministry of Housing and Urban Poverty Alleviation (MoHUPA) launched the PMAY mission in 2015. However, the departments relevant to PMAY such as Town and Country Panning Office (TCPO) and National Institute of Urban Affairs (NIUA) were under the umbrella of Ministry of Urban Development (MoUD). There was a considerable amount of overlap in the functions of the respective ministry. In July 2017, the two ministries were merged to form the Ministry of Housing and Urban Affairs (MoHUA).

At the National level, Central Sanctioning and Monitoring Committee (CSMC) and Central Nodal Agency (CNA) have been formed under PMAY-U to facilitate implementation. CSMC is an important decision making body which reviews the overall mission and monitors the progress at regular intervals. CNAs are formed under the CLSS component to channelize the subsidy to lending institutions and for monitoring the progress of this component. Housing and Urban Development Corporation (HUDCO) and National Housing Bank (NHB) have been identified as CNA (MoHUPA, 2016). The MoHUA, its attached offices and missions at the central level are depicted in Figure 1.

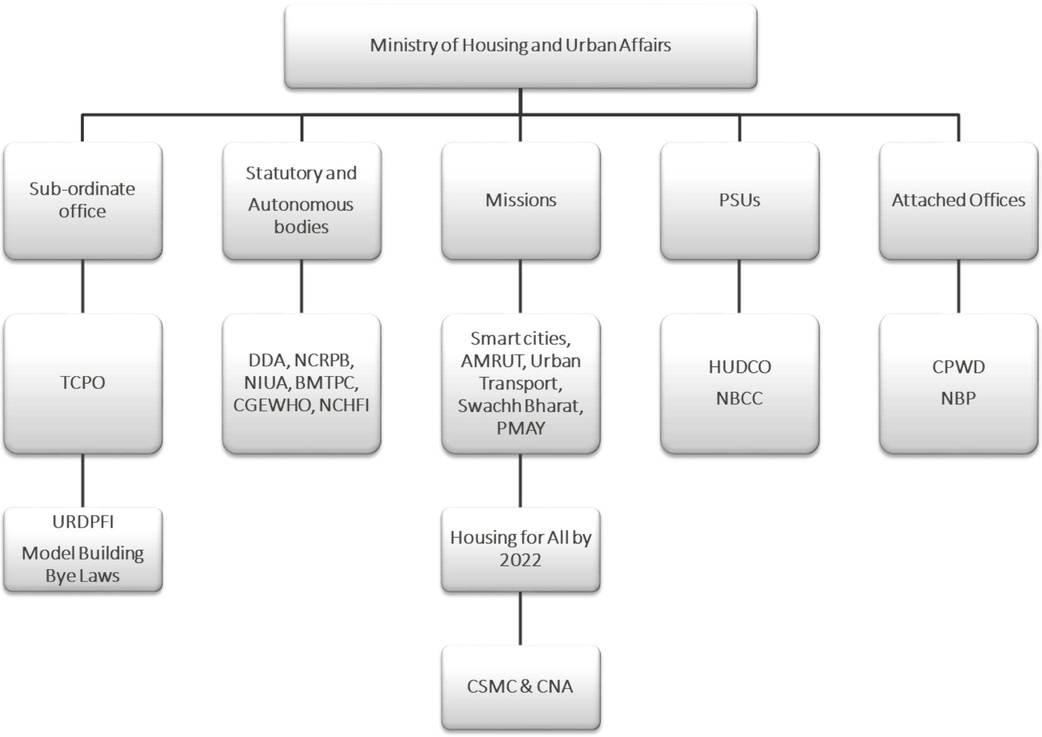


Figure 1: MoHUA and its attached offices and mission at national level

Apart from the mission and its related offices, other MoHUA attached offices such as Building Materials and Technology Promotion Council (BMTPC), TCPO, NIUA, HUDCO etc. play an important role in mission implementation. The TCPO office looks at framing and amending Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines and Model Building Bye Laws. URDPFI guidelines propose outlining of affordable housing projects at Masterplan and Zonal plan levels. The Model Building Bye Laws discusses various designs and construction related parameters, which can promote quality and sustainable design and construction practices (MoHUA, 2018b) (MoUD, 2015) (TCPO, MoUD, 2016).

Table 6: Key stakeholders at national level and its relevance to PMAY

Institutions	Relevant guideline/ code	Relevance to PMAY
TCPO	URDPFI	Outlining of affordable housing projects at Masterplan and Zonal plan levels
	Model Building Bye Laws	Design and construction related parameters which can promote quality and sustainable design and construction practices
BMTPC	Compendium of Prospective Emerging Technologies for Mass Housing	Established by erstwhile MoUD, BMTPC is supporting technology sub-mission of PMAY-U for research and development of faster and sustainable construction technologies and its scalability. Knowledge portal for sustainable habitat providing information on sustainable building construction technologies is also provided by BMPTC.
NIUA		Supported by MoHUA, the institute assists ministry in policy formation
NHB		Financial institution established under Reserve Bank of India is an apex housing finance institution
HUDCO		Financial institution under the aegis of MoHUA with mandate to support affordable housing and urban development
BEE	Energy Conservation Building Code – Residential (ECBC-R)	The code part – 1 requires building envelope compliance with code provisions for an energy-efficient building envelope.

At the **State/ UT level**, a Memorandum of Agreement (MoA) is signed agreeing to mandatory conditions and other modalities between State/UT and Centre. Some of the mandatory conditions are: preparation/ amendment of master plan earmarking land or affordable housing and provision of additional Floor Area Ratio (FAR)/Floor Space Index (FSI)/ Transferable Development Rights (TDR) and relaxed density norms for slum redevelopment and low cost housing.

Further, the State/ UT submit proposals to the Ministry for inclusion of cities. Post approval of cities, they are required to carry out a survey for assessing housing demand and how it is distributed under the four components of the mission. Based on this demand survey, states/cities prepare the Housing for All Plan of Action (HFAPoA) and subsequently the Annual Implementation Plans (AIPs) dividing the task upto 2022.

Table 7: PMAY-U regulatory instruments at state/ city level

Regulatory Instrument	Description
Preparation/ amendment of master plan	Earmarking land or affordable housing and provision of additional Floor Area Ratio (FAR)/Floor Space Index (FSI)/ Transferable Development Rights (TDR) and relaxed density norms for slum redevelopment and low cost housing.
Housing for All Plan of Action Annual Implementation plans	Assessing housing demand and how it is distributed under the four components of the mission Drafting the plan of action till 2022 Synergy with existing City Development Plan, City Sanitation Plan etc.

After approval of HFAPoA and AIPs from State Level Sanctioning and Monitoring Committee (SLSMC), these are submitted to CSMC for approval. States/UTs are required to constitute an inter-departmental SLSMC for approval of AIPs and projects under various components of the mission. SLSMC is in-charge of overall implementation of the Mission and its functions are mentioned in Housing for All scheme guidelines. As per the mission guidelines, Urban Local Bodies should take into account the provisions of the City Development Plan, City Sanitation Plan etc. for achieving synergy with other on-going programs while preparing HFAPoA (MoHUPA, 2016).

Apart from SLSMC, State/ UT has to identify State Level Nodal Agency (SLNA) and set up State Level Mission Directorate for coordination of the scheme and reform related activities. State may nominate a separate SLNA under the credit linked subsidy component of the Mission.

State Level Appraisal Committee (SLAC) is constituted for techno-economic appraisal of Detailed Project Reports (DPRs) submitted by Urban Local Bodies (ULBs)/Implementing Agencies (IA). SLAC submits the report to SLNA which further takes it to SLSMC for its approval. State Level Technical Cell (SLTC) established under SLNA holds the responsibility to provide strategic coordination and support for all PMAY related activities like preparation of HFAPoA, AIPs and other technical activities. SLTC also plays the key role of coordination and overseeing of the Third Party Quality Monitoring Agency (TPQMA). TPQMA has to ensure the quality of construction under various components of PMAY-U (MoHUPA, 2016).

At State/ UT level, government departments such as Town Planning, Urban Development, Housing, Poverty Alleviation and Municipal Administration play a key role in proposal, approval and implementation of affordable housing projects. -They provide the state policies, codes, and guidelines relevant to affordable housing projects which have to be adhered to and play a critical role in initial project approvals, project implementation and final completion certificates.

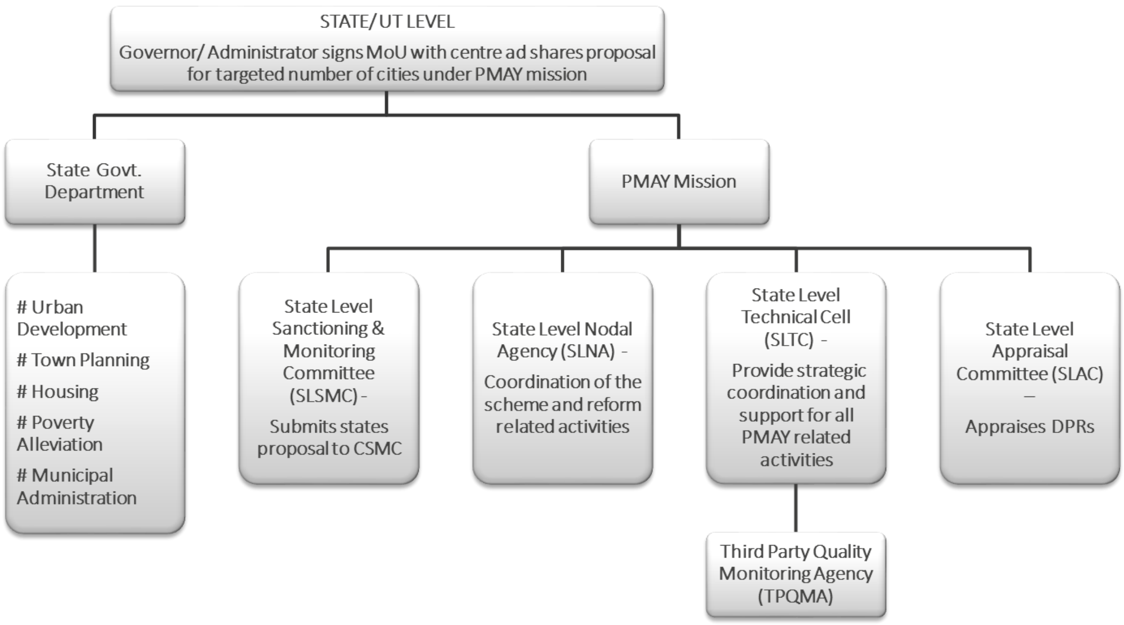


Figure 2: Relevant stakeholders and mission committees at state/ UT level

At **ULB level** a City Level Technical Cell (CLTC) established in the ULBs/IA of the Mission Cities and is responsible for proper implementation of all PMAY projects including quality control. The CLTC plays the key role of coordination and overseeing of the TPQMA on behalf of the ULB/IA (MoHUPA, 2016).

There are multiple regulatory instruments and departments both at the State and City levels to facilitate Mission implementation. The success of the outcomes from the mission is inextricably linked to the existing frameworks, policies and the capacity with the States and Cities. There might be substantial gaps in the process due to lack of updated/existing master plans, city development plans etc. in some states as compared to other, more progressive states, which might not be feasible to address in the short time span till 2022 that the Mission is targeting. While these point to long-term issues for effective urban planning, evaluating their impact on the mission implementation can provide useful clues to the support needed by States/Cities. To identify opportunities for mainstreaming energy optimisation through institutional processes, successful examples from states and cities can also be examined to understand where interventions are needed and likely to be most effective.

1.9. Delivery mechanisms - state/city governments and small and large developers

The mission's four components follow multiple implementation strategies for effective functioning of the mission. The delivery mechanism as per PMAY-U scheme guidelines (MoHUPA, 2016) is as follows:

The ISSR component of the mission aims to leverage the locked potential of land under slums to provide houses to eligible slum dwellers, and proposes redevelopment by the government or through private partnership. In case of private partnership, states and cities may provide additional FAR/FSI or TDR and relax density and other planning norms in some cases, for making projects financially viable,. States/UTs may also allow commercial usage for part of the land/FAR as mixed usage of the land. A viable slum rehabilitation project would have two sub components i.e. slum rehabilitation component- which provides housing along with basic civic infrastructure to eligible slum dwellers and; Free sale component - which is available to developers for selling in the market so as to cross subsidize the project. The beneficiaries for all the sub components are decided by state/ city government. Under ISSR, slum rehabilitation grant of INR 1 lakh per house is provided by centre for all houses built for eligible slum dwellers. States/UTs have the flexibility on how to deploy this central grant, and are allowed to utilise more than INR 1 lakh per house in some projects and less in other projects, while maintaining the overall average of INR 1 lakh per house calculated across the State/UT.

The CLSS component, a demand side intervention provides credit linked subsidy on home loans as per the eligible built-up area and the income group as tabulated in Table 9. HUDCO and NHB are identified as CNAs to channelize this subsidy to the lending institutions and for monitoring the progress of this component. The subsidy is released to each CNA based on utilisation and on claims raised by CNAs.

Table 8: Eligible housing loan amount and its corresponding subsidy under PMAY-U (MoHUPA, 2016)

	Subsidy	Eligible Housing Loan Amount	Sanctioned Carpet Area
EWS	6.5%	6,00,000	upto 30 sq. m.
LIG	6.5%	6,00,000	upto 60 sq. m.
MIG I*	4%	9,00,000	Upto 120 sq m
MIG II*	3%	12,00,000	Upto 150 sq m

Under the AHP component, the government targets to increase availability of houses for EWS where State/UT either through its agencies or in partnership with private sector can plan affordable housing projects. Two types of housing projects are proposed under the component (1) Independent affordable housing project and (2) Housing projects where 35% of the houses are constructed for EWS category. To facilitate private partnership, government has launched Affordable Housing Public Private Partnership (PPP) model for projects on public land and private land. A total of eight models have been proposed by government (figure 3) While the beneficiaries for each model are selected by government, it provides flexibility to private developers and may extend other concessions such as state subsidies, land at affordable cost, stamp duty exemption etc.to promote this component (MoHUPA, 2017). Central assistance of INR 1.5 Lakh per EWS house is available for all EWS houses under AHP component and is provided to the State/ UT. The upper ceiling of the sale price of the EWS houses is decided by States/UTs with an objective to make them affordable and accessible to the intended beneficiaries.

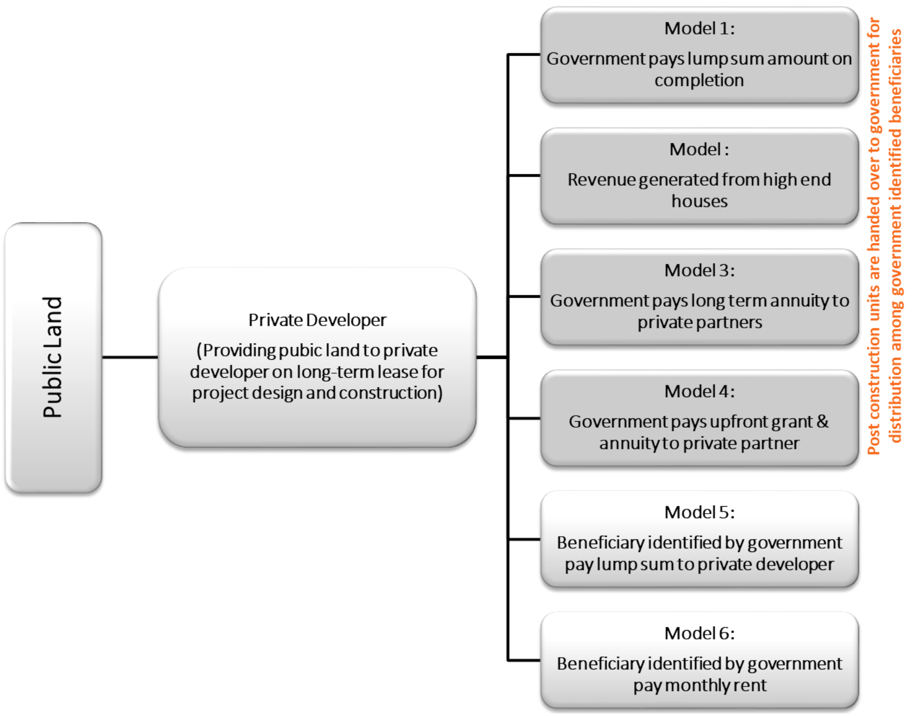


Figure 3a: Affordable Housing Public Private Partnership (PPP) model for projects (MoHUPA, 2017)

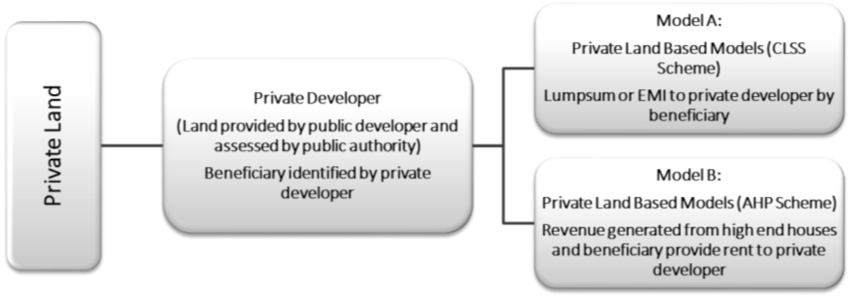


Figure 3b: Affordable Housing Public Private Partnership (PPP) model for projects (MoHUPA, 2017)

The BLC component provides fixed monetary assistance of INR 1.50 lakhs to individual eligible families belonging to EWS category to either construct new houses or enhance existing houses on their own. The central assistance is transferred to States/ UTs and then passed on to the beneficiary.

The Mission supports three distinct housing delivery segments. While under ISSR and AHP components, affordable housing unit design and construction will be governed by the developer (government or government appointed private developer), the type of dwelling unit and their construction under BLC are governed by the beneficiary as they are likely to be self-build housing. CLSS is likely to be market led developer built housing, where the Mission supports beneficiaries through a subsidy in home loans. These require a combination of effective regulatory and financial mechanisms to mainstream energy optimisation strategies.

Moreover, there is likely to be a large variation in the developer built housing as well, as private sector capacities, access to skilled labour and subsequent choice of construction technologies are all likely to vary across large urban centres and smaller cities and towns. Disaggregating the housing demand can help target recommendations to mainstream user comfort and energy optimisation through appropriate design and construction practices and supporting mechanisms.

1.10. The role of financial institutions

Financial institutions like NHB and HUDCO have a key role in supporting Mission implementation as the Central Nodal Agencies and are responsible for channelizing subsidies to financial institutions that provide home loans for the credit linked subsidy (CLSS) component and monitor its progress. Under the mission, HUDCO also assists the Ministry in appraising the *Plan of Actions* and *Annual Implementation Plans* sent by states/cities.

Both NHB and HUDCO provide an opportunity to influence energy optimisation strategies in developer built housing under the CLSS component. Amongst its many initiatives to promote housing, HUDCO’s objective is also to promote alternate, energy-efficient and ecologically appropriate building materials and technologies.

NHB has collaborated with bilateral organizations to promote energy efficient housing in India. In 2011, NHB and the German Development Bank KfW developed the first programme for financing energy efficient homes. Most recently, NHB in collaboration with Agence Française de Développement (AFD) is promoting affordable green housing. Under Sustainable Use of Natural Resources and Energy Facility (SUNREF) Green Housing India project, a financial assistance of Euro 112 million has been sanctioned by AFD. NHB will support eligible affordable green housing projects by refinancing home buyers and developers.

Since a large amount of investment is required under PMAY-U mission, these examples have the potential to create awareness amongst both the beneficiaries and the developers as well as create capacities amongst financial institutions for mainstreaming energy efficient construction through effective financial mechanisms.

4. PMAY Progress - Stock Estimation and its implications

The section assesses the current status of the PMAY-U mission in terms of sanctioned and constructed dwelling units to understand the scale and type of affordable housing that is expected to be built till 2022.

To estimate the total number of dwelling units (DUs) and their construction status, data was assimilated for all states and union territories from various PMAY-U status reports published by the government, Lok Sabha proceedings, Central Sanctioning and Monitoring Committee (CSMC) meetings reports (MoHUA, 2017b) and Indiastat (Indiastat, 2017). While few of these sources provided the overall status of the mission at State/UT level, CMSC meetings and Indiastat data also provided information at the PMAY component level for some of the States/UTs.

The data analysed in the section includes information about dwelling units that have been sanctioned/constructed till December 2017. This analysis was done for the initial 20 million target set out by the Mission when it was launched. Recently, in November 2017, the target was revised to 12 million houses (MoHUA, 2017a). The revised housing demand numbers and subsequent revised PMAY-U target will reduce the States/UTs housing demand which is not reflected in the information presented. The aforementioned change doesn't affect the housing stock sanctioned/ constructed till date.

1.11. Housing demand and construction status

The Missions requires each state/ UT to understand and validate their housing demand by carrying out a demand survey. The estimated housing shortage of 18.76 million and the total Mission target of 20 Million was revised in 2017 to 10 million and 12 million respectively (MoHUA, 2017c). As per the previous target of 20 million dwelling units by 2022, demand for 15.7 million dwelling units was confirmed by the states/ UTs.

A total of 4317 cities (472 class I cities) were targeted to estimate the total housing demand, of which 3541 cities (82%) have completed their demand survey and 776 cities (18%) are still in the process of carrying out the survey (Figure 4). The revised demand for the reduced target of 12 million will require validation through city level surveys for each state/UT. The parameters for this revised target are not available in the public domain and there isn't any clarity on how cities are expected to respond to it, especially where surveys have been completed.

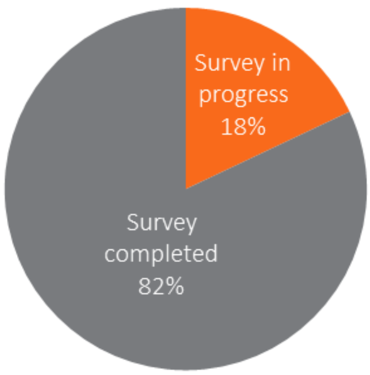


Figure 4: Demand Survey Status in cities

Indian States/UTs are divided into 5 regions - North, South, East, West and North-East (CEA, 2016). The housing demand was categorised region wise as shown in Figure 5. Western and Southern region have the highest housing demand each, followed closely by the northern region. The North-eastern region has only 3% share of the total demand.

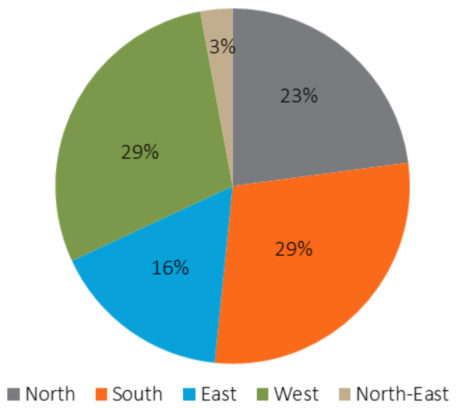


Figure 5: Housing Demand – Region-wise

Figure 6 illustrates the housing demand estimated across all states/UTs. Uttar Pradesh, Maharashtra and Karnataka have the maximum demand followed by Andhra Pradesh and Bihar. The top 10 states constitute 88% of the total demand. This broadly correlates with the top down estimates of urban housing shortage which estimated 70% of the total housing shortage to be in these states. (MoHUPA , 2012b).

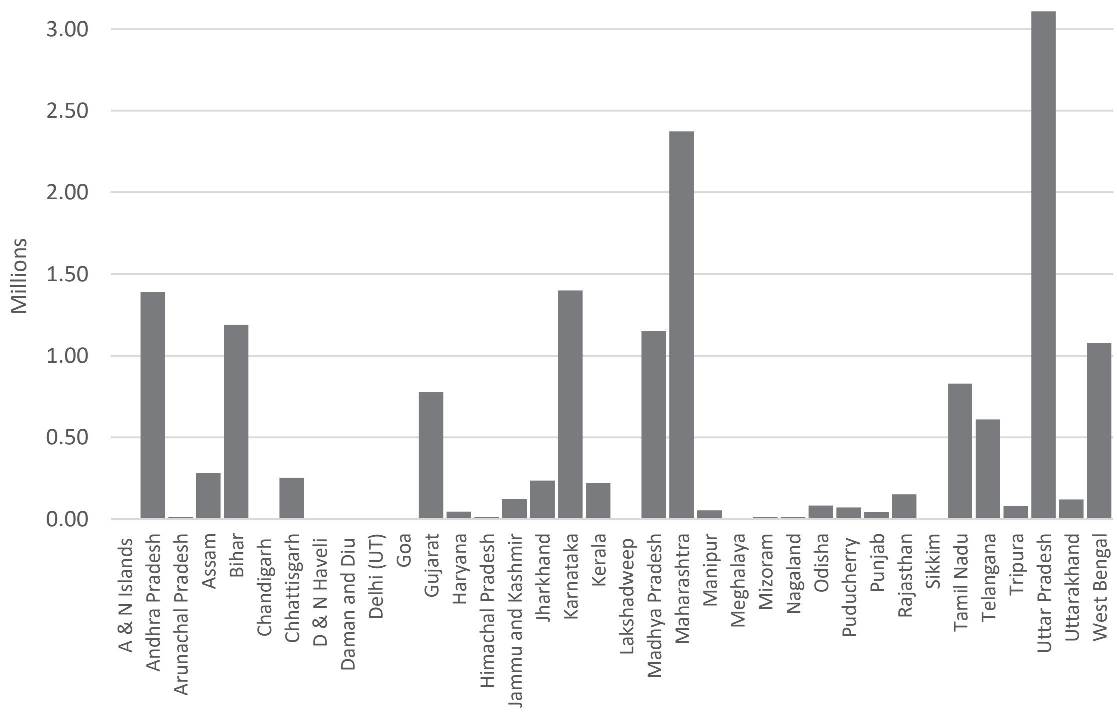


Figure 6: Current demand estimated across all states/UTs (15.7 million DUs)

Figure 7 shows the progress in states with maximum demand. Sanctioned projects refer to projects that have been approved, but have yet not started construction. From the information gathered from CSMC progress reports, it is found that only 32% (approximately 3.8 million) of the total 12 million housing demand has been sanctioned so far. Out of these, Andhra Pradesh has 56% of its total demand already sanctioned while the top three states in terms of demand – Uttar Pradesh, Maharashtra and Karnataka have much lower rates of project approvals. It is important to note that the states now have revised the total housing demand numbers under the mission as per the new reduced target.

Figure 7 : States having highest housing demand and its corresponding sanctioned stock

Figure 8 shows the status of the top 10 states with maximum sanctioned stock. Madhya Pradesh and Tamil Nadu have more than 40% of their sanctioned projects under construction, while progress in other states in terms of beginning construction is slow in spite of approved projects. Completion rates in all states are even lower.

The top 10 states' housing demand, corresponding stock that has been sanctioned, under construction and constructed is listed in Table 9.

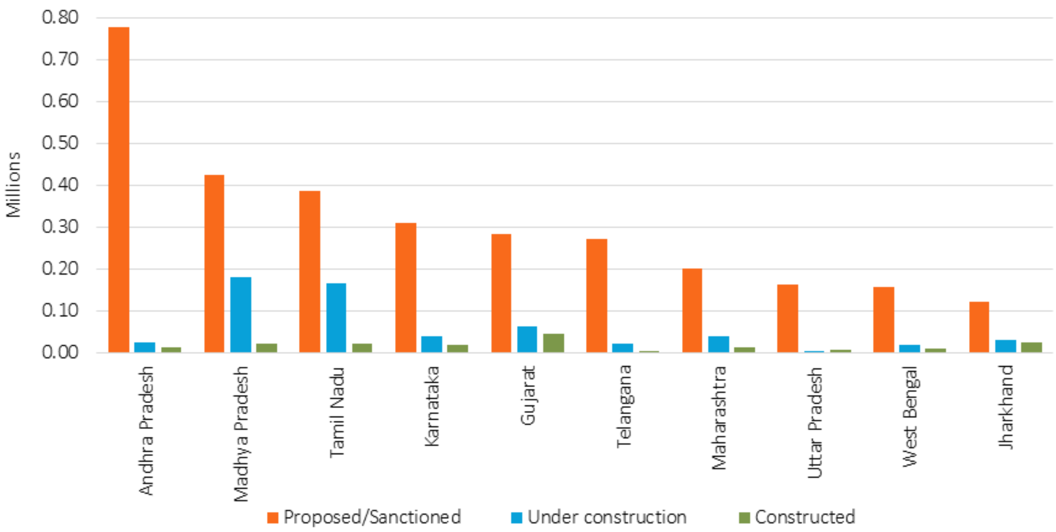


Figure 8: States having maximum number of stock sanctioned and its construction status

Table 9: States having highest housing demand, corresponding sanctioned stock, stock under construction and constructed

States/ UTs	Demand till 2022	Total Sanctioned	Under Construction	Constructed
Uttar Pradesh	3,107,788	163,080	1381	4698
Maharashtra	2,372,908	200,691	39,082	11,503
Karnataka	1,400,000	309,257	37,460	17,666
Andhra Pradesh	1,391,663	778,342	24,535	11,208
Bihar	1,190,000	113,721	26,286	2654
Madhya Pradesh	1,152,000	423,415	180,778	19,263
West Bengal	1,078,224	155,654	18,427	8243
Tamil Nadu	829,174	386,811	164,625	21,998
Gujarat	776,033	283,039	62,245	43,702
Telangana	610,000	270,308	19,946	1837
Jharkhand	236,186	120,182	30,886	24,838

Note: The demand shown above doesn't reflect the revised reduced demand target

The above analysis was validated by data from CSMC meetings, Indiastat as well as PMAY status (MoHUA , 2017d) and Lok Sabha reports (MoHUA, 2018a). The total DUs sanctioned (between 3.2 – 3.8 million) are almost similar across all the sources but variations were found in the construction status presented by PMAY status report and Lok Sabha reports. The CSMC and Indiastat reports' information on construction status is limited to a few states/UTs only. As per PMAY status report and Lok Sabha report approximately 44% – 46% of the total sanctioned stock is under construction and 6% - 8% has been constructed. Whereas, as per AEEE analysis of CSMC meeting reports and Indiastat data 18% stock of the total sanctioned stock is under construction and 5% has been constructed (Figure 9).

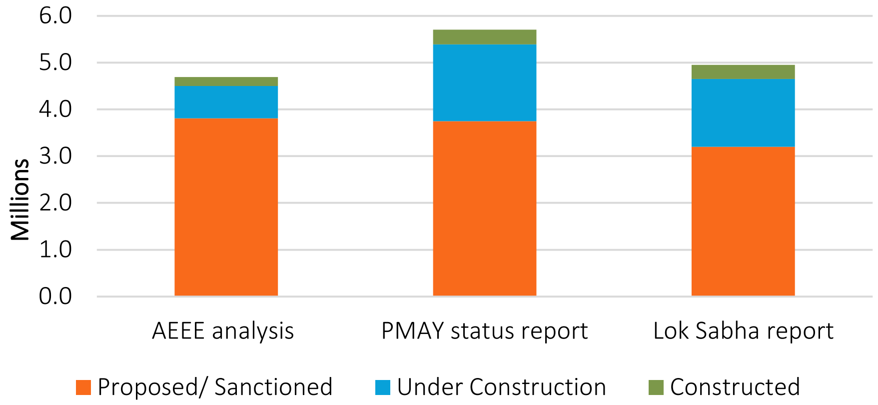


Figure 9: Stock Comparison per different sources

1.12. Component wise stock construction status

The analysis of various CSMC meetings reports and Indiastat data helped in categorising the sanctioned, under construction and constructed stock for all the 4 components of PMAY. The component wise DUs construction status as per AEEE analysis is shown in Table 10.

It is realized that so far out of proposed 12 million stock,

1. 32% of the total housing demand is sanctioned, 6% of the total housing demand is under construction and only 2% of the total housing demand has been constructed.
2. BLC is the most adopted intervention by the States/UTs with almost 60% of sanctioned stock and 12% and 5% under construction and constructed respectively of the sanctioned stock.
3. This is followed by AHP. BLC and AHP together constitute more than 90% of the total DUs sanctioned.

Table 10: Component wise DUs Construction Status

Component	No. of DUs Sanctioned	% DU Sanctioned	No. of DUs Under Construction	No. of DUs Constructed
ISSR	280,305	7%	14,598	1,588
CLSS	70,092	2%	-	490
AHP	1,189,448	31%	232,290	13,043
BLC	2,266,991	60%	442,912	176,325
Total	3,806,836	100%	689,800	191,446

BLC represents the large volume of self-build housing that is expected to come up as part of the Mission. This component caters to individual households improving existing houses or constructing a new one, where land ownership likely belongs to the beneficiary. Hence, disbursal of funds and construction rate both have been the maximum under this component.

In AHP substantial amount of demand has been sanctioned, but there seems to a large time gap between sanctioning and construction. This is largely expected based on the nature and scale of developer led AHP projects requiring multiple approvals and varied set of stakeholders to be taken on board before construction can begin.

CLSS is dependent on the market demand for affordable housing and the reasons for lower number of sanctioned projects cannot be definitely ascertained. However, since the market as not been actively involved in providing affordable housing outside of government supported initiatives, this component requires an understanding of the bottlenecks for the private sector to cater to the affordable housing demand. Both cost of the housing and land costs, as well as, its location and availability in respect to the beneficiary requirements impacting profit margins and scale of projects are often cited reasons for a lack of private sector participation.

ISSR component is the most complex in terms of implementation. Slum redevelopment projects have been historically known to face substantial issues in relocating, appropriateness of proposed housing design solutions, concerns about livelihood during the period of relocation, financing models and selection of private developers amongst others.

1.13. Gaps in data and understanding of energy impacts

The affordable housing shortage and mission targets represent significant amount of construction activity and consequent energy impacts for the country. While the focus of the Mission is on providing affordable housing at a quick pace, the progress status highlights that the actual rate of construction is lagging far behind.

Component wise information is only available at the stage when projects are proposed and sanctioned; hence, it is not possible to say how the total demand is distributed across the four components of the mission.

There are also data gaps in terms of **city specific data**, though demand surveys are carried out at the city level. To assess the energy impact, it will be worthwhile to assess how much of this demand is likely to be concentrated in and around large urban centres vs. in tier 2 and 3 cities.

The cost of housing is inextricably linked to the type of housing, and the capacities and skills of the local construction industry, which will greatly vary across large urban centres and in smaller cities. This will be useful to determine suitable construction technologies and materials for housing projects.

Various case studies from CSMC (MoHUA, 2017b) meetings and BMTPC (2017) provide indicative cost per square feet of the dwelling units for different states including onsite infrastructure. The cost per square feet ranges from INR 1200-2468 (Table 12). The factors for such a large variation in costs of case study projects need to be further assessed.

Table 11: Indicative Cost per square feet

States/UTs	Indicative Cost per sq ft (INR)	Indicative Cost per DU (INR)
Rajasthan	1200	386,400
Karnataka	1356-1659	485,254
Andhra Pradesh	1693	545,146
Odisha	1995	642,390
Uttarakhand	2073	667,506
Telangana	2186	703,892
Bihar	2231	718,382
Tamil Nadu	2235	719,670
Uttar Pradesh	2478	797,916

Affordable housing faces a number of social and economic barriers, specific to the different groups of target beneficiaries. A lot of these underlying issues are outside the scope of this report and analysis, however, it is important to reiterate the integrated nature of the issue. Affordable housing is primarily an issue of land rights and tenure foremost, and its linkage with the right to basic services, livelihood and mobility options within the city. Without these being holistically addressed, it is likely that the large-scale housing projects that are required in urban areas face delays and have low occupancy rates.

An article on slum rehabilitation reported that nearly 26,000 flats (93%) of the total 28,000 built for the poor remain vacant in the absence of a uniform rehabilitation policy and reluctance of dwellers to shift (Hindustan Times, 2017).

According to MoHUA (MoHUA, 2017) report, 80% of the houses completed were occupied in 2017. The recent PMAY progress report and the economic times (Economic Times, 2018) reported that the occupancy increased to 88% in 2018. It is reckoned that this rate of occupancy likely corresponds with the mission progress under the BLC component which are beneficiary led. However, the houses that are being built can benefit from understanding how the design and construction for optimising energy use and providing thermal comfort for all, are also aligned with social and economic objectives of the Mission and provide improved quality, comfort and affordability of future energy costs to the beneficiaries, along with reduced energy use and related carbon emissions in line with the national climate change targets. In the next section, we describe the energy impact of design and construction key strategies for low energy and thermally comfortable affordable housing.

5. Energy impacts of Design and Construction

The large scale of construction of affordable housing as part of the mission will significantly add to the energy consumption from the residential sector. The analysis of on-going PMAY-U projects in various states carried by AEEE and presented in Annex I indicates a general lack of sustainable and climate responsive design and construction. Design and construction information for states was collected from CSMC meeting presentation (MoHUA, 2017b). It is imperative, that this construction follows a low energy and resource efficient pathway. This section looks at key criteria for integrating thermal comfort and energy optimisation strategies.

1.14. The balance of embodied and operational energy in affordable housing

A building requires energy to construct and operate, which can be broadly classified as:

- Embodied energy - energy input in the extraction, manufacture and transportation of building materials as well as the energy required for construction, maintenance, refurbishment and demolition.
- Operational energy - energy used to maintain comfort by space cooling/ heating, lighting, and for running equipment and appliances.

Embodied energy can be reduced by the selection of appropriate low embodied energy materials and construction technologies, while, operational energy can be minimised through climate responsive and thermally comfortable design, reducing the energy needed to actively cool or heat and use electric lighting (during daylight hours) in a building and through use of efficient appliances.

The balance of embodied and operational energy in a building's lifecycle varies greatly. While a large part of the embodied energy of the building is during the construction phase and remains constant through the building's life, the operational energy continues to be added annually. In buildings that are expected to maintain internal comfort conditions through active space cooling or heating such as energy intensive air conditioning, the operational energy is significantly higher than the embodied energy. As a result, building energy efficiency policies such as building energy codes have focussed on reducing operational energy. However, embodied energy significantly contributes to the total energy of the building, when operational energy is less, as is expected in affordable housing, where operational energy is limited to the use of a few appliances and lights currently.

A study in 2011 (EDS, 2011) analysed the long-term energy impact of affordable housing to understand how embodied and operational energy is likely to change over a 20 year period for a typical low cost housing unit, depending on if the housing remains unconditioned or shifts to using air-conditioning. The results are based on simulation analysis of a typical affordable housing block in composite and warm and humid climate. The key parameters include a dwelling unit of 35 sq m and use of three CFLs, two ceiling fans, a refrigerator, television and an evaporative cooler. Figure 10 represents the relative ratios of embodied and operational energy percentage over the 20 year period. The unconditioned dwelling unit is similar to the current scenario, where affordability concerns restrict the use of air conditioning in low cost housing. The energy impact of materials and embodied energy is significantly higher and remains so at the end of the 20 year period. On the other hand, air conditioning use increases the operational energy impact to nearly 68% of the total energy use over the 20 year period.

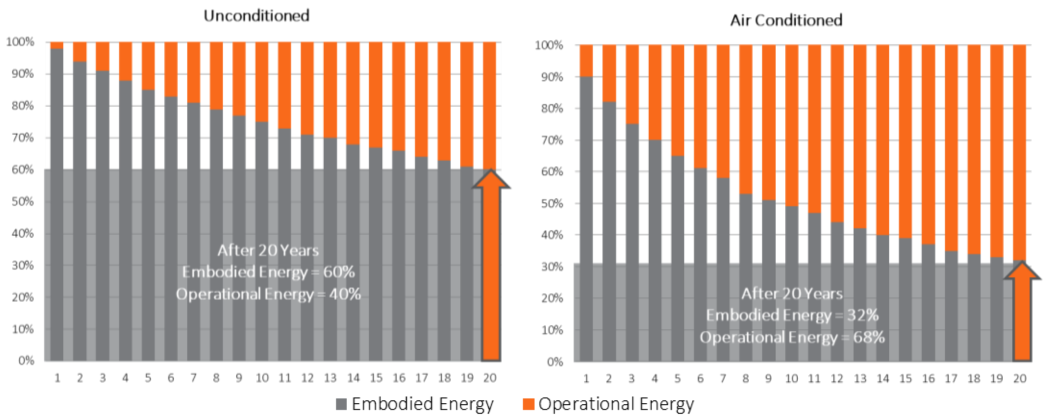


Figure 10: Embodied and Operational energy consumption pattern over 20 years

The likely future scenario for affordable housing is going to be a mix of these. We can expect that with rising incomes, and aspirations for comfort, affordable housing will shift to more energy intensive means for space cooling as and when the occupants can afford air-conditioning. Also, rising temperatures due to climate change and urban heat island effect in urban areas can potentially lead to even earlier adoption of cooling technologies. However, careful design and prioritising thermal comfort within the dwellings now, has the potential to delay this shift for air- conditioned comfort substantially.

The residential sector is already responsible for 23% of total electricity use in the country. Recent estimates indicate that the urban residential sector's absolute energy consumption is predicted to increase by more than eight times in 2050 from 2005 levels, under a business as usual scenario, led primarily by energy needed to cool and light residential buildings significantly (Rawal & Shukla, 2014). Also, 70-80% of the room air conditioning (RAC) use in the country by 2027 is also expected to be in the residential sector (AEEE, 2018)

The possible rate of adoption of air conditioning in affordable housing and its percentage share of the total RAC penetration in the residential sector has not been evaluated. However, since affordable housing will represent a substantial part of the residential sector, it is imperative that it is designed for affordable thermal comfort to delay this use of air-conditioning for meeting comfort requirements as far as possible. Low-cost climate responsive architecture which focuses on passive design strategies hence must be integral to the design and construction process.

Additionally, the scale of current construction also requires strategic interventions for reducing embodied energy as significant material and resource consumption will be required to meet the mission targets. In the short to medium term, the embodied energy impact of affordable housing will be substantial. While there are studies evaluating of the embodied energy impact at the dwelling unit level, there is limited information about the total energy impact of large-scale use and extraction of building materials as well as the impact on the environment. The following sections discuss the embodied and operational energy impact of building design and construction.

1.15. Construction related embodied energy impacts

Embodied Energy is the energy input in the extraction, manufacture, processing and transportation of building materials as well as the energy required for construction, maintenance, refurbishment and demolition.

Embodied energy for materials is complex to calculate. It is essential to know the energy input at each stage of production to estimate the energy embodied in building materials. It also varies considerably depending on how it is calculated as both top down analysis on national industry averages and bottom up analysis of the final product can be carried out.

Further, embodied energy is constantly added to the building through maintenance and refurbishment cycles as well. This requires a complete life cycle analysis of buildings from cradle to grave. It follows that building level embodied energy calculations are complex to evaluate.

1.15.1. Embodied energy impacts of materials and built form

To estimate the embodied energy impacts of buildings, studies generally focus on the embodied energy values of the building material alone, as embedded energy in materials accounts for nearly 98% of the total embodied energy of the building at the building stage. National databases of embodied energy take into account the prevalent processes, fuels, average transportation distances and recycled/ waste content etc. to provide reasonable estimates of representative average embodied energy of common building materials to provide a common baseline.

In India, existing reference datasets of building materials have not been standardized. Embodied energy datasets in India are largely fragmented and available in multiple journal papers. The data also varies based on the purpose of the study and includes national level data, site/ geographical specific data or data that focuses on particular building materials. For example, significant work has been carried out in the brick sector and alternate bricks and blocks as comparison (Reddy & Jagadish , 2003) (Chani et al., 2003). This makes it difficult to compare studies and understand the wider impacts of embodied energy of materials in building types.

A recent comprehensive database of embodied energy has been published by IFC (2017), which is linked to be used in the EDGE green building certification system. The data set can provide a valuable reference to evaluating embodied energy impacts of buildings in the country, allowing comparisons across building types and geographies.

For a typical base case unit, a low to mid rise building, 90% of the embodied energy of a building lies in its structure comprising of roof, floor slabs and the structural frame and walls (EDS, 2011).

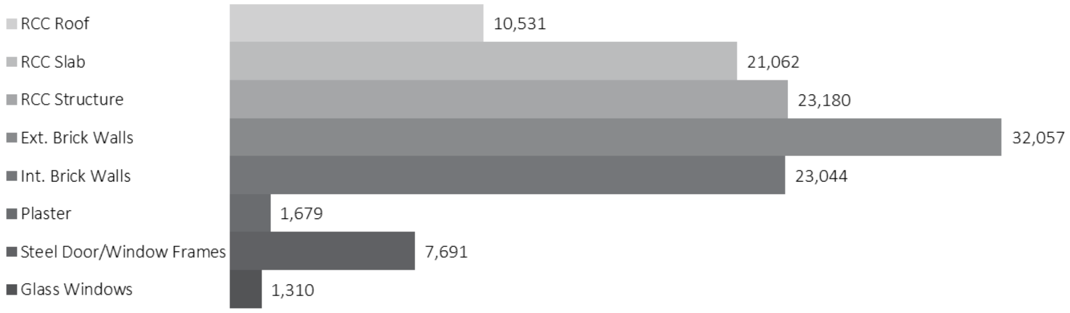


Figure 11: Typical distribution of embodied energy in building components (EDS, 2011)

This is significant to understand when designing buildings for low embodied energy, even if precise values and detailed calculations are not carried out. Hence, embodied energy evaluations over the years have provided a comparative understanding of the amount of energy it takes to make a brick or a block vs steel or glass etc. and allowed for materials to be classified as high, medium and low embodied energy materials. These values when combined with the quantity of materials used in a building represent the embodied energy impact the building. For example, high-embodied energy materials such as cement and steel have a disproportionately higher impact on the total embodied energy, even though their quantities are less. On the other hand, while the embodied energy of a building block or brick might significantly lower, the quantum of bricks/blocks used in a building ensures that it a large contributor to the final embodied energy. Hence, an alternate low embodied energy brick/block will lead to substantial reduction in energy impact. Understanding embodied energy in such a way can allow designers to make informed decisions about the selection of materials and technologies.

Embodied energy of some of the common building materials is tabulated below.

Table 12: Embodied energy of some of the commonly used building materials (IFC, 2017)

Building Material	Embodied Energy (MJ/ kg)
Burnt Clay Bricks (common)	4.4
Flyash Lime Gypsum Bricks	0.83
Cement (Ordinary Portland Cement)	6.4
Steel reinforcement	30
Glass (Float Glass)	17

Figure 12 shows the change in embodied energy of multiple affordable housing projects and based on the change of walling material. The three walling material compared area: Brick Wall, Monolithic Concrete and Autoclaved Aerated Concrete (AAC). A Ground plus three storeys (G+3) (Project 1 & 3) structure has higher or comparable total embodied energy to Project 6 and 7 which are much higher Stilt plus seven storeys (S+7) structures. This is primarily due the change in walling material. Bricks have a much higher embodied energy than AAC block. Change in one material can reduce or increase the embodied energy at the building level substantially.

Further, at a building level, change in the building height and consequent different structural requirements for low, mid and high-rise buildings also have an impact on the embodied energy as can be seen from figure 12 and 13. The embodied energy due to the use of steel is much higher in S+10 and S+11 height structures. The structural requirement of the building corresponding to its height directs the materials usage. Where a low-rise building could be a load bearing structure eliminating or reducing the use of steel (a high-embodied energy material) or have an opportunity to explore low-cost, low-embodied energy construction techniques such as stone masonry, arches, vaults, filler slabs etc.; a high-rise building to be structurally stable relies significantly on the reinforced cement concrete (RCC).

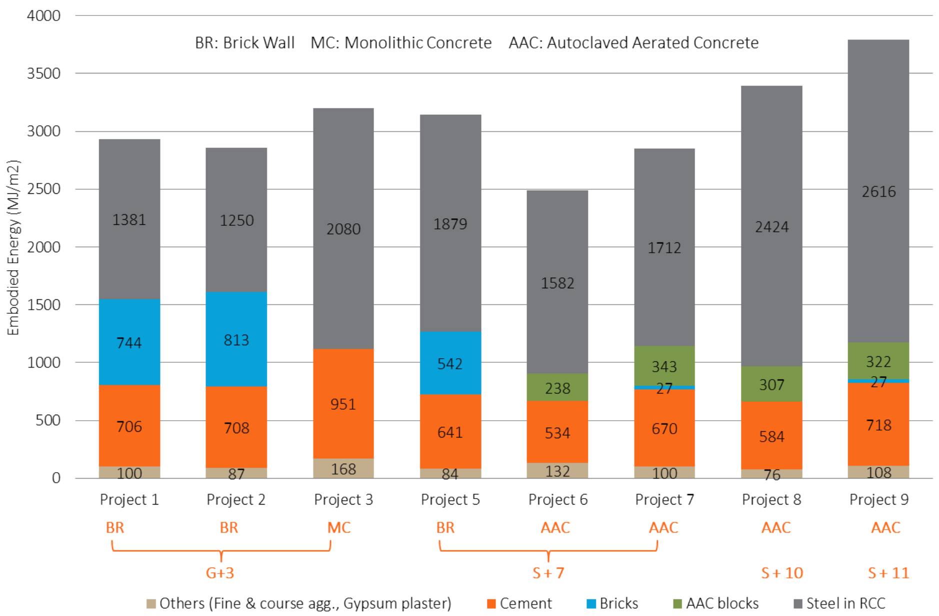


Figure 12: Comparison of embodied energy of multiple affordable housing projects (Lall et al., 2017)

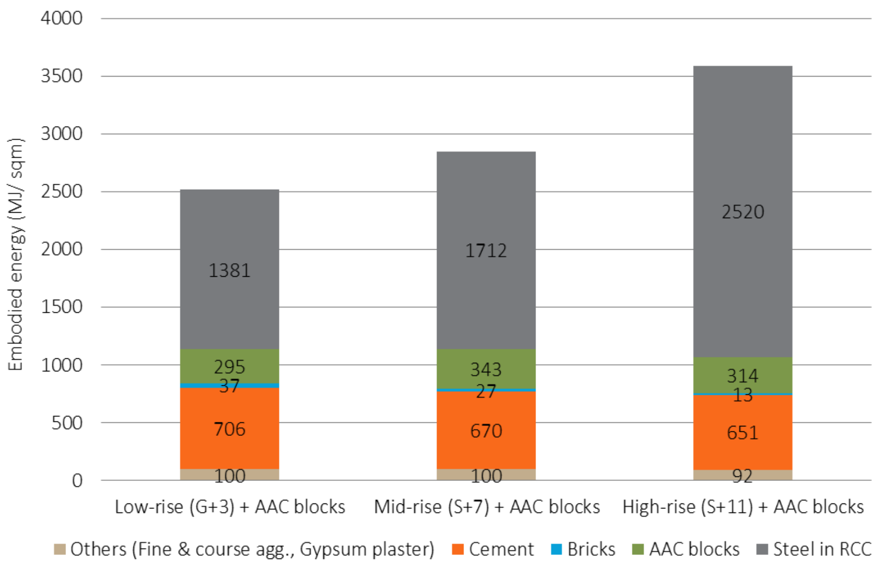


Figure 13 : Average embodied energy in 3 typologies

Hence, while it is useful to replace high embodied energy materials with suitable alternatives, at a building level, change in height and the structural requirements considerably alter the embodied energy even when the same materials are used (figure 13).

To reduce the embodied energy impacts of the affordable housing that will come up as part of the Mission, building design, materials and construction technology selection should not look for one solution that fits all. While high-rise construction is more likely in and around large urban centres, a large part of the mission housing in smaller cities and towns can benefit from low to mid-rise construction. This will significantly impact the embodied energy impact of the housing. This is also likely to relate to the construction capacity and the skill set of the local industry.

1.16. Design and construction related operational energy impacts

Operational energy is required to run building systems to provide thermal comfort (i.e. heating, cooling and ventilation), visual comfort (i.e., lighting) and other common/ individual services. Multiple factors at the dwelling and building level impact overall operational energy, an area well researched and documented for building sector in India. Sufficient database is available detailing low-cost and energy efficient building design and construction practices to enhance user comfort. From affordable housing perspective integration of low-cost and energy efficient building construction to address and enhance user comfort becomes extremely critical for two reasons (1) it ensures thermally and visually comfortable habitats to housing segments which are most vulnerable to climate change impacts and cannot opt for active comfort strategies, (2) to manage the current and future operational energy demand which may increase significantly if households opt for active cooling technologies especially room air-conditioners in the near future.

Within a building, comfort levels vary considerably based on the local climate and building design which define the need for cooling/ heating/ lighting. For example, a building in hot & dry climate require cooling strategies to combat heat; whereas, a building in warm & humid climate require strategies which combat heat as well as humidity. Passive daylight integration strategies also vary based on the outdoor lux levels. This section attempts to delineate the key building design and construction components which impact operational energy at a dwelling as well as building level in affordable housing.

1.16.1. Operational energy impact at dwelling level

At a dwelling level, building design and envelope properties impact the thermal and visual comfort which determines the operational energy. Building envelope (walls, glazing and roof) regulates the heat transfer, whereas building orientation and dwelling design has an impact on daylight integration and natural ventilation within building. Apart from these, appliance penetration and use adds to the operational energy demand. Cost-effective, energy-efficient building envelope and integration of passive measures such as window shading, optimal building orientation and provision of cross ventilation has the potential to reduce the indoor temperature significantly. It is imperative that affordable housing is designed to be responsive to climatic conditions for enhancing the user comfort. This also has an impact on affordability, as energy costs for attaining comfort conditions will reduce for the occupants. Finally, appropriate light and ventilation is also the key to designing healthy living spaces and communities. At a dwelling level, operational energy depends on the following factors:

Thermal comfort: Thermal comfort is the physiological and psychological need of human beings that expresses thermal satisfaction with the immediate indoor environment and is assessed by subjective evaluation (ANSI/ASHRAE 55, 2017). While there are active measures such as cooling technologies, to attain optimum thermal comfort levels indoors, passive measures integrated during building design and construction stages can substantially reduce the need for active measures to heat and cool the building, hence reducing the operational energy. Including them at the design stage is cost effective as these are no/low cost measures that can be easily integrated with careful design and construction.

In a hot climate designing for thermal comfort requires reducing heat transfer from the outside to the internal spaces; whereas in a cold climate heat has to be captured and retained inside the building interior. Passive design strategies which impact thermal comfort level includes (1) Building Orientation - an optimum building orientation focus on restricting the direct harsh sun indoors while integrating glare free natural light and ventilation, (2) Building Envelope which includes wall, roof, doors and windows aims at reducing the thermal conduction between the outdoor and indoor to maintain coolth/ heat within the building for longer duration. The direct heat transfer takes place through glazing, whereas indirect heat transfer takes place through walls, roof and doors. The u-value of the walling and roof material determines the rate of heat loss, where low u-value indicates better insulation property of the material. The heat transfer through windows is determined by Solar Heat Gain Coefficient (SHGC) and low SHGC indicates low heat transmission, (3) Natural Ventilation is dependent on building orientation and design of openings and assists in fresh air movement, elimination of heat and space cooling. Simple strategies such as placement of ventilators above the door or designing openings that facilitate cross ventilation can greatly enhance thermal comfort and (4) Cool Roofs - light colour/ reflective finishes on roof, used in hot climate prevents heat from entering from the roof by reflecting most of the solar radiations. A cool roof can lower the indoor temperatures lower by 2 to 5°C of the top floor (NRDC, ASCI, IIPH, 2017).

According to a study, (BEEP, 2017) in a composite climate, a building envelope with walls of u-value 0.8 W/sq m.K (230mm AAC blocks), southern wall with a u-value 0.3 W/qm.K (230mm AAC walls on both sides with 50mm cavity), roof with a u-vale of 0.56 W/sq m.K (with roof insulation and high-reflective china mosaic finish) , appropriately shaded windows along with optimum building design and layout to enhance ventilation can result in reduction in indoor temperature by 5°C. The u-value of burnt clay brick is 2 W/sq m.K (230mm wall); whereas that of conventional roof is 2.7 W/sq m.K. Amongst the sixteen technologies proposed by BMTPC, the thermal transmittance of the envelope ranges from 0.3 W/sq m.K. to 3.59 W/sq m.K. (BMTPC, 2017). Compared to regular brick walls, the envelope thermal transmittance value of some of the technologies is higher which will adversely affect the thermal comfort level within the dwelling unit. There is an urgent need to recognise the impacts of proposed technologies on thermal comfort, and especially, how it can be achieved through low-cost measures

Another study simulated a prototypical low-cost housing cluster for composite and warm & humid climate the change in demand of operational energy with the change in walling material and indicated fly ash brick and hollow concrete block saves 5% and 10% operational energy respectively as compared to burnt clay brick wall due to change in thermal conductance of the respective materials. The study also indicated that further integration of passive design strategies such as optimum building orientation coupled with appropriately sized shading devices for the windows and provision of cross ventilation can increase the comfortable hours by 60% in composite and warm and humid climate (EDS, 2011) as indicated in Figure 14.

AEEE's Thermal Comfort for All study insists on enhancing thermal comfort and reducing cooling demand through Lean-Mean-Green construct – a hierarchal approach for smart and sustainable cooling strategies which was popularized by building scientist Bill Bordass. The lean stands for enhancing thermal comfort by incorporating better building design (AEEE , 2017a)

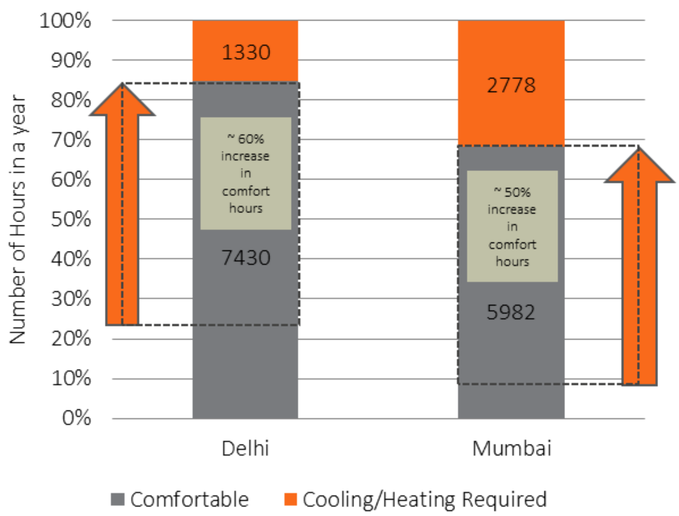


Figure 14: Increase in thermal comfort through passive design (EDS, 2011)

Visual comfort: Visual comfort is dependent on adequate natural light inside during daylight hours so as to reduce the need for electric lighting. It is dependent on the window size, building orientation and glazing visible light transmission (VLT), where high VLT glazing allows most of the daylight pass through. Optimum window-to-wall ratio (WWR) is determined for maintaining both thermal comfort (by reducing direct heat gains) and adequate natural light inside the building. A study analysing affordable housing in Mumbai indicated that with South-East orientation and 20% WWR, the building can save up to 26% in energy needed for lighting energy, or inappropriate design can also potentially increase lighting energy consumption up to 6% (Bardhan & Debnath, 2016).

Appliances: Affordable housing units currently use limited appliances. Commonly used appliances include ceiling fans, lights, refrigerator, television, evaporative cooler and hot water geyser. A 2011 study simulating prototypical low-cost housing units indicated that for a typical base case dwelling unit, ceiling fans and refrigerators are responsible for the highest share of operational energy followed by lighting and hot water as shown in Figure 15. (EDS, 2011).

A more recent survey carried out at affordable housing in Rajkot found that fans are the most commonly owned appliances followed by televisions and refrigerators. The study included survey of 700 number of houses across the EWS and LIG households. Television ownership rates didn't wary across different income group households, however, refrigerator ownership was higher in LIG households (Khosla & Bhardwaj, 2017). The survey also found that 63% of the lights in the affordable housing development were LED (Khosla & Bhardwaj, 2017a). According to AEEE's study (2018), after RACs, fans have the second highest energy consumption of the total energy consumption required for space cooling. Enhancing efficiency of fans along with mandatory energy star labelling can significantly reduce the energy requirement for space cooling at national level and operational energy at the dwelling unit level.

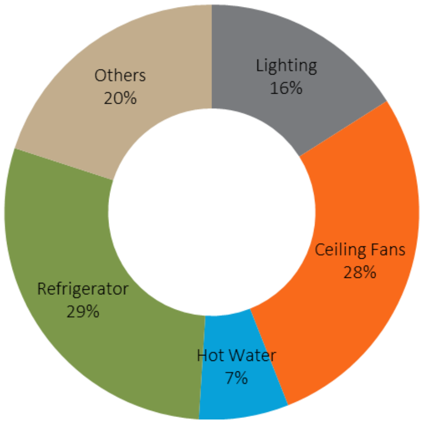


Figure 15: Distribution of typical operational energy consumption

Appliance ownership in the affordable housing sector is minimal currently and the households majorly rely on fans to enhance thermal comfort, with air-coolers in only a few households. For an EWS household with an annual income of about Rs 3 lakhs, it is expected that currently the affordability of the dwelling unit will be of higher priority than comfort. Already, 30% of the energy use is related to cooling related comfort conditions. However, with increase in purchasing power, ownership rates of appliances are likely to increase, including cooling technologies and possibly air conditioners. Additional heat stress due to urban heat island effect and increased temperatures due to climate change is already noticeable in cities. The integration of thermally appropriate design and construction will enable lower energy use currently as well as in the future by delaying the adoption of air-conditioners. While the Mission is not responsible for provision of appliances, strategies for targeted adoption of energy-efficient appliances through other government programmes and schemes will further add to reductions in energy use and enhance affordability for the occupants through reduced energy costs.

1.16.2. Operational energy impact due to building layout and open spaces

At a building level, energy is required to operate common services such as lighting, pumping, lifts etc. Additionally, site planning which includes building placement with respect to surrounding buildings, integration of green areas and building orientation also impacts comfort levels and hence operational energy within the building (as discussed above). Hence, the designing for lower operational energy while maximising user comfort requires strategic integration of design and construction strategies both at the dwelling and the building level. The energy impact of building layout and open spaces can be segregated into:

Energy for common services and potential for renewable energy integration: In a multi storey residential building some of the services such as water pumps and lifts are integrated at the common building level. The provision and hence the energy consumption by common services depends on the number of households as well as the height of the building, as enhanced levels of common service provision are required as the building height increases.

A study analysing affordable housing projects in Rajkot, Gujarat compared the building services energy consumption for low, mid and high rise buildings to understand the relationship between the energy demand of common building services and building height. Increased service provision also results in higher maintenance cost that directly impacts affordability for occupants. The following graph illustrates the pump energy and lift energy per dwelling unit for Ground plus three storey (G+3) and stilts plus seven/ten/eleven storey (S+7, S+10 and S+11) structure and their consequent maintenance cost (Lall et al., 2017)

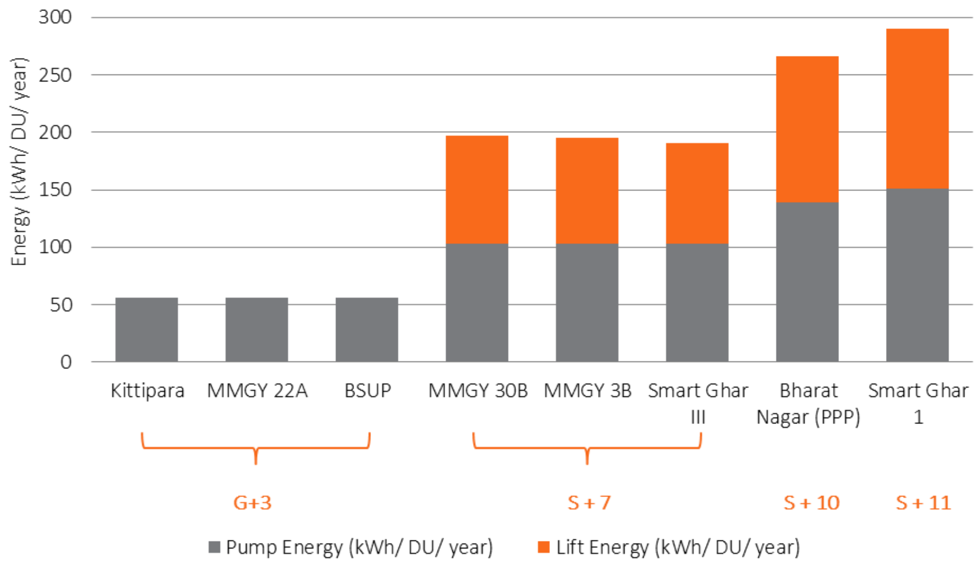


Figure 16: Comparison of common services energy consumption per DU per year

The project infers a rise of up to 4 to 5 times in the energy demand of common services from low-rise to high-rise. The additional operational energy for lifts is a substantial increase in all projects above G+3 storeys. Further, the building height also determines the percentage of energy which can be offset by roof-top solar photovoltaic panels (PV). A low-rise structure has significantly lower common services related operational energy demand. The roof-top solar PV can offset considerable building electricity demand from the grid, as compared to a high-rise structure with the same roof area.

In the affordable housing segment, integration of renewable energy technologies is currently not cost-effective. However, to reduce the energy impact of affordable housing, both energy optimisation and provision of energy from cleaner sources is required. This is optimal in low to mid-rise buildings. Higher buildings have less roof area per household and due to the higher common services energy, the share of RE to contribute to the total energy use of the building reduces greatly. At a city level also, low carbon urban strategies will benefit from this insight on the integration potential of rooftop solar technologies in buildings.

Thermal and Visual comfort: At a building level, thermal and visual comfort is affected by the (1) Height to separation ratio (H:S) between buildings and (2) Surrounding open spaces (MoHUA, 2011) (Lall et al., 2017). The H:S ratio directly impacts the design of building envelope, WWR and fenestration VLT. The H:S ratio and the building orientation also impacts the air flow surrounding the building and can affect natural ventilation within the dwelling units.

Further, the use of hard/ soft surfaces within the surrounding open spaces can promote/ impedes heat retention capacity of the surfaces. In some states, the surrounding open space in housing projects is a function of the plot size rather than the density. Higher density achieved through high-rise buildings has been found to result in lower proportion of open area per person, along with increased parking (paved) area. Higher paved area in the surrounding can exacerbate the urban heat island effect.

Amongst the various uncontrollable and controllable variables contributing to urban heat island, urban infrastructure (land use plan, surface character and building morphology) is a controllable variable and with strategic interventions it can significantly reduce the magnitude of urban heat island effect. (Lall et al., 2014).

The H:S ratio and WWR, also impact daylight integration. Table 13 shows the minimum WWR% with respect to the H:S for achieving adequate daylight levels within a building (MoHUA, 2011).

Table 13: H/S ratio and its corresponding WWR% required for adequate day lighting (MoHUA, 2011)

H/S ratio (height to separation between buildings)	Minimum WWR (%) required for adequate day lighting
1:5	10
1:4	10
1:3	10
1:2	20
1:1	20

2:1	50
3:1	60

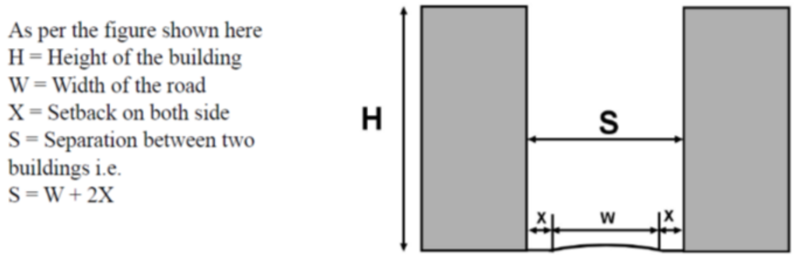


Figure 17: H:S ratio calculation

While there are studies indicating the energy impact of low-rise vs high-rise construction, the potential energy savings from the use of sustainable materials with high solar reflective index (SRI) and by maximising green spaces could be explored in more detail.

To mainstream energy optimisation and user comfort in affordable housing, it is important to integrate low-cost passive design strategies focussing on improving the thermal comfort within the dwellings and reducing operational and embodied energy use. The strategies to enhance energy optimisation and user comfort in affordable housing have been extensively researched and compiled in India; however, their applicability in the on-going projects, specifically in the projects under PMAY-U mission has not been commonly observed. There is a need for better integration of research outcomes in the affordable housing sector policies. Most of the research results highlighted in the previous section can be easily integrated without adding to the cost of the housing projects, but will have a significant impact towards reducing the energy use in affordable housing. Effective communication, and capacity and skill development is required to integrate these strategies in policies and in housing projects.

1.17. Existing policy framework for optimising energy use in buildings

The significant energy impact of buildings has been recognised and addressed in key building regulations as well as green building certifications. These refer to both embodied and operational energy use in the buildings sector. All of these are applicable to affordable housing buildings as well.

The **National Building Code 2016**, includes a chapter on *Approach to Sustainability* recommending several measures for low energy building design and construction including site, form and design where the focus is on site design and development; (1) External Development and Landscape, (2) Building Optimisation focusing on building level strategies such as energy efficient building envelope and integration of renewable energy, (3)Materials which discusses the sustainable alternatives (low –embodied energy) for construction, (4) Building Services Optimisation which discusses passive and active cooling strategies to enhance use comfort (5)Construction Practices and (6) Commissioning, Operation, Maintenance and Building Performance Tracking (BIS, 2016).

The draft **Energy Conservation Building Code for Residential (ECBC-R), 2018** sets minimum energy standards for residential buildings. It is applicable to houses built on plot area ≥ 250 sq m for all five climatic zones. It sets minimum building envelope performance standards to limit heat transfer and for ensuring adequate natural ventilation and day lighting. The draft code requires compliance for for provisions - thermal transmittance (u-value) of building envelope (walls, roof and fenestration); SHGC of fenestrations; minimum openable window-to-floor area ratio for adequate ventilation; and minimum visible light transmittance (VLT) for the non-opaque building envelope components for adequate day-lighting (BEE, 2017).

The **Model Building Bye Laws 2016**, chapter 10 discusses *Green Building and Sustainability* and provides green building requirements for various plot sizes. Apart from highlighting efficient use of energy by installing low energy consumption lighting fixtures, energy-efficient HVAC systems and provision of solar energy/ LED lighting in common area, the policy also discusses use of sustainable building materials for low-embodied energy construction. Further, it refers to green building rating systems such as Indian Green Building Council (IGBC) and Green Rating for Integrated Habitat Assessment (GRIHA) and suggests states to develop their green rating systems to reduce building energy demand and provide comfortable and sustainable habitats (TCPO, MoUD, 2016).

The **green building ratings** for affordable housing have been developed by IGBC and GRIHA. Their approach is to encourage adoption of measures which are simple, low-cost, and enhance user comfort with no/ meagre additional cost to the developer or the occupant. Measures for energy optimisation and user comfort include: (1) Apposite site planning and development to minimise hard paved area and its consequences like heat island effect, (2) Energy efficient building envelope measures (U-value for overall wall assembly, roof and glazing for all five climatic zones along with glazing SHGC), (3) Appropriate shading of envelope openings to reduce heat intake inside building (4) Efficient lighting by promoting daylight integration and efficient lighting fixtures, (5) Use of local materials promoting vernacular architecture and reducing transportation energy, (6) Use of materials with recycled content such as fly-ash, Autoclaved Aerated Concrete (AAC), Cellular Lightweight Concrete (CLC), (6) Adopting alternative construction technologies and materials which are cost-effective and sustainable and (8) Renewable energy integration to meet the energy demand sustainably (IGBC, 2017) (GRIHA, 2018).

In spite of these recommendations in key model policies, energy optimisation strategies have not been mainstreamed in affordable housing, even though there is enough evidence to understand the energy impact as well as suitable measures that can effectively reduce energy use.

1.18. Significance for PMAY

The Energy impact of buildings depends on both the operational and embodied energy within the building materials. While building codes and other energy regulations focus on reducing operational energy use and shifting to decarbonised electricity provision either through onsite or offsite generation, reduction of embodied energy has not been an explicit mandate due to inherent complexities in calculating it. Green building ratings, with a wider mandate on environmental performance of buildings include few criteria on use of locally procured materials and materials accounting for reuse, recycling and/ or incorporating waste materials from other production process such as fly ash.

Estimating precise embodied energy at a building level can be complex in the absence of accepted methodologies for calculation, national datasets and calculation tools. However, its contribution to the total energy of the affordable housing stock as part of the PMAY mission is likely to be substantial, especially, in comparison with the minimal operational energy of affordable housing currently. Within the larger context of energy efficiency in the building sector and associated carbon emissions from the large scale construction expected due to urbanisation, it becomes important to account for strategies that can help in reducing embodied energy in buildings.

- Balance between the thermal performance and embodied energy properties while selecting materials
- Reduction in the use of high embodied energy materials - steel, glass, aluminium, or their replacement with materials
- Replace materials which are used in larger quantities by mass (such as in walls) with lower embodied energy materials or with higher recycled content
- Assess the design and construction technology/ structure for impact on embodied energy.

The building and dwelling unit design can also reduce the operational energy.

- Optimum unit planning to enhance thermal and visual comfort by day light integration, cross ventilation, window shading, low thermal transmittance of envelope and cool roof.
- Site planning to optimize building orientation, WWR and heat island effect for enhanced comfort levels within the building.
- Integration of energy-efficient (star labelled appliances) at household level
- Optimum building height to minimise common services' provision, operational energy and maintenance cost and enhanced RE integration potential
- Targeting low life cycle operational cost rather the low initial building cost by building for affordable maintenance and operation as well.

The mission is being supported by a number of development sector initiatives aiming at sustainable and green affordable housing including energy optimisation and efficiency strategies. IFC has created a coalition of large developers (Godrej Properties, Mahindra Lifespace Developers, Shapoorji Pallonji Real Estate, Tata Housing Development Company and VBHC Value Homes (Outlook, 2017) to collectively address the bottlenecks for green affordable housing supply. The large developers represent the high rise-high volume opportunity for constructing affordable housing. This is likely to be built close to large urban centres. Smaller cities and towns will require different solutions based on the capacity of the local construction industry.

Recently, Bloomberg (MoHUA, 2018c) has announced a technology challenge along with the MoHUA for green affordable housing in line with the mission requirements. While innovation in this segment is a welcome step, apart from a technological solution, affordable housing requires a holistic approach to context and community specific designs and process of construction as well.

Both of these are important initiatives highlighting the need for sustainability integration in affordable housing sector. However, it is also useful to recognise that the mission has a diverse range of housing and project types and one technology or financing solution will not be universally applicable. There is also the need for increasing the capacity at the state and city level to promote effective integration of existing knowledge within the implementation frameworks.

6. Key recommendations and next steps

Pradhan Mantri Awas Yojana (PMAY), Government of India's flagship program aims to provide affordable housing to urban and rural poor. Launched in 2015, the PMAY-Urban is targeting to build 12 million dwelling units by 2022. The focus of the Mission is to build fast and deliver units at an affordable price within the specified period.

Affordable housing narrative is currently driven by the link between *income and built space provisions* and the *cost* of the dwelling unit, as the determining criteria of affordable housing.

The scale of the challenge in meeting the affordable housing demand and the Mission targets necessitates that energy impacts of housing construction are evaluated to avoid lock-in of a large inefficient housing stock. Building to optimise energy use and provide thermally comfortable housing can significantly reduce the energy impacts from the affordable housing sector. Substantial research on thermally comfortable design and construction practices exists; however, it has not been mainstreamed into the policy and the development of housing projects. Most of these measures have no significant cost associated with them, as detailed in the previous sections of the report. Additionally, appropriate energy strategies will effectively improve the long-term affordability for the occupants, by reducing the energy costs of running these houses. This should be accounted for in the affordability discussion, apart from one-time costs of constructing the dwelling units.

Building thermally comfortable housing is also important from a resilience perspective. Urban poor are most vulnerable to climate change impacts such as increased temperature and urban heat island effects due to lack of access to proper housing and common services. Building climate resilient housing will reduce these vulnerabilities from both a health and energy perspective.

This study has carried out a detailed review of regulatory provisions in the Mission, assessed the mission targets and progress, and highlighted key research on appropriate energy optimisation strategies within affordable housing. This is first step to understand the energy impact of affordable housing and also highlight that building thermally comfortable affordable housing does not necessarily require additional cost, but an understanding of parameters which impact energy use and comfort within the dwellings such that they can be mainstreamed in policies as well as design and construction practices.

Below is a summary of the key findings including a discussion on research and data gaps. Apart from the analysis presented in the report, these also include insights from one on one stakeholder conversations, affordable housing workshops and roundtables, as well as case studies reviewed as part of the secondary research.

1. **The mission has a diverse range of housing and project types and any one solution will not be universally applicable.**

   Mission housing is distributed across more than 4000 cities and will need to respond to the local context, climate, state and city level regulatory provisions as well as local construction industry capacity.

   Disaggregating the mission targets into the type of housing (mission components) and its location (large urban centres vs smaller cities and towns) will be useful in evaluating the energy impact and in identifying the range of solutions which balance the need for achieving scale and replication quickly, as well as context specific design inputs to meet the construction targets.

In spite of detailed housing demand surveys by States and Cites, there are evident data gaps. The demand survey data does not provide information at the component level, except for sanctioned projects. Availability of this data will help disaggregate the affordable housing targets by the four components. This study highlights possible barriers for each of the four Mission components based on their progress and literature review. These specific barriers will need to be evaluated and addressed to mainstream energy optimization.

Similarly, city specific demand data is not available. Affordable housing projects in large urban centers are likely to differ from those in smaller cities and towns in their scale (number of dwelling units), private sector capacities, skills and construction materials and technologies as well. Mapping the demand will allow focused inputs into appropriate energy optimisation strategies. The sixteen technologies suggested by BMPTC requires certain scale to be economical and skill set and thus credible dataset will lead to concerted efforts. Our interaction with two developers that incorporate energy parameters in the design and construction of affordable housing projects highlights this difference. The large developer assessed and required high volumes in one place to reach economies of scale for financial viability. The small to mid-level developer worked with participatory design processes for developing the housing project.

2. **The rate of project approval and construction is slow. This provides a window of opportunity to incorporate thermal comfort criteria and energy optimisation strategies in the design and construction of affordable housing.**
   Detailed analysis of government and other available datasets for the affordable housing stock progress under the PMAY mission shows that of the total revised housing demand, 32% has been sanctioned, 6% is under construction and only 2% has been constructed. There are multiple barriers to achieving the desired rate of construction, including state and city level capacity to carry out the varied regulatory requirements from the demand survey to project approvals, construction and delivery of housing as well as market barriers for private sector participation. As a result, neither the government, nor the private sector has been able to build affordable housing at a scale that is required to meet the demand.

   Often, the need for faster construction has been used as an argument to not rethink the prevalent construction and design practices and selection of construction technologies, which lend themselves to faster construction, have been prioritised. The impact on comfort and reducing operational and embodied energy should be part of the technology selection criteria. This requires effective evidence building and communication with relevant national, state and city level government stakeholders along with capacity development of the private sector.

3. **Mainstreaming energy optimisation requires a stronger link between research, practice and policy design.**
   The study has carried out a comprehensive literature review of existing research in energy efficiency strategies for affordable housing. Substantial knowledge on design approaches and technical interventions for achieving thermal comfort, energy efficiency and reducing embodied energy in affordable housing exists. However, research is needed to understand the structure of policy and mission implementation to link it to research recommendations. This study has mapped the regulatory instruments and the role of relevant departments at the national, state and city levels for Mission implementation. Additionally, learning from best practices followed in States/ Cities can provide useful insights. From 1988, MoUD supported Building Centres program to work on low-cost innovative housing design and construction technologies along with engaging with the local community for contextual solutions. Notable building centres include Nizamuddin building centre, Delhi; Nirmithi Kendra, Kerala; and Anangpur building centre, Haryana. The program aimed at innovation and application of appropriate and indigenous technology and materials, skill enhancement and engagement with practitioners to provide local solutions for low-cost housing. (Keswani, 1997). While the program discontinued, proposing an effective roadmap, engaging design professionals and the local community is crucial for effective affordable housing solutions.

   Affordable housing built by Rajkot Municipal Corporation has successfully incorporated thermal comfort and energy efficiency criteria. It is important to understand the process through which design and technical interventions can be mainstreamed and institutionalized. State and City specific process mapping can help understand -

a. Is the state/ city progressive in its development norms and other affordable housing polices?
b. Are their additional state/city subsides for affordable housing?
c. Does the financial status of municipalities have an impact on affordable housing projects?
d. What is the process followed for design and procurement of affordable housing projects?
e. Are there individual champions, which have led to successful outcomes?
f. What are learnings for other states/ cities?

4. **A large proportion of the mission target is likely to be self-build housing. Innovative approaches are needed to mainstream energy optimisation in this segment.**

Subisdy for Beneficiary Linked Construction has seen the highest disbursement rates by the States/UTs as almost 60% of sanctioned stock is under this component. This also represents 12% of under construction and 5% of the sanctioned stock that has been built. Self-build housing as part of BLC forms a significant proportion of Mission targets. Research studies (Lall et al., 2017) estimate it to be half of the total housing target. There is a lack of understanding of measures that can address this segment to integrate design support and low cost and low energy construction materials and technologies. Further exploration of this component can help understand if there is provision for built environment design professionals to meaningfully engage within the Mission for improving the quality of self-build housing in urban areas. Also, how procurement models can be useful for selection of low embodied energy materials for this segment.

Affordable housing faces a range of social and economic barriers, specific to the different groups of target beneficiaries. However, the houses that are being built can benefit from understanding how the design and construction for optimising energy use and providing thermal comfort for all, are also aligned with social and economic objectives of the Mission. This will hence, lead to improved quality, comfort and ensure affordability of future energy costs to the beneficiaries, along with reduced energy use and related carbon emissions in line with the national climate change targets.

Annexure

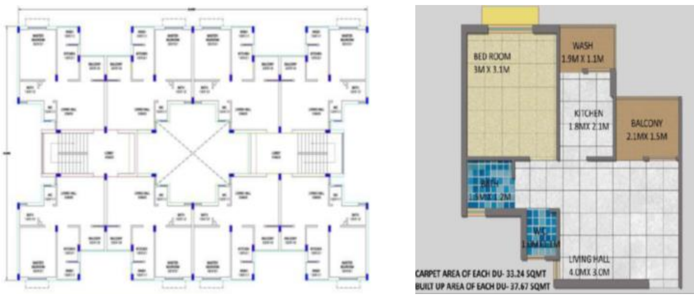
7. Annexure I: Affordable housing design and construction business-as-usual practices

The section delves into on-going affordable housing projects design and construction practices selected by states. Each state provides details on their on-going housing projects to Central Sanctioning and Monitoring Committee (MoHUA, 2017b). Projects undertaken by states (Chattisgarh, Karnataka, Odisha, Rajasthan and Telangana) and two pilot projects undertaken by BMPTC under AHP component are discussed to comprehend the design and construction practices. The projects are evaluated across multiple parameters like: zoning (cluster design), building height, unit design, type of construction technology and type of materials.

Table 14: Cluster design, unit plan & building height for on-going project in various states

CLUSTER DESIGN, BUILDING HEIGHT AND UNIT DESIGN

The images illustrate the model drawing for housing blocks of various projects presented at CSMC meetings.
The buildings designed are low rise structures – G+2/ G+3/ G+4 for majority of constrution, whereas some cities like Surat are also opting for high-rise construction.
While there are windows provided in unit plan to integrate natural ventilation, the provision of cross ventilation is missing in some projects. Window shading is also indicated for some of the projects; however, the unit plan does not explicitly discuss the cross ventilation, window shading and integration of daylight. Also, the window type (fixed/ partial openable/ 100% openable) and size of window shading is not provided. The typical carpet area of all the units is around 30 sq m.

Chhattisgarh	 *Figure 18: Typical Floor Plan & Unit Plan – Chattisgarh*  *Figure 19:Building height – Chattisgarh*
Kartanaka	

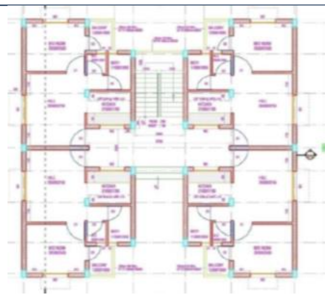


Figure 20: Site Layout & Unit Plan – Karnataka

Odisha

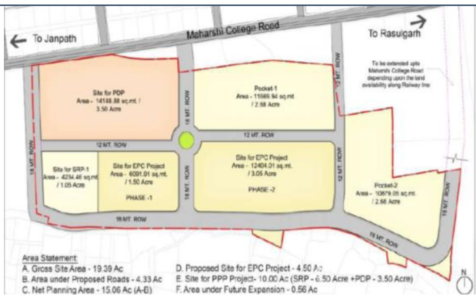


Figure 21:Site Layout – Odisha

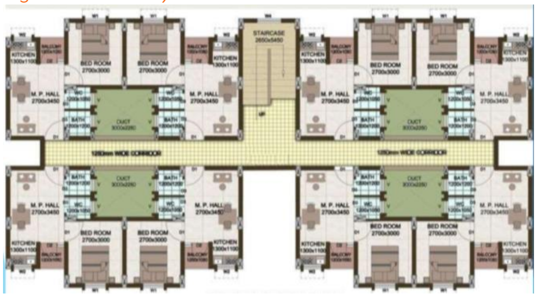


Figure 22: Typical Floor Plan & Unit Plan - Odisha

Figure 23: Building Height – Odisha

Rajasthan

Figure 24: Typical Floor Plan & Unit Plan - Rajasthan

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Figure 25:Building Height - Rajasthan</td></tr>
<tr><td>Telangana</td><td>

Figure 26: Site Plan - Telangana

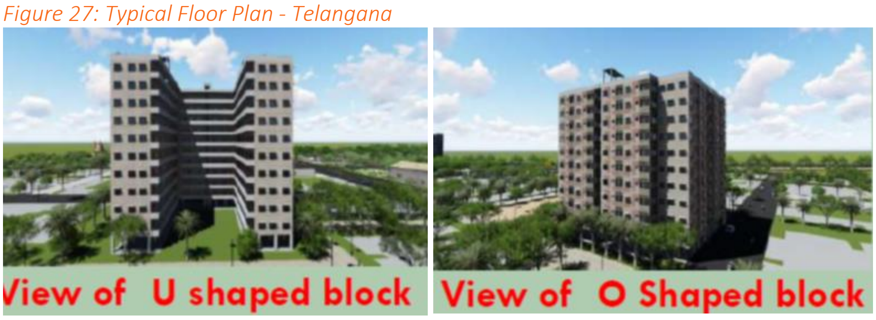

Figure 27: Typical Floor Plan - Telangana


Figure 28: Building Height – Telangana</td></tr>
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Table 15: Type of construction & material selection for on-going project in various states

TYPE OF CONSTRUCTION AND TYPE OF MATERIALS

Different projects have deployed different construction technologies, for e.g. Bhilai Municipal Corporation project is using monolithic construction and CGHB in Naya Raipur is using pre-cast elements.

The materials used for building envelope i.e. outer walls and roof are not discussed. The images presented depicts use of flyash bricks (low-embodied energy & low thermal transmittance material); however there are also projects using materials having high thermal transmittance clearly indicating slight focus on user thermal comfort.

Chhattisgarh	

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Figure 29: Bhilai Municipal Corporation project – Chhattisgarh


Figure 30: Project in Naya Raipur – Chhattisgarh
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<tr><td>Kartanaka</td><td>


Figure 31: Dwelling unit material specification of two projects – Karnataka
</td></tr>
<tr><td>Odisha</td><td>


Figure 32: Envelope materials (Flyash & RCC walls (from left to right)) – Odisha
</td></tr>
<tr><td>Rajasthan</td><td></td></tr>
</table>

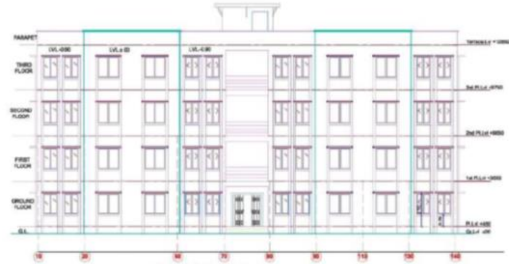
	 *Figure 33: Flyash bricks used for walling - Rajasthan*
Telangana	 *Figure 34: Walling materials (Flyash brocks & burnt clay bricks) - Telangana*

Table 16: Demonstration Housing Project by BMTPC (MoHUA, 2017b)

DEMONSTRATION HOUSING PROJECT BY BMTPC

BMTPC has identified 16 technologies (BMTPC, 2017) to facilitate faster construction; however some of the technologies selected require a certain scale and skill set, which limits their applicability across India. Also the thermal transmittance of building envelope of some of the technologies (i.e. monolithic construction) is much higher than the conventional burnt clay brick and will significantly affect the user thermal comfort indoors.

CLUSTER DESIGN, BUILDING HEIGHT AND UNIT DESIGN	
Bhubaneswar, Odisha (under construction)	 *Figure 35: Site Plan & Typical Floor Plan - Demonstration housing project by BMTPC at Bhubaneswar*

	 *Figure 36:Building Height - Demonstration housing project by BMTPC at Bhubaneswar*
Bihar Shariff, Bihar (under construction)	 *Figure 37: Site Plan & Typical Floor Plan - Demonstration housing project by BMTPC at Bihar*  *Figure 38: Building Height - Demonstration housing project by BMTPC at Bihar*
TYPE OF CONSTRUCTION AND TYPE OF MATERIALS	
Bhubaneswar, Odisha (under construction)	 *Figure 39: EPS technology for construction - Demonstration housing project by BMTPC at Bhubaneswar*
Bihar Shariff, Bihar (under construction)	

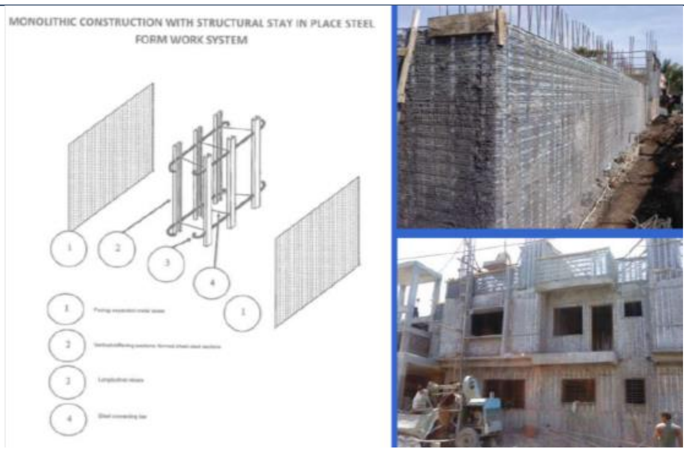


Figure 40:Monolitic construction with structural stay in place steel form work with system - Demonstration housing project by BMTPC at Bihar

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