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Critical Analysis of Net Zero Pathways for Affordable Housing in India

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1 ABSTRACT

The residential floor area in India is expected to more than double by 2040. Ninety-nine percentof this growth is in Low Income Group segment, proving that affordable housing is the future of residential development. This will lead to high energy consumption and carbon emissions. In 2023-24, the building sector accounted for 13% of the total energy consumption in India, of which 82% came from the residential sector. It is thus crucial to ensure that all new residential building stock, expected to last for the next 5 decades, is built in a climate-conscious manner to reduce energy consumption and carbon footprint of the built environment. However, this can only happen if the needs of the affordable housing segment are addressed.

This paper examines the applicability of India's two of four net zero pathways in affordable housing – energy-efficiency, sustainable materials and construction technologies. It analyses regulatory instruments, policies and schemes, and market instruments through the Availability-Affordability-Quality framework, examining if solutions are available, if solutions are affordable, and if solution favours emission reduction.

Findings show that most instruments are designed for an overall built environment, with no specific focus on low-income groups. Of the specific affordable housing policies, recommendations for achieving affordability is found to compromise with quality, particularly considering GHG emissions. Based on the findings, the paper provides three recommendations – (i) developing a unified definition of green, (ii) consolidating policy implementation through unified regulatory mechanisms, and (iii) procurement reforms to unlock potential of sustainable materials/technologies use, to ensure an affordable net zero future for India.

Keywords: Policy implementation, Operational emissions, Net zero built environment, Embodied emissions, Affordable housing

2 INTRODUCTION

India is at a critical juncture where urbanization and its impact on climate are converging. India's urban population is expected to rise from 31% in 2011 to 38.2% in 2036, accounting for an additional 218 million population(National Commission on Population, 2020). This is expected to lead to an increased demand in infrastructure to house and service the additional urban population, with the highest demand expected to be in residential floor space. The urban residential sector was adding 0.52 billion sqm floor space annually in 2020.By 2050, this is expected to go up by 82%, adding 0.95 billion sqm annually(National Institute of Urban Affairs & RMI, 2022). In a business as usual scenario, energy consumption from this will increase threefold, and carbon emissions will quadruple. Therefore, it is crucial to ensure that all new building stock, expected to last for the next five decades, is built in a climate-conscious manner to reduce energy consumption and carbon footprint of the built environment, especially residential buildings.

Additionally, this has to predominantly address the economically weaker sections (EWS) and low-income groups (LIG). Roy & ML, (2020) estimated the urban housing shortage to be 50 million in 2018, of which 99% belonged to EWS and LIG segments. This implies that the bulk of residential development in Indian cities are required to be affordable in nature. Furthermore, considering that 50% of GHG emissions from the residential sector comes from heating and cooling needs, this segment is also impacted disproportionately by rising energy demands. Dong et al. (2021), highlights that Heating, Ventilation, and Air Conditioning (HVAC) systems are energy and carbon intensive, andunaffordable for low-income households. Studies also show that poorly insulatedaffordable housing units pose a higher risk of exposing inhabitants to prolonged energy poverty (Chen & Feng, 2022).

This paper thus hypothesizes that ensuring sustainable development for all new building stock, and achieving India's target of reducing 45% GHG emissions by 2030 and Net Zero by 2070 (Ministry of Environment, 2024)is only possible if the needs of the affordable housing segment are addressed.

2.1 Net zero pathways in India

Currently the building and construction sector contributes to nearly 40% of annual GHG emissions globally. In India, this number stands at 32% (India Third Biennial Update Report to UNFCCC, 2021). Within this, 60-65% comes from operational emissions – primarily from energy use for heating and cooling needs (National Institute of Urban Affairs & RMI, 2022). Of the 35-40% embodied emissions, the most significant portion comes from using energy-intensive building materials and construction processes. This paper identifies fourpathways of emission reduction in the built environment – reducing operational emissions through (i) clean energy transition, and (ii) energy-efficiency; reducing embodied emissions through (iii) incorporating sustainable materials and construction technologies, and (iv) building retrofit.

While the larger research reviews all four pathways, this paper focuses on the following two pathways.

2.1.1 Pathway 1 – Energy Efficiency

The International Energy Agency (IEA) highlights that energy efficiency is the single largest measure in reducing energy demand at source, leading to significant cost savings for consumers (Energy Efficiency – Energy System – IEA, n.d.). 28% of households in urban India are energy poor. (Khandker et al., 2010). In an affordable housing landscape, energy efficiency, especially through adaptive thermal comfort, supersedes other methods of emission reduction.

2.1.2 Pathway 2 – Sustainable materials and construction technologies

From the 35-40% embodied emissions, 23-34% comes from the product stage, accounting for raw material extraction, transportation to site, and manufacturing. Two-to-four percent comes from the construction process stage accounting for transportation to construction site and installation process. Three-to-six percent comes for the building use stage, with the remaining one-to-six percent coming from the end of life stage (Godrej Design Lab, 2024). This paper thus focuses on the product and construction process stage, accounting for 25-38% of overall embodied emissions.

3 APPROACH AND METHOD

This paper hypothesizes that while numerous solutions exist to mitigate operational and embodied emissions in the built environment in India, none are tailored specifically for the affordable housing sector. The study examines existing the identified pathways for emission reduction through a threefold lens – (a) Availability of existing solutions and policy/regulations/instruments through which solution is made available at scale, (b) Affordability of the solution, including incentivisation for LIG segment, and (c) Quality of solution with respect to emission reduction over complete life-cycle.

The following instruments are reviewed to critically examine the net zero landscape in India, cross examining them with respect to affordable housing policies and national and subnational levels.

Instrument category	Description of instrument	Title of policy instrument	Target sector
National net zero targets	National level climate targets and strategies	Fourth Annual Communication and Initial Adaptation Communication, 2024 National Mission for Sustainable Habitat (NMSH) India Cooling Action Plan	Net zero pathways
Regulatory instruments	Legal tools/regulatory frameworks that guide built environment development	Energy Conservation Act Model Building Bye Laws 2016 Development Control Regulations (state wise) Delhi Schedule of Rates 2021	Built environment Net zero pathways
Building codes	National instruments for regulating building design and construction across the country	National Building Code 2016 Energy Conservation and Sustainable Building Code 2024 Eco Niwas Samhita 2024	Built environment Net zero pathways
Policies and schemes	Guidelines on policy/scheme overview, focus, implementation, and impact	Pradhan Mantri Awas Yojana State Affordable Housing schemes	Affordable Housing
Policy support	Design guidelines and compendiums supporting policies	Innovative Construction Technologies & Thermal Comfort in Affordable Housing (RACHNA) Handbook BMTPC Compendium of Emerging Construction Technologies for Housing & Infrastructure	Built Environment Affordable Housing

Green Building Rating System	Rating and certification systems for greening of projects in the built environment	Indian Green Building Council (IGBC) – Green Affordable Housing IGBC NEST and NEST Plus GRIHA framework Green Pro Ecolabeling	Affordable Housing Net zero pathways

Table 1: Description of policy instruments reviewed

3.1 The Availability – Affordability – Quality (AAQ) framework

The Availability-Affordability-Quality (AAQ) framework is used to analyse regulatory and policy instruments across built environment, affordable housing, and net zero pathways. The AAQ framework was developed to review the efficacy of existing solutions in the context of affordable housing, and exploring if affordability comes at the expense of quality. The study applies a mixed method approach of analysis applied against the AAQ framework. Specific research questions for the AAQ framework along with the type and method of analysis applied to explore those questions are described below.

Framework	Research questions	Type of analysis	Method of analysis
Availability	Is a solution available for a specific pathway? If yes, then how is it made available at scale?	Qualitative	Identification and mapping of regulations, policies, schemes, guidelines, market instruments that solve for the identified pathway
	Does the implementation mechanism of identied solutions converge with affordable housing policies/implementation?	Qualitative	Comprehensive flowchart of implementation mechanisms of the policy/scheme/code/rating system co-examined against implementation of affordable housing policies, schemes, and building byelaws; outlining key stakeholder groups, roles and responsibilities, and existing communication channels between parties.
Affordability	Is the solution affordable to EWS and LIG consumers?	Quantitative	Bill of Quantities comparison of a conventional affordable housing unit vs an affordable housing unit incorporating solutions and strategies recommended in solution pathways. Materials reviewed have been taken from RACHNA handbook.
Quality	What is the quality of the solution with respect to emission reduction?	Quantitative	Comparative analysis of impact metrics for all pathways to identify conflicts in quality of output.
	Does achieving affordability impact the quality of the solution?		

Table 2: The methodology framework

3.2 Boundary conditions for analysis

Establishing boundary conditions was necessary in order to measure the efficacy of existing pathways. The following boundary conditions were identified and applied – housing affordability, typical size and scale of affordable housing unit, and scenarios for analysis. These boundary conditions are primarily applied when comparing Affordability Index with respect to solution pathways, and in determining Quality of solution with respect to emission reduction.

3.2.1 <u>Housing affordability</u>

Housing affordability is a key determinant when reviewing the impact of design recommendations, material, and construction techniques on the overall construction cost.

Affordable housing in India targets three specific income groups, with annual household income as stated (Ministry of Housing and Urban Affairs, 2024)

(1) EWS –up to 3,00,000 INR (3450 USD)

(2) LIG –between 3,00,001 – 6,00,000 INR (3451 – 6900 USD)

(3) Middle Income Group (MIG) –between 6,00,000 – 9,00,000 INR (6901 – 10300 USD)

The scope of this paper is limited to EWS and LIG.

As per the Task Force Report on Promoting Affordable Housing, (Ministry of Housing & Urban Poverty Alleviation, 2012), the desirable housing price to income multiple for affordable housing should not be more than 5. However, housing price is dependent on land price and construction cost. Since land prices are highly variable based on geography, and outside the purview of this paper, this study focuses on affordability of construction cost. The study applies a Bill of Quantities comparison, considering a conventional affordable housing unit of 30 sqm carpet area, with an RCC frame construction, with burnt clay brick walls of 250mm thickness, and unplastered RCC slab roofing. The construction cost for the base case is 1101190 INR (12500

USD) overall, or 25700 INR (300 USD) per sqm. This corresponds with the average cost of construction for a 30 sqm basic unit across India (Construction Cost Calculator for House, n.d.). A construction price to income ratio is also presented as a partial measure of housing affordability, primarily considering capital expenditure for materials and construction.

3.2.2 Scenarios for analysis

As per Ministry of Housing and Urban Affairs, (2024), an affordable housing unit is defined as a unit with carpet area not more than 30 sqm. For analysing efficacy of net zero pathways, we consider two scenarios

(1) An independent housing unit of 30 sqm carpet area; 42.86 sqm of total built-up area (considering carpet area is 70% of built up area (Ministry of Housing and Urban Affairs, 2016))

(2) A mass affordable housing complex of 100 units, 10 units each of 30 sqm carpet area across 10 floors; 4286 of total built up area.

4 RESULTS

4.1 Overall findings for pathway 1 – Energy Efficiency

India's Fourth Biennial Update Report (BUR-4) to UNFCCC, a comprehensive review of India's commitments and progress in terms of it's Nationally Determined Contributions, reveals that Energy Efficiency in the built environment has been a priority focus area of the Union Government (Ministry of Environment, 2024). Initiatives such as ENS has resulted in collective energy savings of 4.84 MU between 2021 and 2023. This section further explores the applicability of such measures in the affordable housing segment.

4.1.1 Availability of Energy Efficiency solutions

In affordable housing, thermal comfort and energy efficiency is primarily solved through four interventions

(1) Change in walling materials and technologies

(2) Change in roofing materials and technologies

(3) Passive design techniques such as natural ventilation, shading, daylighting, building orientation.

(4) Energy efficient appliances

This study critically examines intervention 1-3; energy efficient appliances are outside the purview of this research owing to its limited scope in architecture, design, and planning.

In the overall built-environment, interventions are made available at scale through the following instruments

Instrument category	Title of instrument	Description of instrument
National net zero targets	National Mission for Sustainable Habitat (NMSH) India Cooling Action Plan	National level mission on promoting low-carbon urban growth, achieving India's NDCs through built environment interventions, and building resilient cities. National level cooling action plan identifying strategies and cooling pathways for key sectors including built environment.
Regulatory instruments	Energy Conservation Act Model Building Bye Laws 2016	A law that aims to reduce energy intensity of the Indian economy. A model regulatory framework regulating coverage, height, building bulk, and architectural design and construction aspects of buildings, to ensure orderly urban development.
Building codes	National Building Code 2016 Eco Niwas Samhita 2024	National instrument regulating building construction activities across the country. National level energy-conservation building code for residential buildings.
Policy support	Innovative Construction Technologies & Thermal Comfort in Affordable Housing (RACHNA) Handbook	Thermal comfort design guidelines for affordable housing construction.
Green Building Rating System	Indian Green Building Council (IGBC) – Green Affordable Housing IGBC NEST and NEST Plus	Green building rating systems for affordable housing.

Table 3: Energy efficiency instruments in India

However, only the RACHNA handbook and IGBC green affordable housing, NEST and NEST plus rating systems specifically provides recommendations for the affordable housing segment. All other policy and regulatory target the built environment as a whole – with no targeted recommendations for the affordable housing segment.

Eco Niwas Samhita, a national building code on energy efficiency, is applicable only for residential development with an area of 3000 sqm or above, or with a connected load of 100kw (Bureau of Energy Efficiency, 2024). This renders independent affordable housing units ineligible for the code.

Figure 1shows the implementation mechanisms for energy-efficiency solutions, outlining actors, roles and responsibilities, and existing communication channels.

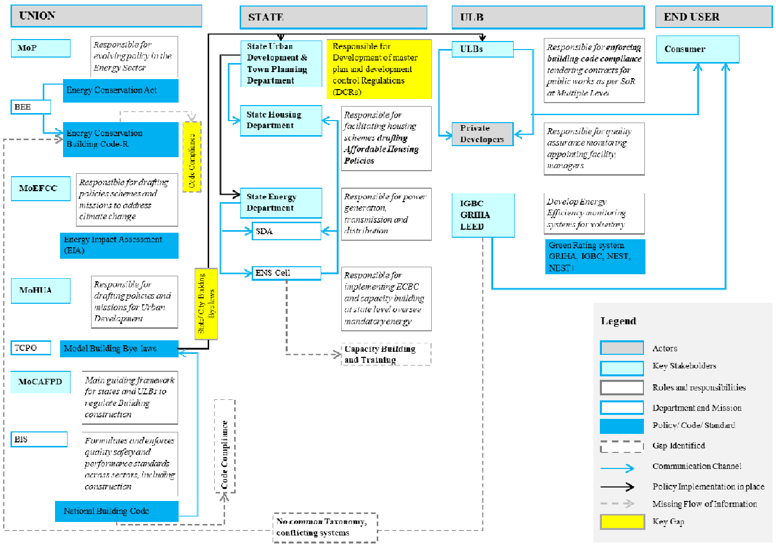

Figure 1: Implementation mechanism for energy efficiency and affordable housing policies

The comparative implementation mechanisms framework of energy efficiency and affordable housing policies reveal that there is currently no convergence between energy efficiency and affordable housing policies directly. Only the parts of the ENS that are incorporated in Model Building Bye Laws (Ministry of Housing and Urban Affairs, 2016, pp. 115-120) are legally applicable to all affordable housing units. ENS itself is not a legally mandated tool; individual state governments are authorised to mandate it across the state. To date, 17 out of 28 Indian states have initiated the notification of ENS (Bureau of Energy Efficiency & Alliance for an Energy Efficient Economy, 2023).

The PMAYhas drafted the RACHNA guidelines focusing on thermal comfort for affordable housing. However, there is limited evidence on its application, currentlyimplemented in only 6 lighthouse projects across India (Ministry of Housing & Urban Affairs, 2022).

4.1.2 Affordability of Energy Efficiency solutions

Based on calculations for standard cost of construction, it is found that walling and roofing materials constitute nearly 60% of the total construction cost. This assessment thus focuses on affordability of these two categories specifically.

In order to measure if existing recommendations are affordable, walling and roofing materials recommended in the RACHNA handbook (Ministry of Housing and Urban Affairs, 2022) or widely used in built construction across India are analysed.Table 2 presents the cost of different walling materials against this base case of an RCC frame structure with burnt clay brick walls and unplastered RCC roof slab.

The comparative construction cost assessment reveals thatmaterials that satisfy the ECBC benchmark of <15W/m2cost significantly higher than the base unit (Case 4 in Table 2). An AAC block with an RCC filler slab that satisfy all thermal comfort benchmarks, cost 31% higher than the baseline.

The construction cost of a unit with AAC walling, and RCC filler slab is 2.8 times the annual income of a EWS consumer, and 0.14 times that of an LIG consumer.

4.1.3 Quality of Energy Efficiency Solutions

The mandatory energy conservation recommendations under ENS consider Openable Window to Floor Area Ratio (WFRop), Visible Light Transmittance (VLT), Thermal Transmittance of Roof (Uroof), Residential Envelope Transmittance Value (RETV) for walls. These mandatory recommendations do not consider thermal emittance as a key criteria; it is provided as an incremental condition in both cases.

Mandatory recommendations for the IGBC green affordable rating system state only U value of roofs ≤ 1.8 W/m2K and glazing ≤ 5.7 W/m2K. The NEST and NEST plus ratings are further relaxed to provide a benchmark of U-value 2.5 W/m2K for walling assemblies. This raises the question of whether the quality of recommendations specifically aimed at the affordable housing sector differs.

Wall	Case – Wall	Case 1 – Base case	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
		250 mm	200 mm	220 mm	300 mm	220 mm	200 mm	150 mm	250 mm
		Burnt clay brick + cement plaster	**CSEB**	**Fly Ash block + cement plaster**	**AAC block**	**Solid concrete block + cement plaster**	**Coffer**	**Reinforced EPS**	**Rat Trap + cement plaster**
	Overall construction cost	*1101189.13*	*1080835.86*	*1051954.16*	*1220512.19*	*1218579.33*	*1091380.94*	*1137820.94*	*1127500.94*
	Difference in construction cost	₹0.00	₹-20,353.27	₹-49,234.97	₹119,323.06	₹117,390.21	₹-9,808.18	₹36,631.82	₹26,311.82
	RETV	*16.62*	*14.35*	*16.34*	*12.35*	*25.48*	*N/A*	*N/A*	*N/A*
	Difference in RETV	0.00	2.27	-0.28	-4.27	8.86	N/A	N/A	N/A
Roof	U value	*1.58*	*1.58*	*1.58*	*1.2*				
	Difference in U value	0.00	0.00	0.00	-0.38				
	SRI	*41.00*	*100.00*	*90.00*	*41.00*				
	Difference in SRI	0.00	59.00	49.00	0.00				
	Overall construction cost	*1101189.13*	*1117180.94*	*1139847.68*	*1089730.87*				
	Difference in cost	₹0.00	₹15,991.82	₹38,658.55	₹-11,458.26				
	Case – Roof	**RCC slab – unplastered**	**RCC slab + white coating – 1 coat**	**RCC slab + white cement tile**	**RCC filler slab – unplastered**				
		150 mm	150 mm	170 mm	150 mm				
		Case A – Base case	Case B	Case C	Case D				

Table 4: Construction cost and quality comparison for recommended materials – energy efficiency

This is further exemplified by the fact that there is no direct correlation between the multiple metrics of achieving thermal comfort, and measuring operational energy consumption or emissions. Operational energy is typically measured through Energy Performance Index (EPI), which represents the annual energy consumption per unit area. However, this includes the performance of appliances, in addition to efficiency through materials and passive design. In the lack of an equivalent metric between individual thermal comfort indices and operational energy, it is difficult to isolate the efficacy of each solution. This could potentially lead to difference in quality of output, as seen in the IGBC affordable housing recommendations.

4.2 Overall findings for pathway 2 – sustainable materials and construction technologies

Embodied emissions contribute to 35-40% of overall built environment emissions in India (National Institute of Urban Affairs & RMI, 2022). This share is expected to rise to 50%, as the share of operational emissions decline over time (Jain et al., 2023). A large part of this shifting balance between embodied and operational emissions is due to policy focus skewed largely in favour of operational emissions. Studies show that weightage given to the use of green materials in green building rating systems and building codes is 8-9% (Jain et al., 2023).

4.2.1 Availability of solutions for sustainable materials and construction techniques

This paper explores the availability of solutions across three areas

(1) Market innovation and availability of products and technologies

(2) Regulatory instruments enabling scaling of innovations

(3) Policies and schemes enabling higher market penetration

The following instruments curate and enable the availability of sustainable materials and construction technologies at scale.

The Compendium of Emerging Construction Technologies (Building Materials & Technology Promotion Council, 2023), presents a list of 69 materials and technologies analysed and curated through a third-party assurance system that evaluates materials and technologies based on (a) Structural performance against vertical & lateral loads, (b) Fire resistance, (c) Protection against rain & moisture, (d) Thermal &acoustic behaviour, (e) Ease of fixing services, (f) Quality assurance, (g) Durability /Service Life. The Compendium is prepared under the ambit of the PMAY scheme, implying economic viability of materials to be a key assessment criteria. The Green Pro Ecolabeling adopts an LCA approach to analyse and curate materials(Greenpro | Home, n.d.). NBC 2016 also includes a chapter on sustainable materials, providing alternatives to carbon intensive materials(Bureau of Indian Standards, 2016). However, there is no standard method of impact measurement and reporting in all three documents. Embodied energy calculation and reduction as a specific target is not addressed in any of these documents.

Instrument category	Title of instrument	Description of instrument
Materials compendium	Compendium of Emerging Construction Technologies for Housing & Infrastructure, BMTPC	List of 69 emerging materials and construction technologies
Ecolabeling	Green Pro Ecolabel Directory – 2025 (5^{th} edition)	Ecolabel certification and directory of 9500 green materials
Building codes	National Building Code 2016 Eco Niwas Samhita 2024	*Refer* **Fehler! Verweisquelle konnte nicht gefunden werden.**
Regulatory mechanisms	Schedule of Rates	Standardized rate document for materials, construction technologies prepared for all public works projects

Table 5: Sustainable materials and construction technology instruments in India

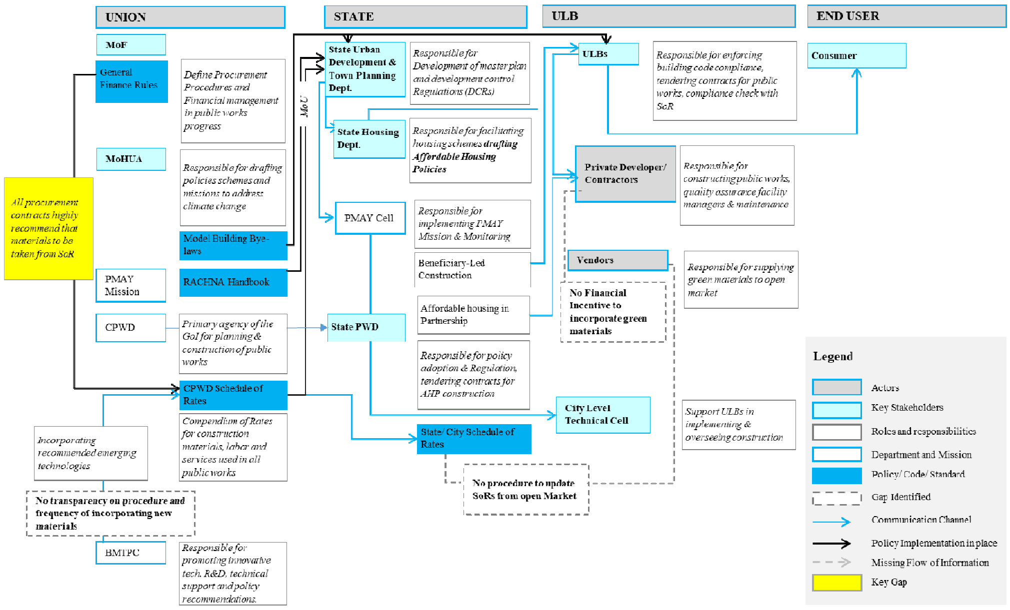

Figure 2: Implementation mechanism for sustainable materials and construction technologies in affordable housing

Finally, none of this instruments serve as mandates to include sustainable materials and construction technologies in the built environment. As per India's procurement regulations, all public works projects,including affordable housing, is recommended to use materials specified in the State Schedule of Rates, adapted from the Delhi Schedule of Rates (DSR) drafted by Central Public Works Department (CPWD). Currently the process of incorporation of sustainable materials and technologies available in the market into the SoR, as well as regular updation, is unknown. In the absence of a regulated system of including recommendations by BMTPC, BIS, and ENS into the CPWD DSR, the process of ensuring the use of sustainable materials and techniques in affordable housing remains arbitrary (refer Figure 2).

4.2.2 Affordability of solutions for sustainable materials and construction techniques

The lack of a standard method of impact measurementpresents a constraint in identifying and thereby measuring affordability of high impact materials.

This paper thus extends the exercise of reviewing recommended/highly used walling and roofing materials to also measure Embodied Energy Value (EEV). The comparative analysis, shown in Table 3, reveals contradictions when concurrently reviewing cost, thermal comfort, and EEV. CSEB has a lower construction cost as well as significantly lower EEV. However, its RETV values are higher compared to both AAC and Fly Ash blocks. AAC blocks, which are superior in terms of RETV values, cost significantly higher and has a significantly high EEV.

	Case – Wall	Case 1 – Base case	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8
		Burnt clay brick + cement plaster	**CSEB**	**Fly Ash block + cement plaster**	**AAC block**	**Solid concrete block + cement plaster**	**Coffer**	**Reinforced EPS**	**Rat Trap + cement plaster**
	Difference in const. cost	₹0.00	₹-20,353.27	₹-49,234.97	₹119,323.06	₹117,390.21	₹-9,808.18	₹36,631.82	₹26,311.82
	Difference in RETV	0.00	2.27	-0.28	-4.27	8.86	N/A	N/A	N/A
	EEV	*20931.24*	*5893.78*	*10721.33*	*20171.29*	*10446.32*	*N/A*	*12292.50*	*17791.55*
Wall	**Difference in EEV**	**0.00**	**-15037.46**	**-10209.91**	**-759.95**	**-10484.92**	N/A	**-8638.74**	**-3139.69**
Roof	**EEV**	*785.35*	*803.06*	*811.53*	*346.48*				
	Difference in EEV	**0.00**	**17.71**	**26.18**	**-438.87**				
	Difference in U value	0.00	0.00	0.00	-0.38				
	Difference in SRI	0.00	59.00	49.00	0.00				
	Difference in cost	₹0.00	₹15,991.82	₹38,658.55	₹-11,458.26				
		RCC slab – unplastered	**RCC slab + white coating – 1 coat**	**RCC slab + white cement tile**	**RCC filler slab – unplastered**				
	Case – Roof	Case A – Base case	Case B	Case C	Case D				

Table 6: Construction cost and quality comparison of recommended materials – embodied energy

4.2.3 Quality of solutions for sustainable materials and construction techniques

Table 3 reveals that most recommendations for materials and construction techniques enabling thermal comfort are done without due consideration of embodied energy values. Given that EEV is a measure of energy consumption and thus is strongly linked to energy efficiency in the overall life cycle of a building, not considering EEV while recommending materials aimed at energy efficiency is a significant gap in the current instruments.

Furthermore, measuring the quality of materials against a specific standard become difficult in the absence of a specific target. The Green Pro Ecolabel (Confederation of Indian Industry, 2025), presents the most comprehensive database of more than 9500 products, materials, and technologies from 450+ companies. The ecolabel however uses an 8 part analysis, using a credit system for scoring and selecting green materials. Life cycle assessment is one of the 8 parts, wherein credits are assigned based on performance improvement in emission reduction, and not against a standard benchmark(Confederation of Indian Industry, 2016).

4.3 Synthesis of gaps in the overall ecosystem

The findings reveal the following gaps in the current ecosystem

4.3.1 Lack of a unified/standard method of outcome measurement

The study reveals that currently all net zero pathways operate in isolation. Extensive solutions exist for both energy efficiency and sustainable materials and construction technologies. However, considering the lack of a unified metric of outcome measurement – such as reduction in GHG emissions or energy consumption across the life cycle, it is difficult to measure the overall efficacy of existing solutions. The lack of unified outcome parameter also leads to quality dilution in the case of affordable housing, implying that affordability comes at the cost of quality.

4.3.2 Lack of a comprehensive implementation mechanism for all net zero pathways

The implementation mechanisms for pathway 1 and 2 revealmultiple gaps in communication between actors at the Union, State and City. Multiple solutions exists for both pathways, with no communication between parties, and overlapping roles and responsibilities. The implementation mechanisms also reveal the lack of robust regulatory mechanisms – building codes are not legally mandated in most Indian states and cities. The ENS policy is not mandated but notification is initiated in 17 states. However, this is also not specifically attuned for the affordable housing sector. The applicability of the code rules out independent affordable homes. The limited implementation of RACHNA guidelines in affordable homes built under PMAY further reveals a gap in robust implementation mechanisms of energy efficiency pathways in affordable housing.

4.3.3 Lack of regulatory mechanisms for incorporation/usage of sustainable materials and construction techniques

While solutions exist for pathway 2, implementation of solutions across scale is impacted by the current procurement system, mandating that only materials incorporated in Schedule of Rates be used for public work projects, including affordable housing (refer Figure 2). This implies that most sustainable materials that currently exist in the market are not used in affordable housing projects, unless specifically incentivised.

5 RECOMMENDATIONS

5.1 A unified definition of Green

Multiple recommendations currently exist for categorically reducing operational and embodied emissions in the built environment. However, the lack of a comparative unit of measurement reveals contradictions in recommendations, and subsequently in quality of output.

This paper proposes that there needs to be a unified definition of "Green" that combines operational and embodied emissions of materials and construction techniques, but one that also factors in construction cost. Such a definition will eliminate contradictions in cost, energy efficiency (reducing operational emissions), and embodied emissions. However, considering that units are not equivalent across the three factors, we propose a normalised scoring method, such that

$$Green\ score = -1 * \left(\frac{c_1-\bar{c}}{\bar{c}} + \frac{o_1-\bar{o}}{\bar{o}} + \frac{e_1-\bar{e}}{\bar{e}}\right)$$

Wherein, c_1 *= cost of material in consideration;* $\bar{c}$ *= mean national cost of material*
o_1 *= operational emission of material in consideration;* $\bar{o}$ *= mean operational emission of building materials*
e *= embodied emission of material in consideration;* $\bar{e}$ *= mean embodied emission of building materials*

Considering that the aim is to achieve lower cost of construction and lower emissions, the normalised calculation will provide results wherein lower the score, better the performance. However, for the sake of readability and ease of understanding, the calculations are multiplied by a factor of -1 to lead to a scoring system where higher the green score, better the overall performance and affordability.

This method requires establishing a national mean for operational and embodied emission of materials. This also enables setting standard targets for the building sector in terms of emission reduction.

5.1.1 Considerations for unified measurement metric for operational and embodied emissions

Currently, operational energy is measured through the EPI, representing annual energy consumption per unit area. However, since this also considers the emissions from active cooling systems and appliances, it is imperative to isolate the energy consumption from heat gain through building envelope, and roof, to impart a green score to specific materials, technologies, and passive design techniques.

Bhanware et al., (2020) reveals a strong correlation between the sensible cooling load of a building and ReTV. This enables the extrapolation of cooling load for each climate zone based on ReTV (Qsensible in kWhth/m2). Considering the method of cooling (natural or air conditioning) can provide a comprehensive scenario of electrical units consumed. Multiplying this value with average emissions factor for electricity in India, stated to be 0.716 kg CO_2 per kWh(Central Electricity Authority, 2023), may give the operational emissions from heating/cooling needs for the specific material. Similar methods can be applied for measuring heat gain, and subsequently GHG emissions of roofing materials using U-value. When considering the Green Score of the whole building, EPI is a better metric, but has to be calculated over time and in a consistent manner.

Embodied emissions may be calculated in the same manner from Embodied Energy Value.

5.2 Consolidating policy implementation through unified regulatory mechanisms

Section 4.3.2 highlights the conflicts in the current ecosystem stemming from a lack of convergence in roles, responsibilities, and communication channels in various policies, schemes, guidelines, and market instruments. The gap in implementation mechanisms can be addressed through two regulatory mechanisms

5.2.1 Mandating recommendations through Building Byelaws

Building codes, policies, and schemes are not legally binding. While ENS can be notified state-vide, for implementation the compliance and mandate is integrated into the building permission process through the Building Byelaws (Government of Karnataka, 2018). This paper thus recommends the development of a streamlined process of integrating key clauses of the Eco Niwas Samhita into the Building Byelaws, specifically addressing the low-income housing segment. The latest edition of the Model Building Byelaws gives specific recommendations for Low Income housing in terms of minimum plot area, minimum dimensions for room sizes and layouts, structural requirements, and regulations for land development(Ministry of Housing and Urban Affairs, 2016). However, a specific chapter on “Green Buildings and Sustainability Provisions”, incorporating recommendations from ECBC 2007, do not provide targeted recommendations for the Low Income housing segment. This leads to blanket regulations, rendering all plots up to 100 sqm ineligible for any sustainability provisions, and mandating all plots above 3000 sqm (including mass affordable housing) to comply with all 10 provisions (Ministry of Housing and Urban Affairs, 2016, pp. 115-120). This paper recommends a specific segment for affordable housing in the“Green Buildings and Sustainability Provisions”, tailored to the recommendations and approach discussed in this paper – to mandate net zero pathways in affordable housing.

5.2.2 Incentivising solutions through Development Control Regulations (DCRs)

DCRs are planning regulations that govern the development of a city through zoning regulations, Floor Area Ratios (FAR), height limitations, set-backs, parking requirements, plot sizes etc. In terms of legal mandates, DCRs supersede Building Byelaws, but are typically implemented in tandem with the later by city governments to guide and regulate development. The provisions in a DCR have been shown to impact housing affordability and influence sustainable development (Niti Aayog, 2021). This paper thus recommends the integration of non-fiscal incentives such as free of cost FAR for mass affordable housing projects that integrate net zero measures, or fiscal incentives such as reduced development fees for projects that meet green building criteria. While this is currently practised through a range of instruments in multiple states across India, there is a need to consolidate these incentives under city-specific regulations to ensure successful implementation on ground.

5.3 Procurement reforms to unlock potential of sustainable materials/technologies use

The findings of this study highlights the procurement challenges in the current landscape of building construction in India – including affordable housing. In order to ensure a sustained integration of sustainable materials/technology in all affordable housing construction, this paper recommends the following

5.3.1 Building a consolidated database of sustainable materials and construction techniques applying a unified measurement metric

Building a consolidated database with a unified measurementmetric is the first step towards procurement reform for sustainable materials/construction technologies. Rawal et al., (2024), and International Finance Corporation, (2017) discuss the development of an embodied energy database for commonly used construction materials using the LCA approach. Such a database provides a clear comparative assessment of all building materials against a unified benchmark. Supplementing this with specific embodied emission reduction targets for the building sector would further strengthen the assessment of building materials/technologies.

The consolidated database of materials should also enable the mapping and curation of manufacturers and suppliers that provide detailed technical specifications of the materials to be used in preparation of construction drawings, tendering, and estimation.

5.3.2 Developing a Green Schedule of Rates (SoR)and Analysis of Rates (AoR)for affordable housing

Such a database can be used to identify cost-effective, high impact materials for affordable housing. This paper recommends the preparation of a Green Schedule of Rates providing standardised rates of materials, technologies, and construction processes/services. The Green SoR should further provide the following information to ensure holistic decision-making in selecting green materials/technologies for construction

- What is the embodied carbon savings of the material?
- What is the operational emissions/utility cost savings over the lifetime of the material?
- How is its overall performance over life time compared to a conventional material it aims to replace?

The Green SoR should be supplemented with a detailed Analysis of Rates of items and services, providing a comprehensive cost analysis for each item. This ensures transparency and accuracy in the costing process. The AoR should further provide a rate comparison between sustainable and conventional materials, to further enable data driven decision making in selection of materials.

Developing a Green SoR that serves as a standardised rate document ensures all public works projects including affordable housing are built using sustainable materials and technologies.

6 DISCUSSION

This paper first examines the applicability of two net-zero pathwaysin the affordable housing segment. The Availability-Affordability-Quality framework applied here aims to comprehensively capture the gaps in the current ecosystem with respect to the affordable housing segment. The analysis reveals gaps that are addressed through three recommendations – 1) having a unified definition of "Green", (2) consolidating multiple instruments and ensuring implementation on ground through two regulatory instruments, building byelaws and development control regulations, and (3) addressing the building construction procurement system through having a consolidated database of low embodied energy materials and preparing a standardised rate document for the same. The implications of this study are discussed further

6.1 Critically considering the affordable housing segment in designing and implementing net-zero pathways

This study highlights that current net-zero pathways do not necessarily consider the needs for the affordable housing segment. Most instruments examined in this study are designed for an overall built environment, with no specific focus on low-income groups. Of the specific affordable housing policies, recommendations for achieving affordability is found to compromise with quality, particularly in terms of overall emission impact. Given that the significant proportion of new building stock is estimated to house EWS and LIG segments, it is crucial to examine and ensure the affordability of recommendations and solutions.

A framework is needed for comprehensively measuring affordability and quality of solutions, which ensures that achieving affordabity does not compromise quality. The study thus draws focus on the process of identifying and developing pathways, proposing that the needs for this segment are considered from the onset of policymaking, and not as an afterthought.

6.2 Developing a unified metric for measuring impact

The comparative analysis of recommendations analysed highlights inconsistencies in the output due to differing objectives. A material that achieves high thermal comfort may have significantly high EEV and construction cost. This thus highlights the need for a unified objective and method of measuring impact.

One potential metric is introduced. A method of developing a green score that combines operational and embodied emissions, and construction cost is discussed. However, the authors acknowledge that there may be other optimal ways of measuring impact that combines different objectives into a unified output. Furthermore, the unified metric method discussed here needs to be developed in collaboration with a wider quorum of technical experts and stakeholders – to ensure that differing objectives and needs are addressed at the onset.

6.3 Developing a consolidated implementation framework

Numerous solutions exist for each pathway discussed. While that implies a strong focus on addressing the issue, the intent may not always result in effective implementation and success on ground. The comprehensive implementation framework reveals that there are significant gaps in policy framing and policy implementation on ground. Actors responsible for drafting and implementing the multitude solutions be aligned. The intent of one policy/regulation can negate the impact of another – ultimately lessening the impact on ground. Thus, a consolidated framework of implementation, new communication channels between actors, and identification of streamlined pathways for on-ground implementation are necessary.

The paper presents an examination of two net zero pathways in the context of affordable housing in India, identifies critical gaps, and provides recommendations to ensure an affordable net zero future for India.

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