Identification of Low Cost Green Options and their Macro-Environmental Impact
Final Report
December 2011
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Executive Summary

Background and housing demand

The building construction industry is a major contributor of environmental pollution, with high levels of energy consumption and greenhouse gas emissions, all of which contribute to climate change. Housing is the single largest sub-sector of the construction industry. It is also a basic need associated with social and economic benefits, and its demand in most emerging economies is substantial. Hence it is a sector with significant potential not to mitigate just the negative impact of climate change on buildings and people, but also to reduce the impact of the construction industry on the natural environment.

Green buildings technology has advanced greatly in recent years, but most ‘high performance’ green buildings are capital intensive, often with high-tech applications that are not in easy reach of the mass housing market. In the developing country context, where huge segments of the population lack access to essential services or housing, the green buildings approach to addressing climate change is perceived to be largely unaffordable. For green technology to be adopted in poorer nations and have scalable impact, it will have to be low-cost and affordable.

According to a 2010 report, buildings in the commercial, office and hospitality sectors are poised to grow at 8% annually over the next 10 years in India. While the retail sector has been growing rapidly at 8% per annum, the residential sector has seen growth of 5% per annum during this period.

*It is estimated that over 70 million New Urban Housing Units will be required over the next 20 Years*

Project objectives and outputs

This project has focused on taking an integrated approach to addressing the issues of low-cost sustainable technology systems, their large-scale replication and their socio-economic and cultural acceptance for affordable housing. While the results may be useful in other developing countries, the focus in this study is India.

The key outputs and findings of the study have been focused on the following -

- Identifying technically viable and socially acceptable ‘green’ alternatives, including passive measures
- Quantifying energy consumption (embodied and operational energy) and environmental impacts
- Identifying barriers to the supply chain
- Strategic recommendations for scale-up of affordable green housing

Affordable green technologies

A comprehensive set of technologies were examined and rated by applying screening criteria to short-list 10 key technologies with most significant environmental impact. Wall systems, roofing, and woodwork for door and window frames account for 60% of the entire construction cost. As a result, a greater emphasis was placed on these components while compiling a list of technologies. The screening parameters used to shortlist technologies were first cost, embodied energy, operational energy, water efficiency (during construction), and cost of scalability & replicability.
The alternatives to brick walls like CSEB, fly ash brick wall or SIP all have a lower embodied energy as well as better thermal insulation, leading to enhanced comfort and energy savings in operation.

There are many other alternatives that meet the criteria, including the Aerated Autoclaved Concrete (AAC) block wall and Cellular Lightweight Concrete (CLC) block. In general, any non-fired material will have a lower embodied energy compared to a fired brick and is a good replacement option.

Roof alternatives that reduce the use of cement and steel also have lower embodied energy, and if the replacement has better thermal insulation, the result can be enhanced comfort as well as energy savings and reduced greenhouse gas emissions.

Other important green building materials include insulated and reflective roofs, which reduce the heat gain into the building and reduce energy use and alternative frame materials for doors and windows. The reinforced concrete frame (RC) and wood plastic composites offer better performance and contain lower embodied energy compared to the traditional steel frames.

In addition to the technologies identified under the ‘short-list’, two tiers of cost neutral initiatives also have been identified which present opportunities for implementation as general policies. It is noteworthy that cost neutral initiatives are mostly aimed at reducing the carbon footprint from operational energy use, whereas the short-listed technologies are aimed more toward reducing embodied energy use.

The **Tier I cost neutral items** are must–dos with low environmental and first costs:

- Energy-efficient fans and water pumping systems
- Natural methods of decentralized water treatment systems
- Passive solar features and design for thermal comfort, day lighting and natural ventilation
- Water-efficient fixtures

The **Tier II items** should be incorporated as far as possible because their relatively higher costs are accompanied by major environmental benefits and short pay back periods. These include:

- Efficient lighting - 1.5 to 2 times the cost of regular fixtures but with a payback period as low as 4-6 months
- Solar water heaters - 5 times the cost of electric water heaters (geysers) with a payback period of 4-5 years
- Rain water harvesting systems with a payback period of 3 years (considering tanker water@ Rs 75 per kl)
Quantifying energy and water savings through low cost green building technologies

In order to quantify the embodied energy and operational energy savings by implementing green building materials and technologies, a base case was developed and then simulated for both Delhi (Composite Climatic Zone) and Mumbai (Warm and Humid Climatic Zone).

The base case indicated that in a typical low-mid rise building, almost 45% of the embodied energy lies in the RCC roof, intermediates slabs, and structural frame. The external and internal walls comprise another 45%. Over 90% of the embodied energy in a housing project, therefore, is in these two categories.

In the case of operational energy, the combined share of cooling and lighting equipment alone, contribute to over 60% of the total electricity consumption.

Efficient building design using building technology that reduces overall heat gain, maximizes day lighting, and uses efficient cooling, lighting and water heating equipment has immense potential to reduce operational energy consumption in affordable housing.

Savings of more than 30% can be achieved in the embodied energy of a typical apartment by using affordable green building materials. 30% material energy savings translates to offsetting:

- 700,000 GWh of energy use
- 560 million tons of CO2 emissions
- 8 new power plants

Operational energy savings of 10-40% can be achieved by incorporating green–building materials, passive design strategies and energy efficient appliances. 10%-40% operational energy savings translates to offsetting:

- 70,000 to 950,000 GWh of energy use
- 60 to 750 Million tons of CO2 emissions
- Up to 11 New Power Plants

In a typical household with 150 liters of water use per person, over 32 liters can be saved by using dual flush toilets. This translates to over **46,000 liters of water** saved per household per year.

The 20-20-20 model

The above analysis shows that IFC-recommended model for green buildings—the 20-20-20 model- is quite easily achievable in the low income housing context.

From the perspective of policy implementation, the objective of setting a viable green standard / target for the housing and construction industry is now achievable at a time of increased interest by industry players, and greater attention towards climate change.
Low-cost green housing

The 20-20-20 savings can be achieved by using the following rules of thumb:

20% Material Savings
- Use low energy walling materials (any one of materials recommended in this study)
- Using low energy roof technology (any one of materials recommended in this study)

20% Operational Energy Savings
- Following passive design principles for appropriate orientation, shading & natural ventilation
- Providing energy efficient lights, ceiling fans and solar water heating

20% Water Savings
- Dual flush toilets
- Low flow fixtures

Barriers and challenges
The critical barriers and challenges to the supply chain of green building technologies include:

Capital cost impact
The incremental cost of green measures is about Rs.100/sq.ft. of built up area, which is approximately a 10% addition to the average cost of construction today (2011). The additional costs are largely due to increased labor and transportation costs and incremental cost of provision of energy efficient lighting, fans and solar water heaters.

Material manufacture, suppliers and vendors
The manufacturing of green technologies is still a niche industry involving small and medium enterprises with the supplier and vendor network being at a nascent stage of development.

Worker skill and familiarity
Shortage of workers trained in the use of new techniques and technologies is also a barrier to implementation of green building technologies as it causes delays and additional costs.

Policy and financing
Till a few years back, the supply of low income housing in India was largely through housing constructed by state housing boards and corporations (HUDCO, MHADA) The Government’s role in proving affordable housing today is still significant through various government programs such as JNNURM and Rajiv Awas Yojana.

While mainstream housing finance providers (banks, housing finance institutions) have traditionally served the middle to high income formal sector, in recent years, the demand for affordable housing has seen the entry of financial institutions and micro-finance companies in the affordable housing space.
Low-cost green housing

Some of the key issues faced by affordable housing finance institutions are:

- Access to low-cost funds
- Government support to lower cost of capital
- Credit risk
- Profitability

International case studies focused on financing and other mechanisms for affordable housing demonstrate that a balanced mix of fiscal measures, municipal level regulation, market interventions and community effort is required to enable affordable green housing. The entry of commercial lending and performance based mechanisms is required to bridge the gap between demand and supply of critical finance and technical assistance.

The policy and financing package recommended under this study include the following measures:

- Regulations/Enforcement – mandatory “green” component in construction financing
- Investment – green mortgages, direct financing, guarantees
- Incentives – tax rebates, lower housing loan interest rates for green housing
- Voluntary initiatives - implementation of green technologies, standardization of green technologies

Next Steps: Pilot Projects

A strong and stable technical and fiscal environment is necessary to drive private investment into affordable green housing. To promote the interest of the commercial investor, the benefits of green affordable housing need to be more measurable with technical risks reduced. High quality technical standards in affordable housing space-design and renewable installations where performance and benefits can be measured and benchmarked will promote investor interest.

Showcasing the identified alternate green technologies in pilot projects will not only provide empirical evidence of the benefits of these low-cost green technologies in mainstream affordable housing projects but will also facilitate better understanding of the supply chain barriers. Measurable performance/benefits will also lead to effective finance mechanisms, policy interventions and commercial investments.
1 The Study - “Green Equals Affordable”

1.1 Objective of the study
This project focuses on taking an integrated approach to addressing the issues of low-cost sustainable technology systems, their large-scale replication and their socio-economic and cultural acceptance for affordable housing. The focus area of this study is India, but the results may be useful in other developing countries. The study focuses on the following:

- Identifying technically viable and socially acceptable ‘green’ alternatives, including passive measures
- Quantifying energy consumption (embodied and operational energy) and environmental impacts of conventional versus green housing
- Identifying barriers to the supply chain in the delivery of affordable green housing
- Developing strategic recommendations for scale-up of affordable green housing

1.2 Scope of the study
The key tasks covered in this study are as follows:

Task 1: Analysis and short listing of existing low cost and green building technologies
Task 2: Cost-benefit and supply chain analysis of shortlisted green technologies
Task 3: Quantification of environmental impacts and brief study of best practices in affordable and green housing finance
Task 4: Strategic policy recommendations and identification of pilot projects
Task 5: Dissemination
Task 6: Applicability to Sub Saharan Africa

This report presents the analysis and findings of Tasks 1 to 4. Task 5 is an ongoing process and Task 6 has been presented has a separate paper. Figure 1 illustrates the approach adopted for achieving the outputs of Tasks 1 through 4.
1.3 Limitations of the study

One, given the wide variations in climatic conditions across various parts of India, the study focuses on only two climatic zones in India – the composite climatic zone (Delhi) and the warm and humid climatic zone (Mumbai). Recommendations for the composite climatic zone are largely applicable to the hot and dry climatic zone of the country as well.

Two, the study is limited to developer-built housing because of its potential for scalability and impact. In other words, individually built housing has not been considered in this work; however, findings from this study will, at a broader level, be applicable to that as well.
1.4 Methodology

The analysis was carried out largely through a combination of desk research, as well as experiences drawn from institutes such as BMTPC\(^1\), developers, non-profits, experts and other stakeholders working in low-income housing space. The figure below shows the broad spectrum of stakeholders who were consulted in the process.

![Figure 2- Key Stakeholders]

Two stakeholder consultation workshops were held: one in February 2011 to get a better perspective of the requirements, issues and challenges faced by the affordable housing industry; and another in September 2011 for dissemination of key findings of the study (see 13.1, Annexure -1 for the key feedback from the stake holder consultations)

1.4.1 Short listing of green technologies

A comprehensive set of technologies were examined and rated by applying screening criteria. A baseline technology was identified for each component (wall systems/roofing/door and window framing). Screening parameters (first cost, embodied energy, operational energy, water efficiency, scalability/ replicability) were established to identify technologies with the greatest environmental impact.

\(^1\) Building Materials and Technology Promotion Council
Based on this screening, a cumulative score was obtained for the baseline technology as well as for each of the alternative technologies. The differential of the two scores was termed the Comprehensive Impact Index for that alternative. Alternatives with high comprehensive impact indices were selected for further analysis for quantification of their impacts through simulations, spreadsheet-based analyses, and supply chain analyses.

1.4.2 Quantification of environmental impact

In order to understand the long term environmental impacts in quantitative terms, prototypical blocks were simulated for both Delhi (Composite Climatic Zone) and Mumbai (Warm and Humid Climatic Zone). It is generally agreed that the low-income housing units under consideration will be unconditioned spaces for which simulations were conducted to quantify thermal comfort. Passive design strategies such as appropriate building orientation, window-wall ratio, and shading were also taken into account in the simulations. In addition, a scenario with cooling and heating systems was analyzed to quantify potential or future impact on operational energy through the use of alternate technologies. Also computed in the study is the cumulative impact of reduction in operational energy over a 20-year time period.
2 The Rationale

2.1 Growth trend of building sector in India

According to a 2010 report, buildings in the commercial & office and hospitality sectors are poised to grow at 8% annually over the next 10 years, the retail sector at 8%, and the residential sector at 5% per annum. For the residential sector, this means a projected increase of some 15 billion sq.ft. of built up space (see Figure 3).

The retail, hospitality and commercial & office sector show the million square feet requirement doubling in a decade. This will increase the influx of people into urban areas for job opportunities, better standards of life and security & safety; this will in turn put pressure on land, supply of quality houses and affordability. Different stakeholders will need to address the rising requirement, how to bridge the gap between supply and demand of houses within the affordable range.
2.2 Housing demand in India

Based on a study of residential housing demand in India\(^2\), it is estimated that the additional demand for urban housing forecasted in India for 2012-13 is about 6.79 million.\(^3\) By 2015 the additional demand for housing is projected at 31 million, and that a large proportion of this will be required in the affordable sector. It is estimated that over 70 million new urban housing units will be needed over the next 20 years (see Figure 4).

![Figure 4 - Urban Housing Demand](source)

The analysis is based on the 11th Year Plan report by Planning Commission and derives an annual growth rate of nearly 4% in housing. People migrating from peri-urban areas to urban areas will also add to this projection of housing demand.

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\(^2\)Bandyopadhyay et al. (2008). This study was conducted by the National Institute of Bank Management (NIBM) for National Housing Bank (NHB) and partially addresses advice of Reserve Bank of India to NHB on studying the housing and real estate sector.

\(^3\) This is based on projections of realized demand for housing through credit supply channel till 2012 (which is closure to figure projected by 11th Planning Commission).
2.3 Housing demand and climate change

As discussed above, with over 70 million new urban housing units required over the next 20 years, the estimated potential environmental impacts can be summarized as follows:

Construction materials required for this would mean

- 2.3 million GWh of energy use
- 1.8 billion tons of CO2 emissions
- 28 new thermal power plants

Assuming the units are not air conditioned, this would mean an additional

- 700,000 GWh of energy use
- 600 million tons of CO2 emissions
- 9 new thermal power plants

And if all new units have air conditioning, then this would imply

- 2.4 million GWh of energy use
- 1.9 billion tons of CO2 emissions
- 28 new thermal power plants

And these new housing units will require over 15 billion litres of water per year The above statistics highlight the massive scale of environmental impact that can be expected from the housing sector if current trends continue unabated. They also underline the importance of the need to mitigate this impact through implementation of sustainable and green housing strategy.
3 What is “Green”?

3.1 Defining ‘Green' buildings

Green buildings are environmentally benign and energy efficient buildings using sustainable construction practices and having a healthy and productive indoor environment, with lowered use of energy and natural resources. They are:

- Sustainable
- Durable/Adaptable
- Cost Effective over the life cycle
- Adopt whole systems approaches

International green building rating systems such as LEED, BREEAM, Green Globes and Green Star are tools developed to rate and/or quantify the performance of buildings against defined indicators and baselines. Specific rating systems for residential development also have been developed. These rating systems rely on the achievement of defined credits or points based on performance and/or prescriptive parameters for evaluating the ‘Green’ quotient of buildings, with a higher focus on performance based parameters. Currently in India there are three green building rating systems that are applicable to residential development - GRIHA, IGBC Green homes and Eco-Housing. While all the three green building rating systems are similar in their overall intent and broad focus areas, differences lie in the evaluation requirements of the parameters (prescriptive and/or performance based) and scope and extent of guidelines provided for achieving the credits.

While performance based parameters allow more room for innovation in achieving a defined goal, their application could be simplified in affordable housing projects by incorporating more prescriptive approaches so as to reduce dependence on complex simulations studies and cumbersome third party verification.

3.2 IFC 20-20-20 model

The IFC has provided a general guideline that housing projects should aim to achieve:

- 20% energy use reduction
- 20% material use reduction
- 20% water use reduction
3.3 Need for ‘affordable’ green housing

As described in the previous chapter, the building construction industry is a major contributor of environmental pollution, with high levels of energy consumption and green house gas emissions, all of which contribute to climate change. Housing is the single largest sub-sector of the construction industry. It is also a basic need associated with social and economic benefits, and its demand in most emerging economies is massive. It is hence a sector with significant potential to not just mitigate the negative impact of climate change on buildings and people, but also reduce the impact of the construction industry on the natural environment.

There has been much advancement in green technology in recent years, but much of this ‘high performance’ green building is high-tech and capital intensive, often with high upfront costs. In the developing country context where huge segments of the population lack access to essential services or housing, this type of approach to addressing climate change is largely unaffordable, and hence, irrelevant. For green technology to be adopted in poorer nations and have scalable impact, it will have to be low-cost and affordable.

Work on green housing so far has been largely limited to standalone projects and projects catering to upper middle and high income groups with mainstream developers only recently entering the green housing space. In the affordable housing space, the use of green building technology and systems has been limited.

For any significant environmental impact, green technologies and materials need to penetrate the mainstream housing industry. In other words, green housing needs to appeal to a much wider audience, i.e. viewed as a socially responsible and commercially viable proposition for the common builder/developer, and an economically and socially viable proposition for the average buyer. Once such transformation begins in the organized developer market, the rest of the market is likely to pick up on it, with a catalytic effect on improving the environment.

In this context, this study seeks to present the case for incorporation of green technologies, materials, and systems in the affordable housing sector in a tangible and quantifiable manner.
4 Identifying ‘Green’ Technologies

4.1 Methodology - arriving at the ‘short list’

The purpose of this task was to identify systems and technologies that are already in the market. A comprehensive set of technically viable and socially acceptable ‘green’ technologies were examined and rated by applying screening criteria to identify 10 key technologies with most significant environmental impact.

4.1.1 Identifying the ‘long list’

A long list was compiled based on currently available technologies encompassing both conventional and alternative practices for the following categories of building components:

1. Walls
2. Roofs
3. Floors
4. Fenestration
5. Framing
6. Partitions & Doors
7. Lighting
8. Water Efficiency & Sanitary Appliances
9. Renewables

A baseline technology was identified for each of these categories. The baseline technology represents the conventional/ predominant practice within that category (e.g., 230 mm brick wall for the category ‘Walls’).

4.1.2 Arriving at the ‘short list’

This long list was scanned and trimmed on the basis of first costs. The purpose of this exercise was to quickly arrive at a list of relevant affordable technologies. The items that would have been expensive and environmentally unsustainable were eliminated. As illustrated in Figure 5, wall systems, roofing and woodwork for door and window frames account for 60% of the entire construction cost. As a result, a greater emphasis was accorded to these components while compiling a list of technologies.
4.2 Analyzing the ‘short list’

The spreadsheet (Refer to Appendix 7) contains over 25 low-cost or green technology alternatives that have been evaluated with five screening parameters as follows:

- First cost [low/medium/high]
- Embodied energy [low/medium/high]
- Operational energy [low/medium/high]
- Water efficiency (during Construction) [low/medium/high]
- Cost of scalability & replicability [low/medium/high]

First cost was determined from manufacturers’ data; embodied energy was calculated based on existing studies; operational energy and/or impact on thermal comfort were calculated using detailed simulation models. The simulation models use a prototypical housing unit aggregated from affordable housing developments in and around Delhi. Water efficiency has been estimated qualitatively based on available analyses. Cost of scalability and replicability was determined through a detailed supply-chain analysis. (See Chapter7).
The low/medium/high scores map on to numbers 1, 2, and 3 respectively – (this simple mapping is later modified to include actual numbers for parameters like first cost and operational energy). Through this, a cumulative score was obtained for the baseline technology as well as for each of the alternative technologies. The differential of the two scores is the Comprehensive Impact Index for that alternative. Alternatives with high Comprehensive Impact Indices were identified for further analysis to quantify their impact through simulations, spreadsheet-based analyses, and supply chain analyses.

4.3 Key shortlisted technologies

Based on the scores established (described in Section 4.2), those technologies with the lowest environmental impact in terms of embodied energy, operational energy and water efficiency (in that order), were shortlisted (see Table 1). For a few select technologies, marginally higher costs than the baseline technology were considered acceptable, given their substantially lower environmental costs and short payback periods, and also the fact that, in most cases, the marginally higher costs are attributed to the less-than-mature markets for these technologies, which can be expected to change over time.

In addition to the shortlisted technologies, a number of cost neutral initiatives were identified. These have been categorized separately from the ‘short-list’ items, as these are viewed as general policies that must be implemented. It is noteworthy that the analysis led to cost neutral initiatives that are mostly aimed at reducing the carbon footprint from operational energy use, whereas the shortlisted technologies lean more towards reducing embodied energy use.

The cost neutral initiatives are grouped into two categories or tiers:

The Tier I items are must dos with low environmental impacts and first costs:

- Energy-efficient fans and water pumping systems
- Natural methods of decentralized water treatment systems
- Passive solar features and design for thermal comfort, day lighting and natural ventilation
- Water efficient fixtures

The Tier II items should be incorporated as far as possible because their relatively higher costs are accompanied by major environmental benefits and short pay-back periods. These include:

- Efficient lighting - 1.5 to 2 times the cost of regular fixtures but with a payback period as low as 4-6 months
- Solar water heaters - 5 times the cost of electric water heaters (geysers) with a payback period of 4-5 years
- Rain water harvesting systems with a payback period of 3 years (considering tanker water@ Rs 75 per kl)
## Table 1 - Shortlisted technologies

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<th>Brief Description</th>
<th>Advantages</th>
<th>Challenges</th>
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<tr>
<td><strong>Wall Systems</strong></td>
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<td><strong>[Base Case: Brick]</strong></td>
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| **White Paint**    | White reflective paint applied to wall surfaces helps lower surface temperatures by reflecting the incident radiation. | • Energy-efficient  
• Enhances thermal comfort  
• Cost-effective | • Needs frequent re-application |
| **Fly Ash Bricks** | Fly Ash Lime Gypsum Bricks (popularly known by its trade name FaL-G) are prepared through blending fly ash, lime, and gypsum in suitable proportions and strengthened through hydration. Portland cement is used as a substitute wherever lime is in short supply. The bricks are dried in the sun and require water curing. | • Does not involve autoclaving or burning of fossil fuels  
• Excellent strength and durability  
• Scalable and replicable  
• Extensively uses by-products or industrial wastes | • Use of water at 500 – 1000 m³ per million brick |
| **Hollow Concrete Block** | Hollow concrete blocks can be quickly assembled, are cost effective and are an environmentally sound option for wall material. It is based on the principle of densification of a lean concrete mix to make a regular shaped, uniform, high performance masonry unit. It is an effective means of utilizing wastes generated by stone crushers, quarrying and stone processing units. | • Light-weight  
• Thermally insulating  
• Conserves top-soil  
• Reduces the cost of mortar  
• Low embodied energy  
• Can be made on site | • Availability of equipment |
### Structural Insulated Panels

**Brief Description:** Structural Insulated Panels (SIPs), consist of an insulating layer sandwiched between two layers of structural board. The insulating layer is typically polystyrene, while the structural panels could be made of sheet metal, plywood, cement, or more commonly, oriented strand board (OSB). Compressed straw is often used as the core material for cost-sensitive projects – making the product ‘greener’ and less expensive but denser and less insulating.

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<th>Advantages</th>
<th>Challenges</th>
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<td>Reduces operational energy by 25-30%; for unconditioned spaces, it enhances thermal comfort</td>
<td>More expensive than conventional wall alternatives</td>
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<td>Components are recyclable</td>
<td>Not readily available in India</td>
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<td>Extremely speedy construction, a 1000 ft² house can be constructed in two days</td>
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<td>Low embodied energy</td>
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</table>

### CSEB

**Brief Description:** The Stabilized Compressed Earth Block (SCEB) Technology is an economically viable and environmentally benign solution for walling, roofing, arched openings, and corbels. The blocks are manufactured using raw earth compacted with a stabilizer such as cement or lime. The compaction may be achieved manually or hydraulically. SCEBs are sundried.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost effective</td>
<td>Availability of machines</td>
</tr>
<tr>
<td>Energy-efficient</td>
<td>Labor intensive and slow manufacturing process</td>
</tr>
<tr>
<td>Cast on site, avoids transportation costs</td>
<td></td>
</tr>
<tr>
<td>Aesthetically pleasing</td>
<td></td>
</tr>
<tr>
<td>Use abundantly available raw materials like cement, clay, and even fly ash</td>
<td></td>
</tr>
<tr>
<td>Low embodied energy</td>
<td></td>
</tr>
</tbody>
</table>

### Roofing Systems

**Base Case: RCC**

**Insulated Roof**

Heat gain through roof surfaces is an important component of the overall heat gain through building envelope in very hot climatic zones. Insulating the external surface of roofs is an appropriate strategy for reducing heat gain and enhancing thermal comfort in hot climates. Expanded or extruded polystyrene provide effective and durable insulation for roofs.

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduces operational energy by 10-15%; for unconditioned spaces, it significantly enhances thermal comfort</td>
<td>Is an ‘added’ expense as it is not an integral part of the envelope</td>
</tr>
<tr>
<td>Components are recyclable</td>
<td></td>
</tr>
</tbody>
</table>
### Reflective Roof Tiles

Many modern buildings in India are constructed of concrete or cinder blocks and are topped with flat, tar-covered roofing. A high-albedo roof is one that reflects most of the incident sunlight and efficiently emits some of the absorbed radiation back into the atmosphere, instead of conducting it to the building below. As a result, the roof stays cooler, with lower surface temperatures, keeping the building at a cooler and more constant temperature.

- Reduces operational energy by 15-20%; for unconditioned spaces, it significantly enhances thermal comfort
- Low-cost, high returns on investment
- Is an ‘added’ expense as it is not an integral part of the envelope

### Precast RC Planks & Joist

The system comprises of precast RC planks supported over partially precast joists. These can also be applied to intermediate floors and result in savings of 20% in overall cost, 25% in cement and 10% in steel as compared to conventional RCC slab floor/roof. The system is suitable for spans of up to 4.2 m, but provision of secondary beams can accommodate larger spans.

- Uses 25% less cement, 10% less steel, and reduces the cost of shuttering and plastering
- Saves on transportation costs
- Speedy construction
- Cost-effective
- Low embodied energy
- Decreased depth increases thermal conductivity, reducing thermal comfort

### Filler Slab

A simply supported roof experiences compressive forces on the upper part and tensile forces on the lower part. The filler slabs are a mechanism to replace the concrete in the tension zone. While concrete is very good in withstanding compressive forces and steel bears the load due to tensile forces, it follows that the lower tensile region of the slab does not need any concrete except for holding the steel reinforcements together. The filler material, thus, is not a structural part of the slab.

- Reduced quantity and weight of material
- Cost-effective (15-25%) while retaining the strength of the conventional slab
- Enhanced thermal comfort due to insulating properties of filler materials
- Low embodied energy
- Slab design requires competent structural engineering
- Requires capacity building for its proper implementation
## Door and Window Frame

### Base Case: Steel

<table>
<thead>
<tr>
<th>Technology/System</th>
<th>Brief Description</th>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
</table>
| **R C F r a m e s** | RCC door frames and lintels are now considered acceptable substitutes for wood and MS frames, especially in low-cost construction. It is a good solution to common problems that cheap wood frames encounter – that of termites, swelling, and shrinking. | • Conserves precious natural resource – wood  
• Cost-effective  
• Can be pre-fabricated on site in bulk, saving transportation costs  
• Excellent strength and durability – more dimensional stability than both wood and PVC | • While this technology is well-established in some pockets like Gujarat, Orissa, Andhra Pradesh, and Karnataka, it would be necessary to create a proper supply chain mechanism for moulds and vibrators thru MSMEs. |
| **W o o d + P l a s t i c F r a m e s** | Wood/plastic composites consist primarily of waste sawdust and scrap PVC generated in the production of wood and vinyl windows, or from post-consumer bottle waste. Wood content ranges from 40% to 70%, depending on the manufacturer. According to recent tests, the frames have roughly the same energy performance as solid wood, but perform slightly better than vinyl window frames. | • Uses recycled materials  
• Reduces operational energy / enhances thermal comfort  
• Excellent strength and durability - more dimensional stability than both wood and PVC  
• Replicable and scalable | • New technology yet to universally endorsed by the construction community  
• More expensive compared to MS frames (but costs are comparable to wood or PVC frames)  
• Not readily available in India |
5 Quantifying “Green” - Potential for Energy and Water Conservation

This chapter quantifies the energy and water savings potential of the technologies identified in Chapter 4 through simulations and spreadsheet analysis.

5.1 Study methodology

In order to understand the long term environmental impacts in quantitative terms, prototypical blocks were simulated for both Delhi (Composite Climatic Zone) and Mumbai (Warm and Humid Climatic Zone). It is generally agreed that the low-income housing units under consideration will be unconditioned spaces for which simulations were conducted to quantify thermal comfort. Passive design strategies such as appropriate building orientation, window-wall ratio and shading were also taken into account in the simulations. In addition, a scenario with cooling and heating systems has been analyzed to quantify potential or future impact on operational energy through the use of alternate technologies.

Also computed in the study is the cumulative impact of reduction in operational energy, and savings in carbon emissions, over a 20-year period for one dwelling unit with an area of 37m².

5.2 Baseline case and energy demand

5.2.1 Developing the base case

As a starting point for all analyses within this task, a prototypical block was established based on several housing developments in and around Delhi (Bawana, Narela, Baprola, Bhogarh, and Omicron). The prototype was developed as an aggregate of typical practices in low-income development in terms of the following: Size of the development, unit size, semi-urban location, building materials vocabulary and number of floors. (See Annexure 2 for details of development of base case)
Affordable housing units built for the Delhi State Industrial Development Corporation and designed by Adlakha Associates were used as a representative prototype or base case for the subsequent analyses. The key parameters of this housing project, the ‘base case’ for this study, are as follows:

- **Building type:**
  - Ground+2 floor building, with 4 apartments per floor
  - 1 BHK Units ~ 35 m2 area

- **Family profile**
  - Family of 4: Husband, wife & 2 Children

- **Appliances in use**
  - 3 CFLs
  - 1 Refrigerator
  - 1 TV
  - 2 Ceiling Fans
  - 1 Evaporative Cooler

- **Typical energy use**
  - Average Electricity Bill Rs. 280/Month (~100 kWh/Month)
  - A cooking gas cylinder of 14.5 kg lasts one month

- **Financial profile**
  - Family Income ~ Rs. 11,000/Month
  - Monthly Rental ~ Rs. 1,500/Month
  - Current Market Cost of the Apartment ~ Rs. 750,000

Based on the architectural drawings and specifications, a detailed simulation model was developed for energy use analysis. The detailed bill of quantities and embodied energy was also calculated.
5.2.2 Embodied energy in the typical base case unit

In a typical low-mid rise building, almost 45% of the embodied energy lies in the RCC roof, intermediate slabs, and structural frame. The external and internal walls comprise another 45% (see Figure 8). Over 90% of the embodied energy in a housing project, therefore, is in these two categories.

Embodied energy for each significant building component was calculated and converted to equivalent carbon emission numbers. Eventually, the combined impact of embodied energy and operational energy was measured as percentage reduction in GHG emissions.

![Embodied Energy (MJ)]

- RCC Roof: 10,531 MJ
- RCC Slab: 21,062 MJ
- RCC Structure: 23,180 MJ
- Ext. Brick Walls: 32,057 MJ
- Int. Brick Walls: 23,044 MJ
- Plaster: 1,679 MJ
- Steel Door/Window Frames: 7,691 MJ
- Glass Windows: 1,310 MJ

Figure 8- Typical distribution of embodied energy in building components
5.2.3  Operational energy use in the typical base case

The energy used in running the household is dominated by ceiling fans and refrigerators, each consuming about 28% of energy, followed by 16% for lighting and 7% for hot water (see Figure 9). The balance 20% energy goes into other household appliances like TV, iron, etc.

![Figure 9 - Distribution of typical operational energy consumption](image)

5.2.4  Long term energy consumption pattern

Figure 10 illustrates the operational energy use in a typical housing unit of this kind over 20 years, and the embodied energy in the construction materials. It is clear that for unconditioned buildings, the embodied energy outweighs operational energy even at the end of 20 years. The embodied energy is 60% of the total energy impact of the project. For air conditioned buildings, the operational energy plays a more important role, being 68% of the total.
5.3 Potential for energy savings

5.3.1 Alternative low energy materials: potential embodied and operational energy savings

5.3.1.1 Wall alternatives

Energy savings from the 4 shortlisted wall materials described in Chapter 4 (in relation to the base case) are illustrated in Figure 11. Alternatives to the traditional brick, such as CSEB, fly ash brick or SIP, all have lower embodied energy as well as better thermal insulation, leading to enhanced comfort and energy savings in operations. There are many other alternatives that meet the criteria including the Aerated Autoclaved Concrete (AAC) block wall and Cellular Lightweight Concrete (CLC) block. The basic rule of thumb from this analysis is that any non-fired material will have a lower embodied energy compared to a fired brick and is a good replacement option.

---

4 Embodied Energy has been calculated per unit floor area of the prototype block (see section 5.2.1) in Mj/m² using documented secondary data (see Table 2).

Operational Energy consumption has been calculated by running simulation scenarios of cooling and heating systems on the prototype base case low income housing block in Delhi which is in the composite climatic zone (see section 5.2.1). The operational energy consumption of the same material can vary for different climatic zones (see Figure 18, Chapter 6).
5.3.1.2 Roofing alternatives

Roof alternatives that reduce the use of cement and steel have lower embodied energy, and if the solution has better thermal insulation, then it can also result in enhanced comfort and energy savings.

Figure 11 - Embodied and operational energy savings wrt brick wall

Figure 12 - Embodied and operational energy savings wrt R.C.C roof
5.3.1.3 Other material and technologies

Figure 13 illustrates some other important green building materials such as insulated and reflective roofs, which reduce the heat gain into the building and reduce energy use and alternative framing materials for doors and windows. The reinforced concrete frame (RC) and wood plastic composites offer better performance and lower embodied energy compared to the traditional steel frames. Roof insulation, while adding to the embodied energy consumption, has significant impact on reduction in operational energy through savings in cooling/heating load.

![Embodied and operational energy savings for misc. green building materials](image)

**Figure 13 - Embodied and operational energy savings for misc. green building materials**

See Table 2 for a full list of these materials/technologies along with their embodied energy, operational energy, and the energy savings over a 20-year period.
## Table 2 - Embodied energy, operational energy and CO₂ emissions for 20 years for alternate building materials

<table>
<thead>
<tr>
<th>Materials</th>
<th>Embodied Energy [MJ/m²] (i)</th>
<th>Embodied Energy [MJ/m² of floor area] (ii)</th>
<th>Operational Energy [Kwh/year] (iii)</th>
<th>Operational Energy (OE) [MJ/m²/Year] (iv)</th>
<th>Total Energy for 20 Years [EE + (OE/3)x20] MJ (v)</th>
<th>CO₂ KgCO₂/m² for 20 Years (vi)</th>
<th>Delta CO₂ (viii)</th>
<th>Cost in [Rs/m²] of floor area (ix)</th>
<th>CO₂ KgCO₂ /per housing unit for 20 years</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walling</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Case: Brick</td>
<td>615</td>
<td>1,139.90</td>
<td>58,912</td>
<td>212,083</td>
<td>474</td>
<td>4,299</td>
<td>3,439</td>
<td>4,562</td>
<td>128,275</td>
</tr>
<tr>
<td>Reflective Paint (White)</td>
<td>51</td>
<td>122.50</td>
<td>54,335</td>
<td>195,606</td>
<td>437</td>
<td>3,036</td>
<td>2,429</td>
<td>1,279</td>
<td>561</td>
</tr>
<tr>
<td>Flyash Lime Gypsum Bricks</td>
<td>242</td>
<td>448.80</td>
<td>53,360</td>
<td>192,096</td>
<td>429</td>
<td>3,310</td>
<td>2,648</td>
<td>791</td>
<td>3,389</td>
</tr>
<tr>
<td>Hollow Concrete Blocks 200mm</td>
<td>193</td>
<td>358.39</td>
<td>52,287</td>
<td>188,233</td>
<td>421</td>
<td>3,162</td>
<td>2,530</td>
<td>909</td>
<td>3,878</td>
</tr>
<tr>
<td>Structurally Insulated Panels (SIP)</td>
<td>553</td>
<td>1,025.97</td>
<td>52,050</td>
<td>187,380</td>
<td>419</td>
<td>3,817</td>
<td>3,053</td>
<td>385</td>
<td>5,364</td>
</tr>
<tr>
<td>Compressed Stabilized Earth Blocks</td>
<td>195</td>
<td>361.64</td>
<td>55,327</td>
<td>199,177</td>
<td>445</td>
<td>3,328</td>
<td>2,663</td>
<td>776</td>
<td>3,389</td>
</tr>
<tr>
<td><strong>Roofing</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Case: RCC</td>
<td>847</td>
<td>847.00</td>
<td>58,912</td>
<td>212,083</td>
<td>474</td>
<td>4,006</td>
<td>3,205</td>
<td>807</td>
<td>119,547</td>
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<tr>
<td>Insulation</td>
<td>117</td>
<td>117.00</td>
<td>54,411</td>
<td>195,880</td>
<td>438</td>
<td>3,034</td>
<td>2,428</td>
<td>777</td>
<td>4,304</td>
</tr>
<tr>
<td>High Albedo Roof (Reflective Tiles)</td>
<td>34</td>
<td>34.00</td>
<td>54,042</td>
<td>194,551</td>
<td>435</td>
<td>2,932</td>
<td>2,345</td>
<td>859</td>
<td>1,851</td>
</tr>
<tr>
<td>High Albedo Roof (White Coating)</td>
<td>23</td>
<td>23.00</td>
<td>54,335</td>
<td>195,606</td>
<td>437</td>
<td>2,936</td>
<td>2,349</td>
<td>856</td>
<td>1,915</td>
</tr>
<tr>
<td>RCC Filler Slab</td>
<td>590</td>
<td>590.00</td>
<td>55,044</td>
<td>198,158</td>
<td>443</td>
<td>3,541</td>
<td>2,833</td>
<td>372</td>
<td>344</td>
</tr>
<tr>
<td>RC Planks and Joists</td>
<td>413</td>
<td>412.50</td>
<td>55,370</td>
<td>199,332</td>
<td>445</td>
<td>3,381</td>
<td>2,705</td>
<td>500</td>
<td>513</td>
</tr>
<tr>
<td><strong>Door &amp; Window Frame</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Base Case: Steel</td>
<td>8,873</td>
<td>6,651.49</td>
<td>58,912</td>
<td>212,083</td>
<td>474</td>
<td>9,810</td>
<td>7,848</td>
<td>6,456</td>
<td>292,730</td>
</tr>
<tr>
<td>Pre-Cast RCC Door Window Frame</td>
<td>288</td>
<td>25.63</td>
<td>58,388</td>
<td>210,197</td>
<td>470</td>
<td>3,156</td>
<td>2,525</td>
<td>5,323</td>
<td>4,412</td>
</tr>
<tr>
<td>Wood Plastic Composite</td>
<td>67</td>
<td>5.99</td>
<td>58,453</td>
<td>210,431</td>
<td>470</td>
<td>3,140</td>
<td>2,512</td>
<td>5,336</td>
<td>3,637</td>
</tr>
</tbody>
</table>
Notes

(i) Embodied Energy of the material in terms of MJ per m² of surface area of wall materials, floor area for roofing materials, and wall area for framing options.

(ii) MJ/m² in (i) above is converted to MJ/m² of floor area.

(iii) Operational Energy (OE) of one low-cost housing block comprising of three floors with four units on each floor in kWh/yr.

(iv) OE in (iii) above converted to MJ/yr (multiplied by a factor of 3.6).

(v) OE/yr in (iv) above converted to OE/yr/m² of floor area (the floor area of the block is approximately 448 m²)

(vi) Total Embodied Energy + Operational Energy of the material over a period of 20 years. OE in (iv) is multiplied by a COP (Coefficient of Performance) of 3 and the number of years (20).

(vii) The Total Energy in MJ in (vi) above is converted to Carbon Equivalent by multiplying by a factor of 0.8.

(viii) The Delta Carbon indicates the net change in Carbon savings with respect to the Base case

(ix) This column indicates the cost per m² of floor area

(x) This indicates the total emissions reduction in kgCO₂ per housing unit over the next twenty years (unit size 37.3 m²).

As can be seen in the table above, while there is reduction in 0.5 to 11 % in the operational energy from the base case technology, in case of CO₂ emissions over a 20 year span there is a reduction of 11 to 68% from the base case.

For example in the case of hollow concrete blocks, while the reduction in annual operational energy is about 12 %, the potential reduction in CO₂ emissions over a 20 year span is about 26%.

In the case of Wood plastic composite frames, the comparative reduction in operational energy is almost negligible, but the reductions in emissions are about 68% from the base technology of steel.
5.3.1.4 Passive design for comfort & energy savings

Incorporation of passive design strategies such as appropriate building orientation and shading devices coupled with low energy strategies can increase the number of comfortable hours by about 60% in both Delhi and Mumbai climates, thus decreasing the requirement of cooling/heating. (See Figure 14 below).

![Figure 14 - Increase in thermal comfort through passive design](image)

Passive design strategies such as application of thermal insulation to the building envelope, day lighting, optimized orientation and appropriately sized shading devices for the windows, tremendously reduce the operational energy and increase the comfort levels. Getting the building orientation right could lead to a significant reduction in heating and cooling loads (see Figure 15 below).
5.3.1.5 Operational energy savings in appliances

Figure 16 shows the distribution of energy consumption in a typical house (base case). The share of cooling and lighting equipment together contribute to over 60% of the total electricity consumption. Efficient building design, using building technology that reduces overall heat gain and maximises daylighting and uses efficient cooling, lighting and water heating equipment has immense potential to reduce operational energy consumption in affordable housing.
As illustrated in Figure 16, lighting constitutes a substantial portion of the total operational energy distribution. Use of efficient internal lighting coupled with day lighting can significantly reduce energy consumption. Under the new Standards and Labeling Program, the Bureau of Energy Efficiency (BEE) has developed an appliance rating system. The rating system is graded across 1 to 5 Stars. The star rating system corresponds to total number of units saved by an appliance. The figures below show the percentage energy savings by using different BEE star rated appliances.

Figure 17 shows that based on the energy use profile and equipment used, savings of 35% in ceiling fans can be achieved through BEE 5 star rated fans, 40% lighting savings can be achieved through use of CFLs and TFLs, over 90% electricity can be saved by using a solar water heaters, and another 25% energy can be saved in other appliances that are BEE star rated. This translates to energy savings of over 300 kWh/yr equivalent to 900 Rs/yr due to efficient lighting, ceiling fans and solar hot waters, which though a small saving, is still net-positive.

---

5 Bureau of Energy Efficiency
As can be seen in Figure 18, energy savings over 100 kWh/year for unconditioned spaces and 790 kWh/year for conditioned spaces can be achieved by incorporation of passive design strategies alone. Energy savings over 375kWh/year equivalent to more than 30% savings can be achieved by incorporating both passive design and efficient appliances in unconditioned spaces. In the case of air conditioned spaces, savings over 1500 kWh/year equivalent to more than 43% savings can be achieved by incorporating both passive design and efficient appliances.
5.3.1.6 Potential water savings

In affordable housing, water savings constitute an important aspect of overall energy savings and emission reduction potential. The figure below considers three cases; a case that represents the water standards mentioned in the National Building Code, a typical case that represents the usual practice, and another case with efficient fixtures. The analysis for the third case considers a combination of low flow fixtures and dual flush in the toilets.

In a typical household with 100 liters of water use per person, over 32 liters can be saved by using dual flush toilets and low flow fixture. This translates to over 46,000 liters of water saved per household per year (see figure 19).

![Figure 19 – Potential water saving in litres per capita per day](image-url)

Water Use in Liters Per Capita Per Day (LPCC)
5.3.1.7 Life cycle energy savings potential

Using passive design strategies in conjunction with alternate building materials, results in approximately 30% reduction in operational energy.

When we compare the base case with a best case scenario using the alternative green building materials and energy efficient technologies, appliances, and passive design strategies, the overall savings that can be achieved are as follows:

- >30% (36,000 MJ) embodied energy savings in a typical apartment, which will offset:
  - 700,000 GWh of energy use
  - 560 million tons of CO2 emissions
  - 8 new power plants

- >10% (400 MJ) operational energy savings in an unconditioned apartment, and >40% (5,000 MJ) operational energy savings in a conditioned apartment, which will offset:
  - 70,000 to 950,000 GWh of energy use
  - 60 to 750 million tons of CO2 emissions
  - Up to 11 new power plants
5.4 The 20-20-20 model for green housing

The earlier sections describe a base case low-income dwelling unit, in which changes to the building envelope through alternative building materials and passive design strategies result in significant reduction in embodied and operational energy consumption. Further savings have been identified in energy consumption by replacing conventional systems (e.g., for hot water) with those run from renewable energy. These savings can have a positive impact on life-cycle consumption (and cost) of energy and water in the typical low-income dwelling unit. The savings achieved in the best case scenario (shown in Figure 20 above) highlight that the IFC-recommended model for green buildings - the 20-20-20 model - is quite easily achievable in the low income housing context.

From the perspective of policy implementation, the objective of setting a viable green standard / target for the housing and construction industry is now achievable at a time of increased interest by industry players, and greater attention towards climate change. The 20-20-20 savings can be achieved by using the following rules of thumb:

20% material savings
- Use low energy walling materials (any one of materials recommended in this study)
- Using low energy roof technology (any one of materials recommended in this study)

20% operational energy savings
- Following passive design principles for appropriate orientation, shading & natural ventilation
- Providing energy efficient lights, ceiling fans, solar hot water systems

20% water savings
- Dual flush toilets
- Low flow fixtures
6 The “ideal” energy consumption scenario for green affordable housing

6.1 Study methodology and assumptions

As elaborated earlier in Chapter 5, in order to understand long term environmental impacts, quantification of potential savings in embodied and operational energy have been done through simulation of a prototypical block for both Delhi (Composite Climatic Zone) and Mumbai (Warm and Humid Climatic Zone). The impacts of materials and technologies were analyzed individually as well as cumulatively and ‘ideal’ energy consumption scenarios have been developed. These scenarios are presented as Combined Cases 1 and 2 each for Delhi and Mumbai climates. The assumptions for these combined cases are described below. Refer to Annexure 6 for details of the simulation assumptions and results.

6.2 Ideal energy consumption scenario for affordable green housing

6.2.1 Operational energy consumption

Base Case

*Key Building Materials* – Brick wall, reinforced concrete roof and steel frames for doors and windows.

*Passive Design Interventions* - Building orientation and the window to wall ratio are optimal for the climate zone.

Combined Case 1

*Key Building Materials* – Fly ash bricks, reflective roof tiles and wood+ plastic composite frames

*Passive Design Interventions* - Building orientation and the window to wall ratio are optimal for the climate zone.

Combined Case 2

*Key Building Materials* – Cavity wall, reflective roof tiles and wood+ plastic composite frames

*Passive Design Interventions* - Building orientation and the window to wall ratio are optimal for the climate zone, horizontal shades and natural ventilation are designed optimally for the climatic zone.
Simulations for conditioned spaces, for Delhi and Mumbai were carried out using the shortlisted building materials individually as well as cumulatively for Combined Cases I and II. The purpose of this analysis was to derive a comparative figure in operational energy by analyzing different materials and passive design strategies in order to obtain a combination of best materials and passive design strategies. Figure 21 summarizes the savings achievable in operational energy as compared to the base case, quantified through the annual cooling and heating load in KWh.
6.2.1.1 Key observations and inferences

In Combined Case I, cumulative savings of approximately 15% can be achieved in both Delhi and Mumbai in the annual cooling and heating loads as compared to the base case.

In Combined Case II, savings of approximately 24.6% in Delhi and 22.4% in Mumbai can be achieved in the annual cooling and heating loads as compared to the base case.

By incorporation of energy efficient appliances up to 40% savings in operational energy can be achieved.

Climatic factors

- Ambient temperatures and solar radiation are very high during summer in New Delhi as compared to Mumbai. Higher temperature is a major cause of discomfort in New Delhi while higher relative humidity is crucial for Mumbai. Mumbai winters are mild and overall temperature in Mumbai remains more or less constant through the year.

Walls

- Fly ash brick wall in combination with reflective paint on exterior are excellent strategies for both New Delhi and Mumbai. For New Delhi, higher thermal mass is required for thermal comfort in unconditioned spaces. SIPs are therefore, a more appropriate technology for conditioned or unconditioned spaces in Mumbai.

Roofing

- Roofs with reflective surface perform well for both New Delhi and Mumbai. Combination of reflective roof tiles and filler slabs will yield good thermal performance.

Door and Window Frames

- There is a marginal difference in performance of precast frames and wood/plastic frames for both New Delhi and Mumbai. Considering material reuse and low embodied energy, wood/plastic composite frames should be preferred.

Passive Design Strategies

- A north-south orientation where in most of the fenestration faces north or south is a very effective passive strategy for reducing solar gains.

- For the base case design, window area is 6.62% of the total wall area. These windows are distributed on all four orientations in different proportions – North (2.21%), South (2.21%), East (1.10%) and West (1.10%). Increasing the window area to 10% and 15% decreases the comfort level for both New Delhi and Mumbai because of additional solar gains as well as heat gain through conduction.

- Shading reduces solar gains and gives better thermal performance for both New Delhi and Mumbai. Providing horizontal shades that are 45 cm deep reduces the operational energy by over 10%. Adding further depth to the shades yields marginal benefits and is therefore not recommended. The benefits of vertical shading are also marginal compared to those of horizontal shades. The strategy is equally effective for both climate zones.
Low-cost green housing

- Natural ventilation is very effective for maintaining indoor comfort conditions when outside temperature is less than the inside temperature. Natural ventilation is highly effective for Mumbai because of mild ambient conditions coupled with high humidity. Openings should be designed and orientated to take advantage of the prevailing sea breeze. For New Delhi, night time ventilation is efficient for pre-cooling the thermal mass as there is a considerable diurnal range for dry-bulb temperature.

- Along with natural ventilation, additional mechanical ventilation (fans) is provided when outside temperature is less than the inside temperature. This additional ventilation causes additional pre-cooling and provides comfortable indoor environment. Mechanical ventilation is crucial for Mumbai to control humidity while for New Delhi it can be primarily used for pre-cooling the thermal mass of the building.

- Higher thermal mass is effective for both New Delhi and Mumbai. It checks the indoor environment from reaching extreme conditions. However, the high thermal mass is more crucial for Delhi. If appropriately designed, building with lower thermal mass can be energy efficient for Mumbai.

6.2.2 Thermal comfort performance

In addition to operational energy, the selected materials were also evaluated for their thermal comfort performance. At present, a majority of low income housing units do not have any provision for cooling or heating. Although this scenario is likely to change over the next 20 years, it was important to assess the selected materials for their potential to enhance thermal comfort of the inhabitants. The Predicted Mean Vote [PMV] has been used as an indicator of thermal comfort for this analysis. PMV uses a thermal sensation scale ranging from -3 (very cold) to +3 (very hot) to represent the ‘vote’ of a large population of people exposed to a particular thermal environment. A PMV value of ‘0’ indicates a neutral or thermally comfortable environment. For the purpose of this study, PMV range from -2 to +2 has been defined as comfortable.

Figure 22 and 23 illustrates the thermal comfort performance using the alternative materials individually as well as for Combined Cases I and II for Delhi and Mumbai Climates. It shows that for New Delhi, the number of comfortable hours increase by 5% for Combined Case I and 12% for Combined Case II, compared to the Base Case.
Figure 22: Impact of selected technologies on annual comfort conditions, New Delhi
For Mumbai, the number of comfortable hours increase by 8% for Combined Case I and 15% for Combined Case II, compared to the Base Case.
7 Supply Chain Analysis: Barriers and Challenges

7.1 Supply chain analysis and identification of challenges

The purpose of this task was to identify the key barriers to replicability and scalability for the technologies/systems short listed in this study.

7.1.1 Introduction

Effective supply chain and construction management are among the key components that contribute to reduction of costs in affordable housing projects. Supply chain management of building materials is central to minimizing costs and wastage of materials, time and labor and optimizing use of construction equipment.

The supply chain analysis of building materials and components encompasses production and availability of raw materials, formal and informal procurement channels, transportation needs, cost structures, reliability, quality parameters and availability of testing facilities.

7.1.2 Methodology

In order to understand the issues involved in supply chain management in low income green housing, the team resorted to a direct approach of discussion & consultation with various stakeholders involved in the manufacture, supply and use of low cost and green building materials and technologies. This includes developers of low income green housing, Building Centres, professionals in the field and NGOs working on policy change & main-streaming of green building technologies.¹

¹ Contacts were established with following agencies in the field:
1. Adlakha Associates-an architectural firm having delivered a series of LCGH projects in Delhi, Contact – Shri Pramod Adlakha
2. Biodiversity Conservation India Ltd, Bangalore- A company focused on involved in green building g construction of a large no of projects, Contact - Shri C Hariharan,
3. Uttarakhand Building Centre, Shrinagar, Uttarakhand- working largely in LCGH& also LCGH for the affluent community, Contact - ShriJagdishNegi,OwnerIncharge
5. Development Alternatives, New Delhi-An NGO of repute, engaged in mainstreaming GBTs for decades, Contact - Dr Arun Kumar, President
7.2 Supply chain barriers

Based on the discussions with the above stakeholders, barriers to key components of the supply chain were identified. These barriers have been described below and the next section presents an evaluation of how these parameters affect the short-listed technologies.

7.2.1 Land

Land availability is among the most critical barriers in the supply chain of low income housing. Besides the issue of exorbitant costs and limited availability of land in urban areas, there is an issue of inefficient and insufficient land records. While some sporadic improvements are happening, by and large, land records are not digitized, and hence lack the desired levels of transparency. Easy availability of undisputed land in viable locations is one of the key pre-requisites for low income green housing projects.

7.2.2 Raw material supply

Developers in large cities often face shortage of supply of bulk raw materials such as stone aggregates and sand. Availability of fly ash of the desired quality is also an issue. Incessant use of fly ash in landfills etc. has jeopardized its availability for construction. The use of alternative materials such as blast furnace slag and crushed/pulverized stone therefore needs to be mainstreamed.

7.2.3 Availability of standard equipment

Due to the small scale of green building construction, implementing agencies have to primarily depend on Micro, Small and Medium Enterprises (MSMEs) which are not very large in number for non-standard equipment. Machinery suppliers in many cases do not provide operating manuals, resulting in hit & trial methods of operation on site, often resulting in poor efficiency and quality.

7.2.4 Fiscal incentives

There is lack of adequate government incentives in terms of exemption/reduction in excise & custom duties for green building products. This slows the process of making these products competitive in the market on price, quality and reduced energy and carbon loads.

7.2.5 Skills deficit

Skills deficit is critical area of concern for most stake-holders. There is a shortage of skilled work-force at most construction sites in India. Large scale capacity building for skilled construction workers at different locations is imperative.

Though a few initiatives in capacity building and training have been taken by Government agencies and some corporate houses (e.g.-CIDC and L&T), a structured and diversified program need to be implemented.
7.2.6 **Trust deficit**
Developers and builders believe that home buyers feel more secure with traditional building materials and technology as compared to alternative materials and technology. Even after so many years of aggressive fly ash use, there is a psychological barrier for an average house-holder, as to why he should build his house from ash. Awareness building for home owners accompanied by large scale implementation in Government housing programs will help to change public perception of alternative and green building materials.

7.2.7 **Standardization & specifications**
Many green technology options do not have BIS standards and do not appear in the schedule of specifications of a large number of major construction agencies in the Government at central & state levels. This acts as a hindrance in main-streaming green building technologies in low income housing construction. It is important that proven green technologies be included in the schedules of specification of government construction agencies.

There is also a lack of sufficient documentation and published research papers on alternative green building materials and technology.

7.2.8 **Finance**
Financial institutions often have reservations about funding alternative technological options. Capacity building of housing finance institution and other stake holders, focusing on long term financial benefits and environmental impacts of green buildings is required.

7.2.9 **Market presence**
For low income green housing to get main-streamed, it is essential that the life-cycle and environmental benefits of green housing are marketed so as to off-set the slightly higher capital upfront costs of green technologies.

7.2.10 **Retail chain**
Retail availability of green technology based building components is very minimal and the sector is highly unorganized. Organized retail chains for scale up and replicability are required for main-streaming green building technologies.

7.2.11 **Research & technology**
While extensive research is ongoing on various green and low-cost technologies by institutions such as BMPTC, there is a large time lag in converting prototypes to scalable and marketable building technologies.

7.3 **Supply chain analysis of shortlisted building technologies**
Summarizing the above observations, a technology-barrier matrix has been developed for the shortlisted building materials to give an insight into the supply chain issues at a glance. The weightage to the barriers have been assigned as Low, Medium & High with a score of 1, 2 and 3 respectively. The cumulative score is representative of the level of intervention required for scaling up the implementation of these materials for low income green housing.
### Table 3 - Technology-Supply Chain Barrier Matrix

<table>
<thead>
<tr>
<th>Building Technologies</th>
<th>Supply Chain Barriers</th>
<th>Intervention for Scale-up</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Raw Material Availability of Equipment Fiscal Incentive Skills Deficit Trust Deficit Standardizations &amp; Finance Barriers Market Barriers Retail Chain Research &amp; Technology Composite Barrier Score</td>
<td></td>
</tr>
<tr>
<td><strong>White Paint</strong></td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Flyash Lime Gypsum Bricks (FaLG)</strong></td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Compressed Stabilized Earth Bricks</strong></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Hollow Concrete Block Wall</strong></td>
<td>Med</td>
<td>Med</td>
</tr>
<tr>
<td><strong>Structural Insulated Panel</strong></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Roof Insulation</strong></td>
<td>Low</td>
<td>Med</td>
</tr>
<tr>
<td><strong>High albedo roofing (China mosaic)</strong></td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td><strong>Precast RC Planks and Joist System</strong></td>
<td>Med</td>
<td>Med</td>
</tr>
</tbody>
</table>
The assessment for the level of intervention required for scaling up the use of these materials for low income green housing has been done based on the composite barrier score. Higher the score, higher is the level of intervention required. The grading for the same has been done as high, medium and low as follows:

<table>
<thead>
<tr>
<th>Composite supply chain barrier score</th>
<th>Level of intervention required for scale up</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 to 16</td>
<td>Low</td>
</tr>
<tr>
<td>17 to 23</td>
<td>Medium</td>
</tr>
<tr>
<td>24 to 30</td>
<td>High</td>
</tr>
</tbody>
</table>

As can be seen from the above analysis, materials such as Structural Insulated Panels, Fal-G bricks and stabilized compressed earth blocks have high supply chain barriers while materials such as China mosaic tile roofing and roof insulation has lesser barriers.
7.4 Summary: Barriers and Challenges

The critical barriers and challenges to the supply chain of green building technologies are summarised below:

**Capital cost impact**

The incremental cost of green measures is about Rs.100/sq.ft. of built up area, which is approximately an additional 10% to the average cost of construction. The additional costs are largely due to increased labor and transportation costs and the incremental cost of provision of energy efficient lighting, fans and solar water heaters.

Annexure 5 presents a cost benefit analysis from the consumer’s perspective showing that the additional cost of green building measures can increase the mortgage burden for a typical household even if the savings in running electricity cost are counted. This is because of frugal use of electricity and cooling by most households to begin with.

An alternate scenario with a 1% rebate in mortgage interest rate reduces the monthly outgo (mortgage + energy costs) enough to offset the increased capital cost.

**Material manufacture, suppliers and vendors**

The manufacturing of green technologies is still a niche industry involving small and medium enterprises with the supplier and vendor network also being at a nascent stage of development. Large housing projects wanting to use green materials often face issues with adequate and timely supply of building materials. Lack of standardization, specifications and use of non standard equipment on site also lead to inefficiency and wastage on site.

**Worker skill and familiarity**

Shortage of workers trained in the use of new techniques and technologies is also a barrier to implementation of green building technologies as it causes delays and additional costs.
8 Financing affordable green housing: Good practices

8.1 Present mechanisms of financing affordable housing /green housing in India

Till a few years back, the supply of low income housing in India was largely through housing constructed by state housing boards and corporations (e.g. HUDCO, MHADA). The Government’s role in providing affordable housing today is still significant through various government programs such as the JNNURM and Rajiv Awas Yojana.

A study by Monitor Group estimates that the present demand for affordable housing (unit price in 3-10 lakhs range) is about 21 million. Realizing this immense potential, the last few years have seen the entry of the private sector in the affordable housing segment market. The same report estimated that there would be 25000-50000 affordable housing for sale in the fiscal year 2010-2011.7

While mainstream housing finance providers such as banks and housing finance institutions have traditionally served the middle to high income formal sector, the demand for affordable housing has seen the entry of finance institutions and micro-finance companies in the affordable housing space.

Gruh (a subsidiary of HDFC) and Dewan Housing Finance Limited (DHFL) are pioneers in providing finance for the affordable housing consumer base. The Micro Housing Finance Corporation is a dedicated startup targeted at the informal sector customers.

MAS in Microfinance and Vehicle Loans and Muthoot Pappachan Group in Gold Loans, have also recently entered this market. Besides the above larger players, there are also companies and organizations like Mahindra Rural Housing Finance Limited and SEWA.

8.2 Issues in financing affordable housing in India

One of the key issues faced in catering to the informal sector are the high transaction costs in serving this segment, in addition to the perceived high credit risks such as uneven paybacks and high NPA of the customer base. Current financing mechanism prevalent in the country mostly targets middle and high income groups of the society, while the households falling under the low income groups find it difficult to secure formal housing finance. Commercial banks and traditional means of housing finance typically do not serve low-income groups, whose income may vary with crop seasons, or is below the ‘viable’ threshold to ensure repayment, or who cannot provide collateral for loans.8

Micro finance institutions are considered the next best option for the informal sector, but they face issues related to longer periods of housing loans, relatively larger amounts of loans and refinancing issues pushing their interest rates to 14 % percent or more which is much higher that standard home loan rates of 10-11%.

8http://www.changemakers.com/node/11805, Competition Framework: How to Provide Affordable Housing
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In addition to consumer finance, developers in the low cost housing space also face project financing issues. To summarize, some of the key issues faced by affordable housing finance institutions include:

- Poor access to low-cost funds
- Lack of government support to lower cost of capital
- High credit risk (or the perception thereof)
- Low profitability (or the perception thereof)

8.3 Good practices in financing affordable/green housing

8.3.1 International examples

Financing and delivery of affordable green housing is enabled by the combined efforts of the government, private sector and the community that uses/owner the dwelling units. Multiple measures, as illustrated below are required for the provision of affordable green housing.

<table>
<thead>
<tr>
<th>ENABLING AFFORDABLE HOUSING</th>
<th>COMPLIANCE</th>
<th>FISCAL</th>
<th>MARKET</th>
<th>COMMUNITY &amp; INFORMAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiatives led by the public/government sector that include policy, mandatory regulations (e.g.: building regulations) and a range of fiscal measures including taxes, grants, housing loans, subsidies.</td>
<td>Initiatives led by the commercial and market sector including performance based contracts and PPP.</td>
<td>Initiatives led by the community, civil society and informal sector including community led asset management and maintenance.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Some of the emerging and current examples in financing affordable green housing to overcome barriers to ‘retro-fitting’ as well as developing new affordable green housing are listed below. In general a range of financial approaches namely ESCOs, funds/grants (buy-downs), commercial lending, guarantee facilities, micro-finance, carbon finance and installations led through community or informal intermediaries have been covered.

Short case studies of these examples are described in Annexure 4

**Good practices examples** -
- Green Mortgages through revolving loan in local currency (Mexico)
- Location Efficient Mortgage (LEM) and Energy Efficient Mortgage (EEM) (US)
- Energy Guarantee Program (US)

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- Green Grants from the Enterprise Foundation’s Green Communities Initiative (US)
- Low Income Housing Tax Credit Equity from Enterprise Social Investment Corporation (US)
- Green Building Tax Credits (US)
- Community Development Finance Institutions (CDFIs) including non-profit loan funds, credit unions, commercial banks, venture capital pools (US)
- Retrofit Revolving Guarantee Fund for retrofitting affordable homes for energy efficiency (UK)

8.3.2 India Examples

While the policy environment in India is maturing fast at the national level, at the state and municipal level, better links need to be developed within building bye-laws and regulations, such that it can facilitate the affordable green housing sector.

National banks and equity investors are by far the most important source of much needed finance for affordable green housing (both retrofits and new) and raising awareness among lenders and overcoming common risks should be priority. Availability of guarantees and similar risk mitigation instruments will facilitate their entry into the market.

Some of the initiatives taken by key stakeholders are mentioned below -

- National banks are putting green products on the market. For instance, State Bank of India is offering 0.25% concession in interest rate and waiver of processing fees on existing home loan products to customers who invest in Green Projects.10

- According to the MNRE11, model regulation/building bye-laws have been circulated by the Ministry of Urban Development to all States and Union Territories for installation of solar assisted water heating systems in new buildings. It is reported that necessary orders have been issued in 21 States. 41 Municipal Corporations/Municipalities have so far amended their building bye-laws, or issued necessary government orders in six States.

- Solar water heating systems are also included in the Energy Conservation Building Code. An energy labeling scheme similar to the star rating scheme for air conditioners and refrigerators is also planned to promote efficient solar water heaters.

- Municipal Corporations are being encouraged to provide rebate in properly tax for those dwellings/buildings where solar water heating systems have been installed. Four Municipal Corporations i.e. Thane, Amravati, Nagpur and Durgapur have announced 6-10% rebate in the property tax for users of solar water heaters.

- At present the Pune Municipal Corporation (PMC) provides a rebate of 10% on property tax for home owners of Eco-Housing certified projects. A rebate on development charges is also given for the developers by PMC for Eco-Housing Projects12

10 http://www.statebankofindia.com/user.htm?action=viewsection&lang=0&id=0,1,20,115,741,750,786
12 http://www.punecorporation.org/pmcwebn/index.aspx
• State Electricity Regulatory Commissions (SERC) /utilities are being encouraged to provide rebates in electricity tariff to such users. The utilities in Assam, Haryana, Karnataka, Rajasthan, West Bengal, and Uttarakhand are already providing such rebates up to Rs. 150 per month per domestic system. Incentives are available for municipal corporations and utilities that promote solar water heating. Solar water heating systems have been incorporated in the new National Building Code.

8.4 Inferences and issues in financing affordable green housing

• While the above described initiatives are a good start, the levels of funding are nowhere near those required to truly scale-up renewable energy and energy efficiency measures in affordable housing.

• Affordable housing projects will often need to aggregate a variety of fiscal incentives and private investment or equity. The entry of commercial lending and performance based mechanisms is required to bridge the gap between demand and supply of critical finance and technical assistance.

• Green lending products such as those offered by State Bank of India for green residential projects are coming on to the market. The success of these will encourage other lenders to follow.

• To promote the interest of the commercial investor, the benefits of green affordable housing needs to be more measurable and technical risks reduced. High quality technical standards in affordable housing and renewable energy installations where performance/ benefits can be measured and benchmarked will promote investor interest. A strong and stable technical/ fiscal environment is necessary to drive private investment into affordable green housing.

• Finally, the involvement of Municipal authorities to accommodate and encourage green affordable housing is a key part of this process and suitable changes need to be made within building bye-laws and their technical capacity to develop and enforce these. Many municipalities cannot afford incentives due to their poor revenue base and lack of technical capacity in developing and enforcing energy efficiency/ renewable energy regulations.

• Tools such as ESCOs, co-operatives and community led asset maintenance and management are not new in India. ESCO based support to municipal services and area based renewable energy has been tried previously in India (such as with the Ahmedabad Electricity Authority through a USAID funded project and Community Asset Management funded by DFID). Lessons should be learnt from these examples.

13 [http://www.statebankofindia.com/user.htm?action=viewsection&lang=0&id=0,1,20,115,741,750,786](http://www.statebankofindia.com/user.htm?action=viewsection&lang=0&id=0,1,20,115,741,750,786)
9 Policy and Financial Packaging

9.1 Key stakeholders

The diagram below illustrates the key Stakeholders and their role in enabling affordable housing.

In India, numerous institutions play overlapping roles in the housing market, and present a complex set of stakeholder interests. To present a uniform package of financial and policy interventions is difficult at best, and further complicates fundamental problems of split incentives between developers and owners for new buildings, and landlords and tenants for rented apartment complexes.

9.2 Policy and regulation background

The Table below has been adapted from a UNEP- Sustainable Buildings and Construction Initiative study titled - Assessment of Policy Instruments for Reducing Greenhouse Gas Emissions from Buildings. While not exhaustive, the major policy instruments have been analyzed qualitatively in the Indian context with their applicability to affordable green housing in order to provide a framework for capturing experiences in the efficacy of various related programs that have been considered or implemented.

### Table 4 - Policy Instruments for Energy Conservation in low income green housing

<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Existing or proposed policy instruments/mechanisms in India</th>
<th>Effectiveness</th>
<th>Cost-effectiveness</th>
<th>Direct applicability to affordable green housing</th>
<th>Special conditions for success, major strengths and limitations, co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control and regulatory mechanisms - normative instruments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Appliance standards</td>
<td>Many state Governments are making it mandatory to use solar water heating system, Compact Fluorescent lamps and BIS marked pump sets in Government and private buildings including industries</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Factors for success: periodic update of standards, independent control, information, communication and education</td>
</tr>
</tbody>
</table>

---

15 Information of Indian policies and regulations sourced from the following web based references:

4. [http://www.nldc.in/docs/REC/RPO%20Regulations/Maharashtra.pdf](http://www.nldc.in/docs/REC/RPO%20Regulations/Maharashtra.pdf)
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<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Existing or proposed policy instruments/mechanisms in India</th>
<th>Effectiveness</th>
<th>Cost-effectiveness</th>
<th>Direct applicability to affordable green housing</th>
<th>Special conditions for success, major strengths and limitations, co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procurement regulations</td>
<td>None</td>
<td>High</td>
<td>High/ Medium</td>
<td>High</td>
<td>Factors for success: Enabling legislation, energy efficiency labeling and testing. Energy efficiency specifications need to be ambitious.</td>
</tr>
<tr>
<td>Energy efficiency obligations and quotas</td>
<td>Under the Electricity Act, 2003, Regulations for Renewable Energy Purchase Obligations have been implemented by the State Electricity Regulation Commissions, e.g. - Maharashtra Electricity Regulatory Commission (Renewable Purchase Obligation, its compliance and REC framework implementation) Regulations, 2010.</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Continuous improvements necessary: new energy efficiency measures, savings target change, short term incentives to transform markets etc. Aggregation presents difficult problem for scale up.</td>
</tr>
</tbody>
</table>

**Regulatory-informative instruments**

<table>
<thead>
<tr>
<th>Mandatory labeling and certification programs</th>
<th>Under the Standards and Labeling Program of the Bureau of Energy Efficiency (BEE) - ACs, Tube lights, Frost Free Refrigerators, Distribution Transformers have been notified under mandatory labeling from 7th January, 2010</th>
<th>High</th>
<th>High</th>
<th>High</th>
<th>Effectiveness can be boosted by combination with other instrument, and regular updates.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mandatory audit programs</td>
<td>None</td>
<td>High but variable</td>
<td>Medium/ High</td>
<td>Medium</td>
<td>Most effective if combined with other measures such as financial incentives, regular updates, Stakeholder involvement in supervisory systems</td>
</tr>
<tr>
<td>Policy instrument</td>
<td>Existing or proposed policy instruments/mechanisms in India</td>
<td>Effectiveness</td>
<td>Cost-effectiveness</td>
<td>Direct applicability to affordable green housing</td>
<td>Special conditions for success, major strengths and limitations, co-benefits</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------------------------------------------------------------</td>
<td>---------------</td>
<td>-------------------</td>
<td>-----------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Utility demand-side management programs</td>
<td>Utility DSM projects such as BESCOM Lighting Initiative in Karnataka, Orissa Industrial DSM program, Gujarat Municipal Water Pumping DSM program, Agricultural Pumps DSM project in Maharashtra have been implemented. Municipal DSM programs are being implemented in the country by 171 urban bodies.</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>More cost-effective in the commercial sector than in residences, success factors: combination with regulatory incentives, adaptation to local needs &amp; market research, clear objectives</td>
</tr>
<tr>
<td>Economic and market-based instruments</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy performance contracting/ ESCO support</td>
<td>Under the NATIONAL MISSION FOR ENHANCED ENERGY EFFICIENCY (NMEEE), Energy Efficiency Financing Platform (EEFP) has been setup to help stimulate necessary commercial funding for Energy Service Company (ESCO) based delivery mechanisms for energy efficiency. 2 FIs have already joined the platform (PTC and SIDBI). Energy efficiency building retrofits using the ESCO model are being implemented in some government buildings as well as in some hospitals and commercial buildings.</td>
<td>High</td>
<td>Medium/ High</td>
<td>Low</td>
<td>Strength: no need for public spending or market intervention, co-benefit of improved competitiveness. In India, ESCO growth has been limited due to reluctance of financing from commercial banks, and may other implementation barriers. The scope for implementation in the residential sector is yet to be explored</td>
</tr>
<tr>
<td>Cooperative/ technology procurement</td>
<td>None</td>
<td>Medium / High</td>
<td>High/ Medium</td>
<td>Medium/High</td>
<td>Combination with standards and labeling, choose products with technical and market potential</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Existing or proposed policy instruments/mechanisms in India</th>
<th>Effectiveness</th>
<th>Cost-effectiveness</th>
<th>Direct applicability to affordable green housing</th>
<th>Special conditions for success, major strengths and limitations, co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy efficiency certificate schemes</td>
<td>Under the Ministry of Power, a Renewable Energy Certificate mechanisms launched in November 2010, with trading commencing in March 2011 through Perform Achieve and Trade (PAT) under the NMEE.</td>
<td>Medium</td>
<td>High/Medium</td>
<td>Low</td>
<td>No long-term experience yet. Transaction costs can be high. Adv. institutional structures needed. Profound interactions with existing policies. Benefits for employment. Applicability and benefits to the residential development sector to be explored</td>
</tr>
<tr>
<td>Kyoto Protocol flexible mechanisms</td>
<td>Under the NMEEE, Bachat Lamp Yojana Program of Action (PoA) being implemented in collaboration with Electricity Distribution Companies (DISCOMs). Bachat Lamp Yojana (BLY) promotes energy efficient and high quality CFLs as a replacement for incandescent bulbs in households at the rate of an incandescent bulb, i.e. Rs 15. This project aims to leverage Clean Development Mechanism (CDM) under the UNFCCC Kyoto protocol</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>So far limited number of CDM &amp;JI projects in buildings. Success factors: Project bundling, Information &amp; awareness campaigns, link to GIS</td>
</tr>
</tbody>
</table>

### Fiscal instruments and incentives

| Taxation (on CO2 or household fuels)     | None                                                                                                                                                                                                                                                   | Low/ Medium   | Low                | Low                                             | Effect depends on price elasticity. Revenues can be earmarked for further energy efficiency improvements. More effective when combined with other tools.                                                      |
## Low-cost green housing

<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Existing or proposed policy instruments/mechanisms in India</th>
<th>Effectiveness</th>
<th>Cost-effectiveness</th>
<th>Direct applicability to affordable green housing</th>
<th>Special conditions for success, major strengths and limitations, co-benefits</th>
</tr>
</thead>
</table>
| Tax exemptions/reductions | Under the NMEEE the following tax exemptions have been proposed -  
• Graded excise duty for STAR labeled equipments in favor of higher efficiencies  
• Income and Corporate tax incentives for ESCOs/ Venture Capital funds, etc. in energy efficiency  
• Providing infrastructure status to ESCO business  
Some Municipal bodies such as in Pune have extended rebates in property tax for Eco-housing certified buildings. | High | High | High | If properly structured, stimulate introduction of highly efficient equipment and new buildings. |
<p>| Public benefit charges | None | Medium | High in report-ed cases | | |
| Capital subsidies, grants, subsidized loans | Under the NMEEE, Partial Risk Guarantee Fund (PRGF) and Venture Capital Fund for EE (VCFEE) are being set up to stimulate commercial lending to ESCO projects. SBI has subsidized interest rates for green building certified commercial and residential buildings. | High / Medium | Low sometimes High | High | Positive for low-income households, risk of free-riders, may induce pioneering investments |</p>
<table>
<thead>
<tr>
<th>Policy instrument</th>
<th>Existing or proposed policy instruments/mechanisms in India</th>
<th>Effectiveness</th>
<th>Cost-effectiveness</th>
<th>Direct applicability to affordable green housing</th>
<th>Special conditions for success, major strengths and limitations, co-benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary certification and labeling</td>
<td>LEED -India, IGBC Green homes, Teri GRIHA and Eco-housing are voluntary green building certification systems, currently available in India. For appliances, under the Standards and Labeling program of BEE, 12 categories of equipment/appliances have been covered of which 4 are under mandatory labeling and the remaining are under voluntary labeling. Rating using star categories of 1 to 5 in increasing order of energy efficiency is being applied.</td>
<td>Medium / High</td>
<td>High</td>
<td>High</td>
<td>Effective with fiscal incentives, voluntary agreements and regulations, adaptation to local market is important.</td>
</tr>
<tr>
<td>Voluntary and negotiated agreements</td>
<td>Building retrofits for energy efficiency using the ESCO model being implemented through funding from organizations such as the 'Clinton Climate Initiative'. Eco-housing program in Pune Municipality is being implemented under a negotiated agreement with Science and Technology Park, Pune.</td>
<td>Medium / High</td>
<td>Medium</td>
<td>Medium</td>
<td>Can be effective when regulations are difficult to enforce. Effective if combined with fiscal incentives, and threat of regulation. Inclusion of most important manufacturers, and all stakeholders, clear targets, effective monitoring important</td>
</tr>
<tr>
<td>Public leadership programs</td>
<td>None</td>
<td>Medium / High</td>
<td>High/ Medium</td>
<td>Medium/ High</td>
<td>Can be used to demonstrate new technologies and practices to clearly state, communicate and monitor, adequate funding and staff, involve building managers and experts</td>
</tr>
<tr>
<td>Policy instrument</td>
<td>Existing or proposed policy instruments/mechanisms in India</td>
<td>Effectiveness</td>
<td>Cost-effectiveness</td>
<td>Direct applicability to affordable green housing</td>
<td>Special conditions for success, major strengths and limitations, co-benefits</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------</td>
<td>--------------------</td>
<td>--------------------------------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Awareness raising, education, information campaigns</td>
<td>Awareness raising and education campaigns being implemented by Government agencies such as BEE as well as programs of non-profit organizations such as the Eco-housing program</td>
<td>Low/Medium</td>
<td>Medium/High</td>
<td>High</td>
<td>More applicable in residential sector than commercial. Deliver understandable message and adapt to local audience.</td>
</tr>
<tr>
<td>Detailed billing and disclosure programs</td>
<td>None</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Success conditions: combination with other measures and periodic evaluation. Comparability with other households is positive.</td>
</tr>
</tbody>
</table>
9.3 Potential strategies to scale up affordable green housing

The housing sector in India is influenced by so many stakeholder interests that the effectiveness of regulation is predicated on the efficacy of enforcement mechanisms. Perhaps one of the most effective methods may be to get intermediary institutions to provide the monitoring needed. For mandatory programs driven by regulations, financial institutions can be intermediaries, whereas investment risks in affordable green housing may be managed through interventions from public financial institutions and utilities. On the other hand, state and local governments can support the public financial institutions and utilities in effective provision of incentives for promoting affordable green housing. Some initial ideas discussed among the project team that need to be structured and tested are presented briefly in the sections below.

9.3.1 Regulation/Enforcement

Financial institutions could potentially play a substantial role in promoting low cost and affordable green housing in India. Perhaps one of the most tested methods has been the promotion of some rating system which defines the performance of the structure, mostly for reduction of operational energy use. For example, the U.S. tried to develop energy efficient mortgages using a home energy rating system since the early 1990s through Fannie Mae. Other such examples also can provide the experience base needed to design and test a similar mechanism in India using the existing rating systems such as Griha, Eco-housing, or LEED for homes. However, such systems are not prescriptive in nature and have not been able to mobilize the markets for low cost affordable green housing on a large scale for numerous reasons.

National Housing Bank

As one of the major institutions for refinancing mortgages, the NHB could play a substantial role in providing a policy framework for lending to low cost affordable housing developments. In addition to adopting a performance goal, such as the IFC’s 20-20-20 model, the NHB also could prescribe a methodology to ensure that other housing finance institutions and banks incorporate systems to promote green housing. Through mortgages, the main influence of the NHB is through the end users reducing operational energy use, and not necessarily in developers reducing embodied energy use. However, a policy push from the NHB could mobilize lenders in turn, to mobilize demand for green housing including the use of products such as those identified in this report. One potential idea discussed by the project team it to work with the NHB to create a mandate for the refinancing to specify that the housing portfolio of banks to be X% “green” (using a gradual/tiered approach), where green is defined as noted in this report.

HFI/ Banks involved in Construction Finance

In addition to the NHB, the housing finance institutions and banks involved in construction finance could have a substantial influence on the developer community. Various financing packages can be developed to incorporate green products, such as the ones identified in this report, to reduce embodied and operational energy use and to achieve the IFC’s 20-20-20 goal. While construction finance can influence mainly embodied energy use, other innovative financial products also may be created to encourage operational energy use reduction through bulk procurement of efficient appliances by developers to reduce operational energy use.
9.3.2 Investment

Investment in the green housing market has been difficult to scale up in new constructions for various reasons, including split incentives between the developers and owners. Whereas the subject of split incentives has been studied extensively for existing rented buildings with landlord-tenant relationships to improve operational energy use, more attention is needed to address the reduction of embodied energy use and to manage the developer-owner split incentives in new buildings. The analysis in this report shows that institutions need to consider innovative financing approaches to enable scale up of investments in low cost green housing.

National Housing Bank

As a mortgage refinancing institution, the NHB could influence the scale up of investment in low cost and affordable green housing by reducing the risks entailed in implementing technologies and systems, such as those identified in this report, which have not become a part of the mainstream market. To promote the market penetration of systems for reducing embodied and operational energy use, the NHB can consider providing incentives which could include, interalia:

- Refinancing long term, ‘green’ mortgages at lower interest rate to banks/ HFIs
- Direct financing to Public Housing Boards, which explicitly promote low cost affordable green housing
- Improved guarantee terms for complexes where green housing is adopted by the developers and their supply chain

Utilities

As key intermediaries in delivering energy and water services, utilities can play a significant role in reducing operational energy use. The main mechanism at the utility’s disposal is the billing collection system which can enable it to influence consumer behavior. Participation of the utility in on-bill collection, financing or shared savings can provide substantial comfort to investors in the ability to capture savings. Policies to enable packaging of financial products which utilize such utility cooperation need to be studied carefully.

9.3.3 Incentives

While the NHB and banks can provide risk reduction mechanisms for incentivizing scale up of investments into the low cost affordable green housing market, there may be a strategic role for state and local governments to provide substantial policy support and incentives.

State/ Municipal governments and Utilities

New construction is dominated by state and local rules and regulations incorporated into development control regulations (DCRs). Indian states can provide substantial policy support for financial packages offered in areas which incorporate green considerations into their DCRs. For example, the state of Maharashtra indicated such support for Eco-housing to be incorporated into DCRs of 800 municipalities. State and local governments also can incentivize new green construction through the numerous tools in their control, mainly through property tax rebates for developers, building materials/ components manufacturers, and also end users. In addition, local governments can work with utilities to provide concessions in electricity water charges, including connection charges, to promote both embodied and operational energy use.
10 Next Steps

10.1 Next steps – Pilot projects

A number of green technologies for affordable housing recommended in this study, for instance, the stabilized earth blocks and hollow concrete blocks, have significantly lower CO₂ emissions and have been around in the market for over a decade. However, they have failed to achieve a full scale-up. This demonstrates that a transformation in the building industry requires a concerted and multi-pronged approach through dissemination of information, capacity building, financing mechanisms, policy and governance.

The international case studies focused on financing and other mechanisms for affordable housing, illustrated in this report demonstrate that a balanced mix of fiscal measures, municipal level regulations and market interventions are required to enable affordable green housing.

Given India’s current environment, affordable housing projects will need to aggregate fiscal incentives as well as commercial investment or equity. Commercial lenders are willing to enter the green market but they will be looking for measurable returns, low risks and confidence in the technology. Once successful, other commercial lenders are likely to follow.

A strong and stable technical/ fiscal environment is necessary to drive private investment into affordable green housing. To promote the interest of the commercial investor, the benefits of green affordable housing needs to be more measurable and technical risks reduced. High quality technical standards in affordable housing space-design and renewable energy installations where performance/ benefits can be measured and benchmarked will promote investor interest.

Showcasing the identified alternate green technologies in pilot low income housing projects, will not only provide empirical evidence of the benefits of these low-cost green technologies, but will also facilitate better understanding of the supply chain barriers. Measurable performance/benefits will also lead to effective finance mechanisms, policy interventions and commercial investments.

The following guidelines can be adopted to identify pilot projects:

- Pilots could be of any of the following types
  1. Construction projects
  2. Building material/technology development
  3. Building material/technology production and supply chain integration
  4. Financing models for increasing market share of identified technologies
  5. Marketing information and dissemination

- Pilots should represent the mainstream and not one-off schemes
- The materials/processes/or technologies employed should be replicable and scalable
- Preferably have governmental and private involvement in financing
11 Bibliography

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18. Reference for embodied energy and comparison of alternate materials –
- R.K.Celly, Green Building Technologies for Sustainable Habitat, Former Executive Director for Building Materials and Technology Promotion Council, Ministry of Housing and Urban Poverty Alleviation, Government of India, Sintex Chair Professor, CEPT University, Ahmedabad,
- https://wiki.bath.ac.uk/display/ICE/Home+Page
- http://deepblue.lib.umich.edu/bitstream/2027.42/75688/1/108819800569726.pdf
- Mr. Satya Narayana, Kinetic Wudplas Private Limited, Wood Plastic Composite Panels and Frames manufacturer
- http://ideas.repec.org/p/ags/hiiedp/26323.html
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- Environmental Design Solutions Database
- Consultation with Contractors and Manufacturers
- http://www.unesco.org/most/asia4.htm
- http://www.environxchange.com/articledetail.php?articleid=221&searchstring=Enter%20Keywords%20for%20Information%20%20Product%20you%20are%20looking%20for
- http://dspace.mit.edu/handle/1721.1/60818
- http://www.cgg.gov.in/pdfs/WP-4-PKM-Housing%20for%20the%20Poor.pdf
12 APPENDIX
12.1 Annexure 1 – Stakeholders’ Meeting [7th February 2011] – Minutes of Meeting

12.1.1 Scope

It was decided that the project would be looking at housing units in price range of INR 300,000 to 1,000,000 (corresponding to Monthly Household Income of INR 8,000 to INR 25,000). The project will take a comprehensive look at ‘green’ technologies encompassing energy-efficiency, water-efficiency, and embodied energy, but eventually identify and focus on high-impact technologies/products/features (based on the experience of stakeholders and industry experts).

12.1.2 Affordable ‘Green’ Housing and Cost Sensitivities

We need a broad-based definition of what is "green" (architectural design elements/ construction technology/ recycling & waste management/ embodied energy).

It was unanimously concluded that high cost measures will fail to initiate the process of market transformation. While some subsidies may be required for to kick-start the process, stakeholders were of the opinion that the impetus must eventually be market driven with scope for scalability.

Exploring PPP opportunities can be a good start to start integrating ‘green’ with the affordable segment. Nearly all participants were of the opinion that the project must aim at generating market participation to avert the danger of it ending up as one of many promotional schemes.

The supply-demand imparity was identified as one of the primary barriers in incorporating a ‘green’ agenda in the affordable segment. Innovative financing models in this segment across the globe should be looked up and opportunities for initiating ‘green’ can be explored through imbibing some of the lessons learnt. Should microfinance models be devised and implemented?

High-impact, no-cost measures like natural ventilation, daylighting, and right orientation should be accorded highest priority.

Can we look at energy generation on large-scale townships/campus development? The focus is to remain on developer built multi-storey housing.

12.1.3 Scalability

This was recognized as a key feature of any model that will emerge from this process. This may be achieved through supply chain interventions (identifying supply chain gaps/ recommendations for subsidies) and vendor development (through capacity building and regulatory changes). Moreover,

- Low-cost high-impact measures should be identified
- Global experience should be leveraged in terms of affordable housing finance
- Partnerships with state central and state governments should be explored as a starting point
- State governments that are already proactive in this space should be identified for collaborative effort
12.1.3.1 Homex Model

Homex of Mexico (and now in India), is a good example of developer that operates in the affordable and middle-income housing sector. They operate through two innovative interventions, one being economy of scale and the other utilization of government land banks for lower costs. The lower costs allow them to absorb the first costs of ‘green’ measures. Moreover, their tight turnaround time budgets (high speed of construction) also contribute towards delivering with low price tags.

12.1.3.2 Banks

A representative from the banking sector stated that banks have yet to explore the ‘affordable’ or ‘green’ territories in detail. So far, the banking industry has not looked at this segment due to poor risk appetite. ‘Green’ has not appealed to the financing industry as their exposure to this concept and its practices are limited. Banks are yet to devise ways to gauge the financial potential or other benefits of the ‘green’ products and technologies before engaging in promoting these. Banks are floundering for technical assistance (through certification or benchmarking) in evaluating the ‘green’ claims of products/technologies/buildings. Establishing a baseline for comparative benefits will help in facilitating financial assistance.

12.1.4 The Context: Urban or Rural

The representative of the housing sector regulator suggested varied approaches to rural and urban markets. He also noted that some states are adopting mandatory environmental clearance requirements imposed by the Ministry of Environment and Forests. Another representative also suggested that a further distinction must be made between metropolises and smaller cities. Affordable housing should be addressed in a holistic manner – this means accounting for commute distance from work place and providing after-sale maintenance facilities.

Should we look at Tier II and Tier III cities for piloting green affordable housing?

Can these models be replicated in Nepal/Bangladesh/sub-Saharan Africa?

What about self-construction customers?

12.1.5 Summary of Stakeholders’ Comments

1. Chittaranjan Kaushik (Milestone):
   - Boisar
   - Implementing sustainable energy practices
     - PVs cost INR 24/sqft, buyers get it for INR 18/sqft
   - Gray water treatment
   - Payback is generally long for green products and technologies - market competitiveness has to be generated for these to thrive on their own
     - Can be enforced through regulations e.g. MoEF

2. Hariharan (BCIL)
   - Have got 2000 houses retrofitted.
   - Improvement measures that they practice are:
Low-cost green housing

- Aerators in all faucets, cost was INR 1,200 for 2 toilets
- CFLs instead of incandescent
- Collectors, with no electrical backup
- Restrictors
- Compost treatment
- Improvement in wiring, saved on heavy load wiring, 3mm for a distance of 20 km.

3. Sachin Khandelwal (ICICI Housing Finance)
   - Financing the vendor & supply chain is an important issue
   - Green technologies and efforts are being incorporated only in high price brackets
   - The economically weaker segment is still not able to access affordable housing - for the VBHC (Jerry Rao Projects) in Bangalore, the minimum monthly income of individuals who placed a booking was found to be INR 36,000
     - It therefore becomes important to identify right customers in right locations - smaller cities can be looked at within this context
   - The risk appetite of the finance industry has been so far been lower towards the affordable segment
     - ICICI is trying to focus on this segment (with loan component of INR 5-20 Lakhs)
   - Evaluating green technologies/products/efforts is difficult from the finance industry perspective as they have no prior exposure to the concept or technology. Estimating ROI and market potential for investments in such projects are tough. Banks are keen on technical support (possibly through certification) for this purpose
     - ICICI also has 150 engineers on its pay roll but would ideally want get external support for technical evaluation and responsibility
   - Emphasis on co-creation of a verifiable mechanism
   - ICICI is ready to finance green affordable projects, but is awaiting good project proposals

4. Sambit Basu (IDFC)
   - People looking at affordable housing are not concerned about environment, in the sense that they are not willing to pay more for environmentally benign technologies
   - Technologies will make sense only when there is scale
   - Waste management should be looked at
   - Overall, a broader definition of green should be formulated

5. Ajay Malhotra (Homex)
   - Made ~60,000 houses last year with ~88% in affordable segment
   - Play on economies of scale, time is of essence to them, margins are low
   - Affordability is 4 to 11 times of minimum wages in Mexico
   - All the workers have social credit and loans are given against that
   - Sales happen as they construct
   - Suggested that those technologies should be explored where scale can be reached
   - Suggested access to credit for minimum wage earners
   - Micro-financing is inadequate to make a large scale impact
   - Speed of construction and scale of financing go together, i.e., those technologies that can improve speed of construction will achieve scale.
6. Chittaranjan Kaushik (Milestone):
   - The affordable housing should be near the workplace, saving on transport is effective increase in affordability. This could well be channelized towards green initiatives
   - Financing is problem for daily wage earners and finance industry will have to start looking at them
   - It is important to improve quality by sustainable means without additional cost implications
7. Nitin (SP office)
   - Cost effective measures e.g. Passive design should be promoted
8. Anil (IIEC)
   - Lobby body with long term vision for promoting green
9. Gaurav (IDFC)
   - PPP model in affordable segment should be explored
10. Hariharan (BCIL)
    - Dynamics between builder, customer, rating bodies and finance industry must be explored
11. Neeraj (IFC)
    - Talked about allocating part of the PPP to this area
12. Praveen Sanjeevi (IDFC)
    - Talked about providing incentives e.g. tax incentives
13. Representative from the architect firm
    - Suggested more sustainable solutions and empowering vendors
14. Vishal Goyal (NHB)
    - Market assessment for KfW line of credit showed that 30% energy efficiency improvement could be achieved for houses between 20-40 lac Rupees.
    - NHB focuses on refinancing through intermediary banks to individuals
    - Urban and Rural markets have to be looked at differently
15. R K Celly (former Executive Director BMTPC, currently at CEPT)
    - Identify supply chain gaps and look at capacity building
16. Prashant Kapoor (IFC)
    - International innovative ideas and best practices in sustainable finance can be looked at
17. Nitin Pandit (IIEC)
    - Access to finance for individuals - potentially through NHB
    - Consider Microfinance
    - Supply chain interventions and private sector vendor involvement
18. Subrata Datta (IFC)
    - To explore how state governments can be involved
    - To see what happens to after-sales, awareness to cultivate healthy usage pattern
19. Anamika (EDS)
    - Generate a baseline for certification?
20. Himanshu (EDS)
    - Community development and social networking
21. Prasoon (EDS)
    - Builders have to start taking initiatives, they are the most influential part of the chain
12.2 Annexure 2 - Quantification of Energy Savings: Developing the Base Case

12.2.1 Baseline Case and Energy Demand

As a starting point for all analyses within this task, a prototypical block was developed using several housing developments in and around Delhi (Bawana, Narela, Baprola, Bhogarh, and Omicron) as reference. The prototype was developed as an aggregate of typical practices in low-cost development across the criteria of:

- Size of the development
- Unit size
- Semi-urban location
- Building materials vocabulary
- Number of floors

12.2.2 Simulation Procedure

This was considered an important step towards quantifying operational energy of materials and technologies. Simulation of the prototypical block was carried out using TAS (Thermal Analysis Software) v9.1.4, which has been developed by EDSL. TAS is dynamic simulation software for analysing building performance. It has three main components. The simulation process in TAS starts with making a 3d model of the project in TAS 3d Modeller. Information regarding type of building elements (walls/floors/roof), shading devices, fenestration, and zones (spaces) are assigned at this stage. The 3D model is then exported to TAS Building Simulator, wherein weather data and calendar (indicating season, weekdays, holidays/weekends) are attached. Material properties (thermal mass/U-value/shading coefficient/density/thickness) are then assigned to building elements. Internal conditions, schedules, aperture types, and other relevant data are also allocated. Finally dynamic simulation is carried out on an hourly basis for 8760 hours of a year to get energy use (kWh) and energy demand (kW) results for the set of building data provided. The results can be viewed and sorted systematically in TAS Result Viewer. All the steps, including terminologies, are explained in detail in the following sections.
12.2.3 Developing the Base Case

As mentioned above, the layout that has been considered for simulation in TAS is based on typical construction practices in India. Typical floor-to-floor heights, numbers of units, areas, and window-wall-ratios (WWR) have been considered.

Internal gains have been assigned under the categories of Occupancy, Lighting, and Equipment. Occupancy gains have been considered for each space based on judgments of typical lifestyle and space usage patterns. For example, we assume that the bedroom would be typically occupied during night time by two adults. Lighting and Equipment gains are also determined based on occupancy schedule. Lighting is typically used in the evening after sunset and during early morning hours during winter. Gains from equipments such as TV, fans, refrigerator, and cooking-related activities, have also been similarly considered.

Table 12.1 – Baseline building parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of floors</td>
<td>3</td>
</tr>
<tr>
<td>Floor-to-floor height</td>
<td>3m</td>
</tr>
<tr>
<td>Number of units in block</td>
<td>4</td>
</tr>
<tr>
<td>Built-up area of each floor</td>
<td>161 m²</td>
</tr>
<tr>
<td>External wall area</td>
<td>208 m²</td>
</tr>
<tr>
<td>Total window area</td>
<td>17.28 m²</td>
</tr>
<tr>
<td>Window sizes</td>
<td>0.2mX1.2m, 0.9mX1.2m and 0.6 mX0.6m</td>
</tr>
<tr>
<td>Total door area</td>
<td>15.12 m² (size 0.9 m x 2.1 m)</td>
</tr>
</tbody>
</table>
Low-cost green housing

Table 12.2 – Baseline building material properties

<table>
<thead>
<tr>
<th>Material</th>
<th>U-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick wall with plaster on both sides</td>
<td>2.8 W/m² °C</td>
</tr>
<tr>
<td>Floor, concrete slab</td>
<td>3.5 W/m² °C</td>
</tr>
<tr>
<td>Glazing, single, clear</td>
<td>5.0 W/m² °C</td>
</tr>
</tbody>
</table>

Table 12.3 – Baseline building internal gains assumptions

<table>
<thead>
<tr>
<th>Internal Gains</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration</td>
<td>.2 Air Changes per Hour (ACH)</td>
</tr>
<tr>
<td>Lighting</td>
<td>5 W/m²</td>
</tr>
<tr>
<td>Equipment</td>
<td>10 W/m²</td>
</tr>
</tbody>
</table>

Figure 2 – 3d Model of the project with doors, windows and shading devices on different floors.

Figure 3 – In plan view, zones are assigned to all the spaces (on all floors) that would impact the thermal or energy performance of the building. E.g., Liv1, Liv2, Bed1, etc. are all different zones. Assigning zone names would be useful to easily identify a particular space and retrieve its temperature profile or energy consumption at the end of the simulation process.
12.3 Annexure 3- Shortlisted Building Technologies

12.3.1 Reflective White Paint

White reflective paint applied to wall surfaces helps lower surface and indoor temperatures by reflecting the incident radiation. This improves the thermal comfort conditions within the space.

**Advantages**

- Is readily available
- Inexpensive, with no additional cost

**Challenges**

- Requires regular cleaning or re-application to maintain its reflectivity

12.3.2 Fly Ash Lime Gypsum Bricks

Fly Ash Lime Gypsum Bricks (popularly known by its trade name FaL-G) are prepared through blending fly ash, lime, and gypsum in suitable proportions and strengthened through hydration. Portland cement is used as a substitute wherever lime is in short supply. Green bricks are dried in the sun for a 24-48 hour period and require water curing.

**1.1.1 Advantages**

- Does not involve autoclaving or burning of fossil fuels
- Conserves precious top-soil
- Excellent strength and durability
- Scalable and replicable, has already found widespread use in Andhra Pradesh, Tamil Nadu, and Delhi
- Extensively uses by-products or industrial wastes
1.1.2 **Challenges**

- Use of water at 500 –1000 m3 per million brick

12.3.3 **Fly Ash-based Hollow Concrete Walling Systems**

Hollow concrete blocks can be quickly assembled, are cost effective and an environmentally sound option for wall material. It is based on the principle of densification of a lean concrete mix to make a regular shaped, uniform, high performance masonry unit. It is an effective means of utilizing wastes generated by stone crushers, quarrying and stone processing units. The technology has high potential in areas where raw materials are easily available. Although applied to a host of housing projects across the country, its current use is cannot be termed widespread. The technology is awaiting adoption on a large scale, with availability of equipment being a major bottleneck. However, it is envisioned that as it attains the required scale, a number of micro enterprise options would emerge. It would lead to enterprises for mould manufactures and/or decentralized production of these blocks.

1.1.3 **Advantages**

- Is light-weight – reduced building weight leads to savings in foundation design
- This offers a remarkable cost-free thermal insulation
- Fly ash, a waste from thermal power plants, can be extensively used - this results in conservation of valuable top soil
- Can be made in a batch plant at site – can easily be scaled and replicated
- Can reduce the use of river-bed sand by half
- Can use composite cement (with fly ash and steel plant slag upto 20%)
- When used efficiently, can significantly reduce the use of mortar (by 60%) by making plastering redundant – this results in additional saving of cement, sand, water and labor
- Lower embodied energy compared to conventional walling systems
- Cost-effective compared to conventional walling systems

1.1.4 **Challenges**

- There would be challenges in terms of availability of equipment all across. But once this technology is adopted on a large scale, a no of micro enterprise options would emerge. It would lead to
enterprises for mould manufactures &/or decentralized production of these blocks. This model is applied on host of housing projects across the country.

12.3.4 **Structural Insulated Panels (SIPs)**

Structural Insulated Panels (SIPs), consist of an insulating layer sandwiched between two layers of structural board. The insulating layer is typically expanded or extruded polystyrene, while the structural panels could be made of sheet metal, plywood, cement, or more commonly, oriented strand board (OSB). Interlocking panels ensure quick construction and tight building envelope, reducing operational energy. Compressed straw is often used as the core material for cost-sensitive projects – making the product ‘greener’ and less expensive but denser and less insulating. OSBs are manufactured from fast-growing trees, wood chips, timber shreds, and saw dust.

SIPs share the same structural properties as an I-beam or I-column. The rigid insulation core of the SIP acts as a web, while the OSB sheathing exhibits the same properties as the flanges.

### Advantages
- Reduces operational energy by 25-30%; for unconditioned spaces, it enhances thermal comfort
- Components are recyclable
- Excellent strength and durability
- Extremely speedy construction, a 1000 ft2 house can be constructed in two days
- Low embodied energy

### Challenges
- More expensive than conventional wall alternatives
- Not readily available in India

12.3.5 **Compressed Stabilized Earth Blocks (CSEBs)**

The Compressed Stabilized Earth Block (CSEB) Technology is an economically viable and environmentally benign solution for walling, roofing, arched openings, and corbels. The blocks are manufactured using raw earth compacted with a stabilizer such as cement or lime. The compaction may be achieved manually or
Low-cost green housing

 hydraulically. Some of the compaction machines produce interlocking blocks that are quick and easy to assemble. SCEBs are sundried.

1.1.7 Advantages

- Are cost effective and energy-efficient
- Are typically cast on site thereby avoiding transportation costs
- Can be manufactured manually as well as through mechanical means
- Are aesthetically pleasing and do not require plastering with its adobe-like appearance, exterior surfaces may be given a weather resistant skin
- Are fire and pest resistant, and virtually sound-proof
- Use abundantly available raw materials like cement, clay, and even fly ash
- Low embodied energy

1.1.8 Challenges

- Availability of machines
- Its manufacturing process is labour intensive and slow

12.3.6 Roof Insulation

Heat gain through roof surfaces is an important component of the overall heat gain through building envelope in very hot climatic zones. Insulating the external surface of roofs is an appropriate strategy for reducing heat gain and enhancing thermal comfort in hot climates. Expanded or extruded polystyrene provide effective and durable insulation for roofs, but are characterized by very relatively high embodied energy and are derived from petrochemicals. Moreover, with cost as a consideration, inverted earthenware pots, cellulose, or fiber glass could be used as insulation.

1.1.9 Advantages

- Reduces operational energy by 10-15%; for unconditioned spaces, it significantly enhances thermal comfort
- Components are recyclable

1.1.10 Challenges

- Is an ‘added’ expense as it is not an integral part of the envelope
12.3.7  High-albedo Roofing (Broken China Mosaic Tiles)

Many modern buildings in India are constructed of concrete or cinder blocks and are topped with flat, tar-covered roofing. Such surfaces absorb the incident sunlight, transferring it to the interiors of the building. The hot ceiling continues to heat up the space – during the day and well into the night - making the spaces unbearably hot throughout the summer season. A high-albedo roof is one that reflects most of the incident sunlight and efficiently emits some of the absorbed radiation back into the atmosphere, instead of conducting it to the building below. As a result the roof stays cooler, with lower surface temperatures, keeping the building at a cooler and more constant temperature. The term, ‘cool roof’ or high-albedo roof refers to the outer layer or exterior surface of the roof which acts as the key reflective surface. These roofs have higher solar reflectance and emissivity than a typical roof surface. This can be achieved through applying broken white china mosaic on the outer roof surface.

1.1.1 Advantages
- Reduces operational energy by 15-20%; for unconditioned spaces, it significantly enhances thermal comfort
- Low-cost, high returns on investment

1.1.2 Challenges
- Is an ‘added’ expense as it is not an integral part of the envelope

12.3.8 Precast RC Planks and Joist System
Precast RC planks and Joist systems are a good system for achieving quick and low-cost construction of low-rise buildings. The system comprises precast RC planks supported over partially precast joists. The RC joists are typically 15x15 cm in section, and upto 4.2 m long. Precast RC planks are typically 30 cm wide, 3 to 6 cm thick (with tapered haunches) and upto 1.2 m long. The components are produced on casting platform at construction site and as soon as wall reaches the floor/roof level, the components are erected, assembled and partly filled up with concrete to form the floor/roof. These can also be applied to intermediate floors and result in savings of 20% in overall cost, 25% in cement and 10% in steel as compared to conventional RCC slab floor/roof. The system is suitable for spans of upto 4.2 m, but provision of secondary beams can accommodate larger spans.

1.1.13 **Advantages**

- Uses 25% less cement, 10% less steel, and reduces the cost of shuttering and plastering
- Saves on transportation costs
- Speedy construction
- Cost-effective
- Low embodied energy

1.1.14 **Challenges**

- Decreased depth increases thermal conductivity

12.3.9 **Fly ash-based Filler Slab Type Roofing Systems**

Filler slabs are based on the principle that a simply supported roof experiences compressive forces on the upper part and tensile forces on the lower part. The filler slabs are a mechanism to replace the concrete in the tension zone. While concrete is very good in withstanding compressive forces and steel bears the load due to tensile forces. It follows that the lower tensile region of the slab does not need any concrete except for holding the steel reinforcements together. The filler material, thus, is not a structural part of the slab. The air pocket formed by the contours of the tiles makes an excellent thermal insulation layer. Mangalore tiles are a popular filler material and are placed between steel ribs while concrete is poured into the gap to make a filler slab. Other favored filler materials include burnt clay bricks, broken concrete pieces, and sometimes coconut shells. Air pockets formed by the contours of the tiles make an excellent thermal insulation layer. The design integrity of a filler slab involves careful planning taking into account the negative zones and
reinforcement areas. The design integrity of a filler slab involves careful planning taking into account the negative zones and reinforcement areas.

1.1.15 **Advantages**
- Reduced quantity and weight of material
- Cost-effective (15-25%) while retaining the strength of the conventional slab
- Enhanced thermal comfort due to insulating properties of filler materials
- Low embodied energy

1.1.16 **Challenges:**
- Slab design requires competent structural engineering
- Requires capacity building for its proper implementation

12.3.10 **Fly Ash-based RCC Door Frames with Lintels**

RCC door frames and lintels are now considered acceptable substitutes for wood and MS frames, especially in low-cost construction. It is a good solution to common problems that cheap wood frames encounter – that of termites, swelling, and shrinking.

1.1.17 **Advantages**
- Conserves precious natural resources – wood; fly ash can also be used in this application
- Cost-effective
- Can be pre-fabricated on site in bulk, saving transportation costs
- Casting the lintel along with the frame further reduces cost
- Excellent strength and durability – more dimensional stability than both wood and PVC

1.1.18 **Challenges**
- While this technology is well-established in some pockets like Gujarat, Orissa, Andhra Pradesh, and Karnataka, it would be necessary to create a proper supply chain mechanism for moulds and vibrators thru MSMEs.
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12.3.11 Wood-Plastic Composite Frames

Wood/plastic composites consist primarily of waste sawdust and scrap PVC generated in the production of wood and vinyl windows, or from post-consumer bottle waste. Wood content ranges from 40% to 70%, depending on the manufacturer. According to recent tests, the frames have roughly the same energy performance as solid wood, but perform slightly better than vinyl window frames.

Wood fiber increases the dimensional stability of the composite material. Dimensional stability is commonly a problem with PVC plastic frame materials. The composite coefficient of expansion more closely matches glass than vinyl and helps keep the seal between the frame and glass intact for long-term performance. Further, the composite does not absorb moisture and will not swell like wood.

The use of recycled industrial and consumer waste in wood/plastic composite windows reduce the use of natural resources. Claims are that they are more durable than windows using wood or vinyl due to their rot resistance and dimensional stability, and are less apt to experience seal failure that would lead to leaking and moisture buildup between panes. Additionally, composite windows have better energy performance than vinyl and aluminum windows.

1.1.19 Advantages

- Uses recycled materials
- Reduces operational energy / enhances thermal comfort
- Excellent strength and durability – more dimensional stability than both wood and PVC
- Replicable and scalable

1.1.20 Challenges

- New technology yet to universally endorsed by the construction community
- More expensive compared to MS frames (but costs are comparable to wood or PVC frames)
- Not readily available in India
12.4 Annexure 4 - International and Indian examples in affordable housing finance and green housing finance

This section provides Indian & International case-study examples of mainstreaming (particularly financing) energy and water efficiency measures to make them affordable within low-income housing schemes.

12.4.1 International Case-study framework and examples

Financing and delivery of affordable green housing will be enabled by the combined efforts of the government, private sector and the community that uses/owns the dwelling units. Case-studies described in this section often reflect that multiple measures illustrated in the table below are required and will enable a successful process.

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<thead>
<tr>
<th>COMPLIANCE</th>
<th>FISCAL</th>
<th>MARKET</th>
<th>COMMUNITY &amp; INFORMAL</th>
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<tbody>
<tr>
<td>Initiatives led by the public/government sector that include policy, mandatory regulations (e.g. building regulations) and a range of fiscal measures including taxes, grants, housing loans, subsidies.</td>
<td>Initiatives led by the commercial and market sector including performance based contracts and PPPs.</td>
<td>Initiatives led by the community, civil society and informal sector including community led asset management and maintenance.</td>
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The following case-studies demonstrate the current and emerging trends in finance for affordable green housing to overcome barriers to ‘retro-fitting’ as well as developing new affordable green housing. The color coding at the bottom identifies what combination of measures are present in each example (compliance, fiscal, market and community/informal).

In general we have tried to cover a range of financial approaches namely ESCOs, funds/grants (buy-downs), commercial lending, guarantee facilities, micro-finance, Carbon finance and installations led through community or informal intermediaries.
Case-study: **Mexico green mortgages**¹⁶

*Finance type: Commercial lending, Grants*

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**Description:** Starting in 2008, IFC provided long-term local-currency funding to Hipotecaria Vertice, a midsize housing finance company in Mexico, to enable it to provide energy-efficient housing solutions for low- and middle-income home buyers. IFC provided Vertice with a revolving loan equivalent to $25 million with the potential to increase the amount by $15 million equivalent in future. The loan will be used to support mortgage origination activities and to provide mortgages to people buying homes that incorporate energy efficiency and natural-resource conservation features. Vertice has pioneered a "green kit" for home builders looking to implement resource conservation measures. Houses that incorporate the kit are eligible for Vertice’s green mortgages and supported by IFC’s loan. Vertice launched its green mortgage product, or “Casa Verde” - in August 2008 and has provided such mortgages in three locations in Mexico: Pachuca Hildalgo, Queretaro and Tijuana, and Baja California.

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Case-study: **Scaling up Solar water heating (SWH) in South Africa**

*Finance type: ESCo, Buy-downs, Feed-in Tariffs, Commercial lending, Insurance*

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**Description:** The SWH industry in South Africa grew rapidly from 1975 to 1983. This was mostly due to marketing efforts by the CSIR. Sales of SWHs slowed down after that initial growth spurt due to the reduction in government support and installations of some poor quality units which gave the industry a bad name. Installations of SWHs have started to pick up again since 2005 when the South African government resumed its promotion of SWHs, mainly through the Central Energy Fund (CEF). The growth in sales was especially significant in the first part of 2008 when the country experienced load shedding due to capacity constraints of the national utility company, Eskom. The doubling of the Eskom subsidy in January 2010 does not seem to have had a significant effect on sales. Following this a Standard Offer Program (SOP) has been introduced to mechanism to acquire demand-side resources (energy efficiency / load reduction) under which a utility purchases resources based on a pre-determined rate (e.g., R/kWh or R/kW). SOP benefits will not be available to individual homeowners, but only to registered energy services companies (ESCo). Commercial lending for end users is available via home loan schemes such as the ABSA Bank provides. There are also proposals to involve the insurance industry. Electric heaters are covered under home insurance and low-cost, high-quality certified SWH could be covered under a similar mechanism. Overall the experience so far has also identified other requisites for SWH market to work:

- Policy framework/intervention for SWH from the centre and from states / municipalities
- Linking of National Building Codes/ Municipal codes with SWH policy

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- Regulatory and legal matters concerned with the sector
- Amendments in policy, laws in line with the national, market and customer interests

The diagram below shows how the ESCO and end-user is organised within the overall scheme.
### Case-study: Affordable and green housing in the United States

**Finance type:** Tax-credits, End-user savings, Commercial lending/ green mortgage

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**Description:** In the US various financial mechanisms and incentives have been operational for green affordable housing. Some of these are as follows:

1. Location Efficient Mortgage (LEM) \(^{17}\)
2. Energy Efficient Mortgage (EEM) \(^{18}\)
3. Energy Guarantee Program \(^{19}\)
4. Green Grants from the Enterprise Foundation’s Green Communities Initiative \(^{20}\)
5. Low Income Housing Tax Credit Equity from Enterprise Social Investment Corporation \(^{21}\)
6. Green Building Tax Credits \(^{22}\)

Some of the policy level initiative promoting affordable green housing are –

- The US Department of Housing and Urban Development (HUD) grants preferences for federal assistance to affordable projects that meet energy efficiency criteria, and new public housing construction must comply with the 2003 International Conservation Code.

- The enactment of federal legislation requiring that all new projects funded by HUD, including those supported by the Community Development Block Grant and HOME programs, meet sustainability and energy-efficiency criteria, would accelerate the development of green affordable housing.

- Regulations effective in fiscal year 2007 require that US public housing projects purchase energy-efficient appliances and encourage local public housing authorities to utilize energy savings performance contracts and the HUD Capital Fund Financing program to become more energy efficient.

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\(^{17}\) [http://www.sprawlwatch.org/locationmortg.html]

\(^{18}\) [http://www.energystar.gov/index.cfm?c=mortgages.energy_efficient_mortgages]

\(^{19}\) [http://www.nchfa.com/nonprofits/HPSystemvision.aspx]

\(^{20}\) [http://www.greencommunitiesonline.org/tools/funding/grants/]

\(^{21}\) [http://www.enterprisecommunity.com/products_and_services/lihtc.asp]

\(^{22}\) [http://www.dec.ny.gov/energy/1540.html]
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### Case-study: Guarantees for new housing and home improvements in Bolivia

**Finance type:** Guarantees, Market lending, Micro-finance

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**Description:** 61% of the Bolivian population live in urban areas. Cochabamba is one of the major urban areas in Bolivia, with up to 70% of the population living in poor housing conditions. 30% of the population in Bolivia do not own houses, and most of the families face problems related to housing quality (design), construction material quality, and deficient access to basic services (drinking water, sewerage, and electricity).

A new approach to providing access to housing finance for low-income households was developed by an international NGO, Homeless International. In cooperation with local partners (a finance institution, a local NGO and a community-based organization), Homeless International provides a guarantee to El Fondo, a financial institution, which in turn lends to the community-based organization or even individual borrowers from a community. Under the agreement Homeless International has provided a deposit of $50,000 as a guarantee for El Fondo's loan provided by funds made available by two United Kingdom based housing organizations. The guarantee fund enables El Fondo to provide credits at an interest rate of 11% for periods of 12-18 months. El Fondo's participation was based on the track record of Prohabitat which had shown that loans of between $500 to $700 per family enable a gradual improvement in the quality of their homes. Once borrowers had completed repaying their loans, they were eligible for further credit. The borrowing requirements include having a site available for house construction or, in the case of renovation loans, having a house that needs work to internal fixtures, like floors, roofs or walls.

### Case-study: Denmark renewable energy co-operative

**Finance type:** Co-operative model, tax-credits, commercial investment, grant/loan

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**Description:** The Middelgrunden Wind Turbine Cooperative was, when formed in 1997, the world’s largest wind energy cooperative, and the project was to be the largest wind farm worldwide based on dual ownership, and the largest offshore wind farm in the world. The 100 GWh produced annually represent approximately four percent of the residential energy needs of the city of Copenhagen, Scandinavia’s largest city. The source of funding of cooperative is the sale of shares. Each share in a wind project entitles the owner to an average annual production of 1 MWh of the electricity produced. In total, 40,500 shares were sold to the members of the cooperative, with most members holding exactly the five shares required to qualify for a simplified tax return and a tax break worth 3,000 DKK per year. The initial price for one share was €567 and is now subject to free trade. For the Middelgrunden cooperative, it was important to sell the totality of its shares before commissioning, as it cannot contract any debts, subject to its own bylaws. In fact, all shares sold were paid upfront to cover the expenses. More than 40,000 shares were sold over a three-year period before 2000, and the rest were easily sold once the project was closer to realization. At the early stage, before permits were obtained and the project became a reality, the wind cooperative financed its work by selling pre-subscriptions, at €7 per share. Nearly 30,000 shares were reserved that way. The economic risk in the project was minimal as the Danish Electricity Act guaranteed a price of 0.6 DKK/kWh (approximately €0.08) for the first 12,000 full-load-hours (12,000 full-load-hours equal six years of operation at Middelgrunden). A minimum sales price of 0.43 DKK/kWh (approximately €0.057) is then offered for 10 years. To be eligible, however, the project had to be approved before the end of 1999; it was approved on 13 December 1999.

The expectations were that the project would give an attractive economic return by dividing the profits equally among
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all shares. It is important to note that, in Denmark, the first 3,000 DKK (€400) of revenue from renewable energy production is tax-free. In the case of the Middelgrunden cooperative, that represents approximately the revenues from five shares. The extra revenues above that limit are subject to a reduced income tax rate of 30 percent. This tax incentive and the cultural appreciation of renewable energy may well explain the popularity of private investment in renewable energy in Denmark. It represents a good return on investment and a means of reducing the income tax burden, which is around 50 percent in Denmark.

The only direct contribution from the government to the project was a loan granted by the Danish Energy Authority, which was used to finance the extensive feasibility study of the Middelgrunden project.

Case-study: UK retrofitting affordable homes for energy efficiency

Finance type: Revolving fund, guarantees

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Description: Radian secured European Regional Development Funding (ERDF) via SEEDA in 2009 to implement the ‘Retrofit South East’ Project. This project aims to develop capacity for low carbon retrofit of social housing. A key aim of the project was to develop a conceptual finance model to address the principal barrier to mainstream retrofit. This work focused on introducing to the UK the proven ‘Retrofit Revolving Guarantee Fund’ (RRGF) mechanism. Led by Global Environmental Social Business (GESB), experts at implementing this sustainable and affordable finance model in Europe to levels where 2% of a national housing stock is refurbished to advanced energy efficiency standards annually, this follows the introduction of the RRGF principle by the World Bank and IFC.

Borrowing for retrofit work takes place against a guarantee fund, greatly reducing the risk for commercial investors issuing loans. Housing providers do not need to borrow against their existing housing asset base for expensive large scale retrofit, so can retain this for use against important new build developments to help increase the supply of social housing.

- The volume of loans, coupled with the de-risked guarantee fund, enables borrowing at lower interest rates than social housing providers are currently able to access. Loans are made based on clear eligibility criteria.
- The guarantee fund, managed by an independent delivery agency, enables the scheme to operate continually in the event of loss or temporary default on loan repayments (as high as 5% default can be accommodated while the fund remains operational) and marks a move away from traditional mortgage based finance and the risk of private sector repossessions.
- The fund earns interest, which pays for the financial management costs of the program, and investment can be returned to original investors at eventual end of program, if required, making it more attractive to fund investors.
- Flexibility to increase size of retrofit program portfolio during the life of the operational fund or to extend programs at the end of their lives.
- Borrowing can take place at a community level to improve loan up take rates by spreading credit risk so that equality of access to loans prevails. Energy behaviour change and local retrofit skills training are introduced as key elements of projects.
- Program management has a strong social dimension and closely engages residents at all stages of the retrofit process through Community Support staff. Loan agreements with residents are clear, concise and simple to understand and complete.
• Residents benefit from a ‘Pay as you Save’ approach, whereby low monthly repayments are less than their overall annual running cost savings post retrofit. This could be paid as a service charge under a voluntary agreement; an increase in rent, where current rent levels are lower than target rent; or as a result of a change in rent legislation or policy. The loan remains assigned to the property.

• The fund can accommodate all available grants and income streams such as FIT, RHI, CESP, CERT, to further reduce the cost of borrowing, the amount of loan or the borrowing period.

• Fund is complementary with existing housing association management practices, including rent collection payments.

• Once operational, the fund is not affected by Government intervention and avoids uncertainty associated with short term grant availability.
**Case-study: UK multi-utility energy-centre approach**

**Finance type:** ESCo, utilities, buy-down, means tested grants, Renewable obligation, feed-in tariffs

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**Description:** Traditionally, utility companies could only generate more revenue by selling more energy. Eco-Centro Gen (ECG) – the utility- offers an alternative product based on a fixed monthly rate for a bundle of services (power, heat, water, Broadband, TV and telephony) for a residential end-user. ECG then educates and promotes incentives for its customers to use less energy. This way, ECG can make more from selling less and makes real inroads into energy conservation.

ECG provides part of the project funding towards design and construction of energy systems and takes responsibility for the ongoing operation and maintenance of on-site energy centres producing power, heat, cooling and state-of-the-art data services, including digital television, telephony and high-speed broadband. The company establishes so-called Energy Centres (see Figure). These can be a simple power generation unit installed inside a power room or on top of the roof (solar panels), but can also require a separate building, or are installed below ground.

The end user does not pay for any incremental installation cost of the alternative energy system, which is carried by the utility. ECG has a lease contract with the management company of the residential property, which allows it to use and service the Energy Centre. The company pays for any fuel and operating cost, and maintains the energy systems, recovering its cost through long term performance contracts with the users. These contracts specify a transparent tariff review mechanism to link energy charges to market rates for electricity and gas. ECG bears all related costs, including

- primary fuel,
- operation and maintenance,
- life-cycle costs/plant replacement,
- insurance/administration, and
- metering and billing.

ECG offers its customers a discounted electricity tariff. throughout the contract period: in agreement with the client, a "basket" of conventional electricity suppliers is selected, an average price calculated to establish the baseline, and a 10 percent discount to this price is provided to the customer, which then is tracked and reviewed on an annual basis. The utility company has third-party private investment interests amounting to £225 million.
### Case-study: Housing For All (HFA) Program, India

| Description | Description: In 2007, Ashoka launched its Housing for All initiative in collaboration with its community of social entrepreneurs and the Hilti Foundation. In India, Housing for All (HFA) India is adopting a model based on their Hybrid Value Chain (HVC) to foster collaboration at large scale between mortgage financers, developers, citizen sector and informal sector clients. For its first such project in India, Ashoka, brought together DBS Affordable Home Strategy Ltd, Ahmedabad-based NGO Saath Charitable Trust, and financial institutions such as SEWA Bank, Gruh Finance, Mass Finance, Shibam Finance and Micro-Housing Finance Corporation. Under the Housing For All initiative the ‘Umang Lambha’ project was launched in May 2010. The project saw around 792 affordable residential units being offered to end users. While Ashoka Foundation facilitates coordination between NGOs and developers, SAATH helps identify and assess authenticity of end users. Under the Ashoka's HFA program, over 10,000 homes are being planned and under construction in six cities including Ahmedabad and Pune, unlocking a market potential of Rs 400 crore. |

| Finance type: Micro-Finance housing loans |

| Market | Community/ Informal |

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### 12.4.2 India – Policies and initiatives supporting green development

On 30 June 2008 the Indian Government announced the National Action Plan on Climate Change (NAPCC). The plan identifies eight core “national missions” running through to 2017. The plan “identifies measures that promote our development objectives while also yielding co-benefits for addressing climate change effectively.” It notes that these national measures will be more successful with assistance from developed countries, and pledges that India’s per capita emissions will at no point exceed that of developed countries even as India pursues its development objectives. The Government of India has advised the state governments to produce individual state-level plans in response to the NAPCC issued in 2008. Many states are making progress towards this objective. Renewable energy and the power sector, energy efficiency and strategic knowledge for climate change have emerged as priority missions and are well underway. The missions will continue to enable compliance, fiscal, market and community level measures that directly affect the affordable housing and its supply chains (particularly cement, brick, aluminum).

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25 Kalra R et al. (2010)
The box below shows key regulations and programs that are in force to deliver the priority missions related to energy efficiency and renewable energy that can impact on the housing sector and related supply chains.

### Relevant policies and measures

**Energy Conservation (EC) Act 2001.** The act was passed by the Indian Parliament in 2001. The Act created the Bureau of Energy Efficiency (BEE) to implement the provisions of this Act. The provisions of this act are reflected in the programs of the National Mission for Enhanced Energy Efficiency (NMEEE) as described below.

**Making the EC Act operational, by strengthening the institutional capacity of State Designated Agencies (SDAs).** The scheme seeks to build the institutional capacity of the newly created SDAs to perform their regulatory, enforcement and facilitative functions in the respective states.

**Key programs in the National Mission for Enhanced Energy Efficiency (NMEEE) implemented by the Bureau of Energy Efficiency (BEE)**

1. **Perform Achieve and Trade (PAT)** The PAT scheme is a market-based mechanism to enhance energy efficiency in the ‘Designated Consumers’ (includes large energy-intensive industries in housing supply chains - power, cement, aluminium, iron and steel, railways). The resulting savings can be traded as Energy Savings Certificates (ESCerts)

2. **Market Transformation for Energy Efficiency (MTEE)** Making energy-efficient products more affordable and mandatory in some designated sectors (mainly industrial). The initiative includes Standards and labeling: Step by step notification for mandatory labeling of equipment and appliance for domestic sectors, hotel equipment, office equipment, industrial products and transport equipment.

**Renewable energy (RE) related policies and measures:** The Government of India has set a target for at least 10% of grid-connected power to come from renewable sources by 2012.

**Electricity Act (EA) 2003: Requirement for states to set RE targets:** Section 86 of the EA 2003 promotes renewable energy by ensuring grid connectivity and sale for renewable electricity. The section creates a demand for renewable energy by requiring State Electricity Regulatory Commissions (SERCs) to specify a percentage of renewable energy to be purchased within the area of a distribution licensee.

**National Electricity Policy (NEP) 2005: Private sector participation:** Section 5.2.20 of India’s National Electricity Policy promotes private participation in renewable energy. “Feasible potential of non-conventional energy resources, mainly small hydro, and wind and bio-mass would also need to be exploited fully to create additional power generation capacity. With a view to increase the overall share of non-conventional energy sources in the electricity mix, efforts will be made to encourage private sector participation through suitable promotional measures.” This includes the enablement of Energy Service Companies (ESCo) for area based energy and energy efficiency provision.

**National Electricity Policy (NEP) 2005: Reducing the costs of renewable energy** Section 5.12.1 of the policy targets the reduction in capital costs of renewable energy technologies through competition.

**National Electricity Policy (NEP) 2005: Preferential tariffs.**

Section 5.12.2 of the policy states that SERCs should specify appropriate tariffs in order to promote renewable energy (until non-conventional technologies can compete within the competitive bidding system), specifying percentages that progressively increase the share of electricity generated from renewable sources.

- Private sector companies can set up enterprises to operate as licensee or power generating companies.

**National Water Mission.**

Identified in the NAPCC the water mission has not yet been operationalized.
**Case study: Reducing Carbon emissions from brick manufacturing**

**Finance:** Concessional debt, grants, equity, carbon finance and energy efficiency savings.

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<td>Fired clay bricks are the preferred walling material in India. India produces 150-200 billion bricks per year. Brick firing is an energy-intensive process and the annual consumption of coal in brick kilns is estimated to be around 25 million tonnes. The majority of brick production takes place on an unorganised (small) scale. The total number of brick-making units across India is estimated to exceed 100,000 and the annual turnover of the industry is estimated at USD 10-15 billion (Rs 45,000-67,500 crores). There is a large potential to save energy and reduce environmental pollution by shifting to efficient and cleaner technology options. A change to appropriate low-cost efficient firing technologies – zig-zag annular kiln and vertical shaft brick kiln (VSBK) can result in 20-60% coal savings over existing kilns. Both the technologies have been proven in India and more than 500 zig-zag kilns and about 100 VSBKs are operational. Overall a 25% reduction in coal consumption in the brick industry can result in 8-10 million tonnes reduction in carbon dioxide through the modification of 30,000 existing kilns into zig-zag annular kilns and construction of 20,000 new VSBKs. The total investment requirement is estimated to be around USD 1100 million (at USD 10,000 per zig-zag kiln and USD 40,000 per VSBK). Such a program of changeover to efficient kilns needs to be supported by a large scale awareness and capacity building initiative to train manpower for the construction and operation of the efficient kilns. Some of the financing mechanisms which have been used for the change to efficient brick kiln technology in India are:</td>
</tr>
<tr>
<td>1. The Khadi and Village Industry Commission’s (KVIC) ‘margin money scheme’ is operated through banks which provide finance for 90-95% of the project costs for village industry projects. Further, 25% of the project cost is provided as a back-ended subsidy for projects with costs lower than USD 20,000 (approx. Rs 10 lakhs).</td>
</tr>
<tr>
<td>2. Carbon finance: The Community Development Carbon Fund (CDCF) of the World Bank has assisted in the development of two brick industry projects in India for the purchase of emission reductions. These projects used VSBK technology and FAL-G technology. On average, each single FAL-G plant with a capacity of 2 million bricks/year was expected to earn carbon revenue (not including the upfront and recurring transaction costs) of approximately USD 3,500–4,000 annually (Rs 1.5-1.8 Lakh).</td>
</tr>
<tr>
<td>3. The Ministry of Micro, Small and Medium Industries scheme for VSBK technology: The Ministry offers subsidy</td>
</tr>
</tbody>
</table>

---

26 Kalra et. al (2010)
on VSBK through two schemes:

- VSBK scheme: Under the VSBK scheme a subsidy at 30% of the project cost, up to a ceiling of Rs. 2 Lakh is provided as subsidy.

- Credit Linked Capital Subsidy Scheme (CLCSS): Under the CLCSS a subsidy at 15% of the project cost, up to a ceiling of Rs. 15 Lakh is provided for technology up-gradation using approved technologies. VSBK is an approved technology under CLCSS.

However, most brick makers require additional support to access finance and technology for any changeover to efficient kiln technologies. New financial products, simplified procedures, greater awareness amongst brick makers as well as financial institutions, supported by a nation-wide technical assistance program is required to mainstream energy efficient technologies in the Indian brick industry.
12.5 Annexure 5 - Sample cost-benefit analysis

A Cost Benefit analysis from the consumer’s perspective shows that the additional cost of green building measures can increase the mortgage burden for a typical household even if the savings in running electricity cost are counted. This is because of frugal use of electricity and cooling by most households to begin with.

An alternate scenario with a 1% rebate in mortgage interest rate reduces the monthly outgo (mortgage + energy costs) enough to offset the increased capital cost. The following table shows a sample of a typical analysis scenario. A detailed analysis needs to be conducted for the pilot phase once a case study project is identified.
**Low-cost green housing**

### Evaluating Cost Benefit from Consumer's Perspective

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 3 + AC included</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green Measures</strong></td>
<td>None</td>
<td>All</td>
<td>Low Cost/No Cost</td>
<td>All</td>
<td>No</td>
<td>All</td>
</tr>
<tr>
<td><strong>AC</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (Included in Mortgage)</td>
</tr>
<tr>
<td><strong>Mortgage (Rs/Month) 6 lacs @12%</strong></td>
<td>7,200</td>
<td>7,600</td>
<td>7,300</td>
<td>7,600</td>
<td>7,200</td>
<td>7,800</td>
</tr>
<tr>
<td><strong>Utility Cost (Rs/Month)</strong></td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>873</td>
<td>873</td>
<td>873</td>
</tr>
<tr>
<td><strong>Utility Savings (Rs/Month)</strong></td>
<td>-</td>
<td>(90)</td>
<td>(90)</td>
<td>(437)</td>
<td>-</td>
<td>(437)</td>
</tr>
<tr>
<td><strong>Final Outgo</strong></td>
<td>7,500</td>
<td>7,810</td>
<td>7,510</td>
<td>8,037</td>
<td>8,073</td>
<td>8,237</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>310</td>
<td>10</td>
<td>537</td>
</tr>
</tbody>
</table>

- **Elec Cost (Rs/kWh)**: 3

<table>
<thead>
<tr>
<th></th>
<th>Baseline</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 3 + AC included</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Green Measures</strong></td>
<td>None</td>
<td>All</td>
<td>Low Cost/No Cost</td>
<td>All</td>
<td>No</td>
<td>All</td>
</tr>
<tr>
<td><strong>AC</strong></td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes (Included in Mortgage)</td>
</tr>
<tr>
<td><strong>Green Mortgage (Rs/Month) 6 lacs @11%</strong></td>
<td>7,200</td>
<td>7,200</td>
<td>6,900</td>
<td>7,200</td>
<td>7,200</td>
<td>7,400</td>
</tr>
<tr>
<td><strong>Utility Cost (Rs/Month)</strong></td>
<td>300</td>
<td>300</td>
<td>300</td>
<td>873</td>
<td>873</td>
<td>873</td>
</tr>
<tr>
<td><strong>Utility Savings (Rs/Month)</strong></td>
<td>-</td>
<td>(90)</td>
<td>(90)</td>
<td>(437)</td>
<td>-</td>
<td>(437)</td>
</tr>
<tr>
<td><strong>Final Outgo</strong></td>
<td>7,500</td>
<td>7,410</td>
<td>7,110</td>
<td>7,637</td>
<td>8,073</td>
<td>7,837</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(90)</td>
<td>(390)</td>
<td>137</td>
<td>573</td>
<td>337</td>
</tr>
</tbody>
</table>
12.6 Annexure 6 - Thermal analysis methodology

Modelling of the project is carried out using Thermal Analysis Softwarev9.1.4 (TAS), which has been developed by Environmental Design Solutions Limited, a development, consultant and software-support company based in UK.

TAS is dynamic simulation software for analysing building performance. It has three main components.

**TAS 3d Modeller:** Simulation process in TAS starts with making a 3d model of the project in TAS 3d Modeller. Information regarding type of building elements (walls, floors), shading devices, fenestration, and zones (spaces) are assigned at this stage. 3D model is then exported to TAS Building Simulator

**TAS Building Simulator:** Weather data and calendar (indicating season, weekdays, etc.) are assigned to the project. Material properties are also assigned to building elements. Internal conditions, schedules, aperture types and other relevant data are also allocated. Finally dynamic simulation is carried out to generate results for the set of building data provided.

**TAS Result Viewer:** The results can be viewed and sorted systematically in TAS Result Viewer.

The above mentioned components of the software, steps (including terminologies) are explained in detail below,
Low-cost green housing

STEP 1:
Simulation process starts by making a 3d model of the project in context. Information regarding type of building elements (walls, floors), shading devices, fenestration, and zone names (spaces) are assigned at this stage.

3d Model of the project with doors, windows and shading devices on different floors.

In plan view, Zones are assigned to all the spaces (on all floors) that would impact the thermal or energy performance of the building. Eg. Liv1, Liv2, Bed1, etc. are all different zones. Assigning zone names would be useful to easily identify a particular space and retrieve its temperature profile or energy consumption at the end of the simulation process.
Building elements are categorised into external walls, internal walls, floors, roof, etc. – based on their physical properties, location or orientation.

Note: Material properties such a brick wall, concrete floor, etc. are not assigned here.

Doors and windows are added to the model with properties described above.

Note: Material properties such as wooden frame, glazing parameters like visible light transmittance, U-value, etc. are not assigned here. These would properties would be assigned in TAS Building Simulator - the next phase of the
STEP 2:
The 3d Model is exported to TAS Building Simulator.

Weather data and calendar (indicating season, weekdays, etc.) are applied to the project.
Weather Data: Information about temperature, humidity, solar radiation, wind velocity, etc. is given to the model for 24 hour X 365 days. (8760 data set)

Calendar: can be used to specify the seasonal variation in building strategies, thermostat, weekdays or weekends, etc. Calendar is made for 52 weeks.

Material properties are also assigned to building elements.
Material properties for opaque elements (external and internal walls, floor, roof, window frame, etc.) and transparent elements (glazing of window and door) are assigned to respective building elements. These are typically composed of various layers of materials. Eg. Brick, plaster, insulation, etc.
Material of each layer are specified as above.

Internal conditions, schedules, aperture types and other relevant data are also allocated.
Internal conditions are assigned to corresponding zones. Eg. ‘Living Summer’ is the internal condition assigned to Living Room during summer. Infiltration, Lighting, Occupancy and Equipment gains can be specified for each and every zone.

Thermostat of internal condition ‘Living Summer’ is set from 26 C to 28 C and the schedule ‘Living’ is assigned.
Schedule: Schedule controls various operations such as opening and closing of windows, maintaining thermostat, specifying occupancy, equipment and lighting gains, etc. ‘Living’ is an example of a schedule.

Aperture type controls opening and closing of doors and windows. Eg. Aperture type ‘Win Bed Summer’ control opening of Bedroom window during Summer. It remains 80% open during time determined by schedule ‘Win Bed Summer’.

Finally dynamic simulation is carried out to get results for the set of building data provided above. This is precisely an hour-by-hour (24hrs X 365 days) calculation of building performance integrating weather data file, building elements, internal conditions, window opening, etc. HVAC systems can also be assigned the project using Macros.
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Results can be viewed in TAS Result Viewer:

![Interface of TAS Result Viewer.](image-url)
Result can be obtained for each zone or group of zones for any range of days of the year.

Image above shows the cooling load of all living room zones of all the three floors of the building for day number 149 – which is the hottest day of the year. Similar data can be available for particular time period. The data is also available in tabular format which can be exported to excel file.
Various strategies, building elements, internal conditions can be assigned and different models can be prepared. Results from each of the model can be compared to determine the best possible combination.

12.6.1.1 Basecase: Simulation assumptions

Following design has been considered for TAS modeling. The building has three floors. The height of each floor is 3m.

Each floor contains 4 residential units and total Built-up area of each floor is 161 sqm. External Wall area is 208 sqm. Total Window area = 17.28 sqm. Window sizes are 1.2mX1.2m, 0.9mX1.2m and 0.6 mX0.6m.Total Door area = 15.12 sqm. Door sizes are 0.9mX2.1m.
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Material properties:
For base case (sim 01), U-value of building elements are as follows:
Brick wall with plaster on both sides – 2.8 W/m² °C.
Floor – concrete slab – 5.7 2.8 W/m² °C.
Glazing – single glazed clear glass – 5.0 W/m² °C.

Internal gains:
Internal gains have been assigned for Occupancy, Lighting and Equipments.
Occupancy gains have been considered for each space based on judgments of typical lifestyle and space usage patterns. For example bedroom would be typically occupied during night time by two adults.
Lighting and Equipment gains are also determined based on occupancy schedule. Lighting is typically used in the evening after sunset and during early morning hours during winter. Gains from equipments such as TV, fans, refrigerator, cooking, etc. have also been similarly considered.
Following is a typical example of internal gains assigned to various zones:

<table>
<thead>
<tr>
<th>Gain</th>
<th>Value</th>
<th>Factor</th>
<th>Setback Value</th>
<th>Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infiltration</td>
<td>2.0 ach</td>
<td>1.0</td>
<td>0.0 ach</td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td>0.0 ach</td>
<td>1.0</td>
<td>0.0 ach</td>
<td></td>
</tr>
<tr>
<td>Lighting Gain</td>
<td>5.0 W/m²</td>
<td>1.0</td>
<td>0.0 W/m²</td>
<td>Living</td>
</tr>
<tr>
<td>Occupancy Sensib...</td>
<td>15.0 W/m²</td>
<td>1.0</td>
<td>0.0 W/m²</td>
<td>Living</td>
</tr>
<tr>
<td>Occupancy Latent...</td>
<td>7.0 W/m²</td>
<td>1.0</td>
<td>0.0 W/m²</td>
<td>Living</td>
</tr>
<tr>
<td>Equipment Sensib...</td>
<td>10.0 W/m²</td>
<td>1.0</td>
<td>0.0 W/m²</td>
<td>Living</td>
</tr>
<tr>
<td>Equipment Latent...</td>
<td>0.0 W/m²</td>
<td>1.0</td>
<td>0.0 W/m²</td>
<td>Living</td>
</tr>
<tr>
<td>Pollutant Generati...</td>
<td>0.0 g/hr/m²</td>
<td>1.0</td>
<td>0.0 g/hr/m²</td>
<td></td>
</tr>
</tbody>
</table>

Thermostats settings: Summer: 26°C to 28°C. Winter: 20°C to 22°C. Rest of the year (mild weather/monsoon): 24°C to 26°C.
This means that during summer the air temperature would be maintained between 26°C and 28°C. In case the room temperature tends to exceed 28°C, the space (to which the internal condition is applied) will be cooled and in case the temperature tries to go below 26°C, heating would start in that particular space.

12.6.1.2 Simulation Cases:

Simulations are carried out in TAS for two different settings:

1) Conditioned Spaces – Thermostats (temperature control) are assigned to the spaces and a comfortable indoor environment is maintained. This requires heating and cooling of space.

2) Unconditioned Spaces – Thermostats are not assigned to any of the spaces and no heating or cooling of the space is provided.

All the simulations are carried out for two different climates – New Delhi (composite) and Mumbai (warm and humid). This would be helpful in identifying the effectiveness of building materials and passive strategies in two different climates.

1) Conditioned Spaces:

Following simulations are carried out for Conditioned spaces:

Sim 01 - A Basecase simulation is carried out against which all the other simulation would be compared. Base case has a typical brick wall, reinforced concrete roof and steel frames for doors and windows. The spaces are assigned internal conditions with temperature control.

A - Simulation for testing impact of Building Material on Building Performance:

Materials for walls, roofs and frames are being replaced one at a time in simulations sim 02 to sim 12. As an example, in sim 02, reflective paint is applied on all the brick walls keeping all other parameters same. The results of the simulation, when compared with base case, would help to quantify the impact of reflective paint.

Sim 02: White Paint – Reflective paint applied on all wall surfaces

Sim 03: Flyash Bricks – Flyash bricks used for all masonry work.

Sim 04: Hollow Conc. Block – Hollow Concrete Block used for all masonry work

Sim 05: Structural Insulated Panel (SIP) – SIP replacing all masonry work.

Sim 06: Compressed Stabilized Earth Blocks (CSEB) – CSEBs used for all masonry work.
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Sim 07: Insulated Roof – Insulation provided over RCC floor. Overall U-value = 0.46 W/m²K.
Sim 08: Reflective Roof Tiles – Highly Reflective tiles over RCC floor.
Sim 09: Precast RC Planks – 60mm Precast RC Planks placed over concrete joists replacing RCC floor.
Sim 10: Filler Slab – RCC slab with a layer of bricks
Sim 11: RC Frames – Precast Reinforced Concrete Frames for Doors and Windows
Sim 13: Combined Case 1 – Flyash Bricks, Reflective Roof Tiles and Wood+Plastic Frame applied to the building at the same time.

B - Simulation for testing impact of Passive Strategies on Building Performance:
Passive strategies significantly affect the building performance. Each of the strategy is applied to the Combined Case 1 one by one in simulations sim 21 to sim 36. For example, in sim 21, orientation of the building is rotated by 90° anticlockwise. All the other parameters (building materials, internal conditions) are kept same as Combined Case 1.

Sim 21: Orientation 90 – Building rotated by 90° anticlockwise as compared with Combined Case 1.
Sim 22: Orientation 180 – Building rotated by 180° anticlockwise as compared with Combined Case 1.
Sim 23: Orientation 270 – Building rotated by 90° anticlockwise as compared with Combined Case 1.
Sim 24: WWR 0.10 – Window to Wall Ratio increased to 0.10 from 0.064 as in Combined Case 1. Window Orientation remains constant.
Sim 25: WWR 0.15 – Window to Wall Ratio increased to 0.15 from 0.064 as in Combined Case 1. Window Orientation remains constant.
Sim 26: WWR 0.20 – Window to Wall Ratio increased to 0.20 from 0.064 as in Combined Case 1. Window Orientation remains constant.
Sim 27: Shading 0.45 – 0.45m lintel projection for all windows.
Sim 28: Shading 0.45 vfin – 0.45m lintel + 0.45m vertical projections on both sides for all windows
Sim 29: Shading 0.60 vfin – 0.60m lintel + 0.60m vertical projections on both sides for all windows
Sim 30: Shading 0.75 vfin – 0.75m lintel + 0.75m vertical projections on both sides for all windows
Sim 31: Wall 1bk/1bk – External wall 1 brick / Internal wall 1 brick thick in Combined Case 1
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Sim 32: Wall 1bk/0.5bk – External wall 1 brick / Internal wall 0.5 brick thick in Combined Case 1
Sim 33: Wall 0.5bk/0.5bk – External wall 0.5 brick / Internal wall 0.5 brick thick in Combined Case 1
Sim 34: Wall 1.5bk/1.5bk – External wall 1.5 brick / Internal wall 1.5 brick thick in Combined Case 1
Sim 35: Wall – Lightweight – External wall lightweight panel / Internal wall lightweight panel in Combined Case 1
Sim 36: Wall & Roof – Lightwt – External wall lightweight panel / Internal wall lightweight panel. Lightweight roof in Combined Case 1
Sim 37: Combined Case 2 – Orientation and WWR are already the best in Combined Case 1. Includes 0.75m hori and verti fins. External 1.5bk and internal 1 bk thick wall. Includes natural ventilation partly.

C - Simulation for testing impact of Natural and Mechanical Ventilation on Building Performance:

Sim 41: Basecase 2 – This is a new base case to model ventilation in an effective way. Material specifications are same as Combined Case 1. The lower limit of the thermostat is set to 0°C during warmer period.
Sim 42: Nat Vent 1 – Natural Ventilation provided (1)
Sim 43: Nat Vent 2 – Natural Ventilation provided (2)
Sim 44: Nat Vent 3 – Natural Ventilation provided (3)
Sim 45: Nat + Mech Vent – Natural and Mechanical Ventilation (7 ach) provided to help pre-cooling.
Sim 46: Combined Case 3 – Combining measures from Combined Case 1, Combined Case 2 and ventilation strategy.

Note: Results for simulations from Basecase 2 to Combined Case 3 cannot be compared directly with other simulations as the basic parameters (thermostat) used are different. These simulations are carried out separately to examine the impact of various natural ventilation rates in detail.

For Mumbai following additional simulations are run:

Sim 13b: Replacing Flyash Bricks with SIP in Sim 13
Sim 37b: Replacing Flyash Bricks with SIP in Sim 37
Sim 47b: Replacing Flyash Bricks with SIP in Sim 46
2) Unconditioned Spaces:

Following simulations are carried out for unconditioned spaces:

Sim 50 - A base case simulation is carried out against which all the other simulation would be compared. Base case has a typical brick wall, reinforced concrete roof and steel frames for doors and windows. The spaces are assigned internal conditions without temperature control.

A - Simulation for testing impact of Building Material on Building Performance:

Materials for walls, roofs and frames are being replaced one at a time in simulations sim 51 to sim 61. As an example, in sim 51, reflective paint is applied on all the brick walls keeping all other parameters same. The results of the simulation, when compared with base case, would help to quantify the impact of reflective paint.

Sim 51: White Paint – Reflective paint applied on all wall surfaces
Sim 52: Flyash Bricks – Flyash bricks used for all masonry work.
Sim 53: Hollow Conc. Block – Hollow Concrete Block used for all masonry work
Sim 54: Structural Insulated Panel (SIP) – SIP replacing all masonry work.
Sim 55: Compressed Stabilized Earth Blocks (CSEB) – CSEBs used for all masonry work.
Sim 56: Insulated Roof – Insulation provided over RCC floor. Overall U-value = 0.46 W/m²K.
Sim 57: Reflective Roof Tiles – Highly Reflective tiles over RCC floor.
Sim 58: Precast RC Planks – 60mm Precast RC Planks placed over concrete joists replacing RCC floor.
Sim 59: Filler Slab – RCC slab with a layer of bricks
Sim 60: RC Frames – Precast Reinforced Concrete Frames for Doors and Windows
Sim 62: Combined Case 1 – Flyash Bricks, Reflective Roof Tiles and Wood+Plastic Frame applied to the building at the same time.
**B - Simulation for testing impact of Passive Strategies on Building Performance:**

Passive strategies significantly affect the building performance. Each of the strategy is applied to the Combined Case 1 one by one in simulations sim 71 to sim 83. For example, in sim 71, orientation of the building is rotated by 90° anticlockwise. All the other parameters (building materials, internal conditions) are kept same as Combined Case 1.

- **Sim 71:** Orientation 90° - Building rotated by 90° anticlockwise as compared with Combined Case 1.
- **Sim 72:** Orientation 180° - Building rotated by 180° anticlockwise as compared with Combined Case 1.
- **Sim 73:** Orientation 270° - Building rotated by 90° anticlockwise as compared with Combined Case 1.
- **Sim 74:** WWR 0.10 - Window to Wall Ratio increased to 0.10 from 0.064 as in Combined Case 1. Window Orientation remains constant.
- **Sim 75:** WWR 0.15 - Window to Wall Ratio increased to 0.15 from 0.064 as in Combined Case 1. Window Orientation remains constant.
- **Sim 76:** Shading 0.60 vfin - 0.60m lintel + 0.60m vertical projections on both sides for all windows
- **Sim 77:** Shading 0.75 vfin - 0.75m lintel + 0.75m vertical projections on both sides for all windows
- **Sim 78:** Nat Vent 01 - Natural ventilation by opening of windows when outside temperature is lower than inside temperature.
- **Sim 79:** Nat Vent 02 - Temperature controlled natural ventilation by opening of windows. Higher ventilation rate than sim 78.
- **Sim 80:** Nat + Mech Vent - Higher natural ventilation along with mechanical ventilation – both temperature-controlled.
- **Sim 81:** Wall 0.5bk/0.5bk - External wall 0.5 brick / Internal wall 0.5 brick thick in Combined Case 1
- **Sim 82:** Wall 1.5bk/1.5bk - External wall 1.5 brick / Internal wall 1.5 brick thick in Combined Case 1
- **Sim 83:** Wall - Lightweight - External wall lightweight panel / Internal wall lightweight panel in Combined Case 1
- **Sim 90:** Combined Case 2 (for New Delhi) - Orientation and WWR are already the best in Combined Case 1. Includes 0.75m horizontal and vertical fins. External 1.5 brick and internal 1 brick thick wall. Includes natural and mechanical ventilation.
- **Sim 90:** Combined Case 2 (for Mumbai) - Orientation and WWR are already the best in Combined Case 1. Includes 0.75m horizontal and vertical fins. External 1 brick and internal 0.5 brick thick wall. Includes natural and mechanical ventilation.
Sim 90 includes best parameter for New Delhi and Mumbai.

**12.6.1.3 Simulation Results:**

The results for simulation of conditioned and unconditioned spaces are as follows:

**1) Conditioned Spaces:**

Results of simulation for New Delhi and Mumbai are given in Table A and B respectively.

*Table 12.4: Simulation results for conditioned spaces for New Delhi (Composite Climate)*

<table>
<thead>
<tr>
<th>Location:</th>
<th>New Delhi</th>
<th>Savings</th>
<th>Savings</th>
<th>Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cooling Load - All Floors</td>
<td>Comparing with Basecase 1</td>
<td>Heating Load - All Floors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>kW</td>
<td>kWh</td>
<td>kWh</td>
</tr>
<tr>
<td>Sim 01</td>
<td>Basecase 1</td>
<td>57,099</td>
<td>1,813</td>
<td>58,912</td>
</tr>
<tr>
<td>Sim 02</td>
<td>White Paint</td>
<td>51,536</td>
<td>9.74%</td>
<td>2,799</td>
</tr>
<tr>
<td>Sim 03</td>
<td>Flyash Bricks</td>
<td>51,637</td>
<td>9.57%</td>
<td>2,919</td>
</tr>
<tr>
<td>Sim 04</td>
<td>Hollow Conc. Block</td>
<td>50,521</td>
<td>11.52%</td>
<td>1,766</td>
</tr>
<tr>
<td>Sim 05</td>
<td>SIP</td>
<td>50,600</td>
<td>11.38%</td>
<td>1,450</td>
</tr>
<tr>
<td>Sim 06</td>
<td>CSEB</td>
<td>52,404</td>
<td>8.22%</td>
<td>2,923</td>
</tr>
<tr>
<td>Sim 07</td>
<td>Insulated Roof</td>
<td>52,725</td>
<td>7.66%</td>
<td>1,686</td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Sim</th>
<th>Description</th>
<th>Sim Cost</th>
<th>Cost Change</th>
<th>Energy Change</th>
<th>Weight Cost</th>
<th>Weight Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 08</td>
<td>Reflective Roof Tiles</td>
<td>51,397</td>
<td>2,645</td>
<td>-45.92%</td>
<td>54,042</td>
<td>8.27%</td>
</tr>
<tr>
<td>Sim 09</td>
<td>Precast RC Planks</td>
<td>52,481</td>
<td>2,889</td>
<td>-59.36%</td>
<td>55,370</td>
<td>6.01%</td>
</tr>
<tr>
<td>Sim 10</td>
<td>Filler Slab</td>
<td>52,473</td>
<td>2,571</td>
<td>-41.80%</td>
<td>55,044</td>
<td>6.57%</td>
</tr>
<tr>
<td>Sim 11</td>
<td>RC Frames</td>
<td>56,602</td>
<td>1,786</td>
<td>1.47%</td>
<td>58,388</td>
<td>0.89%</td>
</tr>
<tr>
<td>Sim 12</td>
<td>Wood+Plastic Frames</td>
<td>56,694</td>
<td>1,759</td>
<td>2.96%</td>
<td>58,453</td>
<td>0.78%</td>
</tr>
<tr>
<td>Sim 13</td>
<td>Combined Case 1</td>
<td>45,623</td>
<td>3,899</td>
<td>-115.08%</td>
<td>49,522</td>
<td>15.94%</td>
</tr>
</tbody>
</table>

## B - Passive Strategies

<table>
<thead>
<tr>
<th>Sim</th>
<th>Description</th>
<th>Sim Cost</th>
<th>Cost Change</th>
<th>Energy Change</th>
<th>Weight Cost</th>
<th>Weight Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 21</td>
<td>Orientation 90</td>
<td>47,013</td>
<td>4,073</td>
<td>-124.69%</td>
<td>51,086</td>
<td>13.28%</td>
</tr>
<tr>
<td>Sim 22</td>
<td>Orientation 180</td>
<td>45,645</td>
<td>4,031</td>
<td>-122.34%</td>
<td>49,676</td>
<td>15.68%</td>
</tr>
<tr>
<td>Sim 23</td>
<td>Orientation 270</td>
<td>47,057</td>
<td>4,045</td>
<td>-123.13%</td>
<td>51,102</td>
<td>13.26%</td>
</tr>
<tr>
<td>Sim 24</td>
<td>WWR 0.10</td>
<td>48,848</td>
<td>3,561</td>
<td>-96.41%</td>
<td>52,408</td>
<td>11.04%</td>
</tr>
<tr>
<td>Sim 25</td>
<td>WWR 0.15</td>
<td>53,205</td>
<td>3,327</td>
<td>-83.51%</td>
<td>56,531</td>
<td>4.04%</td>
</tr>
<tr>
<td>Sim 26</td>
<td>WWR 0.20</td>
<td>58,386</td>
<td>3,117</td>
<td>-71.95%</td>
<td>61,503</td>
<td>-4.40%</td>
</tr>
<tr>
<td>Sim 27</td>
<td>Shading 0.45</td>
<td>44,657</td>
<td>4,116</td>
<td>-127.06%</td>
<td>48,773</td>
<td>17.21%</td>
</tr>
<tr>
<td>Sim 28</td>
<td>Shading 0.45 vfin</td>
<td>43,962</td>
<td>4,299</td>
<td>-137.15%</td>
<td>48,261</td>
<td>18.08%</td>
</tr>
<tr>
<td>Sim 29</td>
<td>Shading 0.6 vfin</td>
<td>43,643</td>
<td>4,402</td>
<td>-142.84%</td>
<td>48,045</td>
<td>18.45%</td>
</tr>
<tr>
<td>Sim 30</td>
<td>Shading 0.75 vfin</td>
<td>43,395</td>
<td>4,490</td>
<td>-147.68%</td>
<td>47,885</td>
<td>18.72%</td>
</tr>
<tr>
<td>Sim 31</td>
<td>Wall 1bk/1bk</td>
<td>45,208</td>
<td>3,759</td>
<td>-107.38%</td>
<td>48,968</td>
<td>16.88%</td>
</tr>
<tr>
<td>Sim 32</td>
<td>Wall 1bk/0.5bk</td>
<td>45,395</td>
<td>3,837</td>
<td>-111.65%</td>
<td>49,232</td>
<td>16.43%</td>
</tr>
<tr>
<td>Sim 33</td>
<td>Wall 0.5bk/0.5bk</td>
<td>46,360</td>
<td>4,892</td>
<td>-169.86%</td>
<td>51,252</td>
<td>13.00%</td>
</tr>
</tbody>
</table>
### Low-cost green housing

<table>
<thead>
<tr>
<th>Sim</th>
<th>Description</th>
<th>Cooling Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
<th>Heating Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
<th>Cooling + Heating Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 34</td>
<td>Wall 1.5bk/1.5bk</td>
<td>44,643</td>
<td>21.81%</td>
<td>2.15%</td>
<td>3,302</td>
<td>-82.16%</td>
<td>28.61%</td>
</tr>
<tr>
<td>Sim 35</td>
<td>Wall – Lightweight</td>
<td>46,621</td>
<td>18.35%</td>
<td>-2.19%</td>
<td>5,447</td>
<td>-200.50%</td>
<td>-74.22%</td>
</tr>
<tr>
<td>Sim 36</td>
<td>Wall &amp; Roof - Lightwt</td>
<td>50,685</td>
<td>11.23%</td>
<td>-11.09%</td>
<td>7,763</td>
<td>-328.22%</td>
<td>-185.20%</td>
</tr>
<tr>
<td>Sim 37</td>
<td>Combined case 2</td>
<td>40,527</td>
<td>29.02%</td>
<td>11.17%</td>
<td>3,873</td>
<td>-113.66%</td>
<td>1.24%</td>
</tr>
</tbody>
</table>

### C – Ventilation Strategies

<table>
<thead>
<tr>
<th>Sim</th>
<th>Description</th>
<th>Cooling Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
<th>Heating Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
<th>Cooling + Heating Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 41</td>
<td>Basecase 2</td>
<td>42,214</td>
<td>2,799</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 42</td>
<td>Nat Vent 1</td>
<td>40,919</td>
<td>3.07%</td>
<td>1,723</td>
<td>38.43%</td>
<td>42,642</td>
<td>5.27%</td>
</tr>
<tr>
<td>Sim 43</td>
<td>Nat Vent 2</td>
<td>40,098</td>
<td>5.01%</td>
<td>1,766</td>
<td>36.91%</td>
<td>41,864</td>
<td>7.00%</td>
</tr>
<tr>
<td>Sim 44</td>
<td>Nat Vent 3</td>
<td>40,004</td>
<td>5.24%</td>
<td>1,450</td>
<td>48.18%</td>
<td>41,455</td>
<td>7.91%</td>
</tr>
<tr>
<td>Sim 45</td>
<td>Nat + Mech Vent</td>
<td>38,929</td>
<td>7.78%</td>
<td>2,923</td>
<td>-4.43%</td>
<td>41,852</td>
<td>7.02%</td>
</tr>
<tr>
<td>Sim 46</td>
<td>Combined Case 3</td>
<td>36,099</td>
<td>14.49%</td>
<td>2,621</td>
<td>6.36%</td>
<td>38,720</td>
<td>13.98%</td>
</tr>
</tbody>
</table>

123
Low-cost green housing

Graph 12-1: Annual Cooling and Heating Load, New-Delhi (From Table 10.1)

124
Key Observations:

Cooling Load is significantly higher than heating load annually.

Wall: Walls with reflective paint as well as flyash brick reduce the cooling load. Flyash brick wall in combination with reflective paint on exterior would give the best thermal performance. Higher thermal mass is crucial.

Roof: Roofs with reflective surface perform considerably well. Combination of reflective roof tiles and filler slabs would reduce the cooling load, especially for topmost floors.

Frames: There is a marginal difference in performance of Precast Frames and Wood + Plastic Frames. Considering material reuse and low embodied energy, Wood + Plastic Composite frames should be preferred.

Orientation: Current orientation as well as orientation obtained by rotated the building by 180° are better mainly because majority of the fenestration faces North and South.

Window to Wall Ratio: For current design, window area is 6.62% of the total wall area. These windows are distributed on all four orientations in different proportions – North (2.21%), South (2.21%), East (1.10%) and West (1.10%). Increasing the window area to 10%, 15% and 20% increases cooling demand primarily because of additional solar gains and ‘cool’ loss through conduction. Increase in WWR decrease heating loads.

Shading: Higher shading gives reduces cooling load and slightly increases the heating load.

Thermal mass: Higher thermal mass decreases cooling load. Materials with same U-value but lesser thermal mass are not efficient.

Natural Ventilation: Natural Ventilation by opening of windows when outside temperature is lesser than the inside temperature helps in pre-cooling of the building. This type of would primarily take place during mild weather. Higher ventilation rates reduces cooling load.

Mechanical Ventilation: Along with natural ventilation, additional mechanical ventilation is provided when outside temperature is lesser than the inside temperature. This additional ventilation causes additional pre-cooling.

SIP wall gives higher savings than Flyash brick wall but it is not efficient for surfaces receiving higher solar radiation. Hence care should be taken in selection of appropriate material with respect to orientation.
Table 12.5: Comparison of Building Materials-Orientation Wise

<table>
<thead>
<tr>
<th>kW</th>
<th>All SouthWest</th>
<th>All South East</th>
<th>All North West</th>
<th>All North East</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basecase</td>
<td>15,614</td>
<td>15,135</td>
<td>13,359</td>
<td>12,991</td>
</tr>
<tr>
<td>White Paint</td>
<td>13,813</td>
<td>13,592</td>
<td>12,140</td>
<td>11,991</td>
</tr>
<tr>
<td>Flyash Bricks</td>
<td>13,836</td>
<td>13,616</td>
<td>12,167</td>
<td>12,018</td>
</tr>
<tr>
<td>Hollow Conc. Block</td>
<td>13,595</td>
<td>13,408</td>
<td>11,820</td>
<td>11,698</td>
</tr>
<tr>
<td>SIP</td>
<td>13,740</td>
<td>13,587</td>
<td>11,680</td>
<td>11,593</td>
</tr>
<tr>
<td>CSEB</td>
<td>14,077</td>
<td>13,845</td>
<td>12,319</td>
<td>12,162</td>
</tr>
<tr>
<td>Insulated Roof</td>
<td>14,595</td>
<td>14,082</td>
<td>12,222</td>
<td>11,825</td>
</tr>
<tr>
<td>Reflective Roof Tiles</td>
<td>14,145</td>
<td>13,676</td>
<td>11,971</td>
<td>11,605</td>
</tr>
<tr>
<td>Precast RC Planks</td>
<td>14,418</td>
<td>13,959</td>
<td>12,231</td>
<td>11,874</td>
</tr>
<tr>
<td>Filler Slab</td>
<td>14,429</td>
<td>13,961</td>
<td>12,224</td>
<td>11,860</td>
</tr>
<tr>
<td>RC Frames</td>
<td>15,454</td>
<td>14,973</td>
<td>13,269</td>
<td>12,906</td>
</tr>
<tr>
<td>Wood+Plastic Frames</td>
<td>15,490</td>
<td>15,007</td>
<td>13,282</td>
<td>12,916</td>
</tr>
<tr>
<td>Combined</td>
<td>12,025</td>
<td>11,824</td>
<td>10,334</td>
<td>10,194</td>
</tr>
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</table>
Table 12.6: Simulation Results for Conditioned spaces for Mumbai (Warm and Humid Climate)

<table>
<thead>
<tr>
<th>Location:</th>
<th>Mumbai</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>kW</td>
<td>Cooling Load - All Floors</td>
<td>Comparing with Basecase 1</td>
<td>Comparing with Combined Case 1</td>
<td>Heating Load – All Floors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>kWh</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

### Material Selection

<table>
<thead>
<tr>
<th>Sim 01</th>
<th>Basecase 1</th>
<th>74,236</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 02</td>
<td>White Paint</td>
<td>68,702</td>
<td>7.45%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 03</td>
<td>Flyash Bricks</td>
<td>68,793</td>
<td>7.33%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 04</td>
<td>Hollow Conc. Block</td>
<td>66,849</td>
<td>9.95%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 05</td>
<td>SIP</td>
<td>64,794</td>
<td>12.72%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 06</td>
<td>CSEB</td>
<td>69,630</td>
<td>6.20%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 07</td>
<td>Insulated Roof</td>
<td>70,576</td>
<td>4.93%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 08</td>
<td>Reflective Roof Tiles</td>
<td>69,552</td>
<td>6.31%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 09</td>
<td>Precast RC Planks</td>
<td>70,428</td>
<td>5.13%</td>
<td>0</td>
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<td></td>
</tr>
<tr>
<td>Sim 10</td>
<td>Filler Slab</td>
<td>70,480</td>
<td>5.06%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 11</td>
<td>RC Frames</td>
<td>73,723</td>
<td>0.69%</td>
<td>0</td>
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<td></td>
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<tr>
<td>Sim 12</td>
<td>Wood+Plastic Frames</td>
<td>73,775</td>
<td>0.62%</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 13</td>
<td>Combined Case 1</td>
<td>63,537</td>
<td>14.41%</td>
<td>0</td>
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</tr>
<tr>
<td>Sim 13b</td>
<td>Combined Case 1b SIP</td>
<td>61,840</td>
<td>16.70%</td>
<td>0</td>
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<td></td>
</tr>
<tr>
<td>Passive Strategies</td>
<td>Sim 21</td>
<td>Orientation 90</td>
<td>64,538</td>
<td>13.06%</td>
<td>-1.58%</td>
<td>0</td>
</tr>
<tr>
<td>-------------------------</td>
<td>----------</td>
<td>----------------</td>
<td>----------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Sim 22</td>
<td>Orientation 180</td>
<td>63,375</td>
<td>14.63%</td>
<td>0.26%</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Sim 23</td>
<td>Orientation 270</td>
<td>64,411</td>
<td>13.23%</td>
<td>-1.38%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 24</td>
<td>WWR 10%</td>
<td>67,495</td>
<td>9.08%</td>
<td>-6.23%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 25</td>
<td>WWR 15%</td>
<td>72,829</td>
<td>1.90%</td>
<td>-14.62%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 26</td>
<td>WWR 20%</td>
<td>78,644</td>
<td>-5.94%</td>
<td>-23.78%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 27</td>
<td>Shading .45</td>
<td>62,233</td>
<td>16.17%</td>
<td>2.05%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 28</td>
<td>Shading .45 vfin</td>
<td>61,256</td>
<td>17.48%</td>
<td>3.59%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 29</td>
<td>Shading .6 vfin</td>
<td>60,808</td>
<td>18.09%</td>
<td>4.29%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 30</td>
<td>Shading .75 vfin</td>
<td>60,459</td>
<td>18.56%</td>
<td>4.85%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 31</td>
<td>Wall 1bk/1bk</td>
<td>63,036</td>
<td>15.09%</td>
<td>0.79%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 32</td>
<td>Wall 1bk/0.5bk</td>
<td>63,333</td>
<td>14.69%</td>
<td>0.32%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 33</td>
<td>Wall 0.5bk/0.5bk</td>
<td>63,964</td>
<td>13.84%</td>
<td>-0.67%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 34</td>
<td>Wall 1.5bk/1.5bk</td>
<td>62,390</td>
<td>15.96%</td>
<td>1.81%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 35</td>
<td>Wall – Lightweight</td>
<td>62,668</td>
<td>15.58%</td>
<td>1.37%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 36</td>
<td>Wall + Roof – Lightweight</td>
<td>64,370</td>
<td>13.29%</td>
<td>-1.31%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 37</td>
<td>Combined case 2</td>
<td>57,618</td>
<td>22.39%</td>
<td>9.32%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 37b</td>
<td>Combined case 2b SIP</td>
<td>54,230</td>
<td>26.95%</td>
<td>14.65%</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
### C – Ventilation Strategies

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Cooling Load - All Floors</th>
<th>Comparing with Combined Case 2</th>
<th>Heating Load – All Floors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sim 41</td>
<td>Basecase 2</td>
<td>42,214</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sim 42</td>
<td>Nat Vent 1</td>
<td>40,919</td>
<td>3.07%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 43</td>
<td>Nat Vent 2</td>
<td>40,098</td>
<td>5.01%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 44</td>
<td>Nat Vent 3</td>
<td>40,004</td>
<td>5.24%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 45</td>
<td>Nat + Mech Vent</td>
<td>38,929</td>
<td>7.78%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 46</td>
<td>Combined Case 3</td>
<td>36,099</td>
<td>14.49%</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Sim 46b</td>
<td>Combined Case 3b SIP</td>
<td>34,814</td>
<td>17.95%</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Graph 12-2: Annual Cooling and Heating Load-Mumbai (From Table 10.3)
Low-cost green housing

Key Observations:

No heating load required in Mumbai.

Cooling Load is significantly higher than heating load annually.

Wall: Walls with reflective paint as well as flyash brick reduce the cooling load. Flyash brick wall in combination with reflective paint on exterior would give good thermal performance. Structurally Insulated Panel (SIP) gives higher savings but are not efficient when the space is to be used as unconditioned space.

Roof: Roofs with reflective surface perform considerably well. Combination of reflective roof tiles and filler slabs would reduce the cooling load, especially for topmost floors.

Frames: There is a marginal difference in performance of Precast Frames and Wood + Plastic Frames. Considering material reuse and low embodied energy, Wood + Plastic Composite frames should be preferred.

Orientation: Current orientation as well as orientation obtained by rotated the building by 180° are better mainly because majority of the fenestration faces North and South.

Window to Wall Ratio: For current design, window area is 6.62% of the total wall area. These windows are distributed on all four orientations in different proportions – North (2.21%), South (2.21%), East (1.10%) and West (1.10%). Increasing the window area to 10%, 15% and 20% increases cooling demand primarily because of additional solar gains and 'cool' loss through conduction. Increase in WWR decrease heating loads.

Shading: Higher shading gives reduces cooling load and slightly increases the heating load.

Thermal mass: Higher thermal mass decreases cooling load. Appropriately designed structures with lower thermal mass can be energy efficient.

Natural Ventilation: Natural Ventilation by opening of windows when outside temperature is lesser than the inside temperature helps in pre-cooling of the building. This type of would primarily take place during mild weather. Higher ventilation rates reduces cooling load.
**Mechanical Ventilation:** Along with natural ventilation, additional mechanical ventilation is provided when outside temperature is lesser than the inside temperature. This additional ventilation causes additional pre-cooling.

**2) Unconditioned Spaces:**

To compare the effectiveness of building materials or passive strategies in maintaining comfortable internal conditions, it is important to determine the level of thermal comfort achieved for various spaces. Thermal Comfort is defined in the ISO 7730 standard as: "That condition of mind which expresses satisfaction with the thermal environment". It depends on metabolic rate, type of clothing as well as air temperature, mean radiant temperature, air speed, and relative humidity of the surrounding environment. Thermal comfort is measured in terms of PMV. PMV represents the 'predicted mean vote' (on the thermal sensation scale) of a large population of people exposed to a certain environment. PMV is derived from the physics of heat transfer combined with an empirical fit to sensation. PMV establishes a thermal strain based on steady-state heat transfer between the body and the environment and assigns a comfort vote to that amount of strain. Lesser the thermal strain on the body, more comfortable would be the space.

The PMV index predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale where

+3 = hot    +2 = warm    +1 = slightly warm    0 neutral    -1 slightly cool    -2 cool    -3 cold

For the current simulation, PMV is calculated for 8760 hours of the year for the regularly occupied spaces (Living Room, Bedroom). The values represented in the table C and D below indicate the percentage of hours falling into a particular range of PMV. Eg. 5% PMV for 1≤PMV≤1.5 indicates that 5% of the total 8760 hours of the year (438 hours) have PMV in the range of +1 to +1.5. For 438 hours, the occupants would feel slightly uncomfortable (on the hotter side). Total percentage of hours for which majority of the occupants would feel uncomfortably hot -1≤PMV<3 (rightmost column) could be used to get a rough estimate of the comfort condition but do not represent the total picture. Changes in PMV values for individual ranges from (1≤PMV<1.5, 1.5≤PMV<2, 2≤PMV<2.5, 2.5≤PMV<3) give a clear picture. This can be particularly observed in the cases sim 81 to sim 83 for New Delhi.
Table 12.7: Simulation results for unconditioned spaces for New-Delhi (Composite Climate), PMV expressed in percentage

<table>
<thead>
<tr>
<th>Location: New Delhi</th>
<th>Predicted Mean Vote (PMV) values in percentage</th>
<th>Total of Range: 1 ≤ PMV &lt; 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 ≤ PMV &lt; 1.5</td>
<td>1.5 ≤ PMV &lt; 2</td>
</tr>
<tr>
<td>sim 50</td>
<td>Basecase 1</td>
<td>5.12%</td>
</tr>
<tr>
<td>sim 51</td>
<td>White Paint</td>
<td>5.50%</td>
</tr>
<tr>
<td>sim 52</td>
<td>Flyash Bricks</td>
<td>5.48%</td>
</tr>
<tr>
<td>sim 53</td>
<td>Hollow Conc. Block</td>
<td>5.34%</td>
</tr>
<tr>
<td>sim 54</td>
<td>SIP</td>
<td>4.75%</td>
</tr>
<tr>
<td>sim 55</td>
<td>CSEB</td>
<td>5.53%</td>
</tr>
<tr>
<td>sim 56</td>
<td>Insulated Roof</td>
<td>5.61%</td>
</tr>
<tr>
<td>sim 57</td>
<td>Reflective Roof Tiles</td>
<td>5.76%</td>
</tr>
<tr>
<td>sim 58</td>
<td>Precast RC Planks</td>
<td>5.65%</td>
</tr>
<tr>
<td>sim 59</td>
<td>Filler Slab</td>
<td>5.63%</td>
</tr>
<tr>
<td>sim 60</td>
<td>RC Frames</td>
<td>5.12%</td>
</tr>
<tr>
<td>sim 61</td>
<td>Wood+Plastic Frames</td>
<td>5.11%</td>
</tr>
<tr>
<td>sim 62</td>
<td>Combined Case 1</td>
<td>6.05%</td>
</tr>
</tbody>
</table>
## B - Passive Strategies

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Strategy Description</th>
<th>Orientation</th>
<th>Energy Consumption</th>
<th>CO2 Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>sim 71</td>
<td>Orientation 90</td>
<td></td>
<td>5.86%</td>
<td>18.14%</td>
</tr>
<tr>
<td>sim 72</td>
<td>Orientation 180</td>
<td></td>
<td>6.03%</td>
<td>16.35%</td>
</tr>
<tr>
<td>sim 73</td>
<td>Orientation 270</td>
<td></td>
<td>5.86%</td>
<td>18.11%</td>
</tr>
<tr>
<td>sim 74</td>
<td>WWR 0.10</td>
<td></td>
<td>5.61%</td>
<td>17.34%</td>
</tr>
<tr>
<td>sim 75</td>
<td>WWR 0.15</td>
<td></td>
<td>5.41%</td>
<td>18.34%</td>
</tr>
<tr>
<td>sim 76</td>
<td>Shading 0.6 vfin</td>
<td></td>
<td>6.05%</td>
<td>16.17%</td>
</tr>
<tr>
<td>sim 77</td>
<td>Shading 0.75 vfin</td>
<td></td>
<td>6.06%</td>
<td>16.06%</td>
</tr>
<tr>
<td>sim 78</td>
<td>Nat Vent 01</td>
<td></td>
<td>6.06%</td>
<td>16.04%</td>
</tr>
<tr>
<td>sim 79</td>
<td>Nat Vent 02</td>
<td></td>
<td>5.99%</td>
<td>12.36%</td>
</tr>
<tr>
<td>sim 80</td>
<td>Nat + Mech Vent</td>
<td></td>
<td>5.78%</td>
<td>11.43%</td>
</tr>
<tr>
<td>sim 81</td>
<td>Wall 0.5bk/0.5bk</td>
<td></td>
<td>5.42%</td>
<td>17.14%</td>
</tr>
<tr>
<td>sim 82</td>
<td>Wall 1.5bk/1.5bk</td>
<td></td>
<td>6.24%</td>
<td>16.32%</td>
</tr>
<tr>
<td>sim 83</td>
<td>Wall – Lightweight</td>
<td></td>
<td>4.73%</td>
<td>19.15%</td>
</tr>
<tr>
<td>sim 90</td>
<td>Combined case 2</td>
<td></td>
<td>5.90%</td>
<td>10.99%</td>
</tr>
</tbody>
</table>

*Note: The table shows energy consumption and CO2 emissions percentages for different simulation scenarios.*
Low-cost green housing

Graph 12-3: Simulation results for unconditioned spaces for New-Delhi (Composite Climate)

Predicted Mean Vote (in %) for materials and strategies - New Delhi.

PMV (hours/year, expressed in percentage)

Building Materials and Strategies simulated in TAS
Low-cost green housing

Note: Range $1 \leq \text{PMV} < 1.5$ means slightly uncomfortable hot environment. Range $2.5 \leq \text{PMV} \leq 3$ means highly uncomfortable hot environment.
**Key Observations for Unconditioned Spaces for New Delhi:**
For maintaining comfort conditions, hotter months are critical than colder months. Significant percentage of hours fall into PMV range $2.5\leq PMV \leq 3$, which indicates that indoor environment is highly hot and uncomfortable. PMV values for other ranges have relatively less variation (between 4 to 7%).

**Wall:** Walls with reflective paint as well as flyash brick perform better than other materials. Flyash brick wall in combination with reflective paint on exterior would give the best thermal performance. SIPs are highly inefficient. Higher thermal mass is very important for unconditioned spaces.

**Roof:** Roofs with reflective surface perform considerably well. Combination of reflective roof tiles and filler slabs would give better thermal performance. Filler slabs have lower embodied energy also.

**Frames:** There is a marginal difference in performance of Precast Frames and Wood + Plastic Frames. Considering material reuse and low embodied energy, Wood + Plastic Composite frames should be preferred.

**Orientation:** Current orientation as well as orientation obtained by rotated the building by $180^\circ$ are better mainly because majority of the fenestration faces North and South.

**Window to Wall Ratio:** For current design, window area is 6.62% of the total wall area. These windows are distributed on all four orientations in different proportions – North (2.21%), South (2.21%), East (1.10%) and West (1.10%). Increasing the window area to 10% and 15% decreases the comfort level because of additional solar gains and ‘cool’ loss through conduction.

**Shading:** Higher shading reduces solar gains and gives better thermal performance. Shading devices should be optimized.

**Natural Ventilation:** Natural Ventilation, by opening of windows when outside temperature is lesser than the inside temperature, considerably maintain comfort conditions in the space. Appropriate opening of windows and allowing colder air to pre-cool the building appears extremely crucial for passive designs. This type of would primarily take place during mild weather and night time. Higher the natural ventilation, more the comfort.

**Mechanical Ventilation:** Along with natural ventilation, additional mechanical ventilation (fans) is provided when outside temperature is lesser than the inside temperature. This additional ventilation causes additional pre-cooling and provides comfortable indoor environment.

**Thermal mass:** Considering the total % of hours in uncomfortable range of $1\leq PMV < 3$, lightweight walls (sim 83 with 32.86% hours in uncomfortable zone) perform better than $\frac{1}{2}$ brick thick (sim 81, 33.48%) and $1 \frac{1}{2}$ brick thick wall (sim 82, 34.46%). However, this does not represent the correct picture. For lightweight walls, percentage of hours in highly uncomfortable range of $2.5\leq PMV < 3$ is 19.15% as compared to 17.14% and 16.32% for 1 brick and $1 \frac{1}{2}$ brick thick wall respectively. This shows that higher thermal mass checks the indoor environment from reaching extreme conditions. Hence buildings with high thermal mass are preferable over buildings with low thermal mass.
Table 12.8: Simulation results for unconditioned spaces-Mumbai (Warm and Humid Climate), PMV values are expressed in percentage

<table>
<thead>
<tr>
<th>Location:</th>
<th>Mumbai</th>
<th>Predicted Mean Vote (PMV) values in percentage</th>
<th>Total of Range: 1 ≤ PMV &lt; 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 ≤ PMV &lt; 1.5</td>
<td>1.5 ≤ PMV &lt; 2</td>
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</tbody>
</table>

### A - Material Selection

| sim 50 | Basecase 1 | 12.31% | 10.48% | 7.73% | 10.50% | 41.01% |
| sim 51 | White Paint | 11.43% | 9.03% | 6.05% | 7.92% | 34.44% |
| sim 52 | Flyash Bricks | 11.41% | 8.97% | 6.00% | 7.88% | 34.26% |
| sim 53 | Hollow Conc. Block | 11.55% | 9.71% | 6.96% | 10.05% | 38.27% |
| sim 54 | SIP | 9.85% | 8.73% | 7.29% | 18.26% | 44.13% |
| sim 55 | CSEB | 11.25% | 8.90% | 5.99% | 8.17% | 34.32% |
| sim 56 | Insulated Roof | 12.52% | 10.83% | 7.08% | 7.44% | 37.88% |
| sim 57 | Reflective Roof Tiles | 12.62% | 9.97% | 6.20% | 6.19% | 34.98% |
| sim 58 | Precast RC Planks | 12.34% | 9.93% | 6.41% | 6.91% | 35.59% |
| sim 59 | Filler Slab | 12.37% | 10.14% | 6.55% | 6.85% | 35.91% |
| sim 60 | RC Frames | 12.25% | 10.43% | 7.64% | 10.36% | 40.67% |
| sim 61 | Wood+Plastic Frames | 12.27% | 10.45% | 7.68% | 10.52% | 40.92% |
| sim 62 | Combined Case 1 | 11.61% | 8.22% | 4.53% | 5.52% | 29.88% |
### B - Passive Strategies

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Orientation 90</th>
<th>Orientation 180</th>
<th>Orientation 270</th>
<th>WWR 0.10</th>
<th>WWR 0.15</th>
<th>Shading 0.6 vfin</th>
<th>Shading 0.75 vfin</th>
<th>Nat Vent 01</th>
<th>Nat Vent 02</th>
<th>Nat + Mech Vent</th>
<th>Wall 0.5bk/0.5bk</th>
<th>Wall 1.5bk/1.5bk</th>
<th>Wall – Lightweight</th>
<th>Combined case 2</th>
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</thead>
<tbody>
<tr>
<td>sim 71</td>
<td>Orientation 90</td>
<td>11.50%</td>
<td>8.65%</td>
<td>4.84%</td>
<td>6.39%</td>
<td>31.37%</td>
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<tr>
<td>sim 72</td>
<td>Orientation 180</td>
<td>11.52%</td>
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<td>5.55%</td>
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<td>sim 73</td>
<td>Orientation 270</td>
<td>11.44%</td>
<td>8.62%</td>
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<tr>
<td>sim 74</td>
<td>WWR 0.10</td>
<td>11.92%</td>
<td>8.63%</td>
<td>5.06%</td>
<td>6.27%</td>
<td>31.88%</td>
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<tr>
<td>sim 75</td>
<td>WWR 0.15</td>
<td>11.75%</td>
<td>8.84%</td>
<td>5.57%</td>
<td>7.46%</td>
<td>33.61%</td>
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<tr>
<td>sim 76</td>
<td>Shading 0.6 vfin</td>
<td>11.65%</td>
<td>8.10%</td>
<td>4.50%</td>
<td>5.39%</td>
<td>29.65%</td>
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<tr>
<td>sim 77</td>
<td>Shading 0.75 vfin</td>
<td>11.68%</td>
<td>8.03%</td>
<td>4.48%</td>
<td>5.29%</td>
<td>29.48%</td>
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<tr>
<td>sim 78</td>
<td>Nat Vent 01</td>
<td>11.46%</td>
<td>8.06%</td>
<td>4.49%</td>
<td>5.39%</td>
<td>29.40%</td>
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<tr>
<td>sim 79</td>
<td>Nat Vent 02</td>
<td>9.51%</td>
<td>5.74%</td>
<td>3.01%</td>
<td>1.04%</td>
<td>19.30%</td>
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<tr>
<td>sim 80</td>
<td>Nat + Mech Vent</td>
<td>7.71%</td>
<td>4.89%</td>
<td>2.39%</td>
<td>0.55%</td>
<td>15.54%</td>
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</tr>
<tr>
<td>sim 81</td>
<td>Wall 0.5bk/0.5bk</td>
<td>11.20%</td>
<td>7.92%</td>
<td>4.73%</td>
<td>5.80%</td>
<td>29.64%</td>
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<tr>
<td>sim 82</td>
<td>Wall 1.5bk/1.5bk</td>
<td>11.76%</td>
<td>8.70%</td>
<td>4.76%</td>
<td>5.88%</td>
<td>31.11%</td>
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</tr>
<tr>
<td>sim 83</td>
<td>Wall – Lightweight</td>
<td>8.89%</td>
<td>7.03%</td>
<td>5.97%</td>
<td>11.79%</td>
<td>33.67%</td>
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<td></td>
</tr>
<tr>
<td>sim 90</td>
<td>Combined case 2</td>
<td>7.68%</td>
<td>4.88%</td>
<td>2.36%</td>
<td>0.53%</td>
<td>15.45%</td>
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</tbody>
</table>

Graph 12-4: Simulation results for unconditioned spaces for Mumbai (Warm and Humid Climate)
Low-cost green housing

Predicted Mean Vote (in %) for materials and strategies - Mumbai

- 1 ≤ PMV < 1.5
- 1.5 ≤ PMV < 2
- 2 ≤ PMV < 2.5
- 2.5 ≤ PMV ≤ 3

Building Materials and Strategies simulated in TAS
Key Observations for Unconditioned Spaces for New Delhi:

For maintaining comfort conditions, hot and humid weather is extremely critical. Winters are not at all cold. As compared to New Delhi, percentages of hours under various ranges are well distributed. Percentages of hours fall into PMV range of $2.5 \leq \text{PMV} \leq 3$ are also lesser which indicates milder climate than New Delhi.

**Wall:** Walls with reflective paint as well as flyash brick perform better than other materials. Flyash brick wall in combination with reflective paint on exterior would give the best thermal performance. SIPs are highly inefficient (unlike the results for conditioned spaces).

**Roof:** Roofs with reflective surface perform considerably well. Combination of reflective roof tiles and filler slabs would give better thermal performance. Filler slabs have lower embodied energy also.

**Frames:** There is a marginal difference in performance of Precast Frames and Wood + Plastic Frames. Considering material reuse and low embodied energy, Wood + Plastic Composite frames should be preferred.

**Orientation:** Current orientation as well as orientation obtained by rotated the building by 180° are better mainly because majority of the fenestration faces North and South.

**Window to Wall Ratio:** For current design, window area is 6.62% of the total wall area. These windows are distributed on all four orientations in different proportions – North (2.21%), South (2.21%), East (1.10%) and West (1.10%). Increasing the window area to 10% and 15% decreases the comfort level because of additional solar gains and heat gain through conduction.

**Shading:** Higher shading reduces solar gains and gives better thermal performance. Shading devices should be optimized.

**Natural Ventilation:** Natural Ventilation, by opening of windows when outside temperature is lesser than the inside temperature, provides comfortable conditions in the space. Appropriate opening of windows and allowing colder air to pre-cool the building appears extremely crucial for passive designs. This type of would primarily take place during large part of the year. Considering higher relative humidity, ventilation is extremely crucial in flushing the building and maintaining appropriate air changes. Higher the natural ventilation, more the comfort.

**Mechanical Ventilation:** Along with natural ventilation, additional mechanical ventilation (fans) maintains more air changes and also helps in pre-cooling the building. Mechanical ventilation is highly recommended, especially when outside temperature (and humidity) is lower than the inside temperature (and humidity).

**Thermal mass:** Considering the total % of hours in uncomfortable range of $1 \leq \text{PMV} < 3$, lightweight walls (sim 83 with 32.86% hours in uncomfortable zone) perform better than $\frac{1}{2}$ brick thick (sim 81, 33.48%) and $1 \frac{1}{2}$ brick thick wall (sim 82, 34.46%). However, this does not represent the correct picture. For lightweight walls, percentage of hours in highly uncomfortable range of $2.5 \leq \text{PMV} < 3$ is 19.15% as compared to 17.14% and 16.32% for 1 brick and $1 \frac{1}{2}$ brick thick wall respectively. This shows that higher thermal mass checks the indoor environment from reaching extreme conditions. Hence buildings with high thermal mass are preferable over buildings with low thermal mass.