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Building Policies for a Better World

Technical Report

RESIDENTIAL BUILDINGS IN INDIA: ENERGY USE PROJECTIONS AND SAVINGS POTENTIALS

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LIST OF ACRONYMS

3CSEP - Centre for Climate Change and Sustainable Energy Policy
AC – Air Conditioners
ADaRSH – Association for Development and Research of Sustainable Habitats
AFD - Agence Francaise de Development
ASHRAE - American Society of Heating, Refrigerating and Air Conditioning Engineers
BAU - Business As Usual
BEE - Bureau of Energy Efficiency
BESCOM - Bangalore Electricity Supply Company
BHK – Bedroom Hall Kitchen
BUENAS – Bottom Up Energy Analysis System
CDD – Cooling Degree Days
CEU - Central European University
CFL – Compact Fluorescent Lamp
CREDAI - Confederation of Real Estate Developers Association of India
ECBC – Energy Conservation Building Code
EJ - Exajoules
EPI - Energy Performance Index
GBPN - Global Buildings Performance Network
GCAM – Global Change Assessment Model
GDP – Gross Domestic Product
GHG – Green House Gas
GRIHA – Green Rating for Integrated Habitat Assessment
HDD – Heating Degree Days
HSMI - Human Settlement Management Institute
HUDCO - Housing and Urban Development Corporation Limited
HVAC – Heating Ventilation and Air Conditioning
IECC - Internal Energy Conservation Code
IGBC – Indian Green Building Council
IMAGE – Integrated Model to Assess the Global Environment
iPETS - integrated Population-Economy-Technology-Science
KfW - Kreditanstalt für Wiederaufbau
kVA – Kilovolts – Ampere
kW – Kilowatt
kWh – Kilowatt - Hour
LPG - Liquefied Petroleum Gas
MESSAGE - Model for Energy Supply Strategy Alternatives and their General Environmental impact
MHUPA - Ministry of Housing & Urban Poverty
MPCE – Monthly Per Capita Expenditure
NHB - National Housing Bank
NSS - National Sample Survey
NSSO - National Sample Survey Office
PMV – Predicted Mean Vote
PNNL - Pacific Northwest National Laboratory
RCC – Reinforced Cement Concrete
SDC - Swiss Agency for Development and Cooperation
SHGC – Solar Heat Gain Coefficient
SVAGRIHA – Small Versatile Affordable GRIHA
TERI – The Energy and Resources Institute

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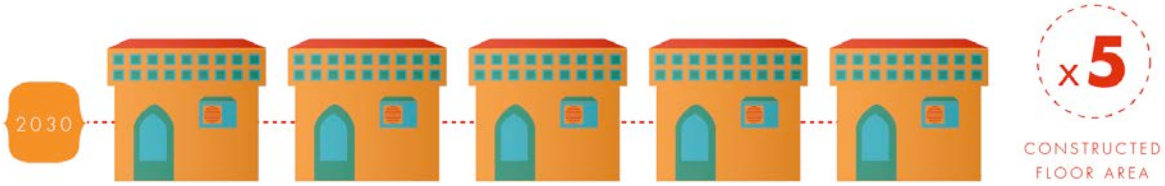
EXECUTIVE SUMMARY

India's domestic energy consumption has increased from 80 TWh in 2000 to 186 TWh in 2012, and constitutes 22% of total current electrical consumption (Central Electricity Authority , 2013). An increase of 400% in the aggregate floor area of buildings and 20 billion m2 of new building floor area is expected by 2030 (Dr Satish Kumar, USAID ECO - III Project, 2011). Furthermore, due to the constant increase of Indian GDP, consumer purchasing power is predicted to grow leading to greater use of domestic appliances. Consequently, household electrical demand is expected to rise sharply in the coming decade. This growth of residential floor space, combined with expectations of improved domestic comfort, will require an increase in electricity production, leading to a significant escalation in damaging emissions.



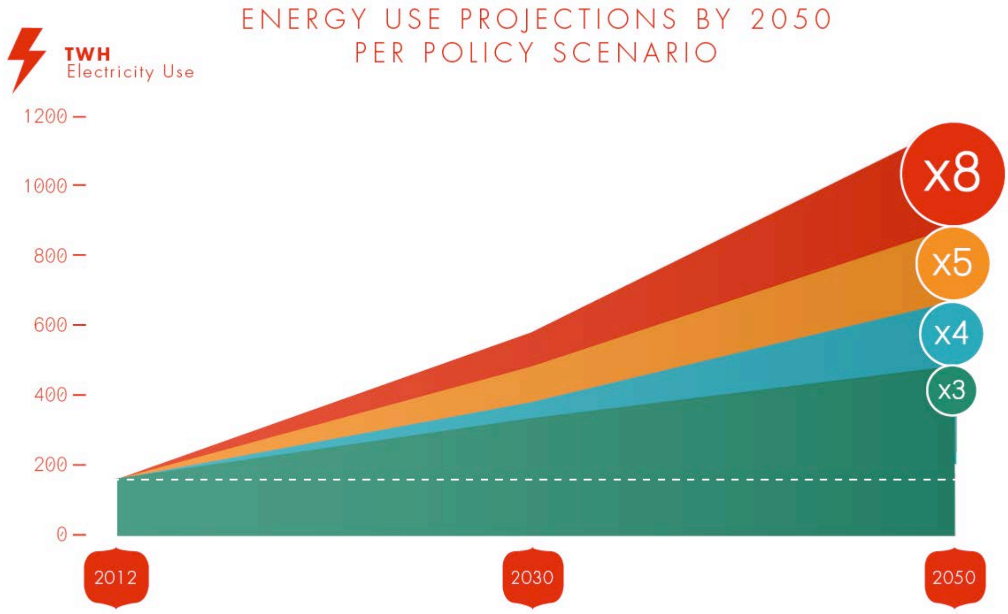
As energy consumption from residential buildings is predicted to rise by more than eight times by 2050 under the business as usual scenario, it is of vital importance for India to develop energy-efficiency strategies focused on the residential sector to limit the current trend of unsustainable escalating energy demand. This study investigates methods of restraining growth in energy consumption in the Indian residential sector and documents energy saving potentials that can be achieved with focused policy and market efforts.

The study conducted a survey of 800 households in four climate zones of India, to map the current penetration rate of appliances and electricity consumption patterns. Key information, including residential unit areas, monthly energy consumption, connected loads and numbers of appliances, together with their power ratings and operational patterns, has been gathered in the survey. The information collected has been analysed to understand current energy consumption patterns for different sizes of residential units with varying occupancy rates, appliances and climate zones.

Building energy modelling has been deployed to quantify comfort benefits and the energy savings potentials of better-performing building envelopes. Energy conservation building code (ECBC) envelope characteristics have been used to determine the features of effective building envelopes. While ECBC is primarily focused on air-conditioned commercial buildings, the specified envelope characteristics in the code provide a benchmark for assessing savings potentials by building envelopes. Building energy modelling has also been used to predict energy consumption increases for higher comfort expectations and appliance usage.

The trends observed in the survey and the building energy modelling analysis, along with information from past studies, have been used to establish residential electricity consumption projections up to 2050. The projections have been partitioned into three end uses (air conditioning, envelope, and equipment) for urban and rural residential sectors. To further identify savings potentials in the residential sector, four projection scenarios have been developed for India: business-as-usual, moderate, aggressive and very aggressive.

Projection scenarios indicate that electricity consumption is predicted to rise by more than eight times under the business-as-usual scenario. Using focused policy and market efforts, moderate, aggressive and very aggressive strategies can limit the consumption increases to five times, four times and three times the current energy usage, respectively. Under the business-as-usual scenario, the annual electricity use per household is predicted to increase from 650 kWh in 2012 to 2750 kWh by 2050. Using a very aggressive policy strategy, the increase in household electricity consumption could be cut to 1170 kWh per household in 2050.



This report demonstrates that a very aggressive building energy efficiency policy and market driven scenario can substantially reduce future energy demand in the residential sector and help India address current challenges posed by the population growth, higher comfort expectations and the increased use of appliances.

To achieve the potentials, the report identifies the following recommendations for action:

Better Data: Introduction of a residential baseline energy data programme using a large survey to provide a detailed picture of current residential energy consumption patterns;

Policy Roadmaps: Elaboration of policy roadmaps that can support the implementation of energy efficiency measures for residential buildings;

Residential Building Energy Code: Development of a specific code focussing on residential building envelope efficiency adapted to the different climate zones to realise the saving potentials of all building envelope components to address the rising demand for thermal comfort.

CHAPTER 1: INTRODUCTION

Rationale

India's aggregated primary energy demand is expected to grow by 2.3 times in the next two decades due to sustained economic growth in the building, transportation and industrial sectors, reaching energy consumption of 40 EJ (Chaturvedi, Eom, Clarke, & Shukla, 2011). Currently, the residential and commercial sectors account for 30% (22% residential and 8% commercial) of total electricity use and consumption in these sectors is rising at 8% annually (Dr Satish Kumar, USAID ECO - III Project, 2011). Due to growing demand for floor space, and to accommodate emerging service industries and urban migration, India expects a doubling of floor space by 2030 (Kumar, Kapoor, Deshmukh, Kamath, & Manu, 2010). The increase in energy intensity per unit area of floor, combined with an increase in floor area, has placed heightened pressure on energy demand for buildings.

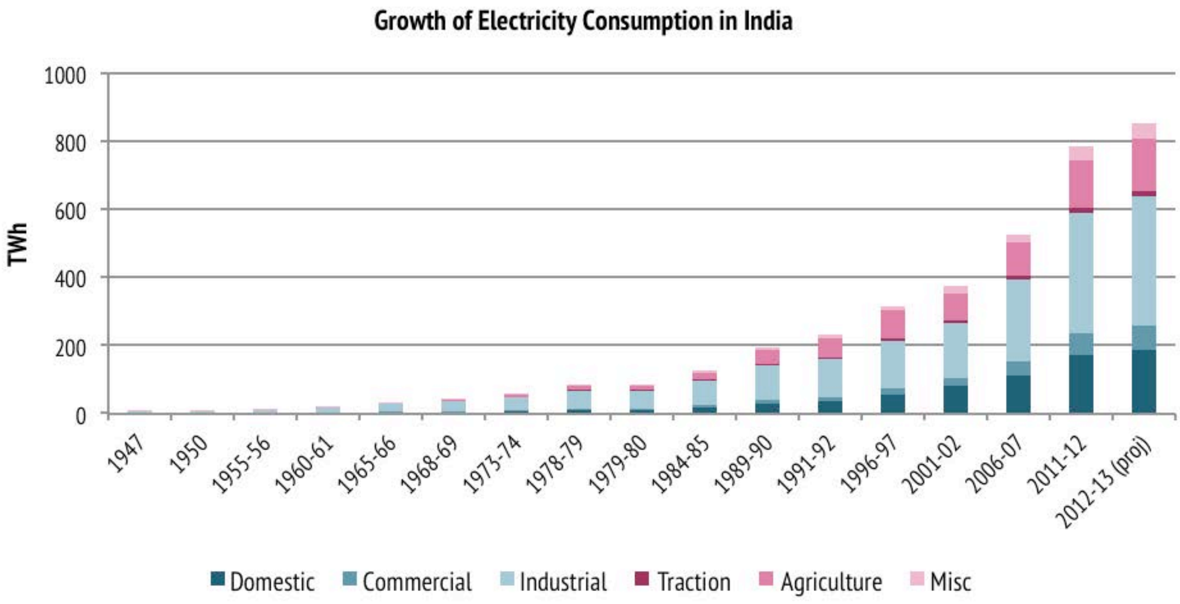


Figure 1: Growth of Electricity Consumption in India (Planning commission, 2011) Source: CEA, 2012

Rising GDP and greater affordability of consumer goods has increased the purchasing power of Indian consumers, resulting in dramatic changes in patterns of energy consumption. Contemporary commercial and residential buildings contain many more electrical appliances. This higher penetration of appliances and increased usage leads to a higher Energy Performance Index in buildings.

However, although the use of energy-consuming appliances is increasing, energy consumption due to building envelope characteristics is expected to remain a significant element in total energy consumption. The building envelope, which consists of external walls, fenestration and roofs, plays a major role in making buildings comfortable, both thermally and visually. When a building does not meet comfort criteria, occupants reply on mechanical and electrical comfort and lighting systems. Reliance on energy driven systems can only be reduced when the building envelope responds favourably to the local climatic context.

A scenario analysis, commissioned by Global Buildings Performance Network (GBPN) and produced by the Centre for Climate Change and Sustainable Energy Policy (3CSEP) of the Central European University (CEU), estimates that India could easily experience an increase in building energy consumption and CO_2 emissions of around 700% by 2050, compared to 2005 levels.

The Bureau of Energy Efficiency, a Government agency, predicts that India's constructed floor area will increase by around five times from 2005 to 2030 (Dr Satish Kumar, USAID ECO - III Project, 2011). This parallels other projections, such as the CEU study, which estimates an increase of around 400% by 2040, and the McKinsey study, which estimates an increase of more than 400% by 2030. These studies predict that India's total residential floor area will be much larger than its total commercial floor area in 2030. CEU data suggests that, by 2050, 85% of floor space will be in residential use, while 15% will be used for commercial purposes.

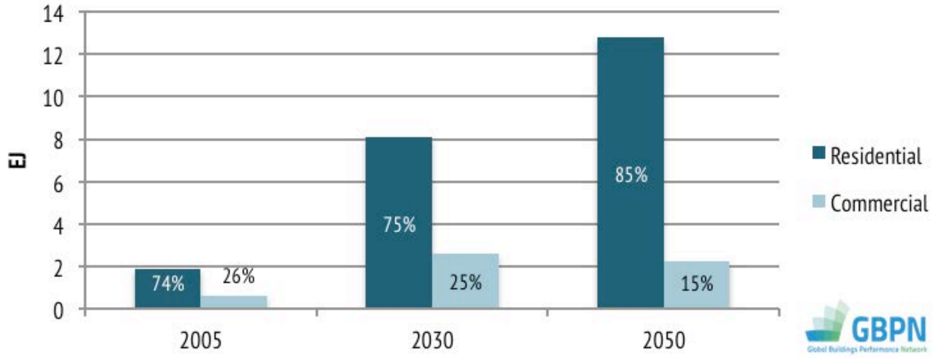


Figure 2: India's moderate efficiency scenario projected energy consumption of India's buildings in 2030 and 2050; percentages represent the ratio of residential and commercial buildings. Source GBPN (2012).

India has begun the gradual introduction of energy efficiency solutions in the building sector. In 2001, the Indian Government introduced the Energy Conservation Act (Bureau Of Energy Efficiency, 2011). As an outcome of this act, a first generation building code, the Energy Conservation Building Code (ECBC), came into effect in 2007. Currently, ECBC applies to buildings that have a connected load greater than 100 kW or contract demand greater than 120 kVA (Bureau Of Energy Efficiency, 2011). In practice, ECBC requirements are generally only applied to buildings with air-conditioned floor areas of over 1000m[2.]

In principle, the ECBC also applies to large residential complexes, when their connected load or contract demand exceeds the thresholds. However, the current national policy priority is to enforce the code at state level for large commercial buildings only. The Bureau of Energy Efficiency has introduced the Energy Conservation Building Code, with effective adoption and enforcement of this code, commercial energy use is predicted to grow from 0.656 EJ in 2005 to 2.648 EJ in 2030.

Single family and multi-family households are expected to show the highest growth rates between 2005 and 2050. Furthermore, CEU projections show that most of the growth in energy consumption will occur in residential buildings. Changes in the residential sector must therefore be handled effectively to secure a low energy future. Ensuring efficiency in this sector can produce a large number of additional advantages, as well as a reduction in energy use.

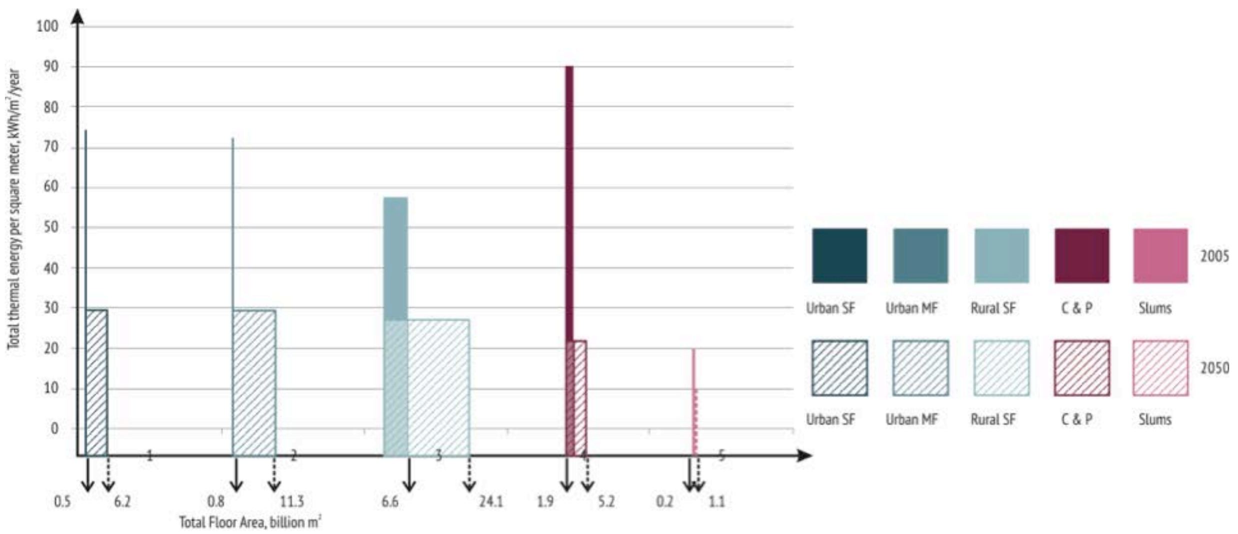


Figure 3: India final energy mitigation potential for Deep scenario between 2005 and 2050. Source GBPN (2012).

Taking into account the increase in building energy use and current policy initiatives (if stringently enforced), CEU's moderate efficiency scenario predicts a growth in India's residential building energy consumption from 1.9 EJ in 2005 to 8.12 EJ in 2030, about a 450% increase.

The study also indicates that buildings have a "lock-in" period of at least 50-60 years. If new residential buildings do not include energy efficiency measures at the initial construction stage, then retrofitting these buildings at a later date may not be the best option, economically. Currently, these residential buildings are not covered by any energy performance or efficiency regulations and consequently, the large savings potentials that exist in the residential sector are not realised.

As part of the ECBC, significant energy abatement projections and baseline studies have been made. However, the contribution of the residential sector to the projections has not been adequately factored in. There are currently no reliable or official estimates of what these energy savings may be (Government of India, 2011). A report by the GBPN on the quality and availability of building performance data around the world showed that the data used for modelling in India is frequently inaccessible and that high quality field study data is required for accurate assessment of the potential savings (GBPN, 2012). In order to influence the residential sector, the knowledge gaps must be bridged. It is therefore essential to perform a deeper baseline study to identify and realise savings potentials in the residential sector.

Adding to the residential buildings sector's energy demand is the migration from informal sectors to the formal housing sector. The Government of India, through a National Agenda, declared 'Housing for All' as a priority for the nation (Ministry of housing and urban poverty alleviation , 2007). This shift into formal housing units (J. Chadchan, 2012) is likely, over time, to result in a huge growth in energy consumption and predicting this will be complex. However, given that low-end residential buildings are likely to follow the same energy path as the high-end sector, this study aims to predict this increase in consumption by using the experience gained from high-end residential buildings, where a similar, measurable, growth is already taking place.

Objectives

The objective of this study is to determine the energy savings potentials in the residential sector, in which overall energy use is projected to grow by 500% to 800% by 2050. An overall scenario assessment of the residential sector has been undertaken to gain a better appreciation of the long-term mitigation potential of this sector. The study specifically focuses on assessing the role of the building envelope in relation to comfort air conditioning systems and appliances in achieving energy efficiency in dwellings.

This study answers the following six sub-objectives:

1. To bridge the current gap between building performance and modelling data.
2. To provide quantitative information on residential building energy use.
3. To determine the severity of growth rates in energy consumption in this sector and identify the savings potentials.
4. To assess the needs and benefits of policy interventions in the residential sector.
5. To recommend future actions to target and harvest saving potentials.
6. To provide a reference point for future residential impact studies.

The report has been developed on the basis of the following three phases:

1. Field Survey: A survey conducted in four different cities representative of the four different climate zones of the country. The following points outline the survey objectives:

- To examine occupancy and floor area distribution in different types of residences.
- To examine appliance ownership patterns in different climate zones.
- To identify air conditioner ownership patterns in different climate zones.
- To interpret energy consumption (EPI) with respect to varying floor areas, number of air conditioners, occupants and climate zones.

- To identify the variation in base load and seasonal load for four climate zones.

2. Building energy modelling phase: Using the EnergyPlus simulation tool, building energy modelling has been used to assess the energy saving potentials and comfort benefits of efficient building envelopes and appliances. The following points outline the objectives of this modelling:

- To assess the role of the building envelope in providing a comfortable indoor environment and to increase the number of comfortable hours through varying building envelopes and air-conditioner and appliance use.
- To extract the potential energy savings from efficient building envelopes at different operational modes in contrasting climate zones.

3. Development of residential electrical energy use projections up to 2050 to identify the savings potentials in the residential sector.

CHAPTER 2: LITERATURE REVIEW

Objectives of the Literature Review

India has strived to provide “homes for all’ since it gained independence in 1947. Numerous programmes and schemes have been introduced and implemented by governments and NGOs. This part of the study deals specifically with recent activity relating to the residential sector and energy. The exercise began with the aim of understanding three distinct but inter-dependent aspects: (1) residential energy consumption (2) floor space availability and future trends and (3) residential energy policy measures. Understanding residential energy consumption in the past and in future is key. The focus was on energy used in acquiring a comfortable indoor environment and not on cooking and other household activities.

The study also aimed to determine the availability of habitable floor space with regard to the current rise in population; future scenarios of population and potential associated increases in residential floor space and also documented the various policy programmes that have been introduced relating to residential energy.

An attempt was made to evaluate the effectiveness of policy initiatives. Data was gathered through available literature and interviews. As previously stated, with the aims of improving housing conditions and responding to the ever-increasing demand for housing in India, a number of housing development schemes, dwellings related studies, and residential finance initiatives have been launched by a range of organisations, for example; the National Housing Bank (NHB), the Housing and Urban Development Corporation Limited (HUDCO), the Human Settlement Management Institute (HSMI), the Confederation of Real Estate Developers Association of India (CREDAI), the Planning Commission of India and the Ministry of Housing & Urban Poverty (MHUPA). In addition, energy efficiency in the residential sector comes under voluntary green building rating systems, such as GRIHA and the SVAGRIHA programme developed by TERI. The India Green Building Council’s Green Homes programme has undertaken pioneering work in the field of green residences and has gained acceptance by mainstream real estate developers. Several bi-lateral and multi-lateral government agencies, such as the Swiss Agency for Development and Cooperation (SDC) and Agence Francaise de Development (AFD), are also working with the Bureau of Energy Efficiency (BEE), and the Ministry of Power, Government of India, to help evaluate current best practice in the Indian residential sector for energy use and savings. These agencies have carried out specific programmes, such as developing capabilities amongst professionals and creating frameworks to assess energy consumption, as well as providing technical assistance to various real life projects to reduce their energy demands during operation.

Employment, Economics and Housing in India

The National Housing Bank (NHB) report reveals that the housing and real estate industry is the second largest employment generator in India, after agriculture. Housing and building activities have significant macroeconomic effects and indirectly contribute to social, physical and psychological wellbeing. Housing shortage is one of the major problems faced by India at present. It is estimated that there are shortages of 18.78 million residential units in urban areas and 43.67 million units in rural areas (National Housing Bank, 2012).

A recent study by Kreditanstalt für Wiederaufbau (KfW) and the National Housing Bank has concluded that, in large cities, the major share of housing demand will be for middle-income housing (income USD 500 to USD 2000 per month – at INR 60 per USD) for dwelling units with prices ranging from USD 25,000 to USD 100,000. The National Housing Bank report also shows a significant increase in housing loans in India since 2000. The report further observes that more loans have been disbursed to middle and higher income groups in comparison with lower income groups (Kreditanstalt für Wiederaufbau & National Housing Bank, 2009). The Indian housing market is characterised by a large informal sector with low penetration of formal housing finance. Apart from housing shortage challenges, the housing sector is also observed to be infrastructure deficit in terms of roads, electricity supply, sanitation and drinking water.

The National Sample Survey Office (NSSO) report shows that 4 per cent of urban and 34% of rural households do not have access to electricity. The report also highlights the differences in levels of access to electricity between urban and rural areas and indicates that only 18% of rural households have access to the three basic facilities (drinking water within premises, sanitation & electricity), whereas access to all three was available to 68% of urban households (National Sample Survey Office , 2010). The Government of India, at both central and state level, has undertaken various initiatives aimed at improving the availability and condition of housing in India.

Improving Efficiency in Urban Infrastructure

A major housing scheme, under the Jawaharlal Nehru National Urban Renewal Mission, focuses on improving efficiency in urban infrastructure, mechanisms for services delivery, community participation and accountability of urban Local Authorities. Another major housing scheme, Bharat Nirman, focuses on the provision of basic amenities, such as drinking water, roads, irrigation facilities, electricity and the construction of houses in rural areas. Indira Awaas Yojana provides cash subsidies to rural "Below Poverty Line" families for the construction of dwelling units using their own designs and technologies. The Ministry of Housing & Urban Poverty Alleviation has an interest subsidy scheme to improve the affordability of housing loans for economically weaker sections (lower income groups) in urban areas. Another scheme, the Affordable Housing Partnership, also facilitates housing for the economically weaker section (lower or middle income group). In this partnership, 25% of dwelling units are reserved for this section under various development projects (National Housing Bank, 2012).

These schemes have tried to address the supply of housing stock. The MGI report indicates that 700-900 million square metres of commercial and residential space is required to be built in India each year (Mc kinsey Global Institute, 2010). The resulting increase in floor space will multiply the demand for and consumption of energy and will contribute to higher GHG emissions. A study, conducted by Krey, highlights that CO_2 emissions are not sensitive to urbanisation rates but are directly linked to economic growth and differences in incomes of urban and rural populations, and estimates a ±7% change in CO_2 emissions with a ±10% change in urbanisation rates. The study focuses on energy use and CO_2 emissions by urban and rural sectors in Asia by using four integrated assessment models - GCAM, IMAGE, iPETS and MESSAGE. It also indicates that, due to projected economic development, per capita final energy use in urban areas is likely to double or triple by 2050, in comparison with 2005 levels, whereas, in rural areas, per capita energy use will not increase by more than 50%. The study also suggests that alternative urbanisation pathways will result in the use of a range of different types of solid fuels and their associated health impacts, particularly in rural regions. The study further observes that rural and urban housing can compensate each other at various aggregate levels, such as per capita energy use and CO_2 emissions (Krey, et al., 2012). To mitigate the upsurge of energy consumption, efficient building envelopes need to be designed and constructed in order to reduce energy consumption in providing for thermal and visual comfort. The National Housing Bank along with Kreditanstalt für Wiederaufbau is promoting energy efficiency in the housing sector.

Rural and Urban Energy Consumption by End-Use Service

A study, conducted by the Pacific Northwest National Laboratory (PNNL) and IIM Ahmedabad, differentiates rural and urban energy consumption by end-use and predicts a rapid expansion in the use of space cooling appliances and a significant increase in energy use for cooking in the future (Chaturvedi, Eom, Clarke, & Shukla, 2011). It is important to note that the increase in the use of space cooling appliances depends on a lack of comfort and residents' ability to own and use cooling systems. The room air-conditioner unit (Split AC and Window AC) market in India has grown from a market size of 1 million units in 2003-04 to 3.5 million units in 2010-11 and 50-60% of domestic air conditioner sales take place in the summer months (Shakti Sustainable Energy Foundation, 2012)The attached figure demonstrates the increasing pattern of energy consumption by service within buildings.

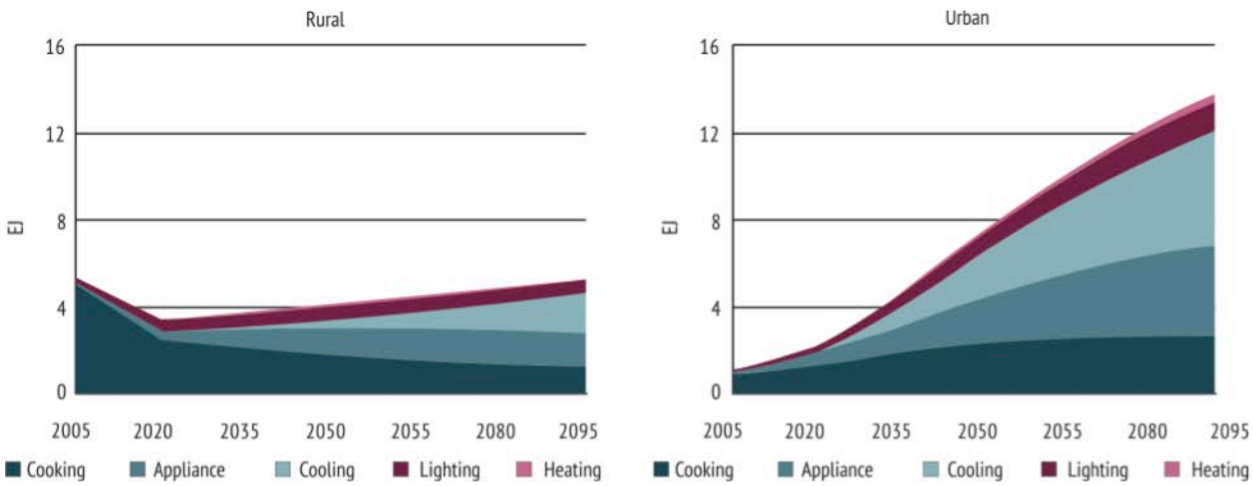


Figure 4: Energy consumption by service in rural and urban area, Source: (Chaturvedi, Eom, Clarke, & Shukla, 2011)

Energy consumption in buildings is dependent on variables such as outdoor climate, building construction and materials, operational modes (for example, naturally ventilated or air-conditioned), occupancy hours, thermal comfort expectations of occupants, office equipment and home appliances. Residential developments are of differing types, such as bungalows, apartments in three and four storey buildings, apartments in 12-16 storey buildings, tenements and row houses. The energy consumption patterns in the residential and commercial sectors are significantly different. However, key influencing variables contributing to increased energy consumption in both types of building are similar, with the distinction that, in commercial buildings, the equipment load is significantly higher due to computers and other office equipment. The heat load generated by office equipment has a direct impact on the consumption of energy for space cooling. In the residential sector, energy consumption for this purpose is much lower.

Commercial and Residential Building Energy Consumption Baseline Study

A commercial and residential building energy consumption baseline study was conducted by Bhatt et al, in which consumption was found to be significantly lower than in the study conducted by the authors of this report. The study assessed various factors, such as specific energy consumption in relation to floor area, specific energy consumption per capita, electrical energy consumption, specific power, electric power and building connected load, which can be used to categorise commercial and residential buildings. The study found that, in the residential buildings, energy consumption due to space cooling and lighting accounts for one third of total energy consumption, whereas, in commercial buildings, it accounts for nearly two-thirds. The study also found that energy consumption in residential buildings is in the range of 1-3 kWh/m^2/month, which translates to 12 – 36 annual kWh per m^2 and suggests that peak load varies significantly between 30-100% based on the prevailing weather conditions (Bhatt, Rajkumar, Jothibasu, Sudirkumar, Pandian, & Nair, 2005).

Energy Consumption and Savings Estimates for the Products Installed

A study conducted by Letschert calculated energy consumption and savings estimates for the products installed in Indian homes by using the bottom up energy analysis system (BUENAS). The BUENAS model uses a set of end-use efficiency scenarios in order to evaluate potential energy savings (and emissions). Once the appliance ownership forecast is established, BUENAS plots this on a timeline of efficiency levels for new products to track the average unit energy consumption of products entering the stock. This is then applied to a stock accounting methodology, which tracks the overall consumption of the national stock for both the base case and efficiency case. The model predicts that a large proportion of households will own major appliances by 2030. It is estimated that, even if the entire stock of appliances by 2030 was energy efficient, this would still only result in 26% of electricity savings for that year. Moreover, while the penetration of domestic appliances is increasing exponentially, the market share of energy-efficient appliances is relatively small (Letschert & McNeil, 2007). Hence, the potential 26% of energy savings might be difficult to achieve.

Residential Baseline Study for Hot Humid Costal Climates in India

In partnership with the Swiss Agency for Development and Cooperation, a bilateral agency working with the Ministry of Power, Government of India, a residential baseline study was conducted for hot, humid, coastal climates to determine the baseline energy consumption of residential buildings. Forty-nine apartment units in Puducherry and 27 apartments, row houses and detached units in Auroville were surveyed. The investigation found that, although local builders were keen to provide energy saving appliances in built spaces, the emerging market segment, which is middle and lower middle class, did not have a preference for this. The survey in Auroville also found that retrofit incentives or subsidies could be effective in encouraging households towards lower energy consumption. The need for public awareness, together with supporting policies, to achieve energy-efficiency in residential buildings was highlighted. The study made several recommendations aimed at improving energy efficiency in the residential sector – access to baseline consumption information, advisory and technical support for residential building developers, well-designed urban planning, and effective incentives, together with regulation and monitoring (Swiss Agency for Development and Cooperation , 2011).

Residential Baseline Study for Composite Climates in India

A further study, carried out by the Swiss Agency for Development and Cooperation, collected data from approximately 836 units on the energy consumption of households in a composite climate, as part of which, a detailed list of electrical appliances and their usage was collected from 30 households. The average resident energy performance index (EPI) was found to be in the range of 45- 50 kWh/m^2/year. The study indicated that households with more than two air conditioners or more than four occupants have EPIs of more than 80 kWh/m^2/year. EPI tends to be 10-15% higher in top floor houses compared to those at lower floors, this is due to exposure to the roof and the cooling energy required for achieving a comfortable indoor temperature. The study also observed that space air conditioning is the biggest consumer of electricity and has a significant impact on EPI. With greater numbers of air conditioning units in households, energy consumption is increasingly driven by the energy requirements of air conditioners (AC). The EPI per AC lies in the range of 10-40 kWh/m^2/year with the average value being 30 kWh/m^2/year. The study found that households with different orientations yield reasonably identical energy performances, indicating that EPI is largely governed by factors of lifestyle and occupancy and not orientation of unit. The EPI per occupant lies in the range of 5-20 kWh/m^2/year with the average value being 15 kWh/m^2/year. This is the range into which nearly 75% of EPIs per capita fall (Swiss Agency for Development and Cooperation , 2010).

Residential Electricity Consumption Patterns in India

A World Bank report in 2008 studied residential electricity consumption patterns in India and developed a modelling framework to project future residential appliance energy consumption scenarios. The study used average household size and per capita income to envisage two household energy scenarios, however it did not take into account the rebound effect. A bottom-up approach was used to estimate appliance energy usage and made the simplified assumption that residential energy usage is solely dependent on household income (The World Bank, 2008). The report also used information from the National Sample Survey (NSS) census data, as well as government agency reports, to calculate average monthly household expenditure. This, together with monthly per capita income (MPCE), was then used to estimate future appliance ownership and electrification rates.

Reducing GHG Emissions in the Building Sector in India

The Climate Works Foundation study on "Reducing GHG Emissions in the Building Sector in India" (Climate Works Foundation, 2010) indicates that the residential sector accounts for 21% of total electricity consumption. The energy consumption distribution in the residential sector is shown in Figure 5 where ceiling fans and lighting constitute the majority of energy use at 62% (Climate Works Foundation, 2010).

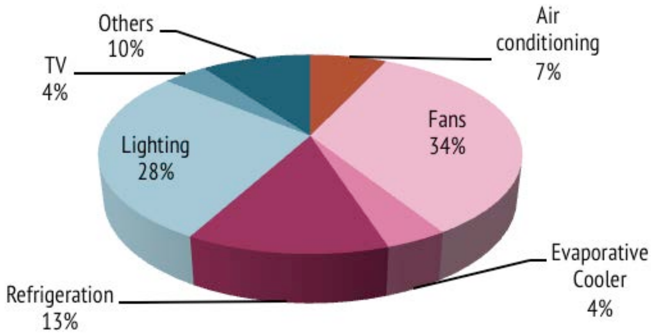


Figure 5: Energy consumption in residential sector (Planning Commission, 2011). Source: Climate works Foundation, 2010

The Climate Works Foundation study (Climate Works Foundation, 2010) also predicts that major growth in the construction industry will be seen in the residential and commercial sectors and will be as much as four to five times 2005 levels (Climate Works Foundation, 2010). Within this, the Indian residential sector will witness phenomenal growth. Some of this is due to higher GDP, population increase, urbanisation and rising incomes (Chaturvedi, Eom, Clarke, & Shukla, 2011). The growth in the building sector can be seen in Figure 6.

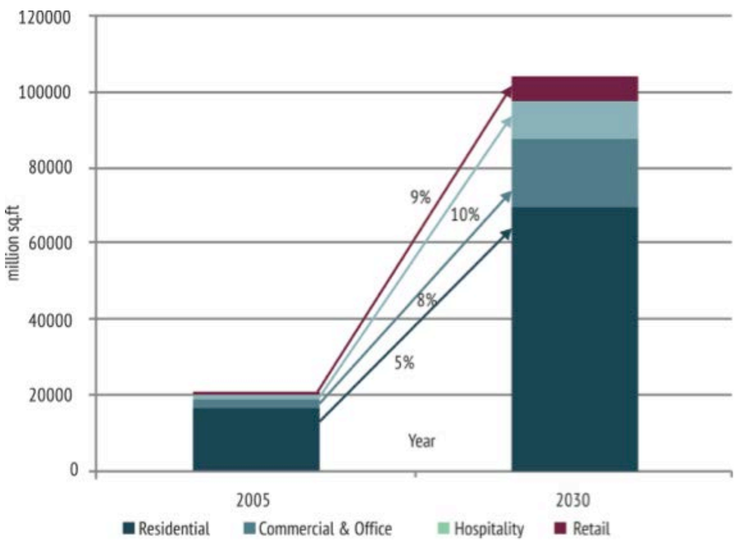


Figure 6: Growth rate of building sector. Source: (Planning Commission, 2011

Government Efforts Towards Energy Efficient Buildings

The increasing demand for buildings and rising energy costs have alerted the Government of India to the importance of energy efficient measures for buildings. The Integrated Energy Policy 2006 (Planning Commission) and the National Housing and Habitat Policy 2007 (Ministry of housing and urban poverty alleviation , 2007), are important policy documents which have laid down recommendations on this issue. The National Housing Bank launched the Energy Efficient Housing Refinance Scheme in 2010-11, aimed at encouraging energy efficiency in the residential sector. A total of USD 2.16 Million (appx. INR 12.96, Crore) refinance disbursements were made available under this scheme. It is expected that this will encourage energy efficiency in residential units in India. The National Housing Bank has also launched a refinance scheme, Equipment in Homes, for the installation of solar water heating and solar lighting to promote the use of energy-conserving solar equipment in the domestic context (Kreditanstalt für Wiederaufbau & National Housing Bank, 2009).

Energy Efficient Measures in Buildings from State Electricity Companies

Energy efficiency measures in buildings are also being encouraged by state electricity companies, municipalities and banks, through rebates in electricity charges for those using solar water heaters, the introduction of voluntary codes and low interest loans for green buildings. For example, BESCOM (the Bangalore Electricity Supply Company) provides rebates in electricity charges where solar heating has been installed. The municipalities of Hyderabad and Pune have produced voluntary codes to encourage green housing. The State Bank of India is offering low interest loans for green housing, including energy efficient elements, and there are incentives for solar water heating in other states (Kreditanstalt für Wiederaufbau & National Housing Bank, 2009).

Green Building Rating Systems

Voluntary green building rating systems, such as IGBC's Green Homes and AaDarsh's SVAGRIHA, are also encouraging the residential sector to achieve energy efficiency.

Bottlenecks restricting the spread of energy efficient measures remain, such as the non-availability of key energy efficient products, the lack of reliable information about the energy performance of products and the lack of awareness by end-users of the potential for energy efficient solutions in housing. In a survey to ascertain energy awareness in India, conducted by Doleschal in five megacities, it was found that the higher educated middle class in India was concerned about air pollution and considered it very important to live in energy-efficient residences. The quantitative study questioned around 1000 people in Mumbai, Bangalore, Chennai, Delhi, and Pune belonging to the well-educated middle class, on attitudes, knowledge and awareness of energy issues. The study found a direct relationship between family earnings and the willingness to pay for energy-efficient residences. Although two-thirds of those surveyed did not know the precise energy consumption of their homes, they were willing to spend more on energy efficiency measures. The study also found large gaps in user awareness of and knowledge about energy-efficiency (Doleschal, Pottgiesser, Akhilesh, Kabre, & König, 2013).

Energy Efficient Housing Refinance Scheme

In 2010-11, the Energy Efficient Housing Refinance Scheme was launched, with the aim of encouraging energy efficiency in the residential sector. A total of USD 2.16 Million (appx. INR 12.96, Crore) refinance disbursements were made available under the scheme. It is expected that this will encourage energy efficiency in residential units in the country. The National Housing Bank has also set up a refinance scheme, Equipment in Homes, for the installation of solar water heating and solar lighting, to promote the use of energy-saving solar equipment in the domestic context (Kreditanstalt für Wiederaufbau & National Housing Bank, 2009).

CHAPTER 3: METHODOLOGY

This section shows the methodology for Phase 1 and 2 of the study – the survey of residential homes and building energy modelling of residential homes.

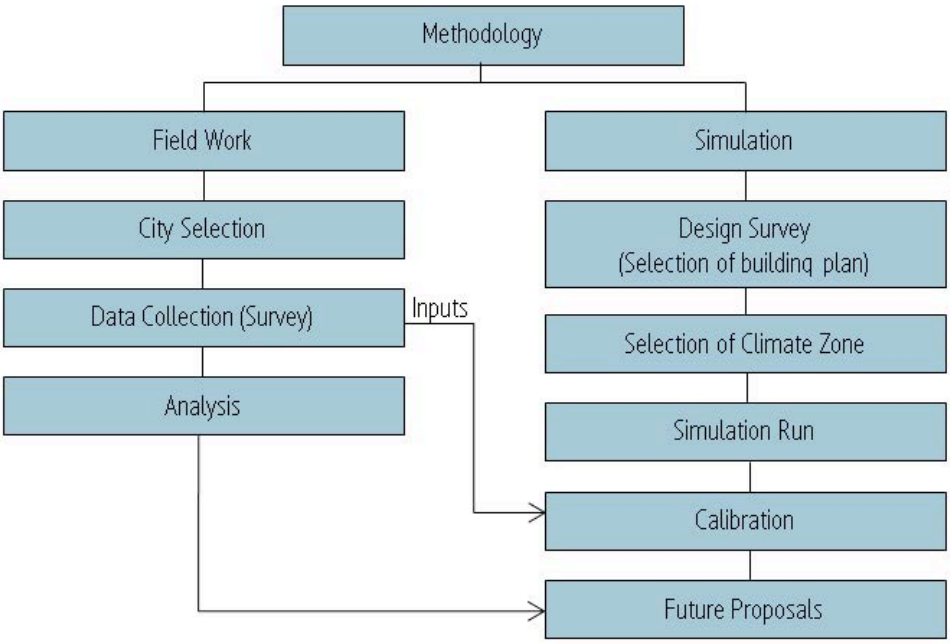


Figure 7: Process showing the methodology of the study

As shown in Figure 7 above, the starting point of the survey was field data collection from four cities representing distinct climate zones in India. Analysis of the survey data helped in comprehending the various factors involved in energy consumption in the Indian residential sector. Findings from the survey and a review of standard floor plans in India helped to develop and calibrate the building energy models for Indian residences.

Survey Methodology

The Literature Review has indicated the need to collect good quality data in order to better understand residential energy consumption patterns and appliance penetrations. The objective of the survey design was to gather residential energy consumption data to complement nationally available statistics.

Scope of the Survey

The total sample size was 800, divided equally between the four cities – each representing a different climate zone. The fifth climate zone of India, cold, has not been included in the sample due to its smaller area and lower urbanisation rates, together with a lower level of construction activity in comparison with the other climate zones (J. Chadchan, 2012)

Based on the literature review and past studies, the following elements have been identified as key variables:

- Residential floor area – It is important to correlate floor area with annual and seasonal energy consumption. Definitions of floor area can vary and this can lead to data interpretation errors. In this study, the survey team has been instructed to measure gross floor area inclusive of enclosed balcony areas.
- Dwelling type and number of floors – The focus of the study was energy consumption in single-family attached/detached homes and multi-family apartment complexes. Surveyors gathered this information based on site observation.

- Number and location of air conditioning systems – The location of air conditioning systems is an important variable in understanding the service level of the home. Typically, residences in India operate in mixed mode, operating air conditioning only when the home is uncomfortable. Primary bedrooms are the preferred location for installing air conditioning systems. Occupants expecting higher comfort and living standards also install air conditioning systems in living and dining rooms. Surveyors gathered this information through site observation.
- Number of bedrooms – The number of bedrooms is an important variable in correlating energy consumption and is related to the number of occupants. Surveyors gathered this information through site observation.
- Number of occupants and age groups – The number of occupants and their age groups is another important variable and this information has been gathered using occupant interview.
- Number of appliances, their power usage and operational patterns – One of the key objectives of the survey was to collect information on appliance penetration. This has been gathered during site visits. Due to the inaccessibility of some appliances and the intrusion on privacy of checking the power ratings of each appliance, sometimes requiring displacement or removal of the appliance, appliance power ratings have been collected in only a fraction of the homes.
- Year of construction –The age of the construction can influence the energy consumption of the building and has been gathered from occupant interview or through background research on the construction.
- Energy consumption (monthly or bi-monthly) – Monthly and bi-monthly energy consumption for the past year has been gathered from utility bills to assess seasonal variations in energy consumption.
- Connected load – Connected load is another important variable gathered during the survey to assess whether energy consumption correlates well with the planned maximum load.
- Floor plan layout, including air-conditioned and unconditioned areas –This information, to analyse the impact of layout as well as to determine the proportions of air-conditioned and unconditioned areas, either required measurement on-site or floor plans, demanding a greater level of involvement by occupants during data collection. Hence, plans of the residential buildings have been collected for only a fraction of the homes.

While the income level of the residence has been identified as an important variable, discussions with several residents indicated a reluctance to share this personal information with the surveyors. Therefore, the location of air conditioners, numbers of bedrooms and air conditioners and the area of the home have been used as an indication of income levels.

Information from a sample of 200 households was gathered in each of four cities. Approximately 30 surveys in each city were conducted with more detailed questionnaires and plans, which attempted to map the characteristics of home appliance use. The detailed survey form and information gathered are shown in Annexes 1 & 2. The total number of households surveyed and the percentages of dwelling types are described in the following sections.

City Selection

The variation in climate, in terms of temperature and relative humidity, leads to varying degrees of comfort and, therefore, energy consumption. Four representative cities based in different climate zones were selected for the survey:

- Ahmedabad, city, representing a hot and dry climate zone (Bureau Of Energy Efficiency, 2011)
- Pune, city, representing a temperate climate zone (Udyayar R, 2013)
- Mumbai, city, representing a warm and humid climate zone (Bureau Of Energy Efficiency, 2011)
- Delhi, city, representing a composite climate zone (Bureau Of Energy Efficiency, 2011)

City Climates

There are various methodologies available for climate classification. The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) defines climate zones with the help of CDD (Cooling Degree Days) and HDD (Heating Degree Days) values which are derived from average weather data files (ASHRAE, 2007). In order to develop understanding of the climates, all four cities were defined using CDD and HDD values and psychometric charts. CDD is a measure of how much (in degrees) and for how long (in days), the outside air temperature was above a given level for which cooling is required. Similarly, HDD is a measure of how much (in degrees) and for how long (in days), the outside temperature was below the defined temperature of the building for which heating is required. They are commonly used in calculating the energy consumption required to heat or cool buildings. The higher the CDD, the more cooling is required and similarly, the higher the HDD, the more heating will be required. The values also give a fair idea of how much more AC or heating will be required for a certain location in comparison with another location. The figures in Table 1 indicate that New Delhi will require more heating in comparison to Mumbai and Mumbai will require much more cooling in comparison to Pune. The CDD and HDD values for the four cities are as follows:

City	CDD @ 18 Deg C	HDD @ 18 Deg C
Ahmedabad	3441	131
Pune	2485	175
Mumbai	3567	0
New Delhi	2928	429

Table 1: CDD and HDD values

Residences in India

Another factor contributing to energy consumption is the number of comfortable and uncomfortable hours indoors. An increase in uncomfortable hours leads to greater consumption of energy for cooling or heating. Figure 8 below show the adaptive comfort standard (ASHRAE, 2010) range of comfortable/uncomfortable hours in each of the cities for a typical building.

Sample size

A total of 785 samples were collected during the field survey. The number of samples collected from each of the cities is shown in the table below:

Location	Number of residences surveyed
Ahmedabad	197
Pune	199
Mumbai	188
Delhi	201

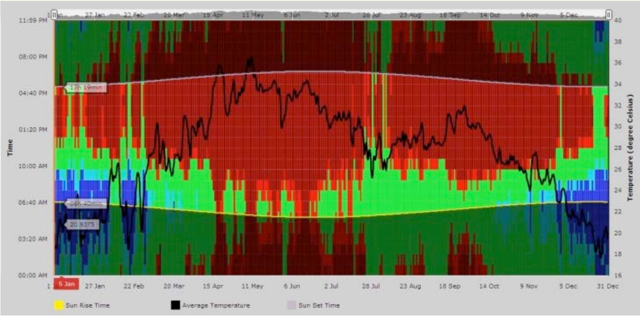
Table 2: Total number of residences surveyed

Within the sample of 785 residences surveyed, households were further categorised as 1BHK, 2BHK, 3BHK and 4BHK (Bedroom/Hall/Kitchen). The sample distribution for bedroom numbers was based on the number of exclusive rooms from 2011 census data (Planning Commission, Govt. of India, 2012), which indicated that 83% of the sample homes had one, two, or three exclusive rooms. Bedroom data was not observed in eight homes in Pune and has not been included in the bedroom calculations. The observed distribution for each category is slightly higher than designed and is attached in the table below:

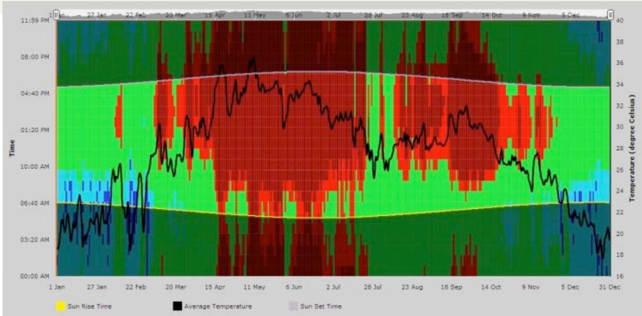
Kind of residences	No. of Residences	%
1BHK	112	14%
2BHK	355	46%
3BHK	265	34%
4BHK	45	6%
Total	**777**	**100%**
Data unavailability	8	1%

Table 3: Sample distribution per cent

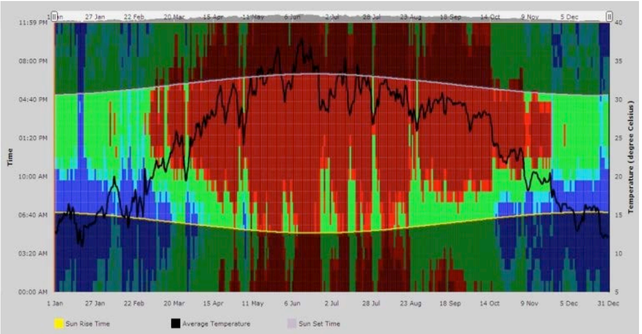
Ahmedabad BAU (Indoor Adaptive Comfort)



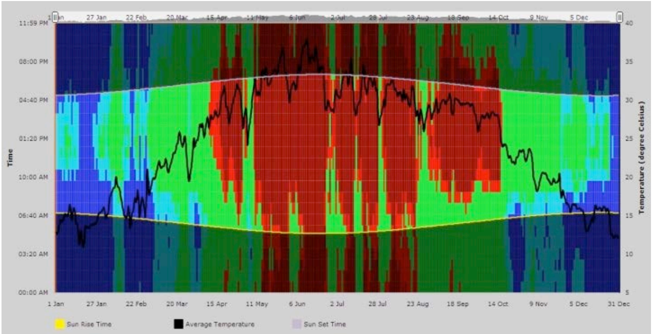
Ahmedabad ECBC (Indoor Adaptive Comfort)



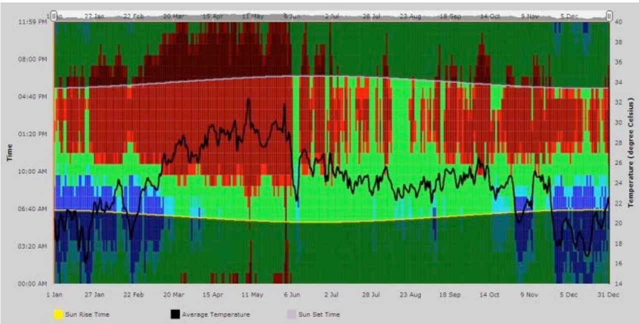
Delhi BAU (Indoor Adaptive Comfort)



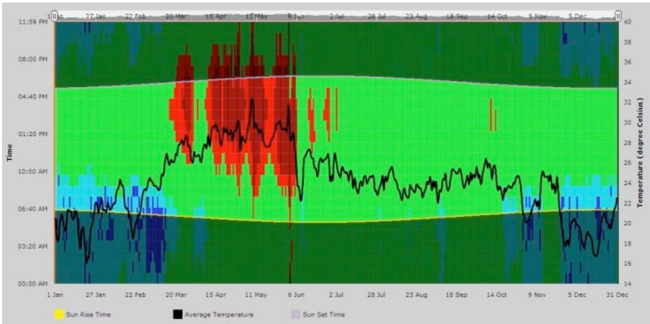
Delhi ECBC (Indoor Adaptive Comfort)



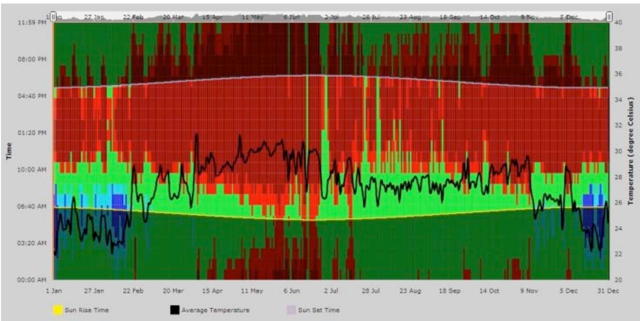
Pune BAU (Indoor Adaptive Comfort)



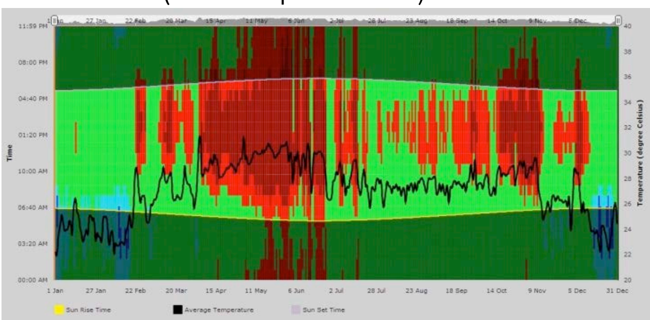
Pune ECBC (Indoor Adaptive Comfort)



Mumbai BAU (Indoor Adaptive Comfort)



Mumbai ECBC (Indoor Adaptive Comfort)



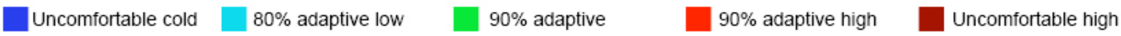


Figure 8: Comfortable hours (based on ASHRAE 55-2010) inside the building for a typical BAU and ECBC building in four cities, Source: CARBSE adaptive thermal comfort tool

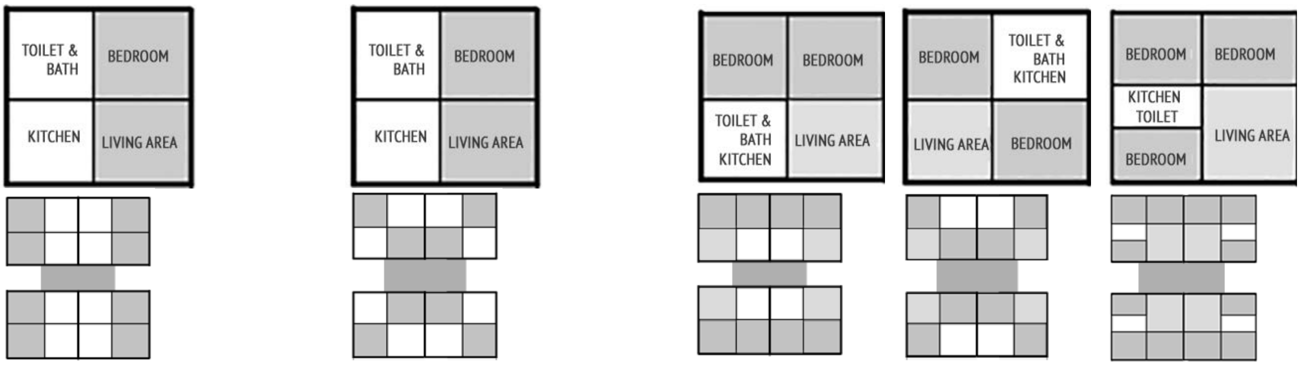
Building Energy Modelling Methodology

Building Energy Modelling was performed, taking into account building geometry, outdoor weather conditions, the thermal characteristics of the building envelope, construction methods and the materials used, building operational modes and appliance usage. The survey data provided input for the building energy modelling calibration. The following methodology was adopted for the building energy modelling run:

Building Plans

A residential building design survey was conducted in order to develop building plans. A range of plans from different cities was collected and their designs considered. Approximately 57 building designs across the country were analysed during the design survey. Two standard building plans were selected for each of four types of residential buildings: 1BHK, 2BHK, 3BHK and tenement, for four different climate zones, with differing construction styles, organisation, ventilation and equipment use.

A 1BHK flat would have either a living area and bedroom to one side or diagonally opposite each other, with other facilities occupying the spaces left vacant. Similarly a 2BHK flat would have either bedrooms to one side or at diagonals, with living area, kitchen and toilet occupying the remaining spaces and a 3BHK would have three bedrooms around the living area with kitchen and toilets. This is (Planning Commssion, 2011)shown in the following plans.



Case 1: 1BHK (type1) Case 2: 1BHK (type2) Case 3: 2BHK (type1) Case 4: 2BHK (type2) Case 5: 3BHK

Figure 9: Indian residential building plan general layout

The plans below were selected following the design survey and were employed in the building energy modelling.

Single unit plan
Carpet area :30sq m

Block plan

Single unit plan
Carpet area :31.16sq m

1 BHK (CASE 1) 1 BHK (CASE 2)

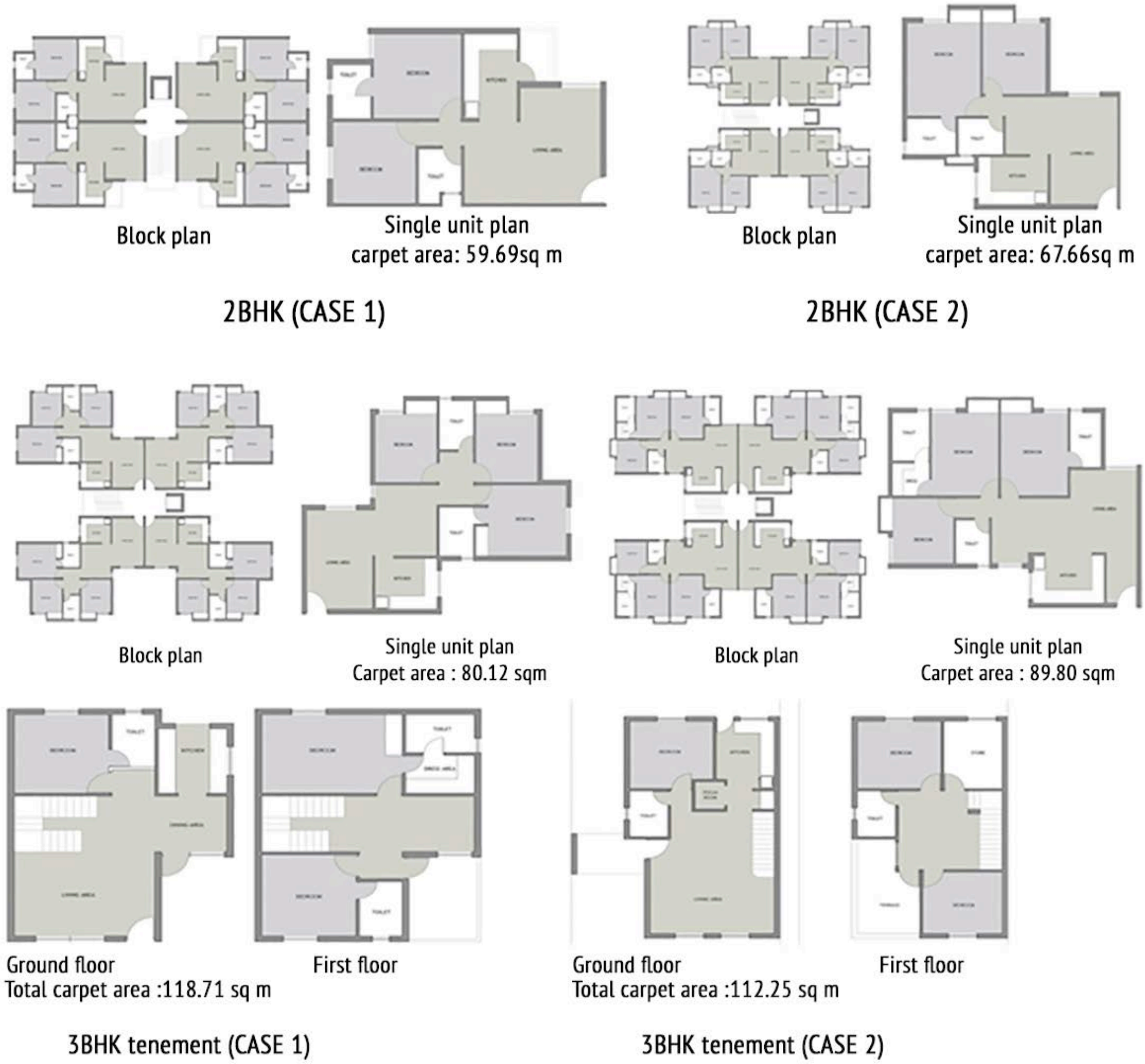


Figure 10: Building plans selected for building energy modelling

The floor area corresponding to each plan is shown in Table 4. During the building design survey it was noted that the majority of Indian urban dwellings use a reinforced cement concrete (RCC) frame for structural stability. This means that beams, columns, intermediate floors and roofs are made out of RCC and walls are of various masonry constructions. It was observed that walls were made from brick and cement block masonry. This is reinforced by census data, which shows that 70% of urban homes have brick wall construction and 64% of urban homes have RCC roof construction (Planning Commission, Govt. of India, 2012). The built-up area is the area of the unit including the space occupied by structural and non-structural elements, such as walls and columns, and common area such as lifts, parking, covered balconies and lobbies. Balconies were found not to contain energy consuming devices with the exception of a single light bulb. The carpet area is generally considered to be 70 per cent of the built-up area.

	Carpet Area (sq.m)		**Built up area (sq.m)**	
	Case 1	Case 2	Case 1	Case 2
1BHK	30	31	43	45
2BHK	60	68	85	97
3BHK	80	90	115	128
3BHK tenement	119	112	170	160

Table 4: Carpet area and floor area for each building plan

Weather data for building energy modelling

Building energy models have been carried out for four cities, which represent four major climate zones of India, namely:

- Ahmedabad (hot & dry climate)
- Bangalore (temperate climate)
- Mumbai (warm & humid climate)
- Delhi (composite climate)

An analysis conducted as part of the ECBC roadmap for Maharashtra (Udyayar R, 2013) considers Pune to have a moderate climate very similar to that of Bangalore, this is further supported by weather data comparisons of Pune and Bangalore. Due to some data constraints, the survey data was collected in Pune, replacing Bangalore, however, Bangalore was used in the simulation of a moderate climate in this study. The temperature, relative humidity, and thermal comfort comparisons of the two cities are compared with that of a warm and humid climate and are presented in Annex 3.

Construction materials, construction methods and their thermal characteristics

To assess the energy efficiency benefits of different envelopes, three types of building envelope have been considered: the Business As Usual (BAU) envelope, the Energy Conservation Building Code (ECBC) equivalent envelope and the ECBC+ envelope, characterised by more exacting requirements than ECBC. In using the ECBC+, construction was selected with regard to economic considerations (Rawal, Vaidya, Ghatt, & Ward, 2012). The selected envelope properties for each are shown below:

	BAU Envelope Properties	ECBC Envelope Properties	ECBC+ Envelope Properties
Wall	230 mm brick wall U-Value - 1.722 W/m2-K	Insulated 230 mm brick wall U-Value - 0.44 W/m2-K	Insulated 230 mm brick wall U-Value - 0.35W/m2-K
Roof	150 mm concrete roof U-Value - 2.942 W/m2-K	Insulated 150 mm concrete roof U-Value - 0.409 W/m2-K	Insulated 150 mm concrete roof U-Value - 0.409 W/m2-K
Window	U-Value - 5.8 W/m2-K SHGC - 0.82 VLT – 0.8	U-Value – 3.3 W/m2-K SHGC - 0.25 VLT – 0.2	U-Value – 3.3 W/m2-K SHGC - 0.20 VLT – 0.16
Floor	U-Value - 2.942 W/m2-K	U-Value - 0.248 W/m2-K	U-Value - 0.248 W/m2-K

Table 5: Building envelope properties. Source: CEPT-TWG Study on tiered approach for ECBC enforcement

A more efficient envelope also reduces air infiltration to the building and requires increased mechanical ventilation to maintain air quality. Hence, the sum of infiltration and mechanical ventilation has been maintained at 1 Air Change per Hour (ACH) for all three envelopes.

HVAC Operation Mode

Based on the survey and discussions with residents, the building has been modelled as a temporal mixed mode building. Temporal mixed mode buildings operate with natural ventilation when comfortable and use air conditioning only when the building becomes uncomfortable. Similarly, the survey data indicates that air conditioners are primarily located in bedrooms. Thus, only the bedrooms have been modelled with air conditioning, while the other spaces are modelled as naturally ventilated.

Occupant behaviour, in terms of running fans and opening windows, has been modelled from an extensive study of occupant thermal comfort (Manu, Shukla, Rawal, De Dear, & Thomas). This study also indicated that Indian occupants feel comfortable at higher temperatures than Fanger's PMV models. Therefore, the adaptive thermal comfort model (ASHRAE, 2010) has been used to determine the occupant's thermal comfort in the building. The thermal comfort study also indicates that window and fan operation is primarily a function of indoor temperatures.

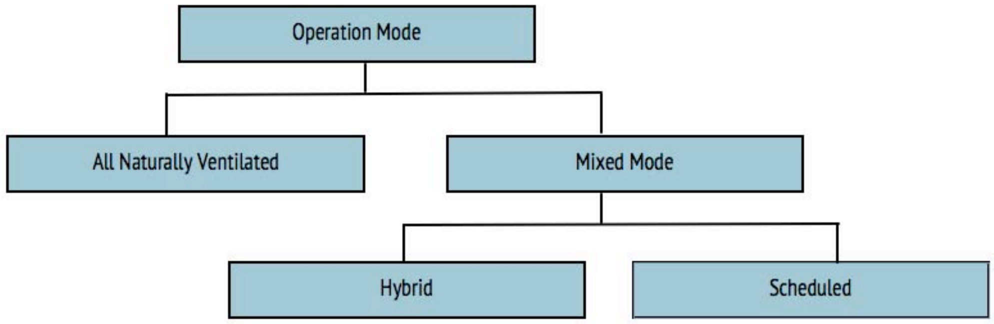


Figure 11: Building operation mode type

Each building design was simulated in three operational modes: naturally ventilated mode, mixed mode with hybrid AC operation and mixed mode with scheduled AC operation. In the fully naturally ventilated operational mode, it was assumed that the internal doors between the rooms were always open and that opening of the external windows would be determined by indoor and outdoor temperatures (Manu, Shukla, Rawal, De Dear, & Thomas). Each room inside a residence was considered as a separate thermal zone. The schedule and occupancy details are listed in Annex 5.

Windows are opened if the zone temperature is higher than the outdoor air temperature and if the zone temperature is higher than the air conditioner's set point, thus all of the thermal zone's operable windows will open only if both conditions are satisfied, Table 6 - Tzone > Tout and Tzone > Tset, where:

Tzone	**Air Temperature inside the zone**
Tout	Outdoor Air Temperature
Tset	Temperature set-point (Taken 2°C less than the comfort temperature based on the adaptive model)

Table 6: Explanation of Tzone

HVAC Controls

Based on discussions with residents on operational patterns, two types of HVAC control strategies have been designed in simulation:

- Mixed mode – AC is available to run from 1800 hours to 1000 hours (overnight) in the bedroom. The air conditioners are turned on when opening the window is not sufficient to maintain the indoor set point. For the remainder of the time, bedrooms are operated in the naturally ventilated mode. Other spaces in the residence are operated in naturally ventilated mode throughout the day. The space set points are calculated based on the ASHRAE 55-2010 adaptive thermal comfort model.
- Scheduled - AC runs continuously in the bedrooms from 1800 hours to 1000 hours (overnight) to maintain space set points, and the windows are kept closed throughout the period. This is considered realistic as the survey revealed that few residents keep windows open at night due to outdoor noise, safety and air pollution.

The AC set-point temperature is set according to the adaptive model (ASHRAE, 2010) and the ventilation control temperature is 2°C below the AC set-point temperature. ASHRAE 55-2010 is followed for non-residential buildings.

Adaptive Thermal Comfort Model

The graphs below show comfort temperature ranges based on the ASHRAE 55 adaptive model for naturally ventilated spaces for the four different cities in India that have been considered for the study. The comfort temperature (tn) is derived from the equation 1:

$$t_n = 0.33 * t_{pma\,(out)} + 17.8$$ ……………………………………………*Equation1* (Source: ASHRAE 55 – 2010)

Where,

tn	comfort temperature, in degree Celsius (°C)
tpma (out)	prevailing mean outdoor air temperature, in degrees Celsius (°C)

Table 7: Equation Explanation of tn and tpma

The comfortable band is derived by offsetting the comfortable zone to 80% and 90% acceptability, based on guidance given in the ASHRAE 55 Standard (ASHRAE, 2010). The comfort zone and city mean temperature is presented in the figure below:

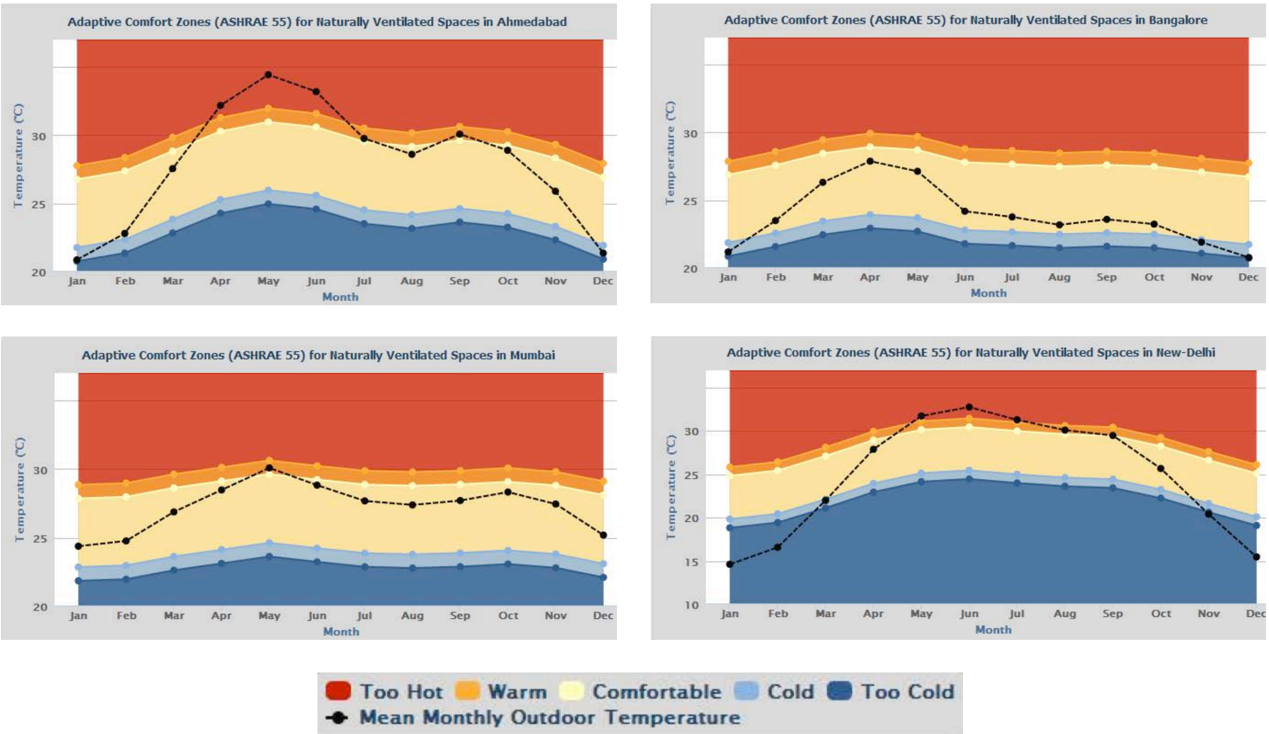


Figure 12: Adaptive thermal comfort zone for each city

The mean temperature has been calculated for each month using dry bulb temperature in the TMY3 weather files. The neutral temperature is then calculated for each month using equation 1 shown above. The set point for each of the cities in various months is shown in the graph below.

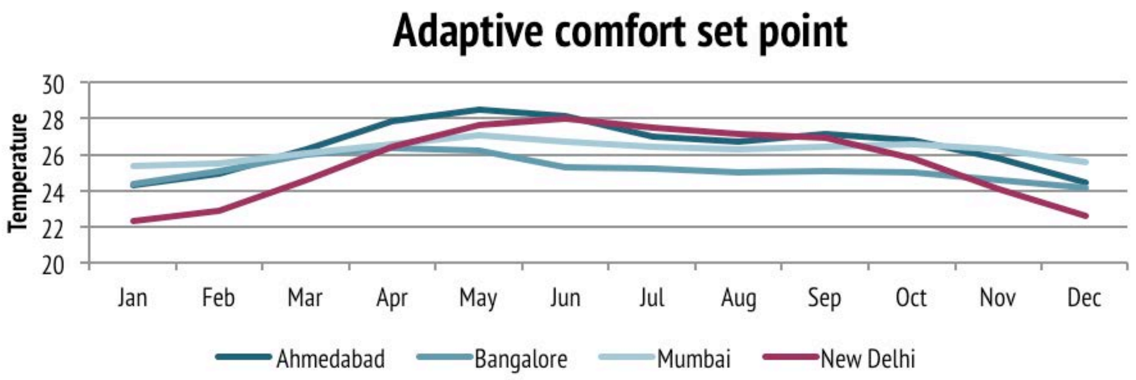


Figure 13: Adaptive comfort set point

Internal Heat Gain

The occupants and appliances add to the building's internal heat gain. The input details for the internal heat gain are as follows:

People	2 persons in 1BHK, 4 persons in 2BHK and 5 persons in 3BHK
Appliances	1120 W in 1&2BHK, 1220 W in 3 BHK

Table 8: Occupants and Appliances, Building Thermal Heat Gain

Details of usage data and equipment schedules have been added in Annex 5.

Building Energy Modelling Run Chart

Each of the envelope and equipment efficiency cases was then simulated twice, once with no appliances and once with the use of appliances. This was done to understand the variation in energy consumption (appliances and AC) due to the appliances' loads. The policy impacts and penetration of BAU, ECBC, and ECBC+ under various projection scenarios has been explained in the methodology of future projections. The following figure shows the building energy modelling run chart for the study:

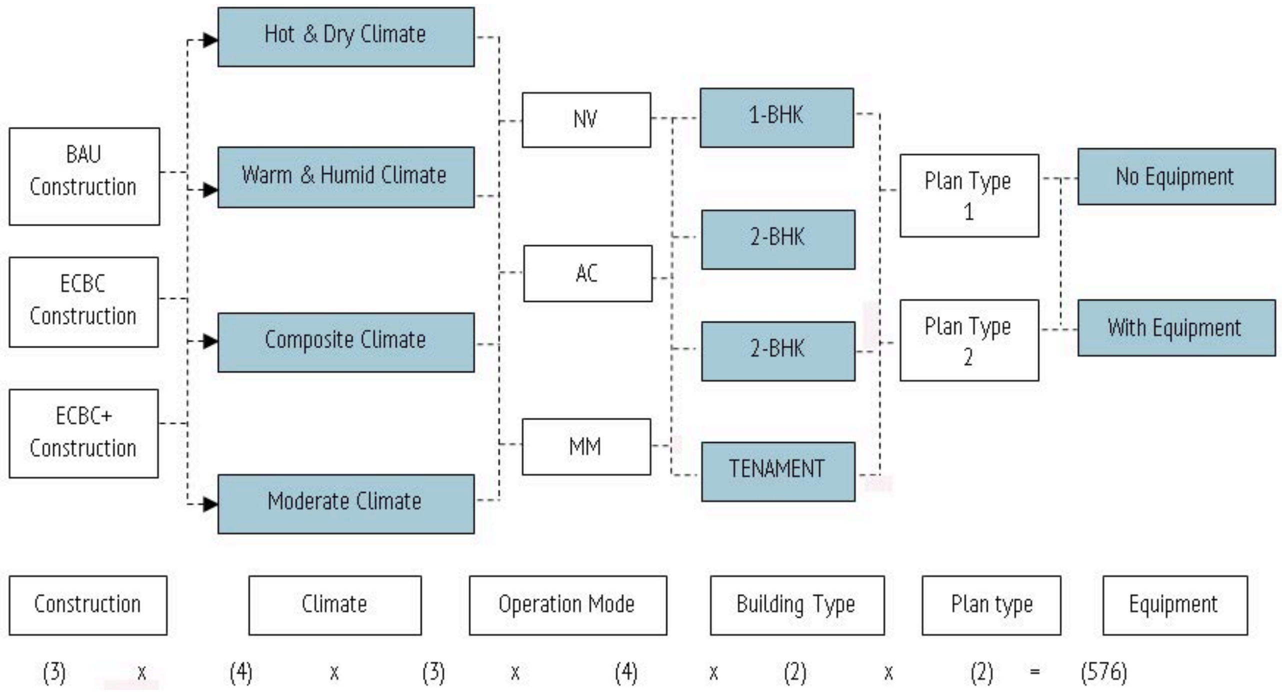


Figure 14: Building Energy Modelling Run chart

CHAPTER 4: SURVEY RESULTS & ANALYSIS

This section consists of the analysis of the survey data.

Survey data analysis

The table below provides average values for the four cities: national averages of the data collected.

	Average		Average
No. of Occupants	4.0	Floor Area	106 sq.m
Connected Load	4.8 kW	Energy Consumption (annual)	3755 kWh

Table 9: National average of data collected

The table above indicates that the average number of occupants in all four cities is 4, Mumbai having the highest average with 4.9 and Delhi having the lowest with 3.4, occupants per dwelling. Also Figure 14 attached below indicates that almost 54% of units have occupancy of 3 – 4 people. The floor area (m^2) and number of dwellings is presented in Figure 15. It indicates that out of 785 units, 48% are 51-100 m^2, and that the average floor area for all four cities is 105.9 m^2. The national average connected load is 4.8kW and national average annual energy consumption is 3755 kWh.

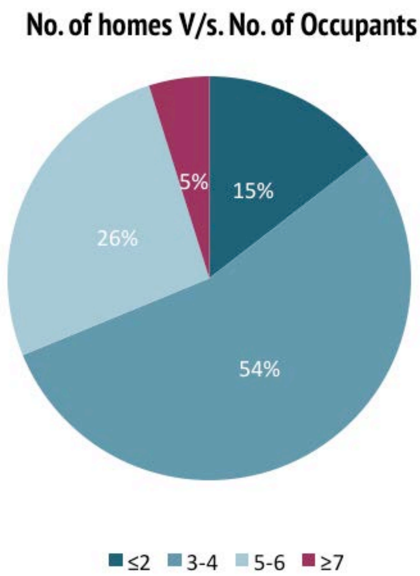


Figure 15: No. of homes vs. no. of occupants

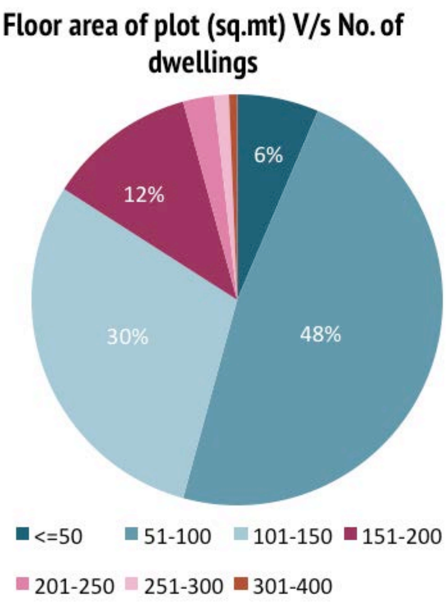


Figure 16: Floor area of plot vs. no. of dwellings

The floor area and occupancy distribution is presented in Figures 16 and 17. As can be seen in Figure 16, 80% of sampled households have 3-6 occupants living in the residence. Similarly, about 78% of sample households have a floor area between 50-150 m^2. This distribution of household area and occupancy is in line with the studies reviewed in the literature review section.

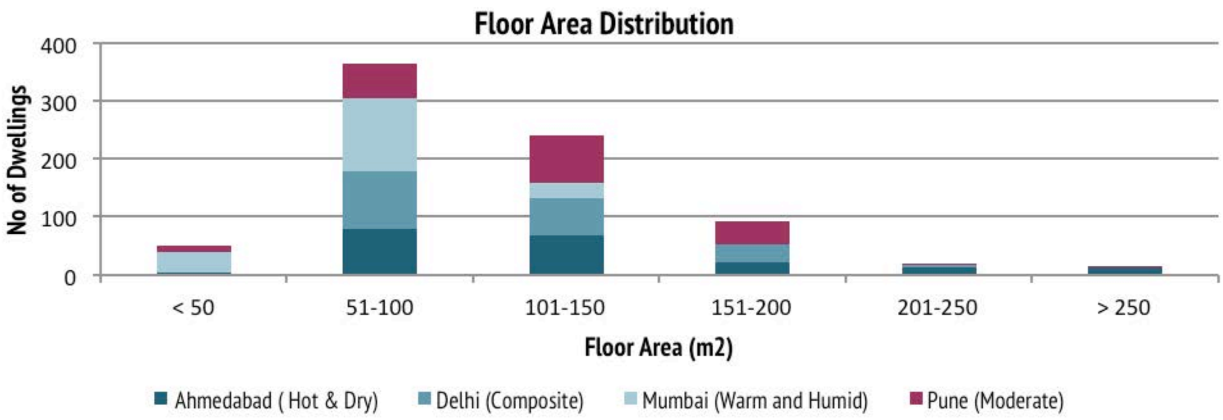


Figure 17: Floor area distribution vs. no. of dwellings

Figure 18 indicates that in Ahmedabad, Mumbai and Delhi the greatest number of units fall into the 51-100 m^2 category, whereas in Pune, the highest number of units are in the 51-100 m^2 range. The majority of higher floor area units are in Ahmedabad and the majority of lower floor area units are found in Mumbai.

Appliance Details

The table attached below provides the national average number of different appliances used in the Indian residential sector. An average household will have approximately 8.0 tube lights, 8.8 CFL/Bulb, and 1.6 air conditioning units. At the city level, Delhi has the highest average with 15 tube lights and Ahmedabad and Mumbai the lowest average with 5.8. For CFL/bulb, again Delhi has the highest average with 12.6 and Mumbai the lowest with 5.8. Delhi also has the highest AC average at 2.4, and Ahmedabad has the lowest at 1.6. The average fan count is 3.3, whereas the air cooler national average is 1.96. The air conditioning units and bedroom distribution is shown in Figure 19 below.

Appliance type	Average	Appliance type	Average	Appliance type	Average
Tube lights	8.0	Refrigerator	1.0	Electric Kettle	0.1
CFL/Bulbs	8.8	Water Pump	0.3	Fans	3.3
Television	1.6	Microwave Oven	0.8	Grinder	0.5
Washing Machine	0.9	Toaster	0.5	Laptop	1.2
Geyser	1.5	AC	1.6	Air Cooler	0.1

Table 10: Appliances national average

Market appliance penetrations are similar for Mumbai and Delhi but vary significantly with Ahmedabad and Pune appliance penetrations. The appliance penetration observed in the survey is higher than indicated by national statistical samples (National Sample Survey Organization, 2001) for urban homes. While this could be due to a small and focused sample size, the sample does indicate an increasing trend of appliance penetration into the market.

The above penetration rate of equipment is higher than the data observed in the literature review. The penetration of the air conditioner is especially high in the selected sample compared to data observed in the studies. Detailed analysis of air conditioners indicated several deviations to the sample data, which have been removed before inputting the characteristics of a typical household in the building energy modelling. While the income level of the residents could not be ascertained due to privacy concerns, the number of air conditioners in a household has been found to be a good indicator of income level.

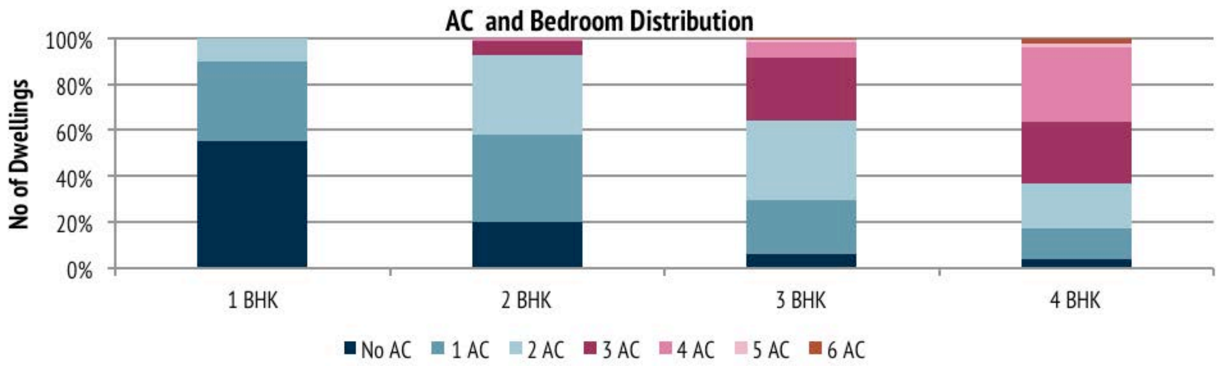


Figure 18: AC vs. Bedroom distribution

The above figure demonstrates the distribution of air conditioners by number of bedrooms. As can be seen in the chart, 1BHK apartments have the maximum number of homes with no air conditioning installed. As the residents move to apartments with more bedrooms, the likelihood of AC installation increases significantly.

Energy Consumption

The average annual energy consumption found in the survey is 3755 kWh. Figure 20 demonstrates the distribution of annual energy consumption among the varying range of floor areas, with different AC units, and belonging to different climate zones. The charts below show that the energy consumption in the majority of units lies below 5000 kWh, and also that Delhi has the highest energy consumption. This is to be expected due to the composite climate; where both heating and cooling are required to keep space comfortable, as well as higher income levels in the capital city. The figures attached below provide an overview of the actual residential building energy consumption scenario.

Average household consumption is higher than in past studies (Swiss Agency for Development and Cooperation , 2011), (Bhatt, Rajkumar, Jothibasu, Sudirkumar, Pandian, & Nair, 2005) this is in line with the increased penetration of equipment observed during the field survey. It is noted that the surveyed households represent the increased energy consumption scenario and can provide representative homes for projecting future energy use.

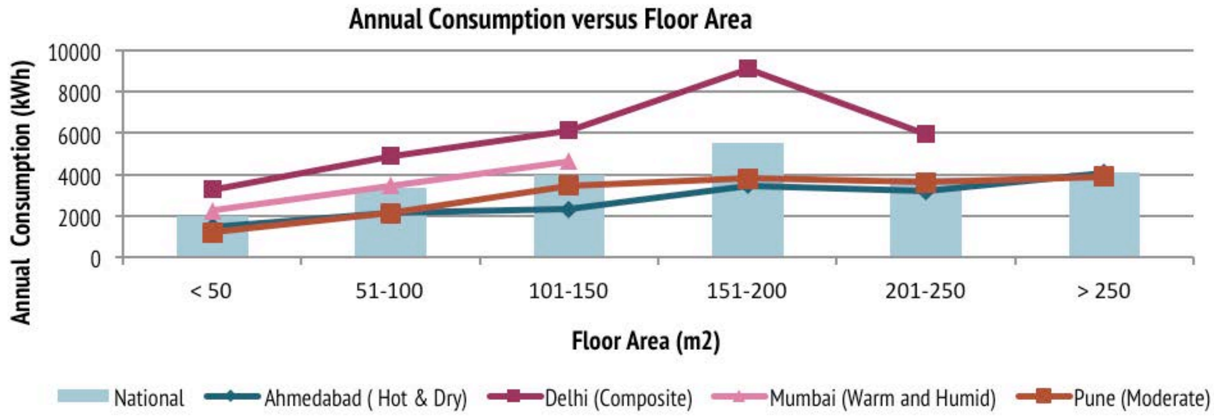


Figure 19: Annual energy consumption vs. floor area (City wise)

Energy Performance Index (EPI)

The EPI values for different numbers of bedrooms with different numbers of AC units are shown in the table below. This demonstrates that a 1BHK unit will have a higher EPI, due to intensification in the use of appliances. Also, residential units with a higher number of AC units have a higher EPI. The increased use of air conditioners has steadily increased the energy consumption of households. However, once the number of air conditioners reaches more than three, energy consumption stabilises or reduces, indicating that usage patterns vary significantly for homes with more than three air conditioning systems.

EPI (kWh/m2)	Number of AC							
Bedroom	0	1	2	3	4	5	6	Average
1	38	50	74					46
2	21	33	52	68	46			40
3	14	22	36	45	40	44	*	35
4	13	14	31	55	52	51	42	42

Table 11: EPI for different unit size and no. of AC

Only one sample was encountered which had three bedrooms with six air conditioning units installed, leading to a very high EPI. This data point has been flagged as an outlier and has been indicated with an asterisk (*) in the above table.

Connected Load

Connected load is an important element in understanding expectations of energy usage and appliance penetration. Typically, households expecting to use more air conditioners and appliances tend to apply for a higher connected load. This section compares the connected load with the energy consumption of the household.

The figure below compares the distribution of connected loads with floor areas for various climate zones. The national average connected load is 4.8kW. Mumbai has a high concentration of units with a lower floor area. Due to the smaller house sizes in Mumbai, there is a higher connected load per floor area for Mumbai residential units, shown in the figure below. In line with higher energy consumption and equipment penetration, Delhi also has a higher connected load in comparison with Ahmedabad and Pune.

Figure 22 plots actual energy consumption and connected load. As can be seen in the chart, the correlation between energy consumption and connected load is poor (R square = 0.16), with many scatters and diverging trends, when compared at the national level. However, when the connected load is mapped within climate zones, the correlation significantly improves (R square = 0.5 to 0.75).

This shows that connected load can be a reasonable gauge for determining energy consumption when looking at homogenous data sets, such as the same city or climate zone. However, connected load is not a good proxy measure when the analysis involves a diverse set of climate zones. Since connected load metrics are also relatively easy to obtain compared with monthly energy use, this knowledge could be helpful in future data collection efforts.

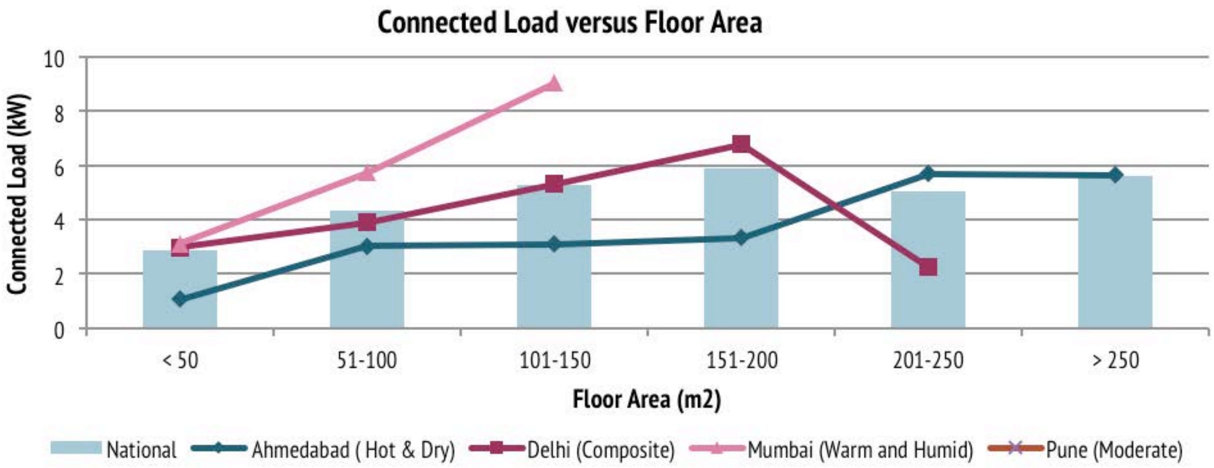


Figure 20: Connected load vs. floor area

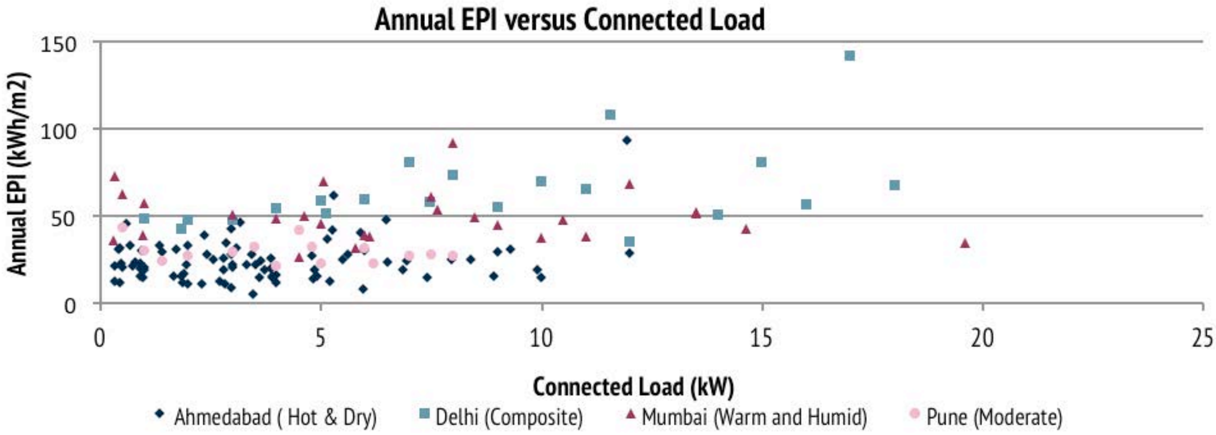


Figure 21: Annual EPI vs. Connected load (City wise)

Base Load and Seasonal Load Consumption

Monthly energy consumption can be very useful in understanding minimum and peak consumption in buildings. Analysis of monthly energy use assists in two aspects, enhanced appreciation as to how climate affects behavioural responses, especially in extreme climates with air conditioners installed, and the provision of reference material for the calibration of building energy simulation models.

The figure below shows the distribution of peak and minimum consumption in a typical residential unit in Delhi (Home 260). Assuming temporal mixed mode operation of buildings, this consumption can also provide the base load and seasonal load of the building. As shown, energy use increases during the months of winter (November to February) and summer (April to September). The months of March, October and November have very similar levels of consumption. The weather is most favourable in Delhi during these months. As shown in Figure 13 above, mean monthly outdoor temperature remains between 20 and 23 degrees during these three months.

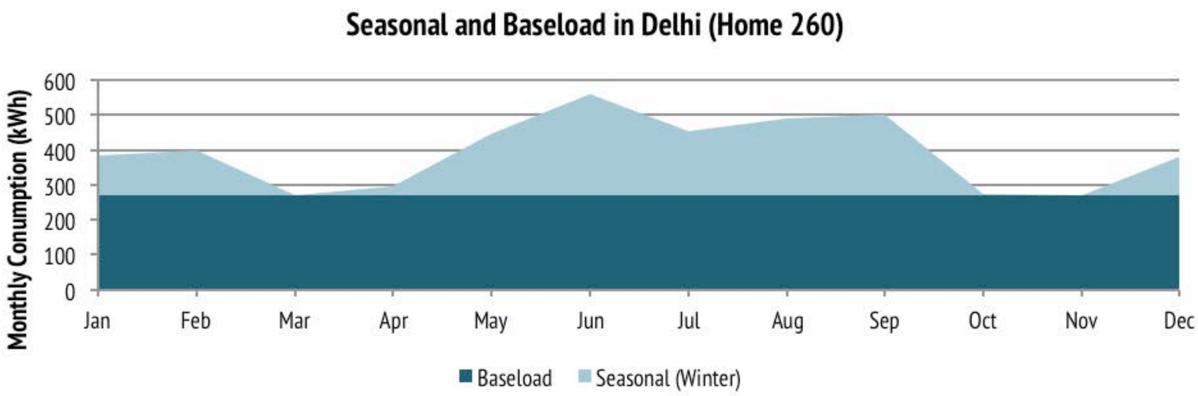


Figure 22: Example scenario: Seasonal load and base load in Delhi

The chart below compares seasonal loads between multiple climate zones. In multicity comparisons, Delhi and Ahmedabad have higher seasonal load ratios in comparison to other cities.

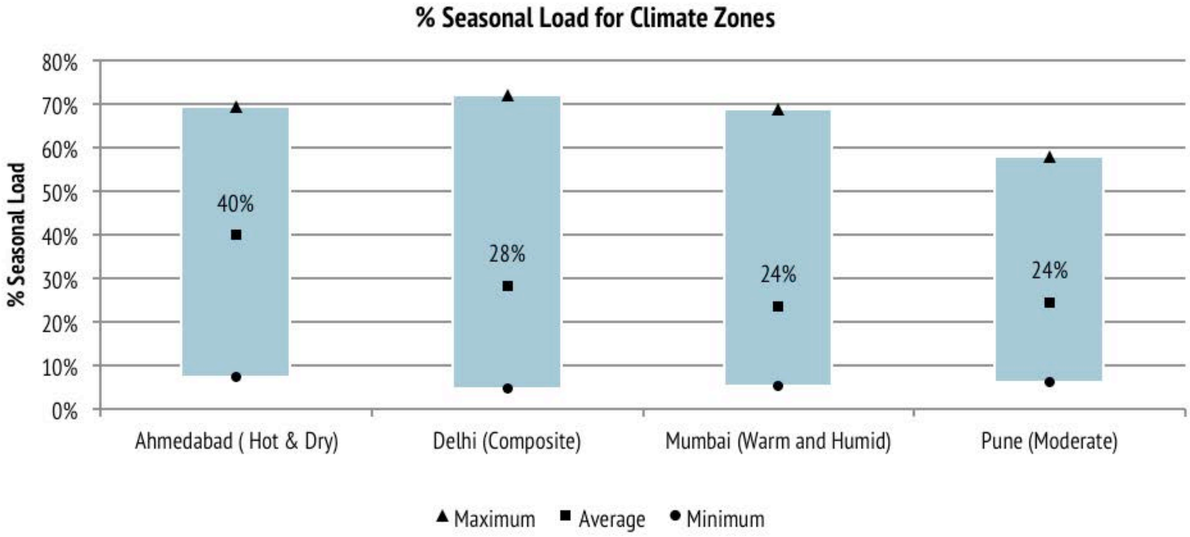


Figure 23: Example scenario: Seasonal load for multiple climate zones

Building energy modelling analysis

Building energy modelling, using EnergyPlus, compared BAU building performance for ECBC and ECBC+ buildings. Four types of building, each with two design layouts, (1BHK, 2BHK, 3BHK, and 3BHK tenement) have been modelled. In addition, each case was simulated with three contrasting styles of operational mode and appliance usage. Initial analysis indicated that, in any particular climate zone, plans with similar floor areas, envelope characteristics, operational modes, HVAC control strategies and appliance usage would have similar energy consumption. This would suggest that, among the studied layouts, floor layout variations would not significantly affect building energy performance.

The comparison of survey results and initial simulation engine results indicated an overestimation of energy consumption in the simulated residences, especially during the season when cooling was required. Based on discussions with residents and analysis of survey data, three causes were identified for these variations:

- Actual operation of bedrooms in temporal mixed mode
- Varied thermal comfort expectations and air conditioning unit usage
- Varied equipment penetrations in comparison with the assumptions made

The data was then calibrated with the help of inputs from the field survey:

- The appliance penetrations and operational schedule was adjusted in accordance with the surveyed data.
- The air conditioning unit availability schedule was changed from 16 hours (1800 hours to 1000 hours) to 8 hours (2200 hours to 0600 hours). This change corresponded with discussions on user behaviour and took into account working hours.

The air conditioning unit usage months have been reduced from yearlong to 3-7 months, depending upon the climate. The heating period has also been adjusted to a timeframe of 2 months (only in the composite climate). The seasonal load and base load analysis provided the necessary information to determine the air conditioning operation of temporal mixed mode buildings.

The calibration graphs have been included and detailed appliance schedules can be found in Annex 5. Following the modifications, simulation results still produced higher-than-average energy consumption. However, the results were much closer (20% EPI variation) to the average of measured survey data and fell within the minimum and maximum values of the city.

The chart below demonstrates that, in hot and dry, warm and humid, and composite climates, ECBC and ECBC+ envelopes can reduce air conditioning energy consumption by 40% and 66% respectively. As expected, in moderate climates, the impact of ECBC and ECBC+ envelopes can eliminate the need for air conditioning and provide 30% overall savings.

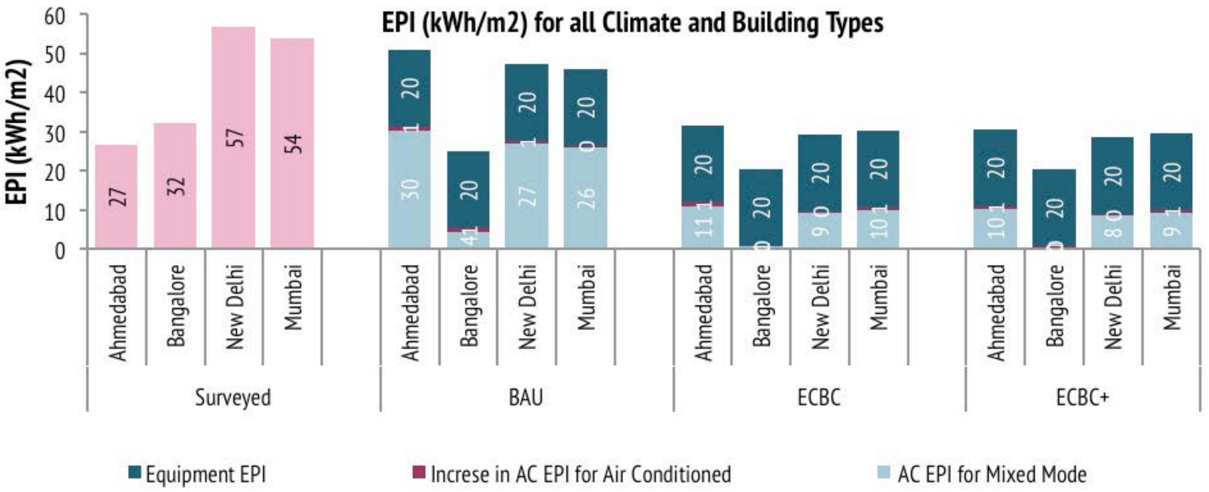


Figure 24: EPI (kWh/ m2) for all Climate and Building Types

As seen in the chart above, the energy consumption of both HVAC control strategies generated near identical results indicating little benefit (only 1 EPI difference) from mixed mode HVAC operation. This approach should be further explored with different set points and comfort levels to evaluate the benefits of mixed mode air conditioning operation.

The following figures demonstrate the equipment and air conditioning energy use in four climate zones. The figures also compare the impact of envelope and air conditioning operation strategies on the energy performance index. Each figure presents EPI for all three envelope construction types (BAU, ECBC, and ECBC+) and operation modes (scheduled and mixed mode).

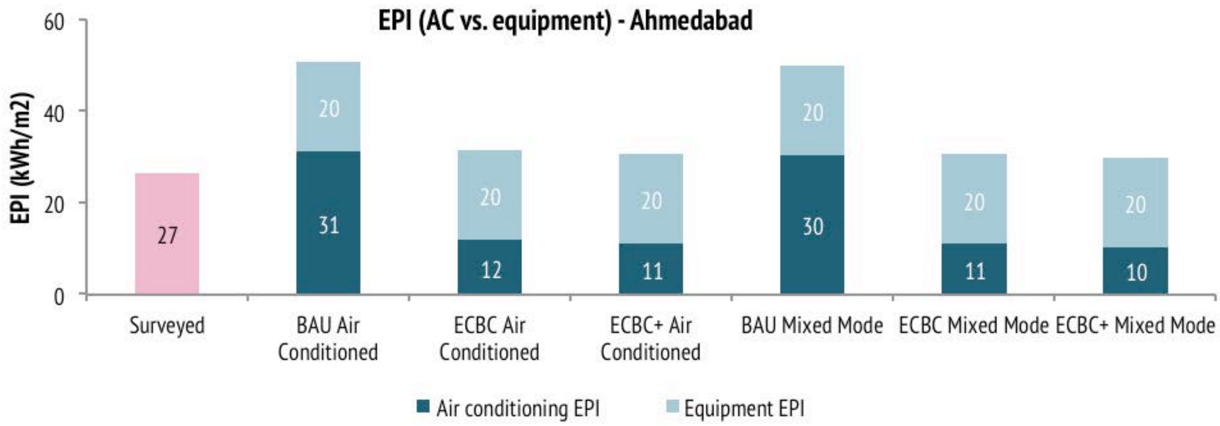


Figure 25: EPI (AC vs. equipment)-Ahmedabad

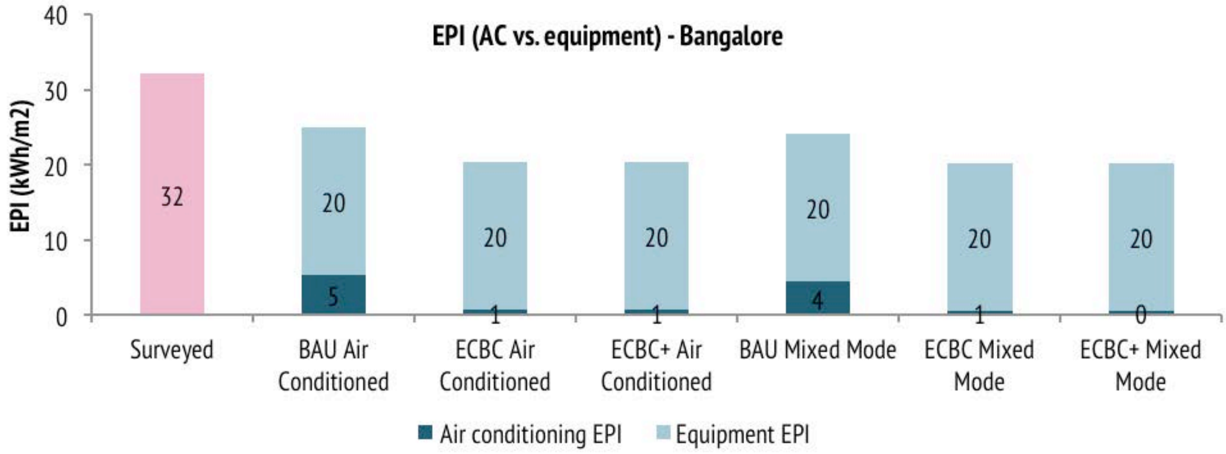


Figure 26: EPI (AC vs. equipment) – Bangalore

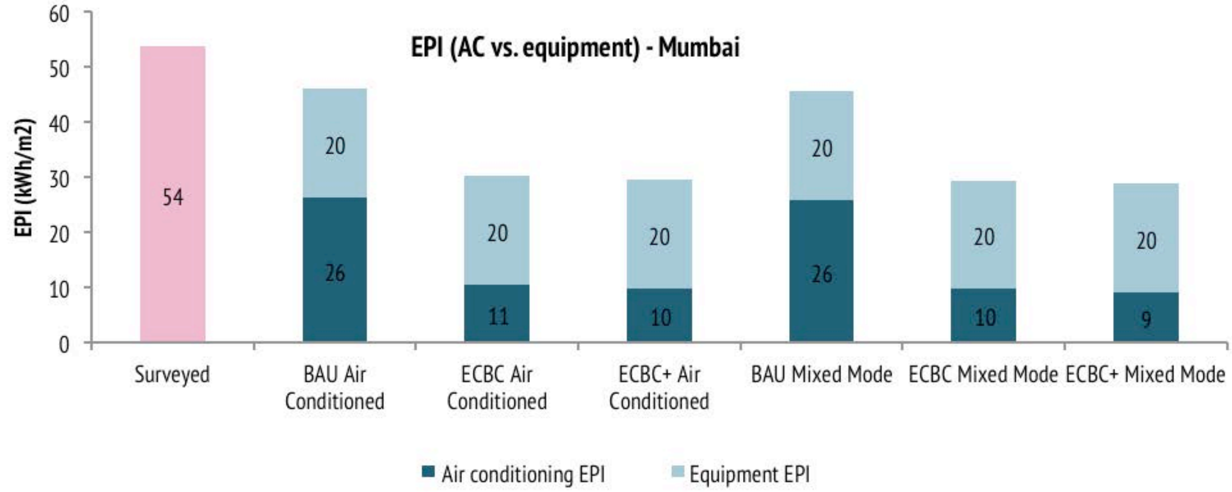


Figure 27: EPI (AC vs. equipment) – Mumbai

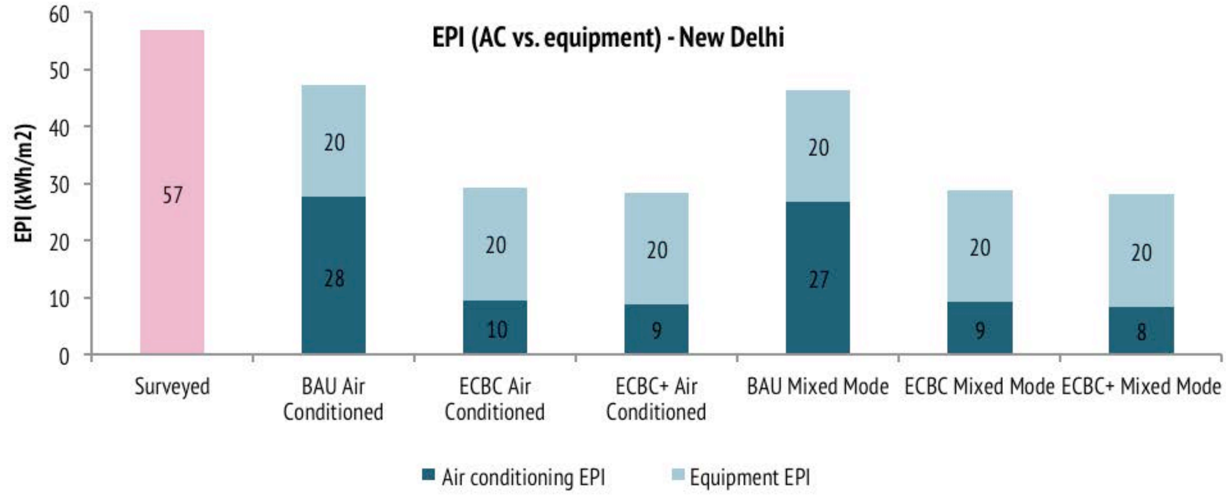


Figure 28: EPI (AC vs. equipment) - New Delhi

Percentage of uncomfortable hours

Figure 29 shows the percentage of uncomfortable hours during occupied periods with BAU, ECBC and ECBC+ envelope characteristics in each climate zone annually and for winter and summer. The increase in uncomfortable hours for BAU has been stacked above the ECBC uncomfortable hours for easy visual comparison. The data has been averaged over 1BHK, 2BHK, and 3BHK apartments. The graph indicates that, using ECBC compliant construction, uncomfortable hours can be decreased by almost 40% to 100%.

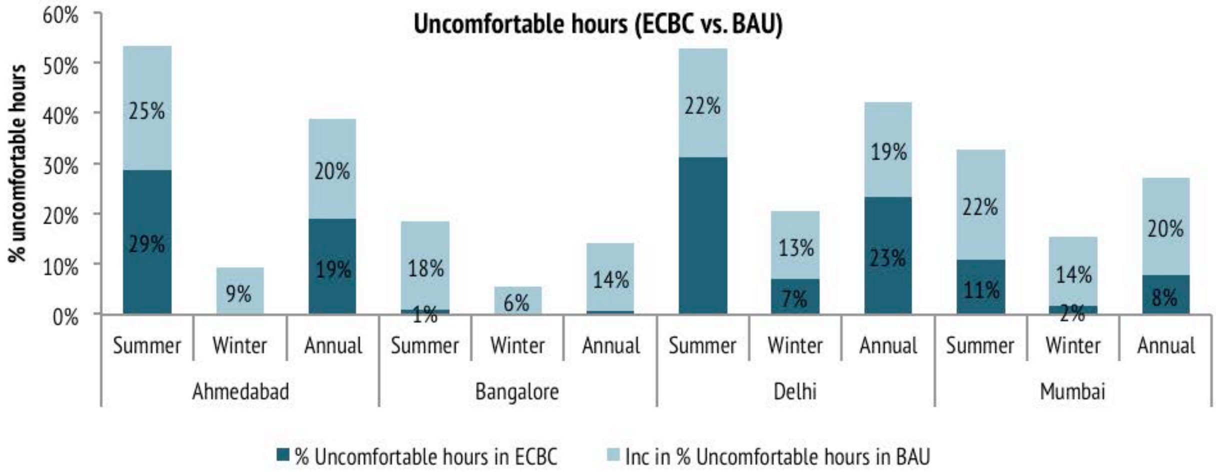


Figure 29: Uncomfortable hours (ECBC vs. BAU)

Figure 30 demonstrates that 15-20% reductions in uncomfortable hours (based on the adaptive thermal comfort model) could be achieved by increasing envelope efficiency in naturally ventilated buildings in various climate zones of India. Energy savings of 40% can be achieved in air-conditioned buildings in hot and dry, warm and humid, and composite climates by increasing envelope efficiency.

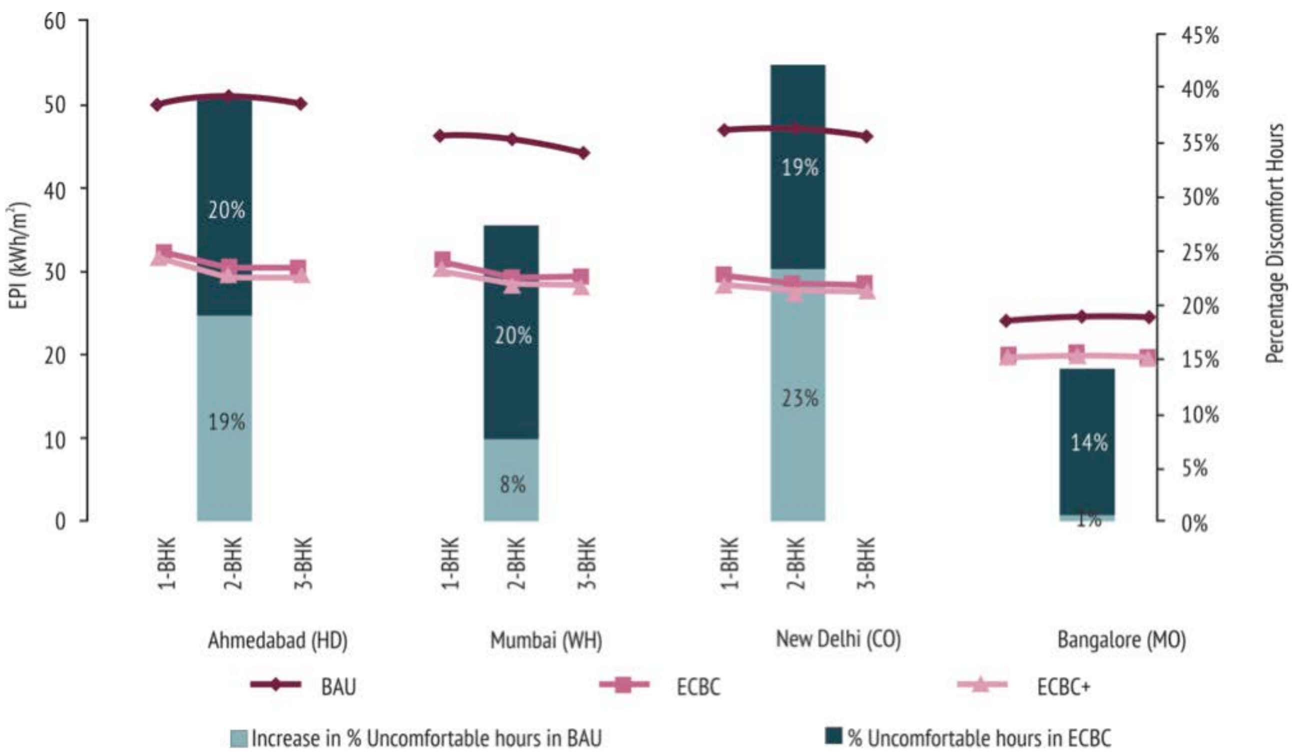


Figure 30: Uncomfortable hours variation with 1 BHK, 2BHK & 3BHK

CHAPTER 5: SCENARIOS FOR ENERGY USE PROJECTIONS

This section consists of the analysis of building energy modelling results and provides four projections for future residential energy use up to 2050.

Projections' Assumptions

The trends observed in the field and building energy modelling analysis, together with information from past studies, have been used to derive residential energy projections until 2050. These projections have been developed to estimate the increase in electricity consumption in the residential sector, and do not include other fuel sources. The following chart outlines scenarios developed for future residential projections:

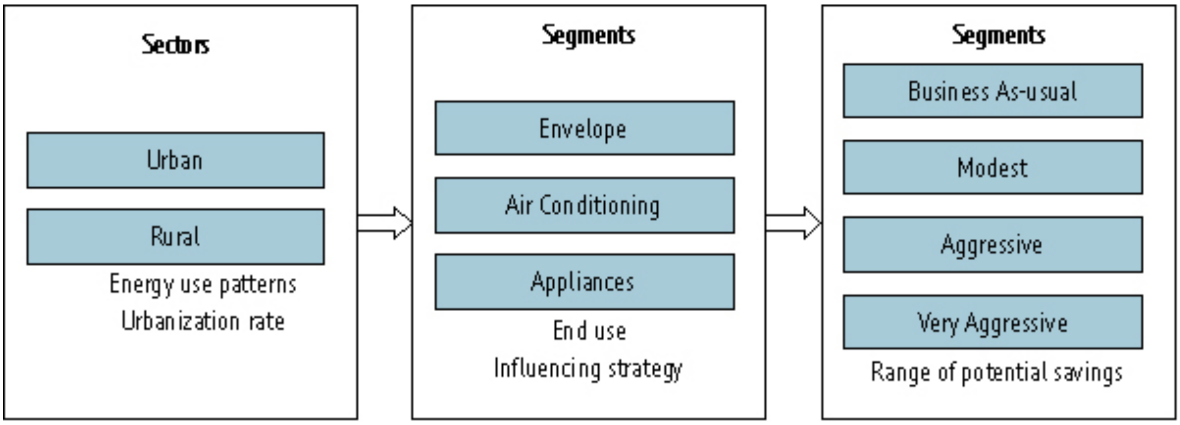


Figure 31: Developed scenario for future residential projections

As established in earlier studies, urban and rural households in India have different energy consumption patterns and, therefore, independent projections have been developed for each sector. This distinction is also important due to rapid rates of urbanisation and differing income levels in rural and urban areas.

The projections have been further differentiated by three end use components: air conditioning, envelopes, and appliances. As shown in the above sections, efficient envelopes can significantly reduce air conditioning energy use in households and thus have been entered as a separate section in the projections. The appliances component comprises of lighting, ceiling fans, refrigerators, televisions and other miscellaneous electrical devices (including cooking equipment).

To further identify savings potentials in the residential sector, four projection scenarios have been developed for India – business-as-usual, moderate, aggressive, and very aggressive scenarios. The business-as-usual scenario represents the natural progression scenario of residential energy use with minimal or no external influence. This scenario is different from a frozen scenario since natural increases in appliance and construction efficiency have been incorporated into the projection.

Projection scenarios are derived using three influencing variables – changes in penetration rate, future increases in efficiency and increases in usage. Due to anticipated population rise and increasing electrification of households, the air conditioning and appliance penetration rate in India is expected to increase dramatically. Since this increase is linked both to population and electrification, the penetration rates of appliances and air conditioners have been assumed to be the same for all four scenarios.

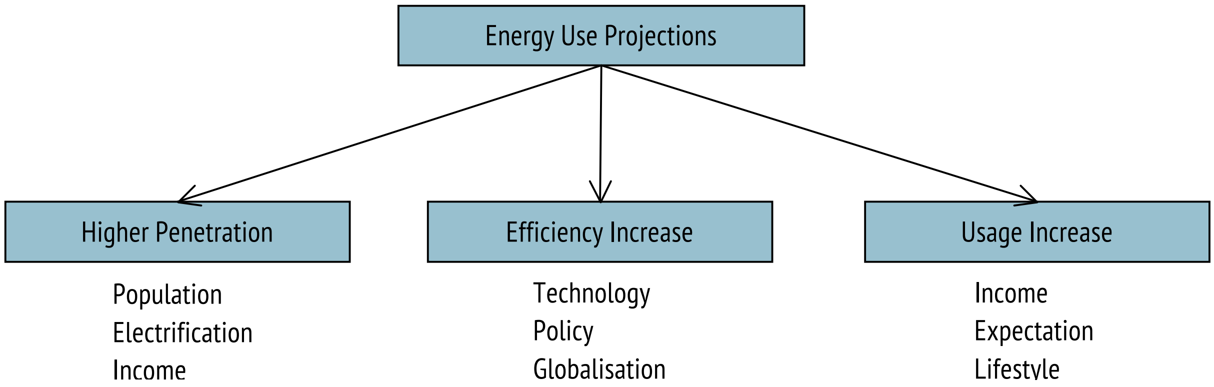


Figure 32: Energy use projections variables

However, penetration of efficient building envelopes into the market is highly dependent on policy interventions and, consequently, different penetration rates have been assumed for the scenarios. Similarly, policy interventions and technological development can significantly impact the penetration of high efficiency appliances and air conditioners into the market. Hence, different average efficiencies have been estimated for the scenarios.

Higher income levels are also expected to change the lifestyle and comfort expectations of Indian residents in future. Such lifestyle change will lead to higher operational hours of appliances and air conditioning as well as increased use of electronic devices. While sustained energy awareness campaigns can produce behavioural changes, this study assumes a uniform increase in usage for all the scenarios.

These projections do not incorporate the potential impact on operational hours from climate change or innovation in space cooling technology (such as solar air conditioning or the emergence of non-conventional cooling technologies), which could influence projected energy consumption considerably. The following table outlines the differences between scenarios. Details of the assumptions made in these projections are provided in Annex 6.

Projection Scenario	**Envelope Efficiency**	**Air Conditioning and Appliance Efficiency**
Business-As-Usual	Business As-usual	Natural Rise
Moderate	ECBC, Low Penetration	Moderate Rise
Aggressive	ECBC, High Penetration ECBC+, Low Penetration	High Rise
Very Aggressive	ECBC +, High Penetration	Very High Rise

Table 12: Projection scenarios for various envelope efficiencies and AC and appliance efficiencies

Population and Urbanisation Projections

The table below lists the population projection used in the study (UN population, 2012; Dhar, 2013):

Year	Population			Household Size		
	Rural	Urban	Total	Rural	Urban	Average
2015	879,712	428,509	1,308,221	4.90	4.25	4.69
2020	903,866	483,044	1,386,909	4.75	4.00	4.49
2025	916,767	542,191	1,458,958	4.60	3.76	4.29
2030	917,670	605,813	1,523,482	4.45	3.54	4.09
2035	906,218	673,584	1,579,802	4.31	3.33	3.89
2040	884,362	742,667	1,627,029	4.18	3.13	3.70
2045	854,130	810,389	1,664,519	4.04	2.95	3.51
2050	816,625	875,383	1,692,008	3.90	2.76	3.31

Table 13: Urban and Rural Projection scenario (UN Population projections, 2012; Dhar, 2013)

The table demonstrates a high projected urbanisation rate in India, with almost 52% of the population inhabiting towns and cities by 2050. Another important variable to consider is future changes in household size. Dhar indicates that the urban sector will move towards the nuclear family basis and predicts that the average number of occupants in urban households will shrink to 2.76 in 2050, compared to 4.25 in 2015. This observation is further supported by survey data where the average occupancy of urban households has been observed to be 4 as opposed to 5.25 in the 2001 census ((National Sample Survey Organization, 2001).

Business-As-Usual Scenario

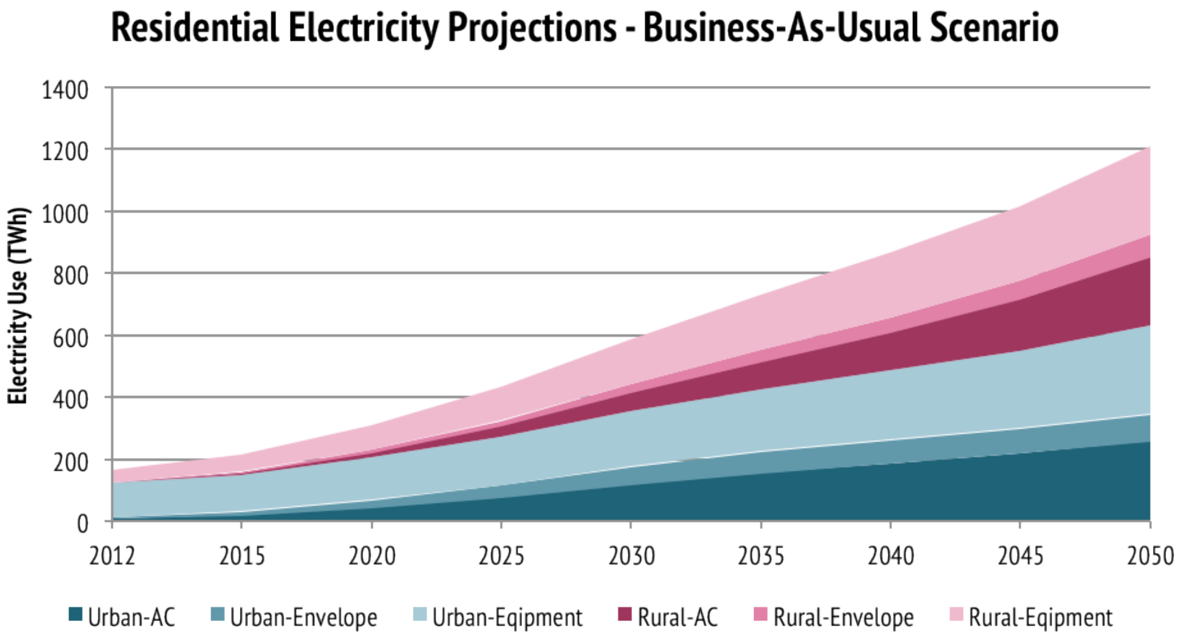


Figure 33: Electricity consumption projection in residential sector- BAU scenario

As seen in the chart above, electricity consumption is projected to rise by more than eight times under the business-as-usual scenario. This rise is driven primarily by three factors – increase in population, greater availability of electricity for residents and higher electricity use for comfort and appliances.

Currently, urban and rural equipment plays a major role in domestic energy consumption and this is expected to continue to increase. Currently, biomass is the primary rural cooking fuel, however, a move towards the use of more efficient fuels, such as electricity and liquid petroleum gas (LPG), is anticipated as these become more readily available.

Moderate Scenario

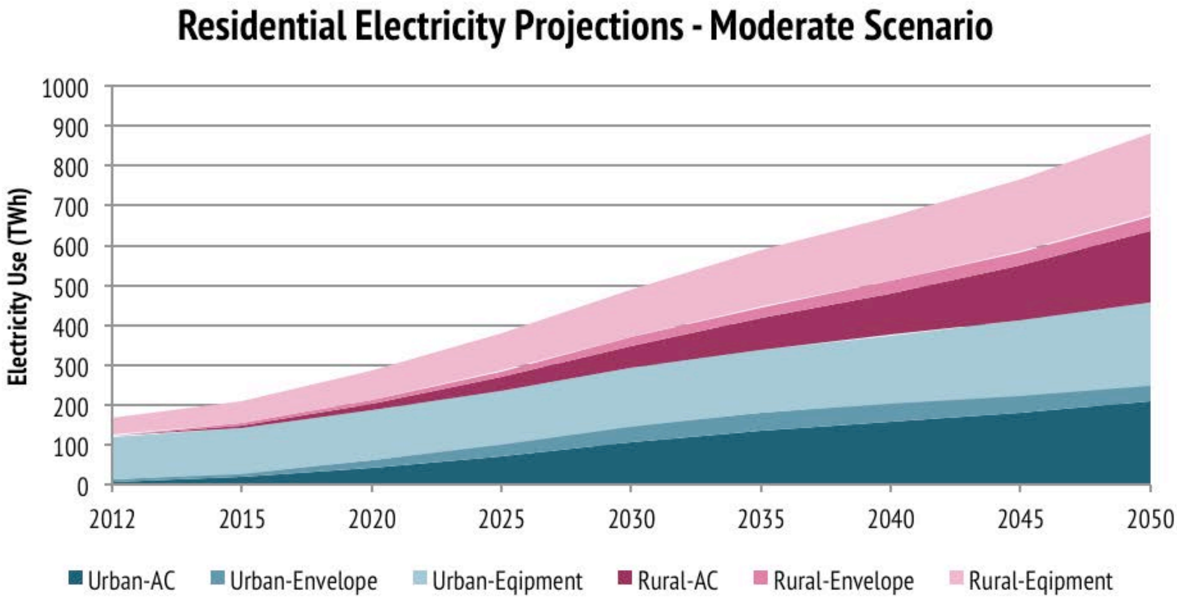


Figure 34: Electricity consumption projection in the residential sector- moderate scenario

The moderate scenario reflects the achievable electricity savings as a result of current policy and market-driven strategies. As seen in the chart above, the rise in electricity consumption can be curbed to a potential fivefold increase. This is a significant improvement on the business-as-usual scenario, showing that a 27% reduction in energy use is achievable with modest efforts.

The moderate scenario demonstrates that the implementation of minimum international codes and standards, such as the Internal Energy Conservation Code (IECC) 2009, can reduce lighting and air conditioning energy use by 35% and 19% respectively.

This scenario assumes a 5% use of ECBC envelopes in the new building market by 2050 as a result of modest policy efforts. Compared to the business as usual scenario, the modest scenario saves energy through the use of efficient envelopes in both urban and rural environments. Penetration of efficient envelopes into the market can reduce the total use of electrical energy in 2050 by 7%.

Aggressive Scenario

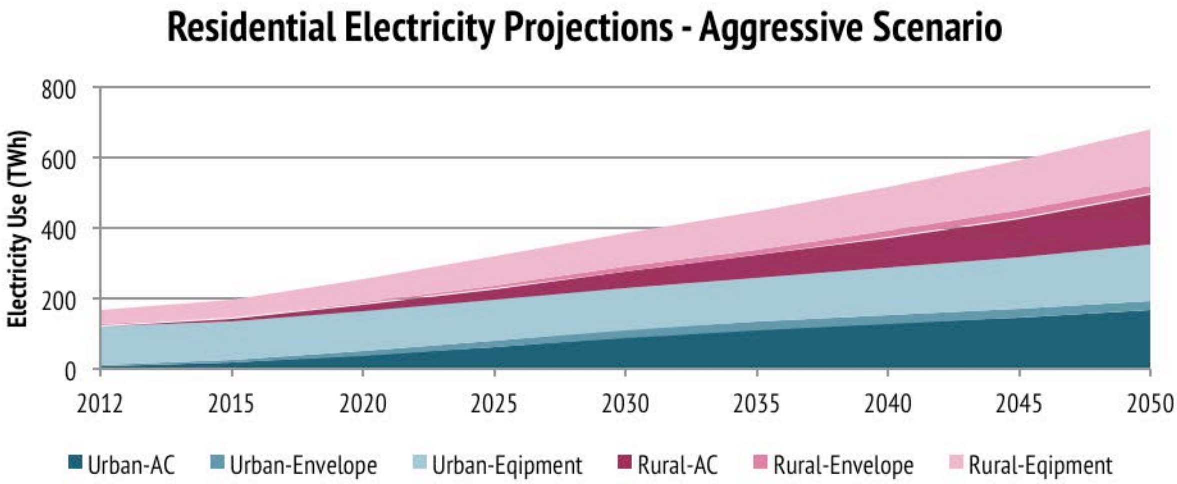


Figure 35: Electricity consumption projection in residential sector- aggressive scenario

The aggressive scenario reflects electricity savings with an aggressive policy and market-driven approach. As seen in the chart above, the rise in electricity consumption can be limited to four times that of current use. This scenario yields an additional 23% of savings over the modest projection scenario and a 44% energy use reduction compared to business-as-usual.

The aggressive scenario demonstrates that using high efficiency conventional air conditioners in new residential buildings can reduce energy use by 35% compared to business-as-usual. Similarly, efficient lighting, ceiling fans, refrigerators, and televisions in new buildings can produce reductions of 50%, 42%, 45% and 33% respectively over the business-usual scenario.

This scenario assumes penetrations of 50% by ECBC and 10% by ECBC+ envelopes in new buildings by 2050 as a result of aggressive policy efforts. A high level of efficient building envelope adoption by the market has the potential to reduce total electrical energy consumption by 9% in 2050.

Very Aggressive Scenario

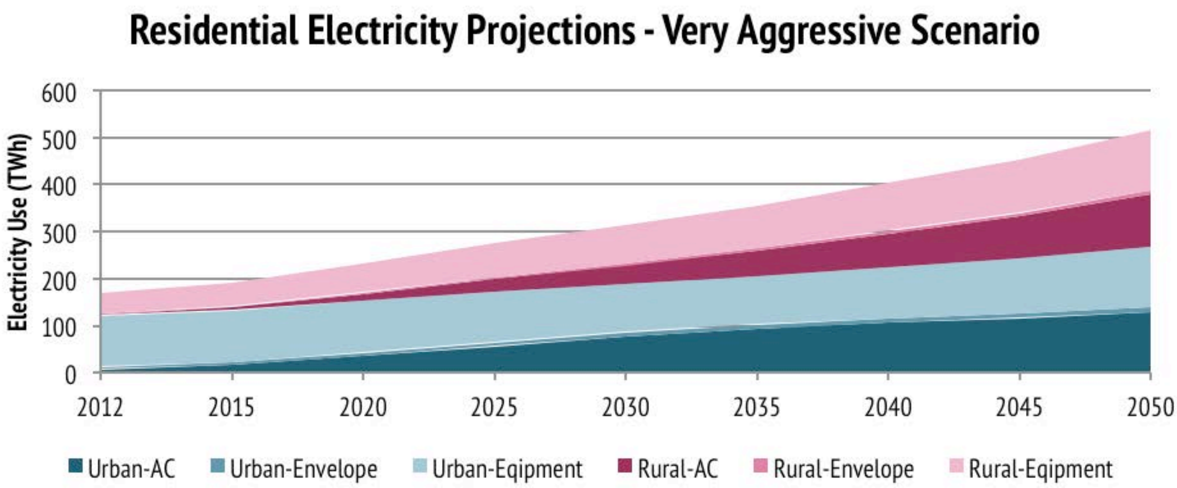


Figure 36: Electricity consumption projection in residential sector- very aggressive scenario

The very aggressive scenario is intended to reflect electricity savings with very focused and aggressive policy and market-driven strategies. Under this scenario, as shown in the chart above, the increase in electricity consumption can be restricted to three times the current residential use. This scenario yields 24% of additional savings over the aggressive projection scenario and a 57% energy use reduction compared to business-as-usual.

The very aggressive scenario demonstrates that using state-of-the-art, conventional air conditioners in residential buildings can reduce energy use by 52% compared to business-as-usual. In this scenario, the use of advanced and highly efficient technology is assumed. Similarly, very efficient lighting, ceiling fans, refrigerators, and televisions in new buildings can produce reductions of 57%, 56%, 56% and 45% respectively, over business-usual.

This scenario assumes a 30% penetration of ECBC+ envelopes generally, and a 40% penetration of ECBC+ envelopes in new buildings by 2050, as a consequence of very aggressive policy and market efforts. High adoption of efficient envelopes in the building sector has the potential to reduce total consumption of electricity in 2050 by 12%.

Comparison of scenario projections

The following chart compares the four projection scenarios by end use:

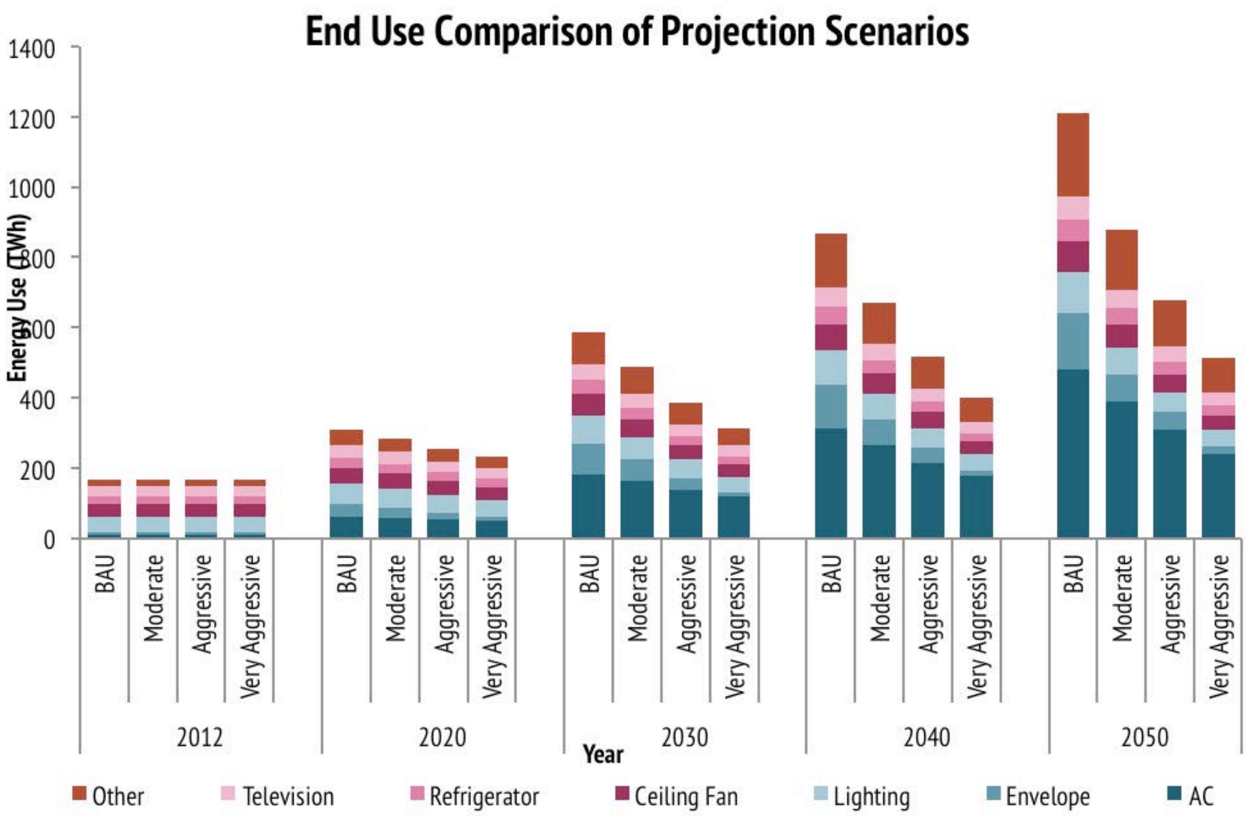


Figure 37: End use comparison of projection scenarios

As shown, policy strategies can have a huge impact on future energy requirements. Very aggressive policy and market efforts can compensate for the impacts of population growth, higher comfort expectations and the increased use of electrical equipment, such as lighting, ceiling fans, refrigerators, televisions and other devices (including VCR, DVD players and mobile chargers).

While efficient air conditioners can reduce energy use by 60%, overall air conditioning usage will continue to rise until 2050. The very aggressive scenario does not account for the development of new, non-conventional cooling technologies, which have the potential to influence future energy use dramatically. In addition, the residential retrofit market in building envelopes in India is difficult to determine and, therefore, zero uptake has been assumed in the projection analysis.
The following chart demonstrates the increase in energy usage per household for the projection scenarios. In the business-as-usual scenario, annual energy use per household is likely to increase from 650 kWh in 2012 to 2750 kWh by 2050. With very aggressive policy efforts, this increase can be reduced to 1170 kWh per household.

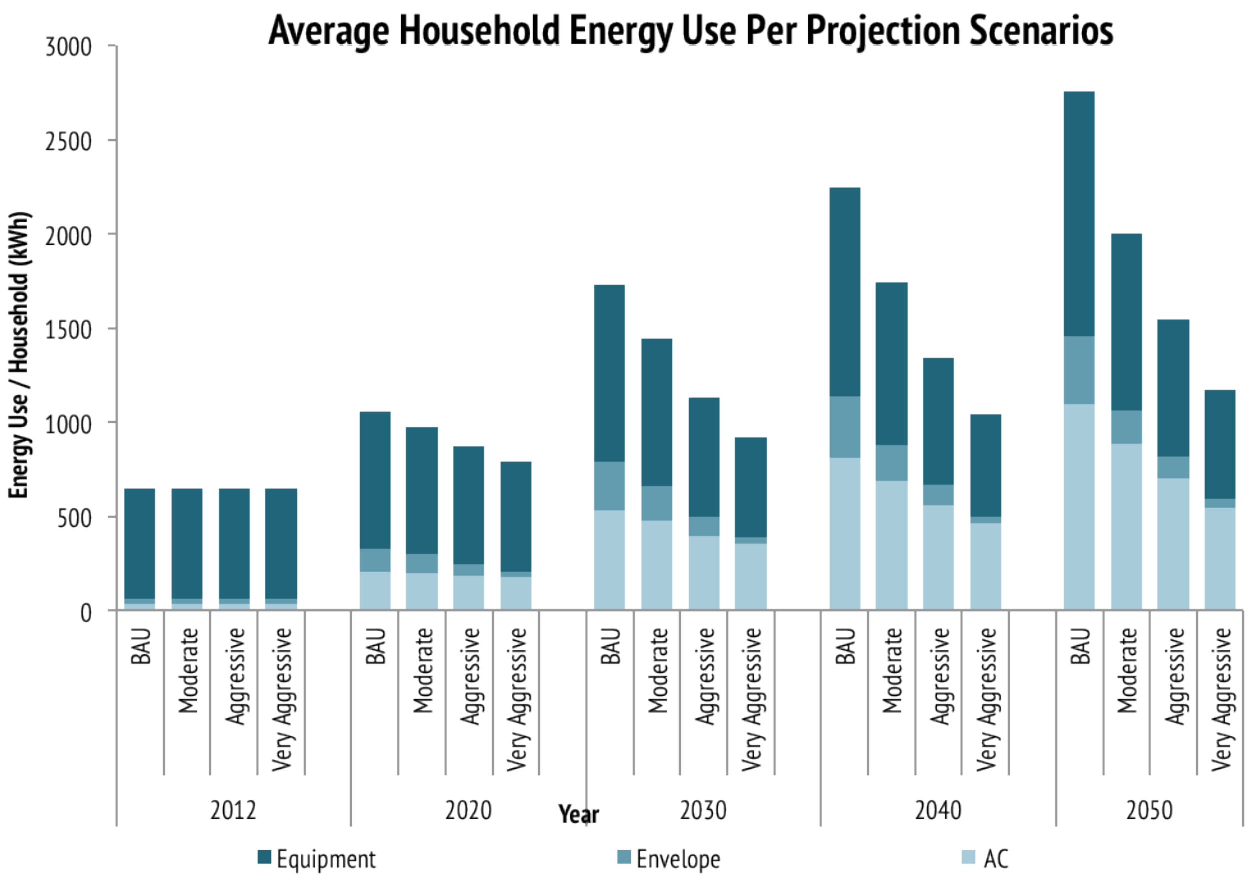


Figure 38: Average household energy use per projection scenarios

CHAPTER 6: CONCLUSIONS AND POLICY RECOMMENDATIONS

Main findings from the Survey

The survey established an essential baseline for estimations of savings potentials in four cities, each representative of a different Indian climate zone.

Assessment of the survey data identified the following major trends in residential energy consumption patterns:

- Residential floor areas for one, two, three and four bedroom properties vary significantly between Indian cities. In addition, connected load versus floor area relationships also show considerable variation, as a result of differences in climate, land availability and real estate values.
- Numbers of air conditioners, dwelling area and numbers of bedrooms are found to be the most significant correlated variables in annual energy consumption. While number of occupants is also an important variable, the correlation between number of bedrooms and number of occupants is strong.
- Levels of appliance penetration are similar for Mumbai and Delhi but vary significantly in Ahmedabad and Pune. Appliance penetration observed in the survey is higher than that recorded by national statistics for urban residences (NSSO, 2011). While this could be due to the small and focused sample size, this does indicate a trend of increasing appliance penetration rates.
- The increase in air conditioners is steadily increasing energy consumption in residences. However, once the number of air conditioners in a household reaches more than three, energy consumption stabilises or reduces. This indicates that usage patterns vary significantly for homes with more than three air conditioning systems. Discussions with experts indicate that additional air conditioning units are frequently not operated, which may be the reason for this. However, the factors influencing EPI stabilisation or reduction should be further investigated in future research.
- The survey results show that 45% of 1BHK units do not have air conditioning units in contrast with only 18% of 2BHK and 5% of 3BHK units. Most households in the survey have air conditioners installed in bedrooms while a few residences also have air conditioners in living rooms. This suggests that dwellings with higher numbers of bedrooms and larger areas have higher comfort expectations.
- Energy consumption within the sample shows wide variations, even among households with equal numbers of air conditioning units and appliances, indicating that occupant behaviour has a significant impact on total energy consumption.
- Connected load and annual energy consumption data gathered in the survey correlate well within a single city. However, the correlation is not strong when data is combined for all four cities. The measure of connected load is relatively easy to collect, compared to annual energy consumption, and can therefore be used as an alternative in estimating the annual energy consumption of a city.
- The survey indicates that occupants prefer to run their residences in temporal mixed-mode operation, using the air conditioning system only when the space becomes uncomfortable. This provides immense opportunity for reducing uncomfortable hours through the use of efficient envelopes, thus lowering space cooling energy consumption.
- Cooling and heating (non-cooling) season loads provide an important insight into energy consumption patterns for a city and correlate well with the number of air conditioners installed in the home. The base load to peak monthly energy consumption varies significantly for the different cities demonstrating the strong interrelationship between climate conditions and energy use. Efficient envelopes can reduce peak energy consumption during the cooling season while increasing comfort in dwellings during non-cooling seasons.

Main Observations from the Energy Modelling Analysis

Building energy modelling has been employed to identify the benefits of efficient envelope and appliance usage. The modelling and analysis results produce the following observations:

- The comparison of survey results and initial simulation engine results indicated an overestimation of energy consumption in residences in simulation, especially during the cooling season. Following discussions with residents and analysis of survey data, two key reasons were identified for these variations. One, the actual operation of bedrooms is in temporal mixed mode and two, the different thermal comfort expectations of Indian residents.
- Discussions with Indian residents and analysis of survey data provided important information for calibrating the simulation models with the survey data. Three main reasons were identified for the overestimation; the temporal mixed mode operation of bedrooms, air conditioning operation hours during the cooling season and the higher thermal adaptation of Indian residents.
- After the modifications, simulation results still showed higher than average energy consumption but provided much closer results (20% EPI variation) to the average of measured survey data and fell within the minimum and maximum values for the city.
- Two air conditioning control strategies were used to simulate occupant behaviour in the bedrooms – mixed mode and scheduled operation. In mixed mode, occupants opened windows and turned off air conditioning when conditions were favourable, while in scheduled mode, the air conditioning was run continuously to maintain space temperature and windows were kept shut. Counterintuitively, the energy consumption of both HVAC control strategies generated near identical results, indicating that there was little benefit (only 1 EPI difference) to mixed mode HVAC operation. This approach should be further explored, with different set points and comfort levels, to evaluate the benefits of mixed mode air conditioning operation.
- Building energy modelling demonstrated that 15-20% reductions in uncomfortable hours (based on the adaptive thermal comfort model) could be achieved by increasing envelope efficiency in naturally ventilated buildings in various climate zones in India.
- For air-conditioned buildings, building energy modelling demonstrated that energy savings of 40% can be achieved in hot and dry, warm and humid, and composite climates by increasing envelope efficiency.

Conclusions from the Energy Modelling Analysis

The trends observed in the field and building energy modelling analysis, along with information from past studies, have been used to derive residential electric energy projections until 2050.

- Projection scenarios indicate that electricity consumption is predicted to increase by more than eight times under a business-as-usual scenario.
- Using focused policy and market strategies, relative energy savings of 27%, 44%, and 57% can be achieved in modest, aggressive, and very aggressive scenarios, compared to business-as-usual.
- Under the business-as-usual scenario, the annual energy use per household is likely to increase from 650 kWh in 2012 to 2750 kWh by 2050.
- With very aggressive policy efforts, increases in projected annual household energy consumption can be reduced to 1170 kWh per household in 2050.

Policy Recommandations

This study provides a baseline for current residential energy consumption patterns in India and highlights the savings potentials that can be achieved by policy efforts. To achieve savings potentials in the residential sector, the following recommendations for action have been identified:

- The introduction of a specific code focussing on residential building envelope efficiency: as highlighted in the study, thermally efficient envelopes can reduce air conditioning energy use significantly in the air-conditioned building operation mode, as well as increasing comfort in naturally ventilated buildings. A residential code focused on envelope efficiency should be developed to realise the savings potentials of building envelopes and increase comfort. The code should be designed to include the following points:
    - Envelope components: the code should specify simple requirements for all envelope components, such as roof, walls, windows, shading devices, daylight devices, doors and floors. Alternatively, the code could provide overall envelope efficiency requirements, allowing designers to trade-off efficiencies in various envelope components.
    - Climate classification: climate plays a major role in energy use in buildings and, therefore, envelope specifications should relate to climate. The code should also encourage the use of the adaptive thermal comfort model in designing climate responsive envelopes.
    - Building operation: the code should encourage the use of temporal mixed mode operation in which the building is operated in the naturally ventilated mode when weather conditions are favourable. This will limit the operation of air conditioning systems to peak season times, when the building cannot maintain required thermal comfort by passive means.
    - Discrete specifications for multiple typologies: while building typology plays a role in energy consumption, for ease of enforcement and implementation the code should provide individual specifications for different types of building, for example, high-rise apartments, low-rise apartments, detached and attached single family homes.
- The introduction of a residential energy data baseline programme: while this study provides an important baseline for assessing residential energy consumption in four cities, a larger survey, with more detailed information, should be undertaken to gain a better picture of residential energy consumption.
    - This survey should specifically address the operational patterns of residences in Indian large and metro cities.
    - The scope of the program could be limited to dwelling units with floor areas of 100 square meters or more, with over 3 kW connected load, to focus on higher energy-consuming residences.
    - Accessibility of data is a challenge in India and, hence, survey data should be gathered through established channels, such as utility bills or property tax collection, rather than approaching individual residents.
    - While organisations such as the NSSO conduct large surveys, the design of these does not include elements for the assessment of energy savings potentials. The consumer expenditure survey and census data should incorporate added variables to improve the usability of collected data in predicting future energy consumption.
    - A common database should be created, with built-in quality checks, standard formats and templates to enable the effective sharing of information from different surveys. Use of open and linked (well documented) data can help to spread information on energy consumption patterns.

Further Action Required

The study also identified further action required:

- Detailed energy consumption monitoring of sampled residential complexes, using smart meters, should also be performed in the five climate zones of India, either for whole buildings or end-use, to gain a fuller understanding of energy consumption patterns in residential buildings.
- This energy use monitoring should be undertaken in conjunction with monitoring of environment and operational modes. This essential, and currently unavailable, data will assist in developing accurate energy consumption estimates and will significantly reduce uncertainties in future projections. In addition, it will assist in more reliable simulations and predictions of building energy use. Detailed data will also help in assessing savings potentials if energy-efficiency as well as demand-side programmes are targeted at residences. This is required for the development of effective energy efficiency policies.
- The cost-effectiveness, as well as return on investment, for efficient envelope components should be calculated for residential buildings to determine the exact requirements for different Indian climates. This would help in the development of guidelines for building envelope design to achieve optimum consumer benefits and assist in policy making aimed at saving energy.
- Cost savings achieved from effective building envelopes could be used for investment in air-conditioning systems and the energy saved by envelopes could be used to extend the supply of energy. These benefits should be documented and guidelines developed for such an approach.
- Current studies only examine residential energy consumption at unit-level. Not included is energy used for elevators, water pumping and common areas. In order to improve the design of cities and communities, baseline facility energy use should be assessed, and savings potentials and best practice guidelines should be developed for the residential sector. This would provide guidance for developers and policy makers in designing energy-efficient communities.
- Currently, most floor space projections are at national level and, while this provides important information for general forecasting, more specific projections should be developed for major cities in India to better plan and design energy-efficiency strategies. With city and county level information factored in, better efficiency plans, appropriate to current urban plans and the purchasing power of communities, could be developed.
- Low energy cooling technology should be evaluated and its suitability for meeting residential comfort requirements explored. As indicted in the projections, air conditioning penetration and energy use is expected to increase exponentially in coming decades and alternative cooling technologies could lead to significant savings.

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Global Buildings Performance Network

Building Policies for a Better World

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About GBPN

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