臺灣能源期刊　第二卷　第四期　第459-480頁　中華民國104年12月
Journal of Taiwan Energy
Volume 2, No. 4, December 2015, pp. 459-480

Examining the Effect of Efficient Construction Material on the Space Cooling Load in India

Astha Ummat[1*]

ABSTRACT

In 2001, India had the second largest urban population in the world, with about 286 Million people living in urban areas across India. As per the Indian Census, 2011, the urban population increased to 377 Million, thereby registering a growth of around 24%. This massive urbanization, coupled with the fact that about 70% of the buildings stock in India that will exist in 2030 is yet to be built, highlights the immense possibility that India has of leveraging the opportunity of energy efficiency and locking in energy savings in the buildings sector. This paper details the subsector modelling methodology of India Energy Security Scenarios, 2047, an energy scenario building exercise on the lines of the UK 2050 pathways calculator. The techniques to factor in a transition towards energy efficient envelopes in newly constructed buildings to arrive at the space cooling demand of the Buildings sector are discussed. Based on a thermodynamic approach, this paper talks about the savings, both monetary and in energy terms, which can be achieved if the country were to transition towards constructing buildings with energy efficient envelopes. The policy measures required to build an ecosystem which would enable this transition are also discussed.

Keywords: U Values, Energy Efficient Construction, Building Material, Space Cooling, Indian Buildings Sector

1. Introduction

1.1. The Energy Sector of India and the Opportunity for Energy Efficiency

Energy is a vital input for any economy, especially so for a developing economy like India. However, the energy scenario in India does not present a very rosy picture. While India supports about 17% of the world's population, it only has 0.4%, 0.4% (Ramana, 2010) and 6% (www.mining-technology.com) of the world's oil, natural gas and coal reserves respectively, a gross inequality considering that it is the fourth largest consumer of energy in the world after USA, China and Russia (Planning Commission, Government of India, 2012-17). The blackouts of 2012 wherein 28 states were hit with power cuts when three of the country's five electricity grids failed, leaving over 700 million people without power, highlights the gravity of the mismatch. The fact that India is importing nearly 80% of its crude oil consumption, 25% of its coal consumption and 35% of its natural gas consumption, the proportions of which are expected to increase in the near future, makes it imperative for planners to strategize India's energy sector and plan interventions in the energy demand

[1] Young Professional, NITI Aayog (National Institution for Transforming India), Government of India
Project Lead, the India Energy Security Scenarios, 2047 Tool
* Corresponding Author, Phone: +91-987-3764449, E-mail: asthaummat@gmail.com

Received Date: September 1, 2015
Revised Date: October 27, 2015
Accepted Date: December 2, 2015

and supply sectors.

Meeting and sustaining a projected 8-9% growth rate of the economy requires India's energy production to also grow at a rapid pace. While changing the supply mix of energy sources towards cleaner sources like nuclear and renewable energy is one way to go, exploiting the large scope of promoting energy efficiency in the energy demand sectors is also an effective solution. According to the India Energy Security Scenarios (IESS), 2047 (www.indiaenergy.gov.in), an energy scenario building tool developed by the Government of India, which enables the user to witness the energy security, land, greenhouse gas emissions and cost implications of his chosen pathway for the energy demand and supply sectors of the economy till the year 2047, if choices are made on the demand side to promote energy efficiency, India would be able to reduce its energy demand till 2047 by 34% as compared to a scenario wherein current policies and processes continue without any changes or drastic technological improvement. This would translate to a reduction in India's total import dependence from 57% to 38% in 2047 and an aggregate cost savings of about 300 Trillion INR. The efficiency gains can be directed to power other demand use areas and can be used to provide energy to the large section of the populace with no access to conventional sources of energy.

1.2. Harnessing the Huge Potential of Energy Savings in the Buildings Sector

Currently accounting for about 29% of the electricity demand in India, one of the growing sectors of energy demand in the Indian economy is the Buildings sector (Planning Commission, 2014). It has been estimated that 70% of the building stock that will exist in the year 2030 is yet to be built (Kumar *et al*., 2010). In the current budget announcement, the Finance Minister also announced that INR 70.6 billion would be spent "developing 100 satellite towns" surrounding large cities. Additionally, stemming from the recent vote in Parliament favouring the entry of foreign retailers, there would be a major rise in demand for commercial retail space. The market size of the real estate sector has been growing at a compounded annual growth rate of 12% per annum (National Skill Development Corporation). This sector, therefore offers tremendous potential to 'lock-in' energy savings if the new construction is energy efficient. Purely considering the commercial space, according to an analysis done by the Natural Resources Defence Council and the Administrative Staff College of India, stronger building efficiency codes and ratings programmes could lead to an estimated 3453 TWh of cumulative electricity savings by 2030, which is the equivalent amount of energy required to power almost 358 million Indian homes between 2014 and 2030. Additionally, 1184 million tonnes of carbon dioxide emissions could be avoided by 2030, equivalent to the annual emissions of more than 17 coal-fired power plants, over the same period of time. This highlights the enormous potential that efficiency improvements in the buildings sector could have in terms of cost savings, energy savings, delivering environmental benefits and tackling climate change (Natural Resources Defense Council and Administrative Staff College of India, 2014).

1.3. Looking Ahead: Assessing the Impact of This Transition in the Long Run

In order to gauge the impact of a transition towards more energy efficient technologies, it is important to see the long term benefits that accrue due to this transition as well as understand the drivers that will enable this transition. The recent construction boom coupled with increasing household incomes and an increased scale and speed of urbanization and migration provides us with a baseline and highlights the huge potential of introducing energy efficiency in the buildings that are yet to be constructed. India has a fantastic opportunity where it can tackle this issue and plan interventions before a major chunk of its buildings are constructed – Something which cannot be planned so easily once a building is already constructed and operational. Saving energy purely by energy efficiency measures would create a positive ripple effect as the energy saved here would be able to fuel other aspects of the growing energy demand in the economy, which in turn would use up lesser energy from other sources than what they would have done in the usual scenario.

In India, even though detailed literature exists on the lighting and appliances sections of the Buildings sector, modelling exercises on determining the cooling load of different kinds of buildings have not been carried out till now. This paper aims to put forth such a methodology and use the results to determine efficiency gains due to the use of more efficient construction material.

1.4. Overview of the Buildings Sector in India

The Construction sector in India is the second largest employer and contributor to economic activity after the Agricultural sector. Construction accounts for second highest inflow of Foreign Direct Investment after the services sector and employs more than 35 Million people. The Indian construction industry is valued at over USD 126 Billion (Make In India, Government of India, 2015). The construction sector can be classified into two sub-segments:

- Real estate (Residential, Commercial/Corporate, Industrial and Special Economic Zones)
- Infrastructure (Transportation, Urban Development and Utilities)

The contribution of the real estate sector to India's Gross Domestic Product (GDP) was estimated at 6.3% in 2013. It is also expected to generate more than 17 million employment opportunities across the country by 2025 (Confederation of Real Estate Developers' Associations of India (CREDAI) and CBRE, 2013).

According to the Twelfth Five Year Plan of the Planning Commission of India (Planning Commission, Government of India, 2012-17), this sector is one of the highest consumers of natural resources and energy. It is now being increasingly realised in the construction industry that sustainable development concepts, applied to the design, construction and operation of buildings, can enhance both the economic well-being and environmental health of communities.

In 2001, India had the second largest urban population in the world with about 286 Million people living in urban areas across India (Vaidya, 2009). As per the Indian Census, 2011, the urban population increased to 377 Million, thereby registering a growth of around 24%. As per recent estimates, nearly 590 Million people will live in Indian cities by 2030.

These statistics paint a picture of the huge opportunity of energy efficiency that exists in the construction sector, in particular, the real estate sector of India. However, although the use of energy-consuming appliances is increasing, energy consumption due to building envelope characteristics, which determine the lighting and thermal comfort level of a building, is expected to significantly influence the total energy consumption of a building. When a building does not meet the comfort criteria, occupants reply on mechanical and electrical comfort and lighting systems (Global Buildings Performance Network , 2014).

Incorporation of energy efficiency in the buildings sector would result in the development of a market for energy efficient products, improved design practices for lighting, natural ventilation/ free cooling systems, lower energy use and electricity bills, reduced connected load and an improved power factor. (Shabnam Bassi, Bureau of Energy Efficiency) However, there exist certain barriers like lack of awareness about the benefits of incorporation of energy efficiency measures, a higher initial cost of energy efficient technologies, lack of information about the payback periods for the same and an asymmetry in the sharing of costs and benefits.

State and local governments, real estate developers, and financial institutions are critical to the successful development and implementation of energy-efficient buildings. While existing government policies, building-rating systems, and active stakeholders do provide a foundation for accelerating progress in energy efficiency, as India's real estate market continues to grow, the current policy framework needs to be further developed and implemented by coordinated stakeholder action. It is therefore critical that these three leading stakeholder groups : state and local governments, real estate developers, and financial institutions drive development and adoption of energy efficiency measures in the buildings market for new construction and major retrofits.

1.5. The Buildings Sector of India Energy Security Scenarios, 2047

India built its first energy calculator (India Energy Security Scenarios (IESS), 2047), on the lines of the UK 2050 pathways Calculator, in February 2014. In order to improve the analytical credibility of the first version of the Indian Calculator, Version 2.0 of the same was developed by the Indian team and was launched on 27th August, 2015. The new IESS, 2047 Version 2.0 improved the analytical ability of the tool by factoring in updated datasets, improved modelling techniques and incorporation of new technologies and sectors that are gaining importance in the Indian Energy Space. The Buildings sector in the IESS, 2047 comprises of three sections: determining the Cooling load for different categories of residential and commercial buildings and the penetration of more efficient lighting and appliances, including cooling equipment, both in the Residential, as well as the Commercial sector. Each of these sections in turn depend on a variety of other variables including Internal Heating Load etc., as will be discussed in the following sections. As a subsection, this paper aims to capture the modelling techniques of determining the cooling load of different types of buildings, which then in turn can be met by different types of cooling equipment with varying efficiencies to translate into an overall electricity demand figure for a particular building. This analysis talks about assessing the impact of using different construction material on the space cooling load of different categories of buildings, both in the Residential and Commercial sectors of India. Even though solar water heaters are finding prominence in the Indian energy space, electric water heaters continue to remain a mainstay in India. To give an overall perspective on the electricity usage in a residential or commercial building, this paper also aims to capture the hot water demand by the aforementioned types of buildings.

As in the UK 2050 pathways calculator, the India Energy Security Scenarios, 2047 also consists of a variety of energy demand and supply sectors of India and four trajectories developed for each of these sectors, encompassing the range of most pessimistic to most optimistic outlooks for each sector. The user can pick a combination of levels from each sector to create his own pathway and witness the implications of his choices on Import Dependence of Fossil Fuels, Greenhouse Gas Emissions, Land use patterns and the Cost to the Economy.

Users are encouraged to look at this paper in conjunction with the excel model of the IESS, 2047 Version 2.0 (Accessible at www.indiaenergy.gov.in).

1.6. Trends in the Indian Buildings Sector

It has been estimated that 70% of the building stock that will be there in the year 2030 is yet to come up in the country (Kumar S. R., 2010) Residential and Commercial sectors account for 29% of the total electricity consumption (Planning Commission, 2014). These highlight the need for incorporating energy efficiency measures in the buildings sector.

Till date, India's policymakers have focused on reducing energy consumption in new commercial buildings, but it is notable that achieving a high target, would depend on the inclusion of the residential buildings sector in the target area. Residential buildings make up 75% of India's construction market, and until now have not been a priority for energy efficiency policy. The potential for expanding and adapting existing energy-efficiency policies to the residential segment is tremendous (The Economist Intelligence Unit, 2013).

1.7. Existing Policy Framework

The National Building Code (NBC) developed by the Bureau of Indian Standards defines norms and standards for health, safety and comfort of buildings and attempts to incorporate sustainable parameters to a certain extent. The Energy Conservation Building Code (ECBC) was launched by the Bureau of Energy Efficiency, Government of India in 2007 as a step towards promoting energy efficiency in the buildings sector.

The Energy Conservation Building Code (ECBC) sets minimum energy performance standards for various components of a commercial building having a connected load of 100 kW and above, and takes into account the climatic zone where the building is located. The purpose of this Code is to provide minimum requirements for the energy efficient design and construction of the buildings.

The ECBC provides design norms for:

- Building envelope, including thermal performance requirements for walls, roofs, and windows;
- Lighting system, including day lighting, and lamps and luminaire performance requirements;
- HVAC system, including energy performance of chillers and air distribution systems;
- Electrical system; and
- Water heating and pumping systems, including requirements for solar hot-water systems.

1.8. Estimation of Space Cooling Load for Different Categories of Buildings with a Focus on Building Envelope

Building envelope refers to the external façade and is comprised of walls, windows, roof, skylights, doors and other openings. The design features of the envelope affect the visual and thermal comfort of the occupants as well as the energy consumption in the building. An integrated building design considers the envelope, heating, ventilation and cooling (HVAC) system (Cooling equipment) and the lighting system as a whole. Altering the specifications of one system can change the performance of the other two significantly.

The building envelope must take into account the external and internal heating loads as well as day lighting benefits. External loads include mainly solar heat gains through windows and heat losses across envelope surfaces. Internal loads include heat released by electric lighting systems, equipment and people working in the Building space. To maintain thermal comfort and minimize the cooling load, the building envelope needs to optimize heat transfer through a variety of interventions including, but not limited to insulation, glazing and using more efficient building material.

ECBC compliant buildings have energy conservation measures like the use of flash blocks (Bricks that minimize heat loss), wall and roof insulation, high performance glass, high Solar Reflectance Index paints, vegetated roofs, Lighting Power Densities of < 1 W/ft^2, high performance chillers, economizers, viable frequency drives and cooling towers, fenestration, designs that increase daylight and reduce the need for daytime lighting, gains from better insulation, plugging of leaks and use of natural ventilation. Table 1 provides information on some basic measures for Energy-Efficient Envelope design.

The modelling of all the above variables, combined, to estimate the cooling load of different types of buildings is beyond the scope of this paper. The present analysis aims to provide a framework focussing on minimization of the thermal heat

Table 1. Basic Measures for Energy-Efficient Envelope Design.

Measures	Wall	Roof	Window
Minimize conduction losses	Use insulation with low U-factor	Use insulation with low U-factor	Use insulation with low U-factor
Minimize convection losses	Reduce air leakage using a continuous air barrier system	Reduce air leakage using a continuous air barrier system	Use prefabricated windows and seal the joints between windows and walls
Minimize moisture penetration	Reduce water infiltration: Use continuous drainage planeReduce air transported moisture: Use continuous air barrierReduce moisture diffusion into the wall: use vapour barrier/ retarder	Watertight airtight: Continuous air barrier, use vapour barrier/retarder	Use prefabricated windows and seal the joints between windows and walls
Minimize radiation losses	Use light coloured coating with high reflectance	Use light coloured coating with high reflectance	Use glazing with low solar heat gain coefficient (SHGC) and use shading devices

Source: USAID ECO-III Project, 2011.

losses by the use of more energy efficient building materials. This analysis also factors in internal heating load due to the occupants of a building.

1.9. Key Policies Considered

Since the buildings sector has inter-linkages with a number of other sectors, both on the demand side as well as the supply side, this modelling exercise aims to project the energy demand in Buildings by taking into account a variety of policies, some that are already in place and some that have been recently launched in India. On the demand side, the Buildings sector has interlinkages with the growth of Industry, Transport, Telecom *etc*. and on the supply side, the Buildings sector witnesses interconnections with the use of renewable energy solutions to power buildings, Solar water heaters to meet the hot water demand of buildings *etc*.

In order to make projections at different stages, some of the policies that have been considered are as follows:

1. Housing for all by 2022: Slum rehabilitation of Slum Dwellers with participation of private developers using land as a resource and Promotion of affordable housing for weaker section through credit linked subsidy. This policy, via the assurance of a house to every citizen of India, is expected to lead to a surge in the residential sector building stock.
2. 24x7 Power for all by 2019: An initiative of the Government of India to provide 24x7, reliable and quality, access to electricity to all citizens of India. This would drastically reduce the backup diesel generation presently required to meet the gap between electricity demand and supply.
3. 100 smart cities: Development of 100 'smart' cities. This includes developing certain new, and retrofitting some old cities, on the parameters of energy efficiency, better solid waste management, more efficient transportation structures etc.
4. Increased adoption of efficient building codes by states.
5. Development of large retrofitting programs for commercial buildings.
6. Standards and Labelling Programme for Appliances.
7. Increased incentive schemes by the Government to promote adoption of energy efficient buildings *e.g.*: Rebate in property tax etc.
8. Expansion of the scope of building codes in terms of Energy Performance Index to help cover more buildings.
9. Market transformation *e.g.* Demand Side Management (DSM) based Efficient Lighting Programme (DELP): DELP proposes to cost barriers to promote LEDs by monetizing the energy consumption reduction in the households sector and attract investments therein. It also evolves a robust business model that secures commercial investment.

2. Categories of Buildings in the Modelling Exercise of the IESS

The exercise aims to capture the potential to reduce energy consumption (by focussing on a reduced space cooling load) in buildings through the use of energy efficient construction material. Efficiency gains due to the adoption of more efficient lighting and appliances, to meet the reduced energy demand, have been considered separately in the residential lighting and appliances analysis which focuses on increased penetration of more efficient lighting and appliances to meet the reduced cooling load. The buildings sector has been defined to include residential and non-industrial buildings.

2.1. Residential Buildings

The categorization of the Residential Building space is done as follows. Firstly, three scenarios on how the structure of cities would pan out till the year 2047 are considered. In the urban spaces in India, three categories of buildings: High rise Development, Horizontal Development and Affordable Housing (A new initiative of the Indian Government in an attempt to provide housing to all citizens till the year 2022) are considered. The three scenarios pan out in different ways, each scenario giving more prominence to one category of building space, till the year 2047. The end objective of this analysis is to be able to capture all scenarios of the development of the Indian building space- as each category of buildings have different energy consumption patterns. A snapshot of the assumptions regarding the split of the building stock in each of the three categories is presented in Table 2.

Secondly, in the Rural spaces in India, three categories of buildings are considered: Pucca House (A house which has walls and roof made of the following material - Burnt bricks, stones (packed with lime or cement), cement concrete, timber, ekra *etc*.), Kaccha House (A house in which the walls and/or roof of which are made of material other than those mentioned above, such as unburnt bricks, bamboos, mud, grass, reeds, thatch, loosely packed stones, *etc*.) and Semi -Pucca house (A house that has fixed walls made up of pucca material but roof is made up of the material other than those used for pucca house) (Ministry of Statistics and Programme Implementation, 2011) Using the Housing for All by 2022, developmental policy of the Government of India as a driver, Kaccha houses and Semi Pucca houses are assumed to phase out till the year 2022, giving way to Pucca Houses in Rural areas.

Table 2. Assumptions Regarding to Percentage of Building Stock under Each Category in the IESS, 2047

Description	Level	2012	2017	2022	2027	2032	2037	2042	2047
Under High Rise	1.0	34%	32%	29%	27%	25%	23%	22%	20%
Under Horizontal Development	1.0	65%	63%	61%	61%	61%	63%	64%	66%
Under Affordable Housing	1.0	1%	5%	10%	12%	14%	14%	14%	14%
Under High Rise	2.0	34%	35%	37%	38%	40%	42%	43%	45%
Under Horizontal Development	2.0	65%	60%	53%	50%	46%	44%	43%	41%
Under Affordable Housing	2.0	1%	5%	10%	12%	14%	14%	14%	14%
Under High Rise	3.0	34%	37%	40%	43%	47%	51%	55%	60%
Under Horizontal Development	3.0	65%	58%	50%	45%	39%	35%	31%	26%
Under Affordable Housing	3.0	1%	5%	10%	12%	14%	14%	14%	14%

The numbers in the table represent the percentage of the building stock under the category.
Source: Author’s assumptions.

2.2. Commercial Buildings

Within the Commercial sector, the area under commercial enterprises has been divided into:

1. Own Account Enterprises (OAE), which are owned individually or run by a family, having no hired employees.
2. Establishments, which are larger than OAEs and are characterised by a hired work-force.

Each of these categories are further divided into the following categories, each having its own distinct pattern of energy consumption:

I- Wholesale Trade. II- Retail Trade. III- Restaurants and Hotels. IV- Transport & Haulage. V- Post & Telecom. VI- Financial Intermediation. VII- Real Estate, Renting & Business Services. VIII- Public administration and defence; compulsory social security. IX- Education. X- Health & Social Work. XI-Other Community, social & personal services. XII- Other.

Figure 1 presents a snapshot of the different categories and subcategories of the components. It explains the categorization of the different kinds of residential and commercial buildings, as used in this analysis. As mentioned above, the buildings sector of India is divided into the Residential and Commercial segments, which are further subdivided into different categories based on the aforementioned criteria. The methodology detailed in the following sections, is utilized to capture the savings in the cooling load for each of the above categories of buildings separately. The entire aim of this categorization is to drive policy towards those patterns of construction that would prove to be most energy efficient.

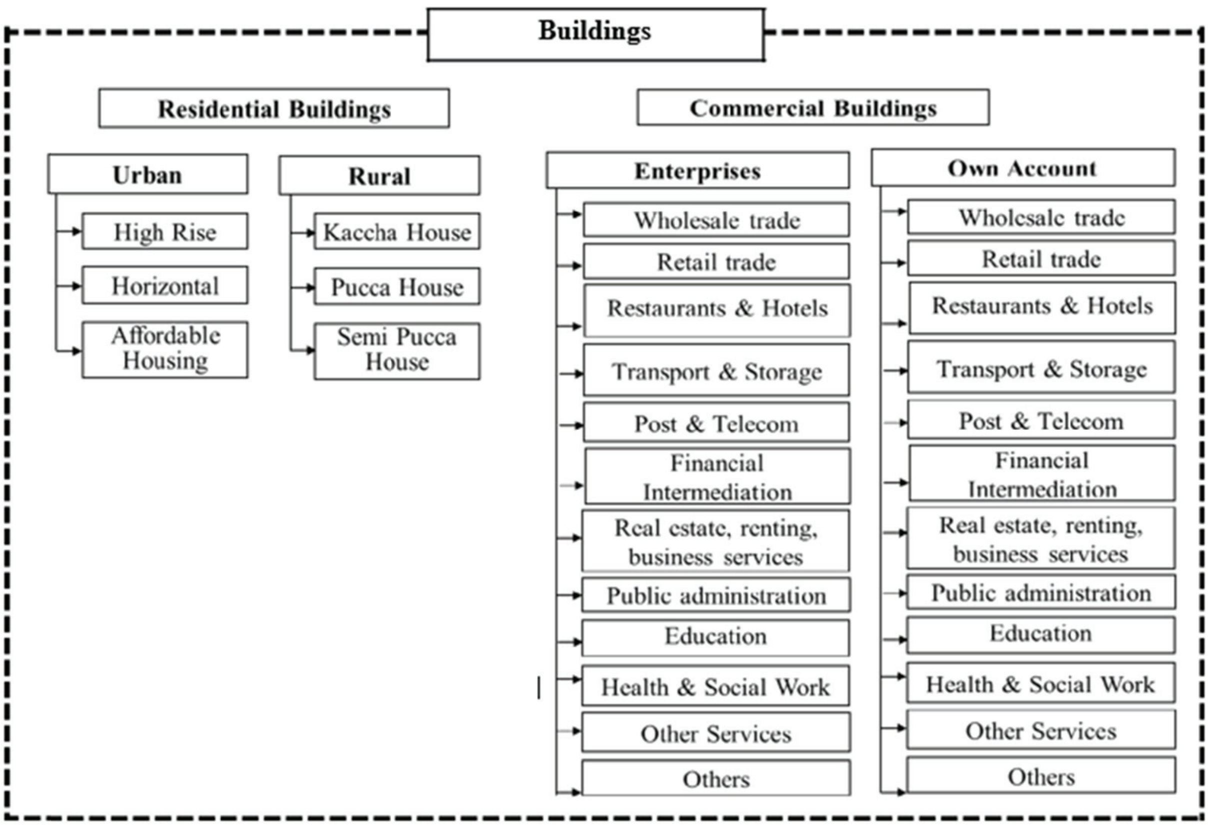

Fig. 1. Categorization of Buildings in the IESS, 2047 Version 2.0 Modelling Exercise
Source: www.indiaenergy.gov.in

3. Interplay of Different Choices in the IESS, 2047

3.1. How the Sector Choices Work in the Buildings Sector Analysis of the IESS

The levers being offered to the user for the Buildings sector in India are as follows:

1. External Temperature Rise.
2. Penetration of energy efficient buildings in the Residential Sector (Expressed as a percentage of the total buildings stock of a particular category of buildings).
3. Penetration of energy efficient buildings in the Commercial Sector (Expressed as a percentage of the total buildings stock of a particular category of buildings).
4. Efficiency of Residential Lighting and Appliances.
5. Efficiency of Commercial Lighting and Appliances.

Three choices are offered to the user on how he/she expects the external temperature to rise till the year 2047. The chosen option for temperature rise impacts the heating and cooling demand for buildings.

3.1.1. For Estimating the Residential Sector Energy Demand

1. The user can pick how he/she expects the structure of cities to pan out in the years to come. (Till 2047 – between high rise development, horizontal development and affordable housing)
2. The user can then pick how many of these structures would use energy efficient building material for construction purposes based on the different policy and behavioural drivers as detailed later in this document.
3. The user then picks the configuration of appliances (of different efficiencies) which will be utilized in these buildings to meet the demand for heating, cooling, lighting etc. Other residential appliances like televisions etc. are also included in the analysis and the choices for energy efficiency configurations for these are also available to the user.

The aggregate residential buildings demand is estimated by a combination of the above levers.

3.1.2. For Estimating the Commercial Sector Energy Demand

1. The user can pick the penetration of energy efficient construction in the commercial building stock. This in turn impact the U values and the resultant space cooling load of the building.
2. The user then picks the configuration of appliances (of different efficiencies) which will be utilized in these buildings to meet the demand for heating, cooling, lighting etc.

The aggregate commercial buildings demand is estimated by a combination of the above levers.

3.2. The Main Outputs of the Analysis of the Buildings Sector of the IESS, 2047

1. Space Cooling demand.
2. Hot water demand.
3. Electricity demand from the different categories of appliances: Category 1: Appliances that meet the heating and cooling demand (Cooling equipment like fans and air conditioners), Category 2: Appliances that meet the hot water demand (geysers and solar water heaters) and, Category 3: Other appliances like lights (Bulbs, Tube lights, CFLs and LEDs), Televisions, Refrigerators and other appliances like Computers, Music systems etc.

As this analysis focuses on harnessing the potential of energy efficiency during the construction of a building and thereby estimating the space cooling load of different categories of buildings, this paper aims to discuss section 1 and 2 of the outputs from this sector.

4. Fixed Assumptions

a) Estimation and projection of floor space per capita

The IESS, 2047 V2 offers the user a choice between three different rates of growth of the economy (7.4% CAGR, 6.7% CAGR and 5.8% CAGR till the year 2047). To incorporate these three levels of GDP growth rates, it is necessary to estimate how demand of the output from one sector would vary as rate of growth of India's GDP varies. Such an exercise was carried out for each of the sector using regression curves. The choice of such a curve for a particular sector was based on: 1. Literature study of that sector that rationalizes the possible relationship between demand activity and rising income levels of a country 2. Studying past trends of GDP v/s demand activity of other countries. The trend of space requirement per capita for the three different growth rates of GDP has been arrived at by analysing the historic growth of residential and commercial floor space per capita viz a viz the GDP, computing the elasticity of activity demand in buildings with respect to GDP and projecting the space requirement till 2047. Based on the above process, it was determined that the buildings sector in India fits into a Gompertz regression (An S shaped curve, which initially increases till a certain level of GDP and the plateaus). As India is undergoing several structural shifts in its development story, the per capita buildings space is expected to steadily rise till the year 2047.

For the 7.4% CAGR of GDP option, Residential floor space per capita is expected to rise from 10.8 m^2/Capita in 2012 to 32.9 m^2/Capita in 2047 and Commercial floor space per capita is expected to rise from 0.6 m^2/Capita in 2012 to 5.9 m^2/Capita in 2047.

b) External temperature

Extensive literature review was done to arrive at an average external temperature for India for summer, winter and monsoon seasons. The user is given three options on how this temperature will rise in the next 35 years to come. The temperature stress scenarios, as entailed in Table 3, are aimed at giving a broad range of possible scenarios as to how the temperature can change in the years to come.

c) Internal thermal comfort temperature

In order to estimate the heating and cooling requirement for the chosen external temperature

Table 3. External Temperature Stress Scenarios in the IESS, 2047

Season	Average Temperature (Degree Celsius)	Temperature Scenarios till 2047	
Summer	37.5	Scenario 1	No temperature rise till 2047
Winter	10	Scenario 2	A 2 degree Celsius rise in temperature till 2047
Monsoon	33	Scenario 3	A 4 degree Celsius rise in temperature till 2047 (Most pessimistic)

Source: Attri and Tyagi, 2010.

scenario, the Internal Comfort temperature depending on the different levels of appliance ownership is estimated for the three seasons, for urban and rural areas separately.

The appliance ownership patterns in urban and rural areas in turn also depend on the three levels of GDP growth of the economy and can be accessed in detail in the documentation of the 'Residential Lighting and Appliances' section of the IESS, 2047.

For the GDP Growth scenario of 7.4% (CAGR) till 2047, the appliance ownership patterns of cooling devices and the internal thermal comfort temperatures for Summer, Winter and Monsoon, have been estimated for the year 2012, and are presented in Table 4 and Table 5 below.

d) Dimensions of different categories of buildings

The Buildings sector aims to encompass different categories of buildings that have been spoken about earlier in this document. For the purpose of the same, the dimensions of the different categories of buildings along with a floor-space ratio has been estimated to arrive at the total area of building space contributing to the generation of energy demand. The dimensions of the different categories of buildings is presented in Table 6. The assumptions around floor area index of these categories of buildings is presented in Table 7.

e) Rate of heat loss (U- Values) for different kinds of buildings and construction material

As a key component of the analysis, in order to measure the gains from using more efficient building material, the U values of the different components of a building belonging to each category (Urban- Code Compliant, Rural-Conventional and Urban- Conventional) are presented in Tables 8, 9 and 10 respectively.

India has six climatic zones: Hot and Dry,

Table 4. Appliance Ownership Patterns of Cooling Devices (Percentage of population)

Appliance penetration	**Region**	**2012**	**2017**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Ceiling Fans	Urban	93%	95%	96%	98%	100%	100%	100%	100%
	Rural	64%	73%	82%	91%	100%	100%	100%	100%
Room Air Conditioners	Urban	7%	15%	24%	32%	40%	45%	50%	55%
	Rural	4%	11%	17%	24%	30%	35%	40%	45%

Source: National Sample Survey Organization, Government of India.

Table 5. Estimated Internal Comfort Temperature for Urban and Rural Areas

Internal Comfort Temperature for Summers	**2012**	**2017**	**2022**	**2027**	**2032**	**2037**	**2042**	**2047**
Urban	30.56	29.91	29.25	28.58	27.90	27.58	27.25	26.93
Rural	32.8	31.8	30.8	29.7	28.6	28.2	27.9	27.6

Calculated using a weighted average of the penetration of different types of cooling equipment and the internal comfort temperature of an individual using that equipment. (24 degree Celsius for individuals possessing air conditioners, and 30.5 Degree Celsius for individuals possessing ceiling fans.

Source: Expert consultations.

Table 6. Dimensions of Three Different Categories of Buildings: Urban, Rural and Affordable Housing

Category	**Urban**	**Rural**	**Affordable Housing**
Area (m^2)	108	108	55
Height (m)	3	3	3

Source: Expert consultations and KPMG India.

Table 7. Floor Area Index of Different Categories of Buildings in the IESS, 2047

Floor Area Index *(The ratio of a building's total floor area (gross floor area) to the size of the piece of land upon which it is built.)*	
High Rise Development	10
Horizontal Development	2
Affordable Housing	3
Kaccha House	1
Pucca House	1
Semi Pucca House	2

Source: Author's assumptions.

Table 8. U Values of Different Components of Categories of Buildings in Urban Areas (Compliant to Energy Conservation Building codes)

Urban- ECBC Compliant (W/m^2/Degree Celsius)	**High rise**	**Horizontal**	**Affordable**
Wall	0.440	0.440	0.440
Roof	0.261	0.261	0.261
Window	0.33	0.33	0.33

Source: USAID India and Bureau of Energy Efficiency, Government of India, Pg 26, 2011.

Table 9. U Values of Different Components of Building in Rural Area (Not Code Compliant)

Rural (W/m^2/Degree Celsius)	**U Value**
Wall	0.16
Roof	0.25
Floor	0.29
Window	0.58

Source: Central Public Works Department, India, 2013; K.I. Praseeda, 2014; Lok Sabha Secretariat, Government of India, 2013.

Warm and Humid, Moderate, Cold and Cloudy, Cold and Sunny and Composite. The U-values vary according to the six climatic zones in India. Due to unavailability of reliable data estimates on the different categories of floor space in each climatic zone, an average of the U values, for all climatic zones has been considered.

f) Percentage of household space to be cooled

Table 10. U Values of Different Components of Building in Urban Area (Not Code Compliant)

Urban- Business as Usual (W/m^2/Degree Celsius)	High rise	Horizontal	Affordable
Wall	1.722	1.722	1.722
Roof	2.942	2.942	2.942
Window	5.8	5.8	5.8

Source: Expert consultations and Global Buildings Performance Network, 2014.

Table 11. Percentage of Household Space Cooled.

	2012	2017	2022	2027	2032	2037	2042	2047
Urban	21.00%	21.78%	23.85%	25.92%	27.99%	30.06%	31.34%	32.63%
Rural	21.00%	21.78%	23.85%	25.92%	27.99%	30.06%	31.34%	32.63%

Source: Benchmarked with International Energy Agency, 2013.

In order to determine the cooling load, and subsequently the energy demand of a building, assumptions regarding the percentage area of a household cooled have been made, and are detailed in Table 11.

g) Hot water demand per household: 20 litres/ day/ capita (Central Public Works Department, India, 2013)
h) Specific heat of water: 4.3 Joules/Gram degree Celsius
i) Average temperature to which water will be heated: 41 degree Celsius (United Kingdom Home Care Association Limited, 2010)
j) Average efficiency of water heater: 54.35% (Bureau of Energy Efficiency)
k) Occupancy heat gains: According to ASHRAE 55, one person occupies 12 m^2 of floor area in a built up space and emits 120 W of Heat. (Expert views from BEE and ASHARE 55)
l) Cooling Degree Days: 3105 (An average of all Climatic zones in India)

5. Methodology

The variables detailed above are used to generate the results though the following methods. The U value of the category takes into account the efficiency of thermal conduction of different kinds of building materials, as are being used in the analysis. These are weighted according to the percentage penetration of energy efficient versus conventional construction as selected by the user.

a) Space Cooling Load for category A = U-value of Category A x Area of Category A, applicable to interventions x Temperature Differential (between external and internal comfort temperature).
b) Space Cooling Demand = Space Cooling Load x Cooling Degree Days of India.
c) Calculation of Hot Water Demand = Hot water demand per person per household x Specific Heat of Water x Temperature Differential x Duration of Hot water requirement.

6. Drivers of the Buildings Sector in India

A number of drivers, both policy and behavioural, are used as the backbone for constructing the four scenarios (levels) of the analysis, both for the residential and commercial sectors. The main drivers of the buildings sector considered for this analysis are as follows:

1. Increased scale and speed of urbanization and migration.
2. An increasing share of the services sector in the Indian economy which increases the demand for office space.
3. Sharp growth in organized retailing, which is expected to grow at over 25% in the next few years (National Skill Development Corporation).
4. Increasing purchasing power of consumers.
5. Wise architectural design/Innovation in architecture and use of material with low embodied energy.
6. Increased awareness and regulatory instruments leading to stricter implementation of green building codes.
7. Increased incentive schemes by the government for transitioning to energy efficient buildings like a reduced tax on investment for retrofitting existing building, reduction in the registration fee, rebates in electricity charges for those using solar water heaters, low interest loans for green housing etc.
8. Single family and multi-family households are expected to show the highest growth rates between 2005 and 2050 (Global Buildings Performance Network, 2014).

7. Assumptions Behind the Buildings Sector Analysis of the IESS

1. The India Energy Security Scenarios, 2047 includes the energy consumed in using these buildings (lighting and appliances).
2. Energy embodied in construction of these buildings and structures is not considered here.
3. The potential to reduce energy consumption through improvement in efficiency of appliances and equipment, already accounted for in the commercial and residential lighting and appliances sectors, is not taken into account.
4. Buildings can be made more efficient by designs and construction material that reduce the need for heating, lighting, ventilation and air conditioning.
5. Energy intensity savings that are realized, over and above what is possible through improvements in appliances and equipment is taken into account.

8. Inter-Linkages with Other Sectors

8.1 Residential Buildings

As detailed in Section 5, Space cooling and water heating demand was calculated on the basis of the temperature differential in different seasons and the thermal conduction capacity of building materials for each type of building, based on its dimensions, both in rural and urban areas. Although not explained in this paper, the subsections below briefly explain how electricity demand of the buildings sector can be arrived at by using a combination of the space cooling load and the penetration of the different categories of lighting and appliances.

1. The estimated space cooling demand is assumed to be met different categories of cooling appliances based on a ratio which is a function of their wattage and efficiency ratios. The user in turn has a choice to pick between different configurations of appliance efficiency based on their efficiency levels. This is detailed in the separate section on the efficiency of residential lighting and appliances in the India Energy

Security Scenarios, 2047. Hence a combination of the trajectories of residential building envelope and residential lighting and appliances give the total demand for electricity in the residential buildings sector in India.

2. The hot water demand calculated is met by two categories of appliances, geysers and solar water heaters. The user has an option to select the different penetrations of solar water heaters, which he can do from the trajectories of solar water heaters, being offered in the supply side. The rest of the demand is being met from various other appliances like geysers etc. The total energy demand from hot water is a combination of the two aforementioned choices.

8.2 Commercial Buildings

A similar approach is followed for estimating the energy demand from commercial buildings. Since the commercial lighting and appliances sector follows a modelling approach which uses the Energy Performance Index as the basis, the savings realized due to utilization of more energy efficient building material is built into estimating the cooling demand.

9. Costing Approach of the IESS, 2047, Buildings Sector

This approach to costing attempts to capture the additional cost of using more energy efficient construction material as opposed to constructing the building with conventional material. Other factors such as the hours of usage, height of the building etc. all remain constant in the two scenarios.

The cost per square meter of conventional building construction material versus energy efficient building construction material was arrived at by an extensive literature review, expert consultations and the Central Public Works Department, Delhi Schedule of Rates, 2014 (Central Public Works Depatment, Government of India, 2014).

On the basis of the dimensions and the penetration of different kinds of buildings, the cost per unit area of conventional and energy efficient construction was arrived at. Following which, based on the energy saved (in terms of a reduced cooling load) by an energy efficient building as opposed to a conventional building, an estimate of an incremental cost per unit saved has been arrived at.

The incremental cost per unit area of constructing a building by using energy efficient building materials is detailed in Table 12 below.

Table 12. Incremental Cost per Unit Area of Constructing Building with Energy Efficient Materials

Wall	INR/ m^2	250
Roof	INR/ m^2	700
Window	INR/ m^2	1300

Source: Expert consultation and Central Public Works Depatment, Government of India, 2014.

9.1 How the Costing Works

The Buildings sector analysis consists of two major components: The envelope interventions which reduce the space cooling load and increasing penetration of energy efficient appliances which meet this cooling load.

The basic principle for the aggregate cost to the economy of the buildings sector is presented below:

As the penetration of buildings with more efficient envelope increases, as mentioned above, the economy would incur additional costs with each unit of electricity saved. However, as the penetration of an energy efficient envelope actually reduces the space cooling load, lesser number of appliances (Energy efficient or otherwise) would be required to meet this resultant demand. Hence, the overall cost of the building sector is a combination of the additional cost of efficiency building materials and reduced cost of appliances used to meet the reduced load. Therefore, over the lifetime of a building, using more energy efficient materials to construct the building actually saves on cost to the economy.

9.2 Costing Sections in the IESS

In the Buildings section of the IESS, 2047 Version 2.0, cost ranges of a) the incremental cost of moving towards more efficient building materials and b) the cost of different categories of energy efficient appliances are mentioned. A combination of the two, along with the aggregate energy demand of the sector gives the total cost of the different levels chosen for penetration of buildings with an energy efficient envelope and different levels of penetration of energy efficient appliances.

10. Trajectories of the IESS, 2047 Building Envelope Optimization Section

Level 1 assumes that compliance to the Energy Conservation Building Codes (ECBC) remains voluntary, as is the case since its inception at the beginning of the 11th five year plan (FYP). Institutional, technological, informational and financial barriers also exist, which hinder the applicability of the same.

Level 2 assumes, as per the Energy Conservation Act 2001, the introduction of a bye law for ECBC compliance in new commercial buildings, and mandatory compliance in government buildings. It also assumes increasing adoption of incentive schemes, like a reduced property tax etc., for the ECBC code in new residential buildings.

Level 3 assumes that along with standard building by laws, there is development of ECBC compliance structures at state level, and the modification of the Energy Performance Index (EPI) bandwidth based scheme to multi variable EPI scheme, both in the residential as well as the commercial sectors.

Level 4 assumes a continuation of the multi variable EPI scheme and increasing mandates in states for implementation of the ECBC code. It also assumes a large scale drive towards making compliance to the ECBC code, mandatory, in new construction, till 2047.

The assumptions from levels 1 through 4 are summarized in Table 13 below.

11. Key Results

Based on the Methodology detailed in Section 5 above, the following results are generated for the reduction in the space cooling load, when a building is constructed using more efficient building materials i.e. results of minimizing the thermal losses in a building.

Tables 14, 15, 16 and 17 below highlight the energy savings potential in both Residential and Commercial Buildings as we move from level 1 to level 4 i.e. move from a pessimistic scenario to an optimistic scenario wherein a large section of the new construction complies to the ECBC code and witnesses the penetration of energy efficient envelope interventions. This keeps in mind the utilization of a specific mix of lighting and

Table 13. Penetration of Energy Efficiency Envelope Interventions till Year 2047 (As Percentage of Total New Buildings Stock)

Penetration of Efficient Envelope Interventions in 2047					
Category	**2012**	**L1-2047**	**L2-2047**	**L3-2047**	**L4-2047**
Residential					
High Rise	1%	10%	50%	75%	90%
Horizontal	0%	5%	40%	55%	80%
Affordable Housing	0%	0%	0%	0%	0%
Commercial	10%	25%	50%	75%	100%

Source: Author's calculations.

Table 14. Reduction in Space Cooling Demand in Residential Buildings by Using Energy Efficient Construction Material

TWh	2012	2017	2022	2027	2032	2037	2042	2047	Reduction
L1	51	96	196	319	503	693	856	970	
L2	51	95	195	316	493	673	823	925	5%
L3	51	95	194	314	489	663	807	901	7%
L4	51	95	194	312	483	652	789	876	10%

Source: Author's calculations.

Table 15. Reduction in Space Cooling Demand in Commercial Buildings by Using Energy Efficient Construction Material

TWh	2012	2017	2022	2027	2032	2037	2042	2047	Reduction
L1	60	74	97	135	200	310	449	618	
L2	60	74	96	133	195	297	420	560	9%
L3	60	74	96	131	190	285	393	502	19%
L4	60	74	95	130	186	275	367	443	28%

Source: Author's calculations.

Table 16. Reduction in Electricity Consumption of Residential Buildings by Using Energy Efficient Construction Material

TWh	2012	2017	2022	2027	2032	2037	2042	2047	Reduction
L1	152	247	411	603	880	1168	1431	1628	
L2	152	246	409	598	868	1141	1387	1565	4%
L3	152	246	409	596	861	1128	1364	1531	6%
L4	152	246	408	593	854	1113	1339	1496	8%

Source: Author's calculations.

Table 17. Reduction in Electricity Consumption of Commercial Buildings by Using Energy Efficient Construction Material

TWh	2012	2017	2022	2027	2032	2037	2042	2047	Reduction
L1	86	105	135	184	267	414	603	826	
L2	86	105	134	181	261	400	574	768	7%
L3	86	105	134	180	257	389	546	710	14%
L4	86	104	133	179	253	378	521	651	21%

Source: Author's calculations.

appliances (taken constant in all sections of this paper to maintain uniformity).

11.1 Cost Savings

Tables 18 and 19 capture the cost savings accrued to the economy (Cumulative Cost from 2012- 2047) from a default case only due to greater penetration of buildings with energy efficient envelopes. The aim of the table is to show how a transition towards buildings with more energy efficient envelopes would result in cost benefits to the economy over a longer period of time. The incremental cost methodology has been adopted assuming that the economy would incur costs of constructing buildings in any case (Level 2 in this case is the default). Energy efficiency interventions would enable the economy to spend less in the longer term. The additional cost in Level 1 is taking into account the additional cost that the economy would have to bear in case there would be a transition to an inefficient path as compared to the default scenario. These savings are over and above what would be realized while using more efficient lighting and appliances. The aim of this analysis is to engender debates and drive policy towards the adoption of building codes in the construction of buildings.

Table 18. Residential Buildings (Savings/ Additional Cost over Default Case- Level 2)

INR Trillion	Level 1	Level 3	Level 4
	+3	-1	-3

Source: Author's calculations.

Table 19. Commercial Buildings (Savings/ Additional Cost over Default Case- Level 2)

INR Trillion	Level 1	Level 3	Level 4
	+2	-2	-5

Source: Author's calculations.

12. Conclusion

This analysis, as a subsection of the entire buildings sector analysis in the IESS, 2047, suggests that leveraging the opportunity of energy savings in the buildings sector by a transition to a more energy efficient stock of buildings will prove beneficial to the economy in the long term. Increased penetration of buildings with a more energy efficient envelope enables a reduction in the energy consumption of a building. This transition also leads to a reduced cost to the economy as opposed to what it would have cost if the economy were to progress as per a business as usual scenario.

Therefore, building an ecosystem of players and policies in India, which support the increased adoption of building codes, especially the adoption of energy efficient envelopes in new construction is essential in the current scenario and should be deliberated upon. Since Buildings have a lock in period of about 50-70 years, interventions taken at a point of time wherein 70% of the buildings stock that will exist in 2030 is yet to be built is a massive opportunity that can be leveraged.

The India Energy Security Scenarios, 2047 allows the user to play on the levers of adoption of energy efficient envelopes in new construction, as detailed in this paper, and supplement these benefits with the increasing penetration of energy efficient lighting and appliances as well.

References

Attri, S. D. and Ajit Tyagi, I. M., 2010. Climate Profile of India.

Bureau of Energy Efficiency. (n.d.). Retrieved from https://docs.google.com/spreadsheets/d/1hkwTseqfly_plkUoGOPcRFFBXCOA46Q

8FzZVJd5gD-Q/edit#gid=0

Central Public Works Department, India, 2013. Integrated Green Design for Urban and Rural Buildings in Hot-Dry Climate Zones.

Central Public Works Depatment, India, 2014. Delhi Schedule of Rates.

Confederation of Real Estate Developers' Associations of India (CREDAI) and CBRE, 2013. Assessing the Economic Impact Of India's Real Estate Sector.

Global Buildings Performance Network, 2014. Residential Buildings in India: Energy Use Projections and Savings Potentials.

International Energy Agency, 2013. Transition to Sustainable Buildings: Strategies and Opportunities to 2050.

K.I. Praseeda, M. M., 2014. Assessing Impact of Material Transition and Thermal Comfort Models on Embodied and Operational Energy in Vernacular Dwellings (India). Energy Procedia, Volume 24, Pages 342-351.

KPMG India. (n.d.). Affordable Housing – A key growth driver in the Real Estate sector.

Kumar, S. R., 2010. Developing an Energy Conservation Building Code Implementation Strategy in India. Energy Conservation and Commercialization (ECO-III).

Kumar, S., Kapoor, R., Rawal, R., Seth, S., & Walia, A., 2010. Developing an Energy Conservation Building Code Implementation Strategy in India.

Lok Sabha Secretariat, Government of India, 2013, August. Rural Housing: Indira Awas Yojana-Reference Note.

Make In India, Government of India, 2015. Construction Sector. Retrieved from http://makeinindia.com/sector/construction/

Ministry of Statistics and Programme Implementation, 2011. Statistical Year Book-Chapter 28.

National Sample Survey Organization, Government of India (n.d.), 2011-12.

National Skill Development Corporation. (n.d.). Human Resources and Skill Requirements in the Building, Construction and Real Estate Services sector (2022).

Natural Resources Defense Council and Administrative Staff College of India, 2014. "Building Efficient Cities: Strengthening the Indian Real Estate Market Through Codes and Incentives", Issue Brief.

Planning Commission, Government of India, 2012-17. The Twelfth Five Year Plan.

Planning Commission, 2014. Final report of the Expert Group on Low Carbon Strategies for Inclusive Growth.

Ramana, M. a., 2010. " Gas hydrate occurrence in the Krishna-Godavari offshore basin off the east coast of India", Exploration & Production, vol.8(1); 22-28.

Shabnam Bassi, Bureau of Energy Efficiency. (n.d.). Roadmap for enhancing energy efficiency in new buildings. Retrieved from http://www.esmap.org/sites/esmap.org/files/1272009111005_BEEC_Shabnam_Bassi.pdf

The Economist Intelligence Unit, 2013. Achieving scale in energy-efficient buildings in India: A view from the construction and real estate sectors.

United Kingdom Home Care Association Limited, 2010. Controlling Scalding Risks from Bathing and Showering.

USAID ECO-III Project, 2011. Energy conservation building code tip sheet: Building Envelope.

USAID India and Bureau of Energy Efficiency, Government of India, Pg 26, 2011. Energy

Conservation Building Code- User Guide.

Vaidya, C., 2009. Urban Issues, Reforms And Way Forward In India,Working Paper, Ministry of Finance, Government of India.

www.indiaenergy.gov.in/demand_building.php, Building Envelope and Design Optimization, EFFICIENT BUILDING ENVELOPE

www.mining-technology.com. (n.d.). "Countries with the biggest coal reserves". From www.mining-technology.com: http://www.mining-technology.com/features/feature-the-worlds-biggest-coal-reserves-by-country/

印度高效率建材對於空間冷卻負載影響之檢視

Astha Ummat[1*]

摘 要

2001年印度擁有2.86億都會人口，居全球第二位。而根據2011年印度人口普查，其都會人口已來到3.77億，增加了24%。此高度都市化程度，伴隨著到2030年的建物存量中有約70%目前尚未興建，凸顯了印度在建築部門的能效及節能上具有極高的潛力。本文詳細描述了印度建築部門能源安全情境的模型方法，並依據英國2050路徑計算器進行2047年建築物能源情境模擬。本文將討論以熱力學方法為基礎，將新建築物朝節能的外殼設計以達到建築部門空調需求的技術方法，及可能的節約(包括能源及金錢)。另外，需採取何種政策措施促使以此轉變而建立一個生態系統，也將一併討論。

關鍵詞：U值、節能建築、建築材料、空間冷卻、印度建築部門

[1] 印度國家轉型研究院青年專家兼印度2047能源安全情境模擬計畫主持人
*通訊作者, 電話: +91-987-3764449, E-mail: asthaummat@gmail.com

收到日期: 2015年09月01日
修正日期: 2015年10月27日
接受日期: 2015年12月02日