Strategies for Energy Efficient Office Buildings in India

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Abstract

Emerging power crisis and reliance on the energy imports puts India on the demand side. A various factors including higher energy prices, increasing environmental concerns, are pushing the country to a tipping position with regards to energy efficiency in buildings. However, it is necessary for an extensive research on energy efficiency in office buildings based on the sustainable principles.

India being a developing country has enormous potential in reducing the energy consumption in the building sector around 40 – 50%. In order to mainstream the issue, BEE (Bureau of energy efficiency) established to promote key energy efficiency initiatives to highlight the relevance of core global issues on energy efficient building design in India. Furthermore, STIL2 project funded by Swedish energy efficiency and conducted by ÅF implemented, in India to provide a holistic approach to achieve the strategic framework in addressing the problem. Therefore, this paper extensively focuses on the energy use of office buildings with sustainable parameters and benefits of STIL 2 statistics in India.

Key words: Energy Efficiency, Strategic Framework, STIL2 statistics, Sustainable principles
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1 Introduction

This paper based on the STIL2 implementation in India. STIL2 conducted by ÅF AB and funded by Swedish Energy Agency, during six years in Sweden, and is a part of the overall project "Improved energy statistics in buildings" started in 2003. During the early 1990’s, the government owned energy company called Vattenfall, conducted a survey about premises in Sweden. The study described energy use and other relevant variables for different types of premises, divided into different categories, in Sweden. The study was called STIL (Statistik i Lokaler/Statistics in Premises). The objective of STIL2 project is to present the energy use in a conventional office building category on a national level. This is made possible through energy audits performed in number of buildings selected through a statistical sample, which allows the results from the audits to be scaled up to national level.

As part of this STIL2 project, I was involved in collection of statistical data for three case study buildings, to highlight the benefits of building statistics in achieving energy efficiency. In addition, I extended my study to indicate that there are varied problems regards to energy efficiency and ecological sustainability, in India.

1.1 Problem Statement

India has strong traditions and history in holistic strategies for buildings and construction. Despite the sustainable buildings agenda, currently receives limited attention in India. In this regard, country accounts for 2.4% of global energy consumption (EIA 2011). India is the seventh largest and second most densely populated country in the world along with growing economic rate of 8.2% (Balachandra 2011). About 1.2 billion inhabitants reside in 3.287.590 sq.km stretching from Himalayas to the tropical rain forest in south. Delhi, the capital city of India considered as one of the fastest developing megacities in the world with a growing population of 19 million and expected to increase over 40% of Indian population by 2020 (Boldt and Das 2008).

The energy infrastructure in India is the biggest and fastest growing among the developed and emerging countries in the world. The peak energy demand increased significantly over the last few decades. The average per capita consumption of electricity in India estimated to be over 714 kWh. However, it is relatively low compared to that of US (15000 kWh) and China (1800 kWh) (Razdan 2010). In India, 54% of electricity generated from Coal, 10% from gas, 21% from
hydro, 2% from nuclear and 10% from RES (Mallah and Bansal 2010). According to (Siddharth 2010), 80% of the rural India got connected to electricity, but only 45% served with dedicated power supply and urban access of 82%. The remaining 20%, who do not have electricity are matters of serious concern.

In December 2010, the installed power generation capacity of India stood at 165,000 MW (Kala 2008). The country's annual energy production increased from about 190 billion kWh in 1986 to more than 680 billion kWh in 2006 (Florini 2011). The demand for electricity is growing at a rate of approximately 5.6% per year (Birol 2010). It also varies between the seasons. The power shortage ranges from 6 – 8% during monsoons and climbs up to 10 – 14% during winter and summer. This deficit leads to considerable load shedding. Other problems in Indian power sector includes technology procurement, inadequate power generation capacity, demand for housing, increased office spaces for multinationals, IT hubs, inefficient use of electricity by the end customer, lack of policy support, large scale power theft and skewed tariff structure.

### 1.1.1 Specific Problem

Today buildings consume over 40% of all primary energy globally. By 2025, the buildings will be the largest energy consumers and emitters of greenhouse gases in the world (EIA 2011). However, in India, the need for construction is brewing with the world’s second largest population housed on a mere 2% of the global land allocation. Overall construction industry being the second largest sector after agriculture, contributing around 7% of India’s GDP growth, forecast to grow at a rate of about 9.2%, as compared to Global average of 5.5%. Likewise, the commercial buildings floor area expected to grow from 659 million Sqm to 1900 million Sqm by 2030 (USAID 2008).

According to (Sathaye 2011), In India, the quantum of demand for commercial office spaces will be concentrated on the seven major cities with a growing estimate of 160 million Square meter to 1300 million square meter by 2014. The power supply will exceed the energy demand as more office spaces will be created by then. The rapid growth in energy use results in growth of additional floor area, increased use of lighting and air conditioning systems. The demand in electricity leads to a significant increase in carbon dioxide (CO₂) emissions and climate change.
Taking Delhi as a case, the electricity demand in this city touched an all-time high of 4823 MW on May 18, 2011. The distribution companies faced the shortfall of nearly 500 MW during the peak load, leading to power cuts ranging from two to five hours across the city (TOI 2011). Meanwhile, the demand for office spaces will be 30 million Square meter by 2014. From the above scenario, Delhi’s energy demand is growing rapidly, and it requires a strong sustainable energy policy. One of the aspects is to promote energy efficiency and renewable energy technologies. The problems that signify the importance of energy efficiency in office buildings;

- Over consumption of energy in office buildings
- Growing population and increased office spaces
- Increased standard of living that would also add to energy usage
- Intermittent power supply, caused by power deficits.

1.2 Aim

A various factors including higher energy prices, increasing demand for power, increase in population and increasing environmental concerns are pushing Delhi to a tipping position with regards to energy efficiency in buildings. Therefore, it is necessary for an extensive research on energy efficiency in the building sector, especially in office buildings as they consume more power. In the light, of the above, the overall aim of this study is to carry out a pilot study in three
of the existing conventional office buildings in Delhi and Chandigarh to analyze the criteria for building statistics and energy efficiency to reduce the energy use. The study also aims to identify the challenges and implications to provide a strategic framework for achieving energy efficiency in office buildings based on the principles of sustainability.

1.3 Research Problems

The questions, the research intended to answer are;

1. What are the existing policies and underlying trends, which would affect energy efficiency in office buildings?
2. How energy statistics for specific building types, relates to reason for the amount of energy use.
3. Based on Challenges identified, what are the strategies for improving the energy efficiency in office buildings be put forward to improve the outcome, based on the principles of social and ecological sustainability?

1.3.1 Delimitations

In terms of different categories of buildings that are there in Delhi and Chandigarh, the study delimited to 20 years old conventional office buildings because of two reasons. First, it is essential to examine the existing conventional office types and their consumption pattern. In order to manage the energy costs of the buildings and it also helps to understand the magnitude of difference between the conventional type and low energy performance office buildings in India. Second, Indian building sector has witnessed, huge interest in the field of energy performance in the last decade. The national energy conservation building code (ECBC) and green building rating systems such as Leadership in energy and environment design (LEED – India) and green rating for integrated habitat Assessment (GRIHA) have also furled this surge in interest. These codes and rating systems based on design intent rather than actual performance during building occupancy. These codes were not primarily designed to assess energy performance of existing buildings nor to reward their performance through a systematic evaluation and award scheme. Further they do not provide defendable energy consumption targets for new buildings based on contextual data. This has serious performance, market and policy implications.
1.4 Significance

Worldwide, 30% to 40% of all primary energy used in buildings. Since the building sector is a significant user of electricity, it is necessary to develop energy efficient strategies to reduce energy consumption in buildings. Buildings also account for a significant amount of carbon dioxide emissions. In India, the demand for electricity is growing at a rate of 5.6% per year (USAID 2007). However, the generation of power has not grown to match the growing demand. If buildings are energy efficient, then the saved energy can be used to serve the rest of the population. If poverty does not prevent them from using electricity, industries would not face massive disruption in their performance and economic activities would operate without any disturbances. (Bhattacharya and Cropper 2010) assert that increased energy efficiency in buildings can provide economic benefits through reduced electricity bills and have a role in reducing total societal energy use. The arguments put forward for improved energy efficiency in office buildings focus on:

- Good practices and successful operations.
- Improved comfort
- Encourage users to act out from awareness to actions.
- Cheaper than investing in increased energy capacity
- Perpetuate the changes by monitoring and communication on the results.

As energy use largely determined by the density of layout, location and orientation, etc. It is high time that government of India formulates strong policies to ensure energy efficient office buildings to tackle the energy crisis in the country. This study expected to provide the following benefits to the development of energy efficient office buildings in India;

1. The study will improve the understanding of conventional office buildings in Delhi and including its energy use.
2. The study will determine the amount of energy used for cooling, ventilation and lighting in conventional office buildings of Delhi.
3. The study will provide guidelines to assist architects and energy experts for designing energy-efficient office buildings in India.
1.5 Scope and Limitations of the research

The study limited in the sense, that it was difficult to determine the detailed technical aspect of the case study buildings in a similar climatic conditions as of Delhi from which energy efficiency criteria determined. Instead, the identification of energy efficient design features depended on an extensive literature study. Another barrier has been the collection of energy audit reports from various officials in India. Since the information is confidential, it has not been possible to summarize the detailed energy structure of the buildings in this study. While analyzing energy efficient principles for office buildings, theoretical limitation given to energy use and sustainable building practice, but the study intentionally limited in scope and likely to scratch the surface of the issues at hand.
2 Methodology

2.1 Research Methodology

Research is the systematic process of collecting and analyzing information (data) in order to increase the awareness of the phenomenon. Redman and Mory.

The research extended to three main phases. First and third phases consist of desktop based studies conducted in AF, Sweden. Second phase; live study in Delhi for two months. The first phase describes the theoretical framework for this study. In addition, it identifies the methodology of analysis and issues that investigated in the case study. First phase, primarily a desk study, encompassed extensive literature reviews of books, journal papers, researches and documents to identify potential for achieving energy efficiency based on sustainable principles that could be used in the context of Delhi.

The second phase involved a field trip to Delhi for two months. The fieldwork consisted of energy audits, building observations and interviews with the occupants and experts of the case study buildings. The case study conducted in three of the existing conventional office buildings in Delhi and Chandigarh used to identify ways to reduce energy use. Quantitative and qualitative data collected from the case study buildings. All the data analyzed during this phase, intended to fulfil the structure outlined in the theoretical framework formed in the first phase.

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<td>5</td>
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<td>2</td>
<td>LEED Consultants</td>
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<td>3</td>
<td>TERI GRIHA Consultants</td>
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<td>IGBC Consultants</td>
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<td>Energy Auditors</td>
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The third phase comprised of a desk study for the second time to analyze and evaluate the data from the first and second phase analysis using quantitative and qualitative methods. The data on energy use of different office buildings analyzed quantitatively. The design features of the office analyzed both quantitatively and qualitatively, according to the basic design principles laid out in the theoretical framework.

2.2 Case Study Methodology

(Yin 2009) defines case study research as an empirical question that investigates a contemporary phenomenon within its real-life context, especially when the boundaries between the phenomenon and background are not clear. According to Yin, the method is the most notable characteristic of a case study (Stake 1995). In accordance with Stake’s definition, every study with a case as the object of study is a case regardless of the methods used. Case study can be regarded as a analysis that incorporates several different methods for collection of data, analysis and processing of findings.

(Yin 2009) differentiates two types of case study: holistic and embedded. The holistic case study focuses on the case as a unit of analysis. On the other hand, embedded case study focuses on case, which functions as the unit of analysis. However, there are also sub units of analysis within the case. In this research, three existing office buildings with high energy efficient potential selected as a primary case and considered as embedded units of analysis. The case study performed in this research is an embedded case study.

(Yin 2009) also differentiates between a single-case design and a multiple-case design. Single case design uses only one case to analyze the research questions. The multiple-case design, two or more cases studied. The research undertaken uses a multiple-case design with three sample office buildings.

(Stake 1995) makes a distinction between three types of case study such as intrinsic, instrumental and collective. Intrinsic case study selected for the better understanding of the case. An instrumental case study examines the case to provide insight into an issue or refinement of theory.
(Stake, 1998). A collective case study is an instrumental study that extended to several cases (Stake, 1998). The case study in this research is instrumental in nature.

2.2.1 Selection of case study
In this research, the three existing conventional office buildings with high energy efficiency potential selected as the primary case. The selection of the case study building based on the following criteria:

- It is characteristic of typical conventional office building in Delhi.
- The energy audit details were available.
- It was accessible.
- The auditors and engineers were cooperative.

2.2.2 Issues Investigated/ unit of analysis
Apart from the design aspects, the following issues in the case study buildings investigated. Energy use for cooling and lighting in conventional multi-storeyed office buildings of Delhi, general behavioural pattern of occupants, role of architects, developers and institutions in designing energy efficient buildings and reducing energy use in existing buildings.

2.2.3 Evaluation of the data
The data gathered for different methods of analysis in order to obtain linkages between the study object and the outcomes with references to the original research questions. Throughout the evaluation and analysis process, options kept open to new opportunities and insights. Data categorized, tabulated and recombined to address the initial purpose of the study. Facts and discrepancies in accounts checked by using triangulation, explained detailing in next section. Data analyzed by placing data into array, creating tables, excel spreadsheet.

2.2.4 Strategies for data analysis
Data analysis strategies divided into a combination of qualitative and quantitative approaches. The following combinations of data collection strategies adopted:

- Qualitative and Quantitative survey of the case study building
- Qualitative and Quantitative semi – structured interviews with direct and closed questions
- Quantitative assessment of energy use
- Qualitative and quantitative architectural drawings of the case
- Archival records of computerized quantitative statistics on the climate of India
- Photographs (Qualitative and quantitative)

2.2.5 Validation of the results:
The data obtained for three sample office buildings from the instrumental case study validated by triangulation. According to (Yin 2006), triangulation is the way of making the case study results valid. (Stake 1995) defines triangulation as a method of multiple perceptions to clarify meaning by identifying different ways to analyze the phenomenon. The case study method, with its use of multiple data collection and analysis techniques provides researchers with opportunities to triangulate data to strengthen the findings and conclusions (Garson 2002)

According to Patton (1990) there are four different methods of triangulation in combination with qualitative methods:

- Data triangulation: several sources used to collect data about the same phenomenon
- Research triangulation: several researchers study the same phenomenon.
- Theory triangulation: same data analyzed using different principles.
- Method triangulation: several methods used to gather data about the same phenomenon.

Among the four methods of triangulation explained above, data triangulation, researcher triangulation and method triangulation used in this study. Data triangulation investigates the use and capacity of cooling systems. Lighting conditions checked through method triangulation (interview, observation, photographs).

2.2.6 Generalization
(Flyvbjerg 2006) has addressed the delusion that one cannot generalize based on an individual case. Therefore, the case study cannot contribute to scientific development. He has revised this case, so that it now says:

'One can often generalize on the basis of a single case, and the case study may be essential for scientific progress via generalization as a supplement or alternative to other methods. However, formal generalization overvalued as a source of scientific development.

According to (Svane 2005), architects normally use a form of systematic generalization known as naturalistic generalization. In naturalistic generalization, the reader or the user of the findings
confront with uncontrollable generalization taking place in the mind. Thus, left up to the reader or the user of the findings in this study to compare the examples and accept this study as one case in her or his collection of related cases.
3  Situation in Delhi

3.1  Energy setting in Delhi
The per capita electricity use in Delhi around 1651.26 kWh, which is almost three times the national average. Delhi is the official capital of India. It is the eighth largest metropolis in the world with a population of 16,753,265 inhabitants (Census 2011). With growing demands in power supply, there is a frequent power disruption and load shedding over four hours a day, along with hot and humid environment. Recently residents in the west and south Delhi had barely two hours of electricity per day. The main problem is demand and supply phase due to growing energy use. Delhi’s peak demand can reach up to 7000MW by 2012 or even more. According to (TOI 2011), the country experiencing a short fall of 73, 326 MU against the demand of 861, 591 MU. During the peak load, there is a demand of 122,287 MW against the available of 110,256 MW and shortage of 12,031 MW, 9.8%.

3.2  Climate of Delhi
It is essential to analyze the climatic context of Delhi and understand the thermal performance of buildings. Knowledge on thermal performance required to minimize the heat gain in the building floor area to avoid thermal discomfort. According to (Zain, Taib et al. 2007) factors that lead to occupancy discomfort are outdoor air temperature, relative humidity, and airflow. Various
strategies also need to be adopted to facilitate air flow, observed by (Zain, Taib et al. 2007) that, if there is no air flow, occurrence of thermal comfort is only 44% occurrences in temperatures below 28.69 °C but an air flow of 0.7 m/s can improve the distribution of thermal comfort to 100%.

Delhi located in the northern part of India at 28.38° N and 77.13° E. The climate of Delhi considered as humid subtropical with high contrast between summer and winter temperatures and precipitation. Furthermore, mild winter begins in late November and peaks in January but severe for its strong fog. Extreme temperature ranges from 0.6 °C (30.9 °F) to 46.7 °C (116.1 °F). The annual average temperature 25 °C (77 °F); monthly mean temperatures range from 13 °C to 32 °C (56 °F to 90 °F). The average annual rainfall 714 mm (28.1 inches), during the monsoon in July and August. (Capital 2011)
Summer Season: The average temperature of Delhi in summer ranges from 25° C to 46° C. May and June considered being the hottest months of the year. Monsoon in Delhi brings some respite to Delhities, but not predictable to analyze the thermal temperature.

Winter Season: In comparison to summer, winters are short. Winter Season begins from November and continues till March. The cold waves from the Himalayan region make the winters in New Delhi exceptionally cold. Temperature falls significantly down to as low as 3 to 4° C.

The following Fig 6 shows the years average weather condition readings covering rain, maximum daily temperature and minimum temperature.
3.3 Energy uses in Indian buildings

India with its vast climatic variation and mixed income groups developed different design patterns to control the energy use. Although energy use in India is below the world’s average, due to lack of implementation of effective energy efficiency measures, Indian building rise to significant energy wastage. The other key problems are illiteracy and poor buying power leading to near zero penetration of energy efficient measures. Both commercial and residential complexes in almost four climatic zones of the country installed with air conditioning, lacks the use of energy efficient measures and basic practices like building insulation. Indian buildings are in different climatic zones of the country as shown in fig 7.

Fig 6: Average temperature and covering rain.
Electricity is a vital energy form used in both residential and commercial building sector in India. Approximately 60% use in lighting and 32% in cooling system (Efficiency 2007). When this large urbanizing population crosses the threshold into a culture of air conditioned comfort in the home, the impact on energy consumption will be severe. As one shifts from circulating fans and evaporative coolers to an air conditioner, the peak demand of electricity increases by six to ten times per unit of conditioned space - an increase from 40 W to 90 W per sq. m of conditioned space (Gupta 2009).

In the current context, 200 million sq. m of installed base in India and expected to increase over 869 million sq. m of additional office space by 2030. 70% of the commercial buildings construction is yet to take place (USAID 2008). According to (Gupta 2009), In India, there is 50% increase in the construction sector offers enormous potential in achieving energy efficiency practise. Only limited number of certified architects in India and expected in future that there will be a shortage of architects and consultants in proportion to the demand for new commercial buildings in the near future.
The three sample buildings selected for the study due to the very high ambient temperature in Delhi. The standard area of the office buildings in Delhi are of 4000 – 5000 m² with an occupancy capacity of 1000 – 5000 persons at a time. So there is great potential for reducing the major energy use in air conditioning in summer and room heaters in winter. (Konar 2008).

3.4 Partners and their activities (Green building council)

India is one of the fastest growing countries with a mere 20, 000 sq. ft in 2003 to 20 million sq. ft of green buildings in 2009 in terms of growth for the construction industry and infrastructural developments (USAID 2009). However, the green building regulations in India is a collection of codes and standards enforced by state bylaw, national building code and the energy conservation building code (ECBC) in collaboration with the leadership in energy and environmental design-India (LEED-India). The standards and guidelines for the commercial sector set by the Indian green building council (IGBC) and TERI-GRIHA (Sabapathy, Ragavan et al. 2010).

The bureau of Indian standards established the national building code (NBC) to provide basic and minimum requirements for efficient energy use. However, it is acclaimed that, codes limited for consumption and performance. Based on the drawbacks, ECBC established to address the issues on a large scale to improve the energy performance of buildings.

3.4.1 Voluntary laws

The voluntary laws in India are explicit in the absence of nationalized green building code. There are several accredited rating systems enforced in the country for promoting green building regulations and development modules. However, the buildings in follow the rules and regulation of LEED established by the U.S green building council and considered as the benchmark by most developers, investors and architects for achieving energy performance index of the buildings. In fact sets the requirements and standards customised according to Indian conditions in terms of the construction, operation and management of buildings to encourage environment-friendly performance.

3.4.2 LEED-India

LEED in India lately receiving some critics from the various organizations for including western countries concept, especially for air conditioning use and temperature control. In addition, LEED forced to enact changes in accordance to Indian context for increasing the efficiency of climatic conditions and sustainability issues for buildings. The key areas to be focussed for amending the system are site development, energy management, selection of materials and indoor
environment. IGBC (Indian green building council) trying to indigenise LEED according to the environmental conditions prevailing in India (Sabapathy, Ragavan et al. 2010). Together with IGBC, first rating scheme created for Indian buildings termed as green gomes rating. Further, from the efforts of IGBC other rating system such as TERI GRIHA and Eco Housing created to offers developers and owners to upgrade the performance of their buildings with minimal energy efficiency requirements (Raghuraman 2010). The basic prerequisites for green buildings;

- Climate-based layouts to reduce energy consumption
- Waste water treatment with zero discharge to outside
- Locally available materials like fly ash blocks used for walls and slabs to maximise the use of recycled material.
- Maximise natural lighting to ensure optimum indoor air quality

3.4.3 India surging ahead
For new construction, India follows the steps of most prominent countries such as Australia and USA in green building mass. This made possible by some prestigious commercial projects developed by Indian construction industry. Presently LEED-India and IGBC offer certifications for two categories. The first includes the builder or the construction company that is developing a particular environmental site/building for a client leased out. The second category belongs to those undertaking a green initiative for their own personal use, and this could either be a commercial space or corporate office. Standards vary for both.

3.4.4 Varied perception
India growing at a rapid pace and a great boom in the construction industry with contradicting mindsets. There are several environmental firms in the country with no regular specification for compulsory green designs. At the same time, there are a number of developers, architects and designers still not yet realised the importance of sustainable construction and green buildings. Unfortunately, the public group and investors are under the misconception that green buildings are expensive and require complete air conditioning. They could not be so wrong, Green buildings, while requires exceedingly (3 to 4 per cent) additional amount of initial investment to offer long-term cost savings, which are likely to have a payback of 2-3 years.

3.4.5 Advantage India
Being a tropical country, there is an advantage of abundant day lighting and can operate an entire building throughout the day without having to switch on an artificial light. The Indian
government has been implementing energy policies and amending them as per the demand route undertaken by sustainable development (Bhattacharya and Cropper 2010). Overwrought by problems that vary from lack of regular electricity supply to inadequate water resources, the challenge before India is to lead the people and economy towards sustainable infrastructure that stands strong despite the hurdles.

3.5 Office buildings and Energy efficiency
The construction of office buildings not focus on energy efficiency in Delhi. Even though, the government of India has adopted building energy codes in all forms of building construction but the codes are yet to be mandatory. Despite the recognized fact that worldwide, 30%-40 % of all primary energy used in buildings. In Delhi, most of the office buildings have not been constructed directly by the end users. So what’s happening is developers, who are doing the construction are not much worried about the running cost of the building that is being the foremost hurdle for the energy conservation. By observing most of the office buildings in Delhi, it seems architects and developers are still not aware of the role, they can play in designing energy efficient buildings. Architects facing a constant pressure from the developers and clients to design multi-stored office buildings with maximum space utilization. For instance, 40% of the building exposed to direct radiation with minimal treatment on facades.

Designs of offices, in general, are not responsive to the requirements of Delhi’s tropical climate. Office buildings designed without giving due importance to the parameters that are responsible for enabling thermal comfort without much dependence on energy use. Dependence on artificial lighting and ventilation is common in all offices. Furthermore, energy use in the commercial sector is increasing dramatically due to the improvements of living standards (Wong and Li 2007).
4 Theoretical Framework/ Synthesis of Concepts

4.1 What is energy efficiency?

Energy efficiency is the application of tools and technology that require less energy to achieve the same utility. A building can be made more efficient by using insulation to help maintain the temperature inside the building, sealing cracks, and using materials that do not conduct heat and cold for window frames. For example, energy-efficient window air conditioners use up to 20 percent less energy than conventional air conditioners but still maintain the same level and quality. (Energy Conservation, 2011: p 49).

Energy efficiency in the context of India based on building efficiency addressed by ECBC (Energy Conservation Building Code), which is the outcome of extensive work by the Bureau of Energy Efficiency (BEE), India and its Committee of Experts. BEE is responsible for carrying out the development of energy efficiency of the economy through various regulatory and promotional instruments. In this field, it referred to as the “Code” that addresses the perspectives of the manufacturing, design and construction groups based on minimum specification for energy efficient building design and utilization (USAID 2009).

The ECBC established based on extensive data collection and evaluation of various building types, building materials, equipments such as air conditioning and lighting. In addition, the code takes into consideration the five distinct climatic conditions in India and the ECBC taken these climatic zones into account for building envelop design. The base case models determined for buildings in these climatic zones provides specification for energy conservation in different building systems such as envelope, lighting, air conditioning, power, hot water. The development of ECBC had involvement of all four main stakeholders: Use, Government and NGOs, Industry and Financing institutions (USAID 2009).

4.1.1 Requirements

ECBC mandatory for all new buildings and retrofitting of existing buildings that have a connected load of 500 kW or greater or a contract demand of 600 kVA or greater. The code applicable to all buildings with a conditioned floor area of 1,000 m² (10,000 sq ft) or greater.
The code mandatory for all other buildings. The present ECBC is first such effort in India. Hence the ease of implementation been a benchmark for designing the code.

**Applicable building systems:** The provision of the code applies to:

- Building envelopes and air conditioned area
- Mechanical systems or equipment such as heating, ventilating and air conditioning
- Service water heating
- Interior and exterior lighting
- Electrical pumps and motors

**New Buildings**

The energy conversation code for the new building requires series of mandatory standards in energy use for the various building parts and systems.

1. *Prescriptive method* specifies minimal parameters for achieving energy efficiency in proposed buildings. In case of designing building envelope component as an example, designers must select the prescriptive method for selecting roof insulation to control the amount of thermal comfort for effective management.

2. *The whole building performance (WBP)* is a substitute strategy to fulfil with the Code. This method is more complicated than the Prescriptive Method, but recommends significant design flexibility. Based on the code, it is important to obtain optimization of energy use in different building category in order to get the best energy efficient solution. The WBP method established to find the annual energy use and compare it with the conventional building model. (USAID 2009).

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**Box 3-A: Steps for meeting ECBC Compliance**

![Diagram](image)

*Fig 8: ECBC compliance process*

*Source: Energy Conservation Building Code, USAIB INDIA, 2009*
Existing Buildings
The existing building goes beyond the conditioned floor area of 1000 m² or more, the compliance must be preceded based on either of the ways:

- The addition of new components and external systems must be installed on the code specification Or
- The addition of the new equipments together with the whole existing structure, must be implied with the following code requirements.

Exception to above:
Any air conditioning with its components provided by existing systems need not proceed with the requirement of the code. In case of installing new air conditioning unit in the existing building, must comply with the specific requirement of the code. Example: An existing warehouse measuring 120m x 60m not air conditioned features an administrative office (30m x 30m) located in one corner. The administrative office needs to be transformed into the warehouse. The renovation of new office space measures 30m x 15m from unconditioned to the conditioned space. The existing HVAC system has enough capacity to serve the extra space. However, it is essential that new ductwork and supply registered to be installed to provide the additional space.

Fig 9: proposal of an office expansion

4.1.2 Trends
In this section, two of the best energy efficient companies in Delhi discussed and compared, according to their policies;
Jackson company focuses on strategy that involves managing recent technology, providing a stimulating workplace, smart transparent system and maintaining a strong focus on quality, health, safety and environment. Their principles designed alongside the installation of their products such as Power generators and power plants as well as switchboards such as power control centre, motor control centre, switch board plant, installations and quality initiatives. (Holcim 2010).

- To develop knowledge on the health and safety effects of products and waste materials.
- To manage the facilities to protect the health and safety environment of the employees and customers and provides effective improvement to prevent pollution and other negative impacts.
- Improvements made on a regular basis by use of the best design and management practice.
- To assess the degree of health and environmental performance on a regular basis and provide relevant information to officials, employees and customers.
- Today environmental degradation is quite common resulting from urbanization and severe shortage in energy due to a rapid growth in demand. The best solution is effective energy management and exceptional service for clients.

Power pulse group, on the other hand, focuses on the following principles:

- To set up a new enterprise within a short time to reach the maximum capacity.
- To manage organization under Expansion and growing energy demand.
- To help develop industry in order to have provisions for backing up for critical loads.
- To minimize capital investments in captive power facilities.
- To manage large order that needs to be executed with a necessity for short term additional power.
- To manage limited power during planned plant shut downs.

4.1.3 Need for Energy Auditing
Conversion of energy audits into actual projects is very low, even though a large number of building energy audits conducted in India. The reason being, most energy audits lie under the category of “one size fits all” and are directed on laying the ground work for large capital intensive projects even though the country does not hold organized energy services and financing sector that can implement the recommendations contained in some of the energy audits.
Experience from around the world and in India has shown that there are many energy saving chances that can be pointed out in focused energy audits and which does not require a huge capital outlay and relies more on the technical knowledge, expertise, and experience of engineers and service providers (Zhu 2006). In order to systematically realize those savings and use energy audits leading to a better energy policy are being formulated for the building sector are the major goals of this guide. By knowing what to expect from the audit process and implementing audit recommendations, owners will be better equipped to maximize the benefit of the energy assessment in realizing energy and cost savings.

*According to ECBC, the auditing is categorised under pre-assessment and post-assessment.*

### 4.1.3.1 Pre-Assessment

The Pre-Assessment stage includes all steps that are required leading up to the actual assessment that involves benchmarked indices for different types of commercial buildings, a screening tool to assess if a building energy assessment should be undertaken for the facility, the formation of an Energy Efficiency Committee, preliminary data gathering, a self assessment to determine the level of assessment required, and the steps required to find and hire an auditor/consultant.

The assessment section gives an outline of each level of building energy assessment, and what level of effort and results can be expected of each. Additional information is given on performance contracts as they relate to higher level of assessment.

### 4.1.3.2 Post-Assessment

The post-assessment section provides information on how to apply and precede constant energy savings based on the results of the building energy assessment, including implementation, operation and maintenance changes, measurement and verification, and the review process.

Through the introduction of the Energy Conservation Building Code in 2007 [ECBC] (USAID 2009), BEE has taken steps to ensure that future construction will meet energy efficiency criteria. For existing buildings, these codes applied for certain renovations/retrofitting. In addition, buildings or building components that have a connected load of 500 kW or a contract demand of 600 kVA or greater,” reporting requirements for all included facilities anticipated. At present this code is voluntary, but it is anticipated that, it may become mandatory in due course. BEE has also instituted the national energy conservation.
4.1.3.3 Cost Savings
Building owners, facing rising energy costs, are seeking ways to reduce costs. Employing energy efficient practices and retrofits can be a simple, affordable and effective way to achieve operating cost reductions. Some retrofits may be more cost intensive initially, but the long-term energy savings provide building owners the needed financial justification for undertaking such large scale projects.

4.1.3.4 Availability of Funding Sources
Multiple funding sources may be available to building owners to perform energy assessments, both internal and external to the organization. Internal funding may come from either the operating or maintenance (O&M) budget or from the capital improvements budget. The changes in energy cost could be immediately realized in the operating budget, so this project could be funded by O&M source. Many of the improvements may require capital funding, so this alternate internal budget may also be used to provide the required resources.
Organizations may even wish to work outside of the existing budgetary constraints to borrow money for an energy cost reduction program if they feel that the savings in energy costs would make this a sound economic decision. External funding sources are available from a variety of sources. Funding an energy assessment can be done as a part of a larger performance contract where the cost of the assessment and following implementation would be carried by an energy services company (ESCO). The resulting energy savings will be used to pay the implementation costs and the ESCO’s fees. Additional funding may also be available under programs such as the Kyoto Protocol’s Clean Development Mechanism which acts as means of channelling funds for greenhouse gas reduction from developed countries to developing and transition countries in exchange for Certified Emission Reductions to assist them in meeting their Green House Gases (GHG) reduction goals.

4.2 Sustainable construction and Sustainable development
Sustainable development and architecture are complex subjects linked with many other issues. In order to make the concept of sustainable construction easier in buildings, it is necessary to focus on two target issues to assess the extent of buildings relates to sustainable development. Before getting into the details of target issues, it is crucial to know that these issues were aligned with the primary goals of rio agenda, significant improvements and advancements in construction practice can contribute towards global sustainability (Jefferson 2006)..
4.2.1 Quantum change and transferability

The design, materials and techniques of sustainable construction demonstrates fundamental principles on environmental and affordable buildings of various types. Nearly all interior and exterior walls must use cement-stabilized compressed-earth block and cement-stabilized fly-ash lime-gypsum block. The production of local materials requires the need of local labour and low energy to point towards the future of effective industrialized production of natural, reliable, low-energy building materials. When sustainable construction and production of local materials widely adopted, helps to reduce the energy and CO2 emissions to a great extent. By offering its R&D as the first stage of commercialization, the project is a catalyst for the mass production of green building components, (Wentz, D. 2008)

Sustainable buildings conserve the natural resource, reduce greenhouse gas emission and avoids negative impact on the environment. Green buildings keep the natural environment and ecosystem healthy and benefits the surrounding by reducing waste, and controlling pollution by recycling the resources.

4.2.2 Ecological quality and energy conservation

Efficiently built in reinforced concrete and masonry uses less than half the reinforcing steel used in similar structures of conventional design. The approach holds significant potential for reducing resource use and greenhouse-gas emissions. The sustainable buildings usually use natural, recycled, renewable, and reusable materials embodying low process energy. Highly energy intensive materials like aluminium shunned; others, such as glass and steel, used frugally. (Wentz, D. 2008). Eighty percent (by volume) of the building materials sourced within 500 km of the site, thus holding down CO2 emissions of transport. All rainwater on the site used to recharge the groundwater. All recycled wastewater treated on site, used for irrigation and other grounds. A hybrid air-handling unit integrates evaporative cooling and refrigerant-based cooling to minimize energy use for air conditioning by 30%.

4.3 Towards sustainable technologies

Sustainable energy is the most prominent source in the current situation of construction growth. It uses minimal resources, elimination of natural resources and no direct or indirect impacts on the built environment and well being. There is overlap with lack of appropriate technology to control the needs of the population in developing countries in emphasizing the ecological sustainability principles. There are two aspects to be considered for sustainability;
4.3.1 Energy
The buildings consume energy in five different ways. The first, related to the manufacturing of materials, components and systems termed as embodied energy. Second, associated with transportation of materials to the site known as grey energy. Third, Induced energy applies to the energy expended in the construction itself. Fourth, energy spent in the running of the building, as long as the building occupied termed as operating energy. Finally, a building also consumes energy in its final disposal or, eventually, in its recycling, which is the disposal and recycling energy phase (Presas 2005). Considering all the five phase, the most intensive phase is the operational one, which corresponds to the life cycle of the building – usually estimated at 60 years or as long as the building occupied.

Buildings are large users of materials with a high content of embodied energy. The buildings usually processed with many different materials constitute total embodied energy of the building. Sometimes, the materials are complex and require a greater amount of processing and consumes higher amount of energy leads to higher levels of pollution at the end construction phase. For instance, high embodied energy materials like concrete, aluminium and steel responsible for a large amount of CO₂ emission. In case of India, average annual growth rate of 8.1% in manufacturing (Ibid.). Yet from the above discussion, more energy consumed in the operation phase than in the construction phase of the buildings (Mihelcic 2010).
There is a gap between increasing in construction costs and promoting building’s energy efficiency. Typically construction costs increase by 3-5%, if energy efficient solutions incorporated in the buildings. Despite the fact, reducing overall energy use in buildings has an immense impact on life cycle cost of the buildings.

4.3.2 Materials
Each year three billion tonnes of raw material estimated (40 – 50% of total flow in the global economy) used in the manufacturing of building products and components worldwide. Raw materials for the construction industry must be extracted, processed, transported, added in the construction phase and finally disposed of, and there are certainly many environmental impacts related to all these stages. The pursuit of technological development since the industrial revolution and the gradual emphasis on generating a common global style in architecture, particularly soon after the Second World War, developed the use of steel, glass, aluminium and concrete. These materials with high embodied energy, and often leads to pollution, which puts a burden on architects worldwide to regain a more pragmatic approach towards their use (Mihelcic 2010).
However, the possibility intensified with other material like prefabricated ones. Now office buildings designed for global cities seeking to achieve an image in adopting materials used in their facades and to comply with ecological conditions, eventually requiring a formulation or conception of global architectural identities in the envelope/interior design. For instance, in India, current annual consumption in manufacturing of building materials is 2500 x 106 GJ and estimated to be around 5000 x 106 GJ in 2020 (Presas 2005).

<table>
<thead>
<tr>
<th>Category of Materials</th>
<th>Energy Intensity (Range GJ/Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Very High Energy</strong></td>
<td></td>
</tr>
<tr>
<td>Aluminium</td>
<td>200-250</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>50-100</td>
</tr>
<tr>
<td>High Energy</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>12-25</td>
</tr>
<tr>
<td>Glass</td>
<td>5-8</td>
</tr>
<tr>
<td>Cement</td>
<td>8-10</td>
</tr>
<tr>
<td>Plasterboard</td>
<td>8-10</td>
</tr>
<tr>
<td><strong>Medium Energy</strong></td>
<td>3-5</td>
</tr>
<tr>
<td>Lime</td>
<td>2-7</td>
</tr>
<tr>
<td>Clay Brick and Tiles</td>
<td>1-4</td>
</tr>
<tr>
<td>Gypsum plaster Concrete:</td>
<td>0.8-1.5</td>
</tr>
<tr>
<td>In Situ</td>
<td>0.8-3.5</td>
</tr>
<tr>
<td>Blocks</td>
<td>0.1-5</td>
</tr>
<tr>
<td>Precast</td>
<td>0.1-5</td>
</tr>
<tr>
<td><strong>Low Energy</strong></td>
<td></td>
</tr>
<tr>
<td>Sand, Aggregate</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Material</td>
<td>Energy Intensity Range</td>
</tr>
<tr>
<td>----------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>Fly ash</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Blast Furnace slag</td>
<td>&lt;0.5</td>
</tr>
</tbody>
</table>

Table 1: Energy Intensity range for building materials  
Source: B.V. Reddy, 2008

4.4 Energy efficiency Policy and Implications

The government of India made efforts to encourage energy efficiency in buildings by institutionalizing energy conservation act in 2001. Later in 2002, bureau of energy efficiency established to mandate energy efficiency in operation and construction phase at national level. The BEE initiated some research and policy support in promoting energy efficiency (Laustsen 2008).

4.4.1 Energy Conservation Building Code

Office buildings are of great importance for India’s energy demand, and with the rapid increase in office floor space changes the goals from state to national around reliable energy. The addition of office floor space also provides an opportunity for implementing sustainable design and construction practice in an effective way. To exploit this opportunity, BEE and USAID on collaboration developed voluntary energy conservation code for large scale commercial buildings.

The Energy Conservation Building Code (ECBC) provides certain guidelines for new buildings, including the heat reduction facade (windows, walls, roof) and the effectiveness of the space conditioning, lighting, electrical and water systems in the building (USAID 2009). The energy conservation code established in consultation with trade organizations, government body panel, researchers and international advocacy groups applying the experience accumulated through the creation of similar codes around the world. The technical energy conservation code just not enough to drive towards energy efficiency requires initiatives to promote code targets among investors and contractors (USAID 2008).

4.4.2 Energy Benchmarking and Building Labelling

In order to achieve energy efficiency, the significant challenge is the measuring progress. One way to quantify the effectiveness of a building is benchmarking, comparing the results and performance of two similar buildings or more to verify the data to benchmark. The problem with
benchmarking is that, size of the building varies exponentially and hard to come up with the genuine comparison (Raghuraman 2010). In United States, these obstacles overcome in recent years through innovative energy star portfolio manager. It is possible to establish star rating and label schemes to provide energy efficiency attributes to investors, owners and various other stakeholders, when two similar buildings compared together (e.g. annual energy use divided by floor space)(Sabapathy, Ragavan et al. 2010).

BEE and ECO III projects, established labelling schemes and benchmarking for Indian building sector, by accumulating the experiences from U.S star rating program. The first task is compilation of statistics on energy use and other features of buildings using extensive data collection. With this information as a base, next step is to establish benchmarking system, so that investors and stakeholders can evaluate the effectiveness of buildings based on comparable building results. Finally, Indian government established star rating program to regularize the data for easy access. Star rating program for office buildings launched in India on early 1990, and other building categories included over the time. BEE and ECO III continued to refine the methodology for comparing building performance in support of building labelling and benchmarking in India (USAID 2008).
Fig 12: BEE Star rating label
Source: Energy conservation building code, 2009

<table>
<thead>
<tr>
<th>Appliance</th>
<th>Refrigerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brand</td>
<td>Godrej</td>
</tr>
<tr>
<td>Model/Year</td>
<td>GFE 25 TY / 2010</td>
</tr>
<tr>
<td>Type</td>
<td>Frost Free</td>
</tr>
<tr>
<td>Gross volume</td>
<td>231 liters</td>
</tr>
<tr>
<td>Storage volume</td>
<td>211 liters</td>
</tr>
</tbody>
</table>

*Under test conditions, when tested in accordance with relevant standards. Actual electricity consumption will depend on how the appliance being used.
BEE developed the star rating schemes for buildings to increase the energy efficiency activities in both residential and commercial complexes. The programme based on actual performance of the building, in terms of energy use (in kWh per sq.m per year) targeting both air conditioning and non air conditioning office buildings in three climatic zones such as warm humid, composite, and hot and dry. The programme designed to rate office buildings on a 1-5 star scale, with 5-Star labelled buildings being the most energy efficient. EPI in kWh per sq. m per year considered for rating the building. The Star rating scheme provides public recognition to promote energy efficient buildings and creates a demand side for such buildings (Efficiency 2007).
5 Case study findings and Discussion

5.1 An Overview of the case study buildings

Three sample buildings selected for the study. Three of these buildings were multi-storeyed conventional office buildings. Though these buildings are partly and fully air-conditioned, they have incorporated climate-responsive techniques, such as shading devices, SPV panels, appropriate window to wall ratio, and integrated use of daylight to reduce energy use. These types of buildings are common in Delhi and other metro-cities in India, because of the increasing land demand and the dynamic changes in the urban lifestyle. The selection of the buildings made in consultation with the bureau of energy efficiency and other stakeholders. The results derived from the energy audits performed by AF, during the case study and compared with the results from the bureau of energy efficiency recent audit reports. The details of the case study buildings summarized below;

Sample 1: Bureau of Energy Efficiency, New Delhi

![Fig 14: Bureau of energy efficiency, Sewa bhavan, New delhi.](image)

Sewa Bhawan situated in the West Block area at R.K.Puram in New Delhi. Sewa Bhavan houses the head office of Central Electricity Authority, Central Water Commission, Bureau of Energy Efficiency (BEE), Registrar office of census and sub-offices of CPWD. The total area of the building is 43,400 m², and in that 8,840 m², are air conditioned. The total annual electricity consumption of the building is 40,860 kWh.
**Sample 2: Regional Passport office, Chandigarh**

This building owned by the ministry of external affairs, CPV division, New Delhi. It is a regional passport office for some districts of Punjab, Haryana & Himachal Pradesh. The total area of the building is 4250 m$^2$ and total annual electricity consumption are 2,21,000 kWh. In addition, energy consumption pattern of this building shown in chart 1; the building consumes 35% for air conditioning and 25% for lighting devices.

**Sample 3: Telephone exchange building, Chandigarh**

This building is owned by Bharat Sanchar Nigam Ltd. It is the 7th largest telecommunication company in the world, providing comprehensive range of telecom services in India. In this
building, five exchanges have been installed with a total capacity of around 60,000 lines. It caters to almost whole of north block of Chandigarh. The total area of the building is 7350 m² and total annual electricity consumption of this building is 29,42,000 kWh. The energy use pattern of this building is shown in chart 2;

5.2 **Comparison of conventional building type with low energy performance building type**

Based on the case study, the trends of energy use and performance parameters are established. The findings relevant to the study are summarized in Table 2.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Conventional buildings</th>
<th>Low energy buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design features</strong></td>
<td>Long façade East – West</td>
<td>Long façade North – South</td>
</tr>
<tr>
<td></td>
<td>No shading</td>
<td>No shading</td>
</tr>
<tr>
<td></td>
<td>Single glazed windows</td>
<td>Mix of single and double glazed windows.</td>
</tr>
<tr>
<td><strong>Lighting system</strong></td>
<td>No daylight integration</td>
<td>Daylight and artificial light integration</td>
</tr>
<tr>
<td></td>
<td>No lighting controls</td>
<td>Occupancy sensors and dimming controls</td>
</tr>
<tr>
<td></td>
<td>Lighting power density is in the range 15–20 W/m².</td>
<td>Lighting power density is less than 15–20 W/m².</td>
</tr>
<tr>
<td></td>
<td>Visual comfort maintained as per the National Building Code 2005.</td>
<td>Visual comfort was maintained as per the National Building Code 2005.</td>
</tr>
<tr>
<td><strong>Air conditioning system</strong></td>
<td>No natural ventilation or passive cooling techniques.</td>
<td>Circulation areas are naturally ventilated.</td>
</tr>
<tr>
<td></td>
<td>Chillers used are reciprocating chillers.</td>
<td>Chillers used are screw and centrifugal chillers.</td>
</tr>
<tr>
<td></td>
<td>Percentage of air-conditioned area to built-up area is above 60%.</td>
<td>Percentage of air-conditioned area to built-up area lies in the range 50%–65%.</td>
</tr>
<tr>
<td></td>
<td>Chiller coefficient of performance was on the lower side.</td>
<td>Chiller coefficient of performance is on the higher side.</td>
</tr>
<tr>
<td></td>
<td>Sq.m/TR (tonne of refrigeration) lies in the range 9–15.</td>
<td>Sq.m/TR lies in the range 32–42.</td>
</tr>
</tbody>
</table>
Thermal comfort was maintained as per the National Building Code 2005.

<table>
<thead>
<tr>
<th>Energy performance</th>
<th>Lighting Performance Index lies in the range 37–60 kWh/m²/year.</th>
<th>Composite – 183 kWh/m² per year (10 hours operational)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Thermal comfort maintained as per the National Building Code 2005.</td>
<td>Composite – 144 kWh/m² per year (10 hours operational)</td>
</tr>
</tbody>
</table>

Table 2: Comparison of design features between conventional and low energy office buildings

Source: High performance commercial buildings in India, 2010

5.3 Energy use in the case study buildings

The age of the case study buildings is around 20 years. Hence, there is enormous energy saving potential in these buildings. The building equipments were not properly maintained and require energy efficient measures to reduce consumption level by 20 – 25%. Audits performed with portable, sophisticated & diagnostic measuring instruments in all primary equipments such as motors, transformers, pumps, lighting, air conditioning units, lift, and ventilators. Buildings past records utilized to make use of some historical data. Air conditioning and lighting consumes about 35% and 25% of energy use. However, the results of all three case study buildings were similar. Hence, comparative study made in consumption pattern of the buildings and highlighted in chart 3 and chart 4.
5.3.1 Lighting system

Lighting is an essential use in all the building complexes. The power use in these case study buildings is about 25% of the total energy use. The consumption pattern of lighting appliances in case study buildings shown in chart 5. Standard quality conventional fluorescent tubes with electromagnetic chokes consume 52 W power against 28-32 W consumed by energy efficient tubes and electronic chokes; GSL and halogen lamps are most deficient. Based on the study, there is a possibility for replacement of existing 40 W fluorescent tubes with 30W T5 tubes and electronic chokes. Innovations and continuous improvements in the field of lighting gave tremendous energy saving opportunities in these buildings around 25% - 30%. The energy saving potential is calculated by incorporating the bureau of energy efficiency star rating appliances shown in appendix.
5.3.2 Air conditioning

The energy use of air conditioning system depends upon compressed ratio, cooled room temperature, heat gain through openings, walls, roofs, glazing etc. In these buildings, window and split air conditioners installed. All these comfort system operates 6.5 months from April to mid October from 9am to 5pm. During one month, office opens for about 22 days. It is necessary to calculate the working hours of these cooling systems annually, to evaluate the behavioural pattern of the systems, and to reduce the level of consumption by incorporating the energy efficient measures. The annual consumption of the cooling systems in these case study buildings shown in chart 6. Some significant drawbacks highlighted during the observation; there is no temperature indication on any air conditioners, and no thermostat is working to reduce the air conditioners, when any set/desired temperature reached. Most of the AC’s installed in these buildings were 2 tons, and none of the installed ones, found star rated. In many offices, doors remain open. One reason is that 3 to 4 officials are occupying one room, and someone or the other is always coming/ going through it. It is necessary, in some single occupancy offices also, 20 – 25% door found open. None of above provisions can be fitted as these are not techno-economically viable. It is necessary to fix good quality door closure springs, which would close the door smoothly. Following solutions are the most efficient and cheapest to reduce the consumption by 30 – 35%

- Minimizing heat gains through walls and doors
- Minimizing heat gain through open doors
- Using high efficiency lighting produces minimum heat
- Reducing cooled air temperature
- Purchasing star rated air conditioners
- Better maintenance of the installed systems
Pumps and Blowers: The annual consumption of the pumps and blowers is about 10% in these case study buildings. The level of consumption for mixed pumps shown in chart 7. The pumps and blowers designed to operate within a certain range of head & capacity, but their efficiency is optimal only at rated head & capacity. On an average, only 3-4 water supply pumps installed. The rated parameters are as per actual requirement. However, the saving potential is exceptionally low. So it is necessary to at least install pressure gauges on all pumps and blowers. For small variations, the savings offset by their own losses. From the above measures, the energy saving potential in reducing the consumption is around 5%.

5.3.3 Monitoring & targeting

It is an essential management tool to control energy consumption. Monitoring gives existing energy consumption pattern, and targeting is desirable/achievable energy consumption pattern.
By regular monitoring & targeting, it is possible to keep 5 to 20% energy. For its effective function, proper documentation of energy use and production need to be maintained.

5.4 Energy saving potential in three sample buildings

The findings from three case study buildings measured by calculating the average consumption of primary data’s such as Air conditioning, lighting system, water pumps, computer equipment, motor load and miscellaneous. From the audits, the energy saving potential determined in these buildings by incorporating star rated energy efficient appliances. There is enormous potential for energy efficiency about 30 – 40% in these buildings shown in chart 8. The second bar for each month in the chart 8 shows the saving potential difference after incorporating the energy efficiency measures.

![Chart 8: Energy Saving Potential](source: Author’s own creation)

5.4.1 Benefits of STILL 2 Implementation in India

STIL2 conducted by AF AB for the past 6 years and is a part of the overall project for improved energy statistics in buildings. With STIL2 projects, the rate of consumption level can be traced to reduce the energy use. The purpose of implementing STIL 2 protocol in India is that BEE (Bureau of energy efficiency) panel in India has taken several initiatives to mandate the energy audits for various government office buildings and planned to mandate energy audits for all
commercial buildings, as well. It is to ensure that recommendations of the audits implemented in the stipulated time.

In the current context, of building consumption, in India, several energy audits performed in government buildings across the country, but there is no program for implementing the energy efficient strategies. Nevertheless, audits conducted by BEE are not sufficient enough to make up with energy saving potential. Based on the BEE’s recent audit reports, comparing the results with other buildings was a difficult task, because the number of organization involved in the audits and led to different output in the results.

The benefit of STIL2 implementation in India is to have a holistic approach in performing the energy audits and a strategic framework for improved building statistics in the commercial sector. A way forward, it is necessary to make STIL 2 projects mandatory in large scale to monitor the performance level of the buildings and reduce the energy use with energy efficient measures.

5.5 Challenges of sustainable design and renewable energy in Delhi

Existing buildings are a serious consideration towards achieving socio-ecological sustainability. Mostly, all the built structures in Delhi require a significant design renovation work to make them approach sustainably. Today, there is an opportunity to incorporate sustainable design principles in most of the existing structures. For instance, natural ventilation and day lighting eliminates the use of non renewable energy, provides a healthier and participatory environment for users to redesign.

An analysis of space and functional components relates to the interior and exterior conditions, with availability of sustainable resources such as light, heat and ventilation). The orientation of the functional design layout based on the sun’s radiation and exterior based elements (for e.g. Reflectance off other buildings, facade treatment, prevailing breezes, solar heat gain and day lighting) can have a positive impact on performance and well being of the user by eliminating the use of non renewable energy.

5.5.1 Use of renewable energy

Renewable source such as wind, solar, biomass and geothermal provides the necessary energy for the building energy demand. Availability of resources is the basic requirement. In the context of Delhi, solar energy is the only available renewable source utilized in a practical and cost
effective manner for urban township. In the current scenario, the biggest challenge of implementing solar technology is the capital cost. For example in TERI-GRIHA and LEEDS classification, installing certain amount of renewable systems is mandatory, but the biggest problem is the overall cost of the technology and its implication. There is a widening gap between the initial cost and payback period, still not large enough from renewable energy compared to the investments made in alternative energy like coal that people find it extremely easy to take up. Some of the states in India have smart grids, there people are following renewable energy and feeding into the grid, because the rate of base they feed into the grid is twice the rate higher than the price they pay for the electricity. So they have a net profit over and above everything. Hence, there are strategies, which come into place but everywhere else is centrally the cost, which is the deterring factor. In fact, the capital cost would be nearly USD 5 million to set up a photovoltaic plant to produce 1 MW of electricity, (Wentz, D. 2008). This is exponentially high and makes it not suitable for commercial uses for now. "Solar technology has still not reached a point, where it can be used for commercial solutions. This is exactly, where innovation can play a vital role.

5.6 Energy efficient design features – A way forward

The theoretical framework in this study contains a list of basic principles and strategies in achieving energy efficiency in office buildings. Out of the various aspects discussed in the theoretical framework, only certain aspects selected to meet the goal of this study and also be applied in the context of Delhi. The features selected pertain only to the building design, cooling and lighting to reduce the energy use in buildings. The selected features need to be strongly enforced to reduce the cooling energy and it does not affect the energy used for electrical distribution equipments in the buildings. It must also be stressed that, as this study focuses on potential energy savings by adopting sustainable design principles.

5.6.1 Strategy for sustainable design and urbanism

Most buildings constructed and used are far from being eco-friendly or sustainable. Their energy use and imposition on natural resources are enormous. According to the World watch institute about 40% of the total energy use dedicated to construction and operation of buildings, (Wentz, D. 2008)
The design and development of new buildings based on concepts of socio-ecological sustainability and implementation of appropriate retrofit options to the existing buildings sector, with an association reduction in both local as well as global emissions. The strategies for sustainable building development outlined below.

- Maximize the use of renewable energy and natural resource management in the building environment.
- Minimize the use of energy and water to avoid the negative effects on built environment.
- To ensure the validity of building system functions for proper maintenance and operation.

5.6.2 Integrated approach to the building design

An integrated approach to building design involves the rational use of resources and energy efficiency measures. According to (Damtoft, Lukasik et al. 2008) buildings should reflect the above concerns by providing and/or adopting the following measures:

- Improved building envelope and system design
- Water conservation and efficiency measures
- Energy conservation and efficiency measures
- Increased use of renewable energy resources
- Elimination of hazardous substances in the surrounding environment
- Efficient use of resources and materials
- Selection of materials and products that reduce safety hazards and cumulative environmental impacts.
- Use of recycled content and environmental friendly products
- Salvage and recycling of waste and building materials created during construction and demolition.
- Prevention of generation of toxic materials and emissions during construction, operation, and decommissioning/demolition.
- Implementation of maintenance and operational practices to avoid effects on the natural environment and people.
- Reuse of the existing infrastructure, establishment of facilities near public transport systems and consideration of development of contaminated properties.

The adoption of the above features results in buildings that have

- Lower maintenance costs,
- Reduced operational energy.
Lower emissions of air pollution,
Healthier and more productive occupants,

Some alarming facts about Gurgaon discussed below (TERI 2010)

Located on the outskirts of Delhi, Gurgaon is a fast growing urban centre going through a rapid development. Today, buildings in Gurgaon require a large amount of energy intensive materials like steel and glass during their construction and operation phase. They contribute significantly to the green house gas emissions and consequently, to climate change. In Gurgaon, it is necessary to develop and adopt sustainable design principles for the risk free environment.

- The annual demand and use of electricity are both increasing at a rate of 17% while supply is increasing only at 5%-7%.
- About a quarter, of the electricity supplied (20%-25%) lost in transmission and distribution.
- The water level is going down as the exploitation of ground water increased due to lack of adequate water supply for the construction and operation.
- Most of the high rise office buildings operated on 100% captive power plants that work on high speed diesel. This led to increase in air pollution and higher levels of particulate matter.
- Management and treatment of sewage is inefficient and inappropriate.

The above facts give an idea of how beneficial it is to seek sustainable building design principles in a developing country like India.

5.7 Barriers related to designing energy efficient buildings

Energy efficient strategies identified in this study are through excessive literature review. The study also shows the proficiency of these strategies. Despite the effectiveness of these features, there are barriers that may impede the construction of energy efficient buildings.

- Knowledge gaps
- Technological gaps
- Lack of awareness
- Effective enforcement of policies
- Lack of financial incentives
5.7.1 Knowledge Gaps
Knowledge gaps amongst consultants, designers, policy makers, investors and consumers, act as a major obstacle for incorporation of sustainable design practices. The construction industry remains unaware of the environmental impacts of its operations and the economy, environmental and health benefits of using green and effective strategies, products and appliances. Sustainable design and energy efficiency in buildings were not part of the core curriculum in any Indian school of architecture. All architectural and engineering schools and colleges should establish related courses in their curriculum (Dey 2009). There are an urgent need for effective and extensive capacity building and awareness creation programme at all stakeholder levels.

5.7.2 First Costs
A main obstacle for implementing sustainable building principles in construction projects are fear of high initial cost to carry out cost benefit analysis. Need for collective knowledge on incremental costs and benefits, due to an increasing number of green buildings in the country. This would assist in overcoming the perception that efficient, green and sustainable buildings are expensive. All consultants are on the verge to help design energy efficient buildings should follow the life cycle analysis approaches to encourage stakeholder buy-in.

5.7.3 Lack of Technology
Lack of technology is quite common in developing countries in achieving the targets. In case of solar panel installations, south facing heat exposed building facade, wastage of water and electricity due to lack of flexible connections are the issues of great importance due to technical difficulties must be addressed by incentives and subsides for manufacturers and suppliers. Lack of knowledge is also a obstacle to overcome these difficulties, must be addressed through awareness campaigns and programmes.

5.7.4 Awareness
Awareness and knowledge are the key aspects in achieving energy efficiency in buildings. For instance, lack of awareness among the consumers regarding the socio economic and health benefits of using such green rated appliances and BEE labelled products. It is necessary to promote awareness about the availability of such efficient products and their life cycle cost benefits. In spite of high initial cost, the organizations should focus on marketing the life cycle cost and cost saving potential of such energy efficient products (Wentz, D. 2008). The economic benefits of BEE-labelled products should be marketed too.
5.7.5 Enforcement and implementation

To encourage adoption of large scale sustainable building design and use of energy efficiency products required enforcement of strategies. The concerned stakeholders require a greater contribution to address the absence of support for monitoring and mandatory policies and subside. The specification for incorporation of sustainability parameters in construction projects, by state and central government required critical revision among others. Although there are national level building regulations, but in case of environmental approval and implementation of energy efficiency measures for large constructions lacks regulatory framework mechanism and monitoring by state/central environment dept/ministries. There is a need of independent agencies to build strong monitoring protocols to mandate large construction projects using energy efficient measures such as sustainable construction practise, cooling and lighting systems into office buildings by central/state environmental assessment committees.

Sustainable building solutions addressed only in the national building code, not in Building bylaws nor urban planning bylaws (Dey 2009). At the national level, an effort should be made to incorporate energy building performance index and energy efficiency measures into the building bylaws. Even though, the government body organization BEE has taken several initiatives to mandate energy audits both in residential and commercial buildings, but it still remains essential to ensure that the recommendations of the audit implemented in a stipulated time.

5.7.6 Financial incentives

Lack of financial incentives also acts as an obstacle in implementing large scale sustainable building design. The builders do not directly benefit by incorporating energy efficient/green design features in new development. In case of large scale implementation of green building design, there is a matter of spilt incentive for builders, which needs to be resolved. Thus, with lack of incentives for builders to incorporate energy efficient features in their construction, the access to appropriate technologies limited in the commercial sector (Wentz, D. 2008). Financial incentives such as tax breaks could be linked to rated buildings. The section above highlights the steps taken up by various stakeholders to manage construction towards a minimum detrimental impact on the environment.
6 Recommendations

1. Public policies in India should adopt a sustainable development debate and environmental policies should protect the earth’s ecosystem. Special to current trends, a more participatory approach should be embraced by government and energy planning institutions for fighting the global menace. Furthermore, the concept of ecological behaviour should be encouraged amongst people.

2. Further to the better upgrading of regulatory mechanisms, regulators must be authorized to facilitate the creation of markets and the setting up of effective tariffs. Given the current pricing mechanism in the energy sector, which is distorted, there is an irrational tax, which makes the business unsustainable. Therefore, in order for the energy sector financially viable and sustainable, the pricing and the tax structures need to be appropriately rationalized.

3. The failure of the Indian Eco-labeling program (managed by the bureaucrats). The green rating program initiated by CSE – a NGO made success by providing an reasonable schemes to various stakeholders. BEE in order to manage energy efficiency projects, should rely more on NGO’s without grant and support from foundations managed by mega corporations.

4. Standardization of energy audits in both commercial and residential building sector to improve the building statistical data, harmonized, disseminated and enforced. In addition, training and accreditation also need to be improved, so does quality control.

5. Awareness and Knowledge: The awareness by itself can discourage the use of inefficient appliances. Also, initiatives need to be taken on teaching the energy ratings. Often, lack of information is the main thing precluding the adoption of any energy efficiency technology.

6. Redistribution of subsidies: subsidy schemes should be devised targeting the individual groups/sectors only.
Conclusion

The demand for building appliances with any green rating requires motivation due to high initial incremental costs for green buildings. Adoption of the rating systems can be encouraged by incorporating property tax deduction or other subsidies from the government. Nevertheless, the mandatory of energy efficiency policies at all local level to implement compliance with GRIHA or LEED rating systems required. From the study, the established statistics for building types correlated with the amount of energy use could be applied to identify potential areas for reduction in energy use, and can present regulatory data for the various building types. From the audits, it has proved that the energy saving potential is around 25% - 30% in these buildings by incorporating energy efficient measures.

In order to mainstream compliance with ECBC, the large knowledge gap amongst people exists at different levels; way forward is to development on construction, local design and materials, suitable to the environment and put in force the implementation of policy in the building sector. To make it more effective and accountable, BEE should be made an autonomous institution and encouraged to incorporate more NGOs from inception to implementation stages of different programs it undertakes.

Thus in conclusion, ecological sustainability should be the foremost concern; ironically in India, over the last few decades, people moved steadily away from sustainable habitat design and this fact hinged on the most recent ways of buildings. The reason is that the twin forces of globalization and urbanization, buoyed by economic advance, are moving the country to a high level of consumption. It has believed that superficial and artificial demand of the built environment, going against the principles of sustainability. Therefore, the change can be brought by increasing the awareness and knowledge to the people for new construction practise and better lifestyle.

From the study, it is implicit that, there is a need for further research in regularization of data to analyze the behaviour trends of the building types.
8 Criticism and further research

As a young researcher, I had faced problems during my initial stages of work in data collection on specific target issues due to switch over of issues on regular basics. However, the study managed to provide extensive information on the situation faced in India with a solution to overcome the energy demand by incorporating the measures. Even though as a researcher, i had a broader perceptive about the issues in terms of ecological sustainability, but narrowed down due to time constraints and limits of the project. Further research required in this study on regularization of data for the building statistics and behavioural pattern of the occupants to get detailed analysis data to take it into a another level.
9 Appendix

9.1 Appendix 1: Interview outline

1. What do you think the biggest problem facing in reducing the energy consumption in office buildings?
2. Why are they problems?
3. What underlying reasons lead to these problems?
4. Do you think stakeholders are in general effectively addressing this issue?
5. How could the planning principles play a key role in improving its efforts?
6. What are the barriers for improvement?
   - Financial constrains
   - Policy framework
   - Technical Framework
   - Recommendations for overcoming barriers.
7. Have you been previously involved in SED projects?
8. Do you think today’s pattern and trends in overall energy demands are sustainable?
9. What is your opinion about challenges and implications of sustainable energy systems in Delhi?

Part II - For Other Stakeholders

Name of Organization:
Full Name Respondent:
Position in Organization:

1. Stakeholder and basic characteristics
   - Can you tell me an overview of your organization and what it does?
   - Is your work limited to a particular area of the country?
   - How long has it been in existence?
   - What kind of initiatives has been taken to achieve energy efficiency?

2. Interests and how affected by the problem(s)
   - What is the mission, goals, interest of your organization?
   - What are your organizations interests when it comes to Sustainable building construction and Energy efficiency?
   - Are you in anyway affected by the challenges that come with inadequate SED

3. Capacity and motivation to bring about change
   - What is the capacity and motivation of you organization to meet the challenges of energy efficiency in office buildings

4. Possible actions to address stakeholder interests
   - What are some of the possible actions you can take to warrant SED and your interests?

5. Any special concerns about the challenges of Energy efficiency in Delhi?
## 9.2 Appendix 2: List of Instruments used in energy auditing

<table>
<thead>
<tr>
<th>S.No</th>
<th>Instruments</th>
<th>Features</th>
<th>Make &amp; Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Digital Temperature Hygrometer</td>
<td>Temperature and Humidity</td>
<td>CIE 500 to 1200 C</td>
</tr>
<tr>
<td>2</td>
<td>Digital Infrared Pyrometer</td>
<td>Distant temperature measurement using infrared between 50 to 500 C</td>
<td>Meghatech, USA</td>
</tr>
<tr>
<td>3</td>
<td>Digital Anemometer Rotating Wane Type</td>
<td>Air Velocity</td>
<td>Lutron AM 4201</td>
</tr>
<tr>
<td>4</td>
<td>Portable Three Phase Load Manager</td>
<td>(HP, KW, Volt, Amps, P.F, KVAH, KVARH, Neutral current, Frequency, Harmonics, AC/DC 3 Phases/4 Wire, Un Balance Load with data logging facility)</td>
<td>Krykard ALM 30</td>
</tr>
<tr>
<td>5</td>
<td>Digital Technometer</td>
<td>Contact cum Non contact type to measure rpm and rotational speed</td>
<td>Lutron 2234</td>
</tr>
<tr>
<td>6</td>
<td>U- tube Manometer</td>
<td>Differential Pressure</td>
<td>Skylab</td>
</tr>
<tr>
<td>7</td>
<td>Lux Meter</td>
<td>Lumens</td>
<td>Lutron Limited, Taiwan</td>
</tr>
</tbody>
</table>

## 9.3 Appendix 3: Saving potential for lighting

All the data in the table are manipulated for confidential purpose.

<table>
<thead>
<tr>
<th>Title of recommendation</th>
<th>Replacing 150 W halogen lamps with 2x28 W T-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description of Existing System and its operation</td>
<td>Presently 150 W halogen lamps are in use at entrance area at the ceiling</td>
</tr>
<tr>
<td>Description and Proposed system and its operation</td>
<td>Replace 150 W halogen lamps with 2x28 W T-5 lamps</td>
</tr>
</tbody>
</table>

### Energy saving calculation

<table>
<thead>
<tr>
<th>Energy consumption of each of the fittings</th>
<th>150 W each for halogen lamps and 60 W each for 2x28 T-5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nos. of lamps used as decorative lighting</td>
<td>20nos.</td>
</tr>
<tr>
<td>Total nos. of hours used per day</td>
<td>1.5 hrs</td>
</tr>
<tr>
<td>Total nos. of days in use per year</td>
<td>240 days</td>
</tr>
</tbody>
</table>

### Cost Benefits

<table>
<thead>
<tr>
<th>Energy Saving potential for each of the lighting</th>
<th>150-60 W = 90 W (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Annual Energy saving potential</td>
<td>90x1.5x20x240/1000 units = 648 units</td>
</tr>
<tr>
<td>Annual cost saving</td>
<td>20%</td>
</tr>
</tbody>
</table>
## 9.4 Appendix 4: Saving potential for Air conditioning system

All the data in the table are manipulated for confidential purpose

<table>
<thead>
<tr>
<th><strong>Title of recommendation</strong></th>
<th>Install energy savers at all the window/spilt air conditioners and water coolers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description of Existing System and its operation</strong></td>
<td>Window/spilt air conditioners and water coolers keep on running till the desired temperature (as per the thermostat settings) is achieved</td>
</tr>
<tr>
<td><strong>Description and Proposed system and its operation</strong></td>
<td>Energy savers should be installed on each of the air conditioners and water coolers which are basically a timer controlled ON-OFF device and it has been observed that there is no noticeable change in the comfort level even when AC and water cooler is switched off intermittently for some time in between.</td>
</tr>
</tbody>
</table>

### Energy saving calculation

| **No. of window/spilt Air conditioners** | 300 |
| **No of water coolers** | 40 |
| **Average energy saving expected after installation of energy savers** | 20% |
| **Average electricity consumption of window/spilt ACs of 1.5 TR as per analysis done.** | 1.9kW |
| **Annual running of window/spilt air conditioners/water coolers.** | 9hrs/day x 150 days/year x 0.66 average running factor 891hrs |
| **Average electricity consumption of water coolers** | 1.25 kW |

### Cost Benefits

| **Annual Energy Saving potential** | (1.9x300 + 1.25x40) x 891x0.25 = 98,081 units |
| **Annual cost saving** | 35% |
9.5 Appendix 5: Saving potential for Pumps

All the data in the table are manipulated for confidential purpose

<table>
<thead>
<tr>
<th>Title of recommendation</th>
<th>Description of Existing System and its operation</th>
<th>Description and Proposed system and its operation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Replacement of two pumps (out of total four water pumps) with energy efficient pumps</td>
<td>There are four axial pumps of 30 hp each to pump water from underground tank to overhead tanks in two sets. In each set, there are two pumps; one working and one stand-by. The efficiency of all the pumps is very low. (around 46%) One pump in each set will be replaced with energy efficient pump. The stand by pumps will not be replaced to keep the investment low. The new pumps with 66% efficiency with 25 hp motor will pump the same amount of water per hour and save energy.</td>
</tr>
</tbody>
</table>

### Energy saving calculation

<table>
<thead>
<tr>
<th>Average power drawn by each of 30 hp motor loading survey</th>
<th>18kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated power drawn by 25 hp motor</td>
<td>15kW</td>
</tr>
<tr>
<td>Average total run of all the pumps each day</td>
<td>16 hours</td>
</tr>
<tr>
<td>Annual energy saving</td>
<td>(18-15) x 16 x 365 units = 17, 520 units</td>
</tr>
</tbody>
</table>

### Cost Benefits

<table>
<thead>
<tr>
<th>Annual Energy Saving potential for all the four pumps</th>
<th>17,520 units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual cost saving</td>
<td>15%</td>
</tr>
</tbody>
</table>

9.6 Appendix 6: Annual energy saving in lighting and air conditioning

All the data in the table are manipulated for confidential purpose

<table>
<thead>
<tr>
<th>Description</th>
<th>40W fluorescent tubes - 540</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing fitting</td>
<td>40W+ conventional choke - W</td>
</tr>
<tr>
<td>Proposed fitting</td>
<td>28W+electronic chokes - W</td>
</tr>
<tr>
<td>Saving per set/hour</td>
<td>Watt</td>
</tr>
<tr>
<td>Saving per annum for 9x240hrs</td>
<td>kWh</td>
</tr>
<tr>
<td>Total electrical energy saving</td>
<td>200 tubes - kWh</td>
</tr>
<tr>
<td>Air conditioning load saving</td>
<td>Tons hours</td>
</tr>
<tr>
<td>Total electrical energy saving</td>
<td>kWh</td>
</tr>
<tr>
<td>Annual cost saving</td>
<td>Ruppes</td>
</tr>
</tbody>
</table>
10 References


Boldt, J. and A. Das (2008). "STUDY ON ENVIRONMENT AND ENERGY IN INDIA."


TERI (2010). "TERI Energy Data Directory ".


