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DISCUSSION PAPER

Indian Urban Building Sector: CDM Potential through Engergy Efficiency in Electricity Consumption

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Indian Urban Building Sector: CDM Potential through Engergy Efficiency in Electricity Consumption

ABSTRACT

Indian economic growth is likely to lead to a huge increase of energy use in buildings but so far, policies to address this issue are lacking. Standard building energy use concerning glazing, air conditioning and lighting in different climatic zones across India leads to energy use per m^2 which is 3-4 times of the German average. We assess the potential to improve building energy efficiency and how measures in the building sector could be framed as projects under the Clean Development Mechanism. CDM case studies for large buildings in the Indian public and private sector are presented. They achieve annual greenhouse gas reductions of 500 to 10,000 ton, which may not be sufficient to overcome the CDM transaction cost barrier. Despite short payback periods, the high initial investment and lack of integrated building management makes these projects additional. Large-scale appliance dissemination programs for air-conditioners and Compact Fluorescent Lamps (CFLs) may offer interesting opportunities if the monitoring challenge can be overcome.

Key words: CDM, energy efficiency, India, buildings

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Energy efficiency is the relative thrift or extravagance with which energy inputs are used to provide goods or services.

1. Indian energy situation in a global context

1.1 India: energy and economy

The second most populous and seventh largest country in the world, the Republic of India is a political leader among developing nations. The country spans numerous geographical zones, including deserts and jungles, farms, and sprawling cities. Its boundaries extend north to the Himalayas and south to the Peninsula that juts into the Indian Ocean. The world's largest democracy, the country is home to over one billion people living in various climatic zones.

Energy consumption, economic growth, and population have strong interconnections in India. GDP (Gross Domestic Product) grew at an average rate of 4.9% per year in the past three decades until 1990. Significant economic reforms in 1991 spurred economic activities leading to an average growth rate of 6.7% during 1992–96. The South-East Asian economic crisis in 1997 put a brake on the accelerating growth rate, though in 1998 the economy revived, averaging 6.1% from 1997 to 2000.

India ranks sixth in the world in terms of energy demand accounting for 3.5 % of world commercial energy demand in 2001. With a GDP growth rate of 8 % set for the Tenth Five-Year Plan (2001 – 2006), the energy demand is expected to grow at 5.2 %. Still, at 479 kg of oil equivalent (kgoe), annual per capita energy consumption is low even compared to other developing countries.

The country has seen an expansion in total energy use during the last five decades, with a shift from non-commercial to commercial sources of energy. Accordingly, the production of commercial sources of energy has increased significantly. Table 1 indicates the trends in production of various primary commercial energy resources.

Table 1: Trends in commercial energy production in India

Item	Units	Production					
		1960-61	1970-71	1980-81	1990-91	2001-02	2006-07
Coal	mt	55.67	72.95	114.01	211.73	325.65	405.00
Lignite	mt	0.05	3.39	4.80	14.07	24.30	55.96
Crude Oil	mt	0.45	6.82	10.51	33.02	32.03	33.97
Natural Gas	BCM	-	1.44	2.35	1.79	29.69	37.62
Hydro Power	BkWh	7.84	25.25	46.54	71.66	82.80	103.49
Nuclear Power	BkWh	-	2.42	3.00	6.14	16.92	19.30
Wind Power	BkWh	-	-	-	0.03	1.70	4.00

Source: Planning Commission (2002)

Since the upheaval of the first oil crisis, the supply and demand trajectories of the Indian energy sector have undergone changes in response to economic, demographic, and technological factors. While technological innovations increased market opportunities and suitable policy reforms have boosted the country's energy supply potential, a rise in the national income, population, and enhanced economic activities have led to an even more strongly escalating demand for energy. In contrast to China, the overall energy intensity of the Indian economy increased during the 1980s and early 1990s.

International concern for rising anthropogenic greenhouse gas (GHG) emissions and potential dangerous consequences of global climate change led to negotiation of the United Nations Framework Convention on Climate Change (UNFCCC) during the Earth summit in June 1992, signed and ratified by India. Indian per capita CO_2 emissions averaged $1/12^{th}$ of high-income countries in the 1990s. In fact, per capita emissions in India were approximately half of those of low and middle-income countries for the same period. While home to 17% of the world's population, India only has a 5% share of world GHG emissions. Still it ranks 5^{th} in the world after the U.S., China, Russia, and Japan.

1.2 Climate policy challenges in India

With a view to reduce GHG emissions, the Union Government of India along with many international agencies has taken steps towards efficient and optimized energy utilization and simultaneously employing various means to check financial as well as environmental losses due to wastage of energy. However, for many years, efforts to finance energy efficiency and conservation measures have bypassed the building sector. The Clean Development

Mechanism (CDM) of the Kyoto Protocol is an opportunity to change this situation. Through the CDM, greenhouse gas reduction in developing countries can be credited to industrialized countries that have to achieve their emission targets. Top down analysis shows that the CDM could account for between 33%-55% of the total reductions required to achieve by annex B countries by the year 2010. The corresponding CDM flows could be between $5.2-$17.4 billion. Using marginal costs of abatement in different countries to estimate the flow of CDM funds it is estimated that India would collect between 7%-12% of the total global market for CDM-led investment (Jotzo and Michaelowa 2002).

Recently, international agencies have started to address end-users to modify their behavior and attitude to achieve efficient energy usage. This has created an opportunity for the building sector to make its voice heard in the corridors of potential international funding agencies in view of its capacity to come as seedbed for CDM project.

Synergies between top-down energy efficiency initiatives in the building sector and bottom-up development of its CDM potential have to be exploited. Improvement of end use energy efficiency as well as use of renewable sources of energy will pave the way further. If novel organizational forms to implement an optimal combination of both can be developed, it could lead to significant foreign investment in the form of CDM money.

2.Energy and building sector in India

The need of developing countries to improve living standards and reduce poverty is well understood and energy is the prime resource for development. Though, the total energy use, which one of the major sources of emissions is increasing in developing countries, their per capita energy consumption still remains far below then that of developed countries.

2.1 Residential energy use and the role of buildings

The building sector plays an important role in the energy expansion described above. We differentiate between commercial and residential buildings. The Indian residential sector consumes about 201,000 mtoe (million tons of oil equivalent), which is about 11% of world's energy consumption in residential sector (Earth Trends Country Profile 2003), so halfway between the population share and emission share. In Indian households energy is mainly used for cooking, heating & cooling and lighting. Only the later two relate to buildings. Cooking and lighting are almost independent, whereas other demands are region specific and climate dependent.

A major portion of energy demand in this sector is met through non-commercial fuels such as fuelwood and dung. The rural household sector, which is the largest energy-consuming sector accounting for 75% of the total energy consumed by the domestic sector, depends largely on traditional fuels. According to the 2001 census of India, only 43.5% of rural households have an electricity connection and more than 85% of electrified rural households use it for lighting purpose only. 90% of rural households are dependent on biomass fuels such as fuelwood, dung, and agricultural residue for their energy demand (TEDDY 2003).

The Indian urban sector which accounts for 28.4% of the country's population is consuming a proportionate share of energy (close to 25%) but around 87% of the urban population has access to electricity for meeting their energy demand. The urban sector is therefore highly dependent on clean energies like electricity and LPG gas. With growth in the economy of the country, the per capita income is increasing and thus the purchasing power for a more sophisticated lifestyle with extensive usage of electricity is rising.

The United Nations human settlement indicators for India shows a clear drift of rural population towards urban centres. During the last two consecutive censuses (1991 – 2001), it has been observed that the urban population growth rate was 31.4% whereas the rural population growth rate was 21.2%. Table 2 shows the level of urbanization for the country and expected percentage of urban population for the year 2005. This drift of population towards urban centers essentially for search of better facilities, amenities and better job opportunities is further promoting clean energy consumption and increased energy demand, a large part of which is related to buildings.

Table 2: Level of urbanization in India

Year	Level of urbanization (%)
1970	19.8
1975	21.3
1980	23.1
1985	24.3
1990	25.5
1995	26.8
2000	28.4
2005	30.5

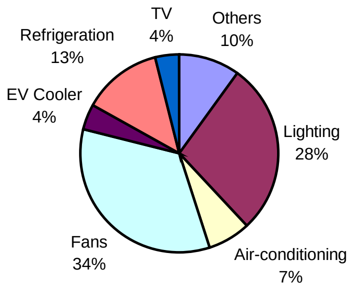
Source: UN (2003)

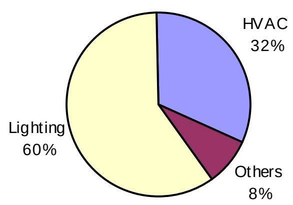
2.2 Electricity use in buildings

The emergence of a middle class during the 1980s and 1990s is a remarkable social development in India. This group, composed of prosperous farming families and urban-based professional, administrative, and business class, has driven the movement toward modernization by demanding a loosening of economic controls, better education for children, and an improved standard of living.

Thus during the last decade, in the residential and commercial sector, there has been a rapid increase in the consumption of electricity at a rate of about 13.2%. Growing electrification and more comfortable style of living have been the main causes of this increase. The electricity consumption in this sector is essentially in buildings and building establishments for various uses; the distribution is illustrated in Figure 1.

Figure 1: Annual Electricity Consumption in Indian Buildings





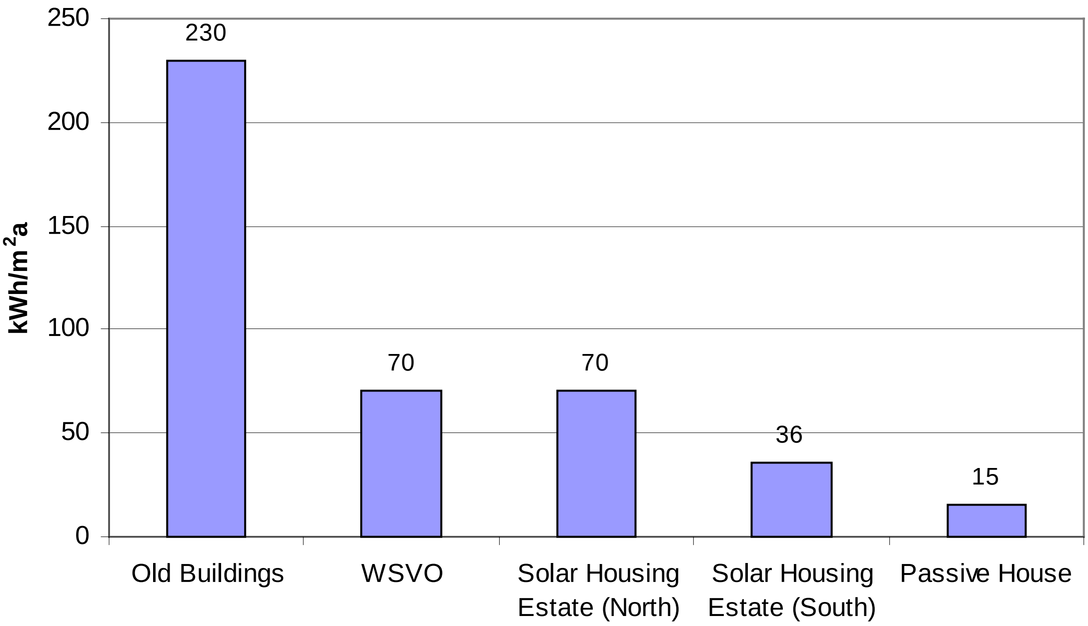
Residential Building Sector
Annual Consumption = 116 TWh

Commercial Building Sector
Annual Consumption = 33 TWh

Source: (CMIE 2001)

In comparison to the energy consumption in buildings in the developed countries, the Indian buildings consume more energy especially for heating and cooling. The total specific energy consumption for conditioned buildings may range from 280 kWh/m^{2}a to about 500 kWh/m^{2}a compared to less than 100 kWh/m^{2}a in temperate climates as the situation in Germany shows (see Figure 2).

Figure 2: Reduction of Specific Residential Energy Consumption in Germany



Source: Vassen (2002)

WSVO: Building in compliance with German Heating Efficiency Ordinances (Wärmeschutzverordnungen)

2.3 Energy efficiency policies in India

Due to the increase in economic activity and the concurrent increase in energy intensity, energy supply could not follow energy demand particularly in the electricity sector. After the Government's measures in the second half of 1990's aimed at restoring the financial viability of state owned power utilities were unsuccessful, a new Electricity Act was passed in June 2003. Moreover the Energy Conservation Act has provided a framework for promoting energy efficiency (EE) in the country. The Bureau of Energy Efficiency (BEE) has been set up to facilitate implementation of the provision of the Act.

Launching the Bureau of Energy Efficiency (BEE) action plan for promoting energy efficiency in the country, Prime Minister Vajpayee announced in 2002 that all the Government Organizations should bring down their energy consumption by 30% and Private Organizations by 20% over a period of 5 years. Improvement in the building sector is one of the agenda in the BEE's Action Plan.

2.4 CDM and the building sector

The country has the opportunity to learn from the mistakes of the Western industrialized countries with regard to fossil fuel dependency, artificially low energy prices, and a retroactive search for energy efficiency programs and strategies. India has a window of opportunity to do it right the first time, to marry economic growth with energy efficiency. India can create new strategies for long-term energy reliability and efficiency.

Now with the Clean Development Mechanism (CDM), a new possibility of clubbing energy efficiency measures with reduction in GHG emissions is in place, which opens a new era of possibilities to attract international investments in such initiatives. This study will therefore essentially concentrate on current usage of electricity in urban India (residential and commercial sectors) and possible GHG emission reductions through implementation of such measures leading to possibilities of presenting such initiatives in the form of a CDM project.

3. Indian buildings and energy use

3.1 Climatic zones and Indian buildings

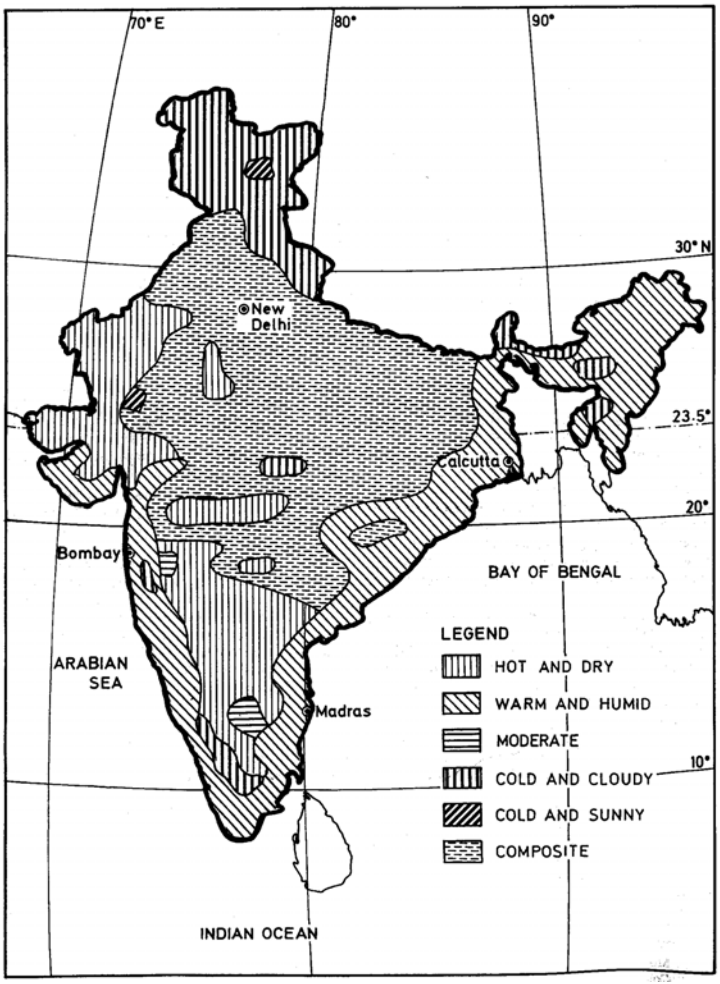
The country possesses a large variety of climates, ranging from extremely hot desert to high altitude locations with severe cold conditions similar to northern Europe, and therefore different energy usage patterns and demand. On the basis of hourly temperature, various climatic parameters and solar radiation data recorded at 233 stations, located in various parts of India, the country is divided into six climatic zones (Bansal and Minke 1995). These six climatic zones, a key city in each zone and the main forms of energy demand are:

1. Hot & Dry – Jodhpur (High Cooling)
2. Warm & Humid – Bombay (Ventilation)
3. Moderate – Bangalore (Lighting)
4. Cold & Cloudy – Shimla (Medium Cooling, Heating & lighting)
5. Cold & Sunny – Leh (High Heating)
6. Composite – Delhi (High Cooling & Medium Heating)

The factors that therefore will govern the energy usage inside the building can be classified as:

1. Energy consumption on the basis of climatic zones: Hot & Dry, Warm & Humid, Composite, Moderate, Cold & Cloudy and Cold & Sunny
2. Energy consumption on the basis of building usage: Residential and Commercial
3. Energy consumption on the basis of civic facilities: Urban and Rural housing
4. Energy consumption on the basis of conditioning: Conditioned and Non-conditioned buildings

Figure 3: Climatic Zones of India



3.2 Energy consumption in Indian buildings

India, because of its vast climatic diversity and various income group developed different housing patterns which influence energy consumption. Although energy consumption in India is below the world's average, still due to lack of implementation of effective energy efficiency measures Indian buildings give rise to significant energy wastage. The other major reason is illiteracy and poor buying power leading to almost zero penetration of energy efficient devices. Both commercial and residential establishments with installed air-conditioning systems in almost all the six climatic zones of the country lacks the usage of energy efficient devices and basic practices like building insulation. All this leads to a considerable over-consumption of electricity in a country, which is already suffering from a power deficit. The annual average energy consumption for heating, cooling and lighting in typical air-conditioned Indian buildings in different climatic zones of the country are given in Table 3.

Table 3: Specific energy demand in air-conditioned Indian buildings in different climatic zones of the country (Singh 2002)

Window Type	Window Area % to floor area	Climatic Zone	U - Value of the Building[1] (W/m^2K)	Energy Demand per unit area ($kWh/m^2/a$)
Single Glazed	10%	Hot & Dry	1.716	324 (61 - 69)*
Single Glazed	20%	Hot & Dry	1.892	400 (45 - 46)*
Single Glazed	10%	Warm & Humid	1.713	380 (65 - 69)*
Single Glazed	20%	Warm & Humid	1.887	418 (44 - 47)*
Single Glazed	10%	Composite	1.711	339 (44 - 70)*
Single Glazed	20%	Composite	1.883	376 (35 - 44)*
Single Glazed	10%	Moderate	1.693	148 (68 - 72)*
Single Glazed	20%	Moderate	1.847	163 (44 - 46)*
Single Glazed	10%	Cold & Cloudy	1.681	151 (74 - 79)*
Single Glazed	20%	Cold & Cloudy	1.823	157 (46 - 54)*
Single Glazed	10%	Cold & Sunny	1.687	530 (65 - 67)*
Single Glazed	20%	Cold & Sunny	1.835	600 (38 - 43)*

* The values given in parenthesis are the annual lighting energy demand in various climatic zones and their variation depending upon the orientation of the window and is included in the total energy demand.

In non-conditioned dwellings, the lighting energy demand is almost same whereas the heating and cooling energy demand is limited to the extent of using mechanical ventilation techniques through the use of air-coolers and fans.

The housing pattern and the respective energy demand in all the climatic zones shows a considerable variation. The new Energy Conservation Act for efficient use of energy in various establishments accounts for the energy efficiency in commercial sector, but the residential sector is still not properly addressed. In normal course of construction, the usage of insulation and efficient glazing system is still very limited and the benefits of employing energy efficiency measures have still not percolated among the masses.

3.3 Building use and occupancy

The latest available data from census of India (2001) clearly displays a major share of buildings is used for residential purposes both in urban and rural areas. Table 4 shows the usage pattern of buildings on the basis of civic facilities (urban and rural) and building usage (residential and commercial).

[1] The *U* value is the total heat transfer coefficient of a system (W/m^2K), which includes conductive, convective, and radiative heat transfer. It therefore represents the heat flow per hour through unit area for a unit temperature difference between the indoor and the outdoor.

Table 4: Census houses and the use to which they are put

S. No.	Details	Total	%	Rural	%	Urban	%
A	Number of census houses	249,095,869	100	177,537,513	71.3	71,558,356	28.7
A1	Vacant census houses	15,811,192	6.3	9,359,172	5.3	6,452,020	9.0
A2	Occupied	233,284,677	93.7	168,178,341	94.7	65,106,336	91.0
B	**Uses of occupied houses**						
B1	Residence	179,275,605	76.8	129,052,642	76.7	50,222,963	77.1
B2	Residence-cum-other use	7,886,567	3.4	6,046,812	3.6	1,839,755	2.8
B3	Shop, Office	13,390,292	5.7	5,566,717	3.3	7,823,575	12.0
B4	School, College	1,502,353	0.6	1,229,122	0.7	273,231	0.4
B5	Hotel, Lodge, Guest House	521,598	0.2	266,963	0.2	254,635	0.4
B6	Hospital, Dispensary	603,897	0.3	340,293	0.2	263,604	0.4
B7	Factory, Workshop	2,210,912	0.9	986,629	0.6	1,224,283	1.9
B8	Place for worship	2,398,650	1.0	1,982,515	1.2	416,135	0.6
B9	Non-residential use	25,494,803	10.9	22,706,648	13.5	2,788,155	4.3

Table 5: Urban population distribution – states and union territories: 2001

State	Total population	Urban population	Percentage
Jammu & Kashmir	10,069,917	2,505,309	24.9
Himachal Pradesh	6,077,248	594,881	9.8
Punjab	24,289,296	8,245,566	34.0
Chandigarh*	900,914	808,796	89.8
Uttranchal	8,479,562	2,170,245	25.6
Haryana	21,082,989	6,114,139	29.0
Delhi	13,782,976	12,819,761	93.0
Rajasthan	56,473,122	13,205,444	23.4
Uttar Pradesh	166,052,859	34,512,629	20.8
Bihar	82,878,796	8,679,200	10.5
Sikkim	540,493	60,005	11.1
Arunachal Pradesh	1,091,117	222,688	20.4
Nagaland	1,988,636	352,821	17.7
Manipur	2,388,634	570,410	23.9
Mizoram	891,058	441,040	49.5
Tripura	3,191,168	543,094	17.0
Meghalaya	2,306,069	452,612	19.6
Assam	26,638,407	3,389,413	12.7
West Bengal	80,221,171	22,486,481	28.0
Jharkhand	26,909,428	5,986,697	22.3
Orissa	36,706,920	5,496,318	15.0
Chhatisgarh	20,795,956	4,175,329	20.1
Madhya Pradesh	60,385,118	16,102,590	26.7
Gujarat	50,596,992	18,899,377	37.4
Daman & Diu*	158,059	57,319	36.3
Dadra & Nagar Haveli*	220,451	50,456	22.9
Maharashtra	96,752,247	41,019,734	42.4
Karnataka	52,733,958	20,503,597	27.1
Goa	1,343,998	668,869	49.8
Lakshadweep*	60,595	26,948	44.5
Kerala	31,838,619	8,267,135	26.0
Tamil Nadu	62,110,839	27,241,553	43.9
Pondicherry*	973,829	648,233	66.6
Andaman & Nicobar Islands*	356,265	116,407	32.7

** Union territory*

Also there is a huge difference of occupancy density and urbanization of various regions of the country. At one of the spectrum is the National Capital Territory of Delhi with 93% of its population living in urban areas, at the other end, Himachal Pradesh is least urbanized state with only 9.8% urban population. Table 5 displays a distribution of percentage of Indian urban population.

The next important key player is linked to the financial status and thus the distribution of household dwellings in urban areas also varies on the basis of occupancy per unit area and number of persons in a dwelling. Table 6 details the distribution of households by size and number of dwelling rooms in urban areas.

Table 6: Distribution of households by number of dwelling rooms

Occupancy	**Number of Rooms [Distribution of 28.4% urban population]**					
	One	Two	Three	Four	Five	Six & Above
One	1,183,840	399,144	162,049	59,540	18,875	25,844
Two	2,192,291	1,170,049	542,763	222,499	70,852	79,771
Three	2,867,712	2,030,408	1,071,521	422,455	133,739	134,333
Four	4,287,935	3,762,948	2,156,011	970,646	304,948	296,151
Five	3,555,063	3,259,185	1,828,577	852,649	312,879	305,025
Six to Eight	3,914,185	4,081,811	2,423,077	1,337,179	506,761	604,798
Nine & Above	851,768	1,153,903	992,933	791,882	405,944	700,485

Indian urban households use various sources of energy for lighting purposes, the primary source is electricity but around 10% of urban population (mostly underdeveloped, unauthorized and slum areas) still use kerosene for lighting purposes. Table 7 gives the distribution of urban Indian households by source of lighting.

Table 7: Distribution of urban households by source of lighting

Source of Lighting	**Population**	**Percentage**
Electricity	47,028,369	87.6
Kerosene	6,231,038	11.6
Solar energy	128,136	0.2
Other oil	38,259	0.1
Any other	78,098	0.1
No lighting	188,476	0.4

4. Measures to reduce building energy use and their relation to CDM

The change in energy use over time is driven by a combination of efficiency, weather, behavioral, and structural effects that may be only partially separable and may differ among energy services. Therefore, the task of measuring and assessing energy efficiency and its change over time consists of the following:

1. Deciding which effects should be considered as inherent in efficiency measurement and which are due to weather, behavioral, and structural changes to be eliminated or, at least, recognized in the measurements. This is particularly important for the assessment of baseline emissions.

2. Creating an appropriate categorization of energy services that provides the best possible starting point to assess efficiency measures

The following measures can be considered:

1. Reducing the energy demand in air-conditioned buildings while maintaining comfortable living conditions.
2. Reducing the electricity consumption in non-air-conditioned buildings through natural cooling (ventilation and earth air tunnel systems) and energy efficient fans.
3. Reducing the lighting energy demand through energy efficient light systems.
4. Switching to solar and other renewable sources of energy.

Building sector energy efficiency projects can qualify as CDM provided that they achieve real and measurable emission reductions. The challenge is to prove that the energy efficiency improvement would not have happened otherwise, i.e. that the project is “additional” (Greiner and Michaelowa 2003). This depends on the circumstances, such as financing and technological barriers. The CDM Executive Board has put a strong emphasis on additionality determination during the last year.

To get a rough idea about the overall CDM potential in the building sector, we first do a top-down assessment of the energy saving potential by adopting the following procedure:

1. Analyzing the current rate of energy consumption in Indian building sector – Residential and Commercial
2. Comparison with other countries having building energy efficiency codes and its effects.
3. Suggestion of possible energy efficiency measures in buildings and estimation of payback period.
4. Verification of actual energy savings through monitoring.

4.1 Energy efficient glazing system

Windows bring light, warmth, and beauty into buildings and give a feeling of openness and space to living areas. They can also be major sources of heat loss in the winter and heat gain in the summer. In 1990 alone, the energy used to offset unwanted heat losses and gains through windows in residential and commercial buildings cost the United States $20 billion (one-fourth of all the energy used for space heating and cooling). However, when properly selected and installed, windows can help minimize heating, cooling, and lighting costs.
Indian buildings still lack the use of energy efficient glazing system, whereas more and more buildings are being converted into air-conditioned buildings without implementing any energy efficiency measures in almost all the climatic zones. This indicates a considerable amount of electricity wastage in Indian housing, which can be reduced easily through energy efficient glazing.
A significant reduction in specific energy demand is possible just by replacing the current single glazed windows with energy efficient multiple glazed windows. Simulations were carried out on six cities representing one climatic zone each for ascertain the amount of possible savings in different climatic zones. In hot & dry with double glazed, double glazed Low-E and triple glazed energy efficient windows, savings of 5% to 27% were observed for 10% and 20% glazing area respectively. For other five climatic zones the possible savings are given in table 8.

Table 8: Energy saving potential of multiple glazed windows over single glazing (24 hours usage)

Window Type	**Percentage Area**	**Specific Energy Demand kWh/m^2/a (includes lighting) [Percentage saving as compared to the single glazing]**				
		Warm & Humid	Composite	Moderate	Cold & Cloudy	Cold & Sunny
Double Glazed	10%	350 [7.8]	299 [11.7]	139 [6.1]	145 [3.9]	472 [9.6]
	20%	385 [7.8]	334 [11.1]	145 [11]	150 [4.4]	514 [10.9]
Double Low-E with Argon	10%	336 [11.5]	286 [15.6]	134 [9.4]	142 [5.9]	428 [19.2]
	20%	369 [11.7]	323 [14.1]	137 [15.9]	147 [6.3]	446 [25.6]
Triple Glazed Energy Efficient Windows	10%	322 [15.3]	268 [20.9]	124 [16.2]	140 [7.8]	401 [24.3]
	20%	354 [15.3]	307 [18.3]	129 [20.8]	145 [7.6]	431 [28.1]

+ The percentage area is window area (percent of floor area)

These simulation results are on the basis of 24 hours usage of the building and can fit well for the residential sector. For commercial sector buildings operation for 8 hours a day and 5 days a week, the results indicate a much better saving potential in most of the climates except moderate and cold & sunny because the buildings are in use during day hours. Simulations were carried out for 20% window area (generally practiced in commercial buildings for natural lighting) with 5 days a week and 8 hours of operation. The results obtained are tabulated below in table 9.

Table 9: Energy saving potential of multiple glazed windows over single glazing (for commercial buildings)

Window Type	Percentage saving as compared to the single glazing					
	Hot & Dry	Warm & Humid	Composite	Moderate	Cold & Cloudy	Cold & Sunny
Double Glazed	15.8	8.1	14.3	6.2	5.7	11.3
Double Low-E with Argon	26.1	12.3	14.7	16.2	6.8	26.9
Triple Glazed Energy Efficient Windows	28.1	16.5	18.6	21.5	8.1	28.7

It is therefore established that use of energy efficient glazing in air-conditioned buildings can considerably reduce the heating and cooling energy demand with a slight increase in lighting energy demand due to reduction in visible transmittance of window. For a typical Gurgaon office block of 10,000 m^2 with an energy use 400 kWh/m^2, a reduction of energy demand by 15% would translate into 0.6 GWh. Even if the lower values of Bhatt et al. (2004) are taken, at 250 kWh/ m^2 the savings would still reach 0.375 GWh.

The main barrier to glazing improvement is the initial price differential. Prevailing market rates for available window types in India are given below:

Table 10: Market price for available double glazed windows (Sintex Industries)

Type of window	**Thickness of glazing layer**	**Type of frame**	**Market price $/ m^2**
Single Glazed	4 mm	Vinyl	60
Double Glazed	4 mm with 12 mm spacing	Vinyl	96

Only double glazed windows are available on of the shelf basis; windows with higher efficiency levels are not available in India.

4.2 Optimization of glazing area and building insulation

Walls and roof offer more resistance to heat transfer as compared to glazing system because of their thermal mass, and act as a low pass filter to the climatic parameters leading to a phase lag between the external and internal temperature peaks. Still walls and roof are a major source of heat loss (cold climates) and heat gain (hot climates) in buildings. Thus insulating the walls with suitable insulation material will further improve the performance of buildings and reduce the amount of heat or cooling required to keep the temperature comfortable inside the building.

Optimization of glazing area can also play a major role in reducing the heating and cooling energy demand. Glazing tends to reduce the lighting energy demand by using day lighting whereas along with light the rate heat exchange of the building with outside environment also increases. Thus optimum scenario is fixing the size of glazing on the basis of minimum specific energy demand considering both air conditioning and lighting inside the building.

A combination of simulation tools (DOE 2.1E, EnergyPlus and GenOpt 1.0) has been used to optimize the glazing area in insulated buildings representing different climatic of the country (Singh 2002). This optimization is done on the basis of opening and orientation of the glazing system. The simulation results for best orientation corresponding to the minimum specific energy consumption are given in Table 11.

It makes clear that a significant reduction in energy demand is possible if energy efficient glazing is combined with best orientation (for lighting), opening area (for heat exchange) and building insulation (for increasing the resistance to heat exchange). The results so obtained are comparable with specific energy demand of buildings in many developed countries and can be implemented in new constructions and major retrofitting.

From table 11 it is observed that the lowest possible energy consumption can be achieved in hot & dry and warm & humid climates with very small opening, which is not practical considering the building aesthetics. Further simulations have been done to analyze the specific energy demand of the buildings by increasing the glazing area. It has been observed that in hot & dry climate, north facing double glazed window continues to save energy up to even 12.5% of glazing area. In warm & humid climatic conditions, double glazed window continues to save energy up to 12.5% in both north and south facing conditions.

Table 11: Best orientation and the corresponding specific energy consumption ($kWh/m^2/a$)

Window Type	Orientation	Percentage Window Area	Lighting Energy	Cooling Energy	Heating Energy	Total Energy
Hot & Dry Climate						
Double Glazed	South	5	81.5	94.881	9.56	185.941
Double Glazed Low-E	South	5	82.9	88.391	9.42	180.711
Triple Glazed	South	7.5	82.4	77.647	8.97	169.017
Warm & Humid Climate						
Double Glazed	South	5	82.04	24.856	-	106.896
Double Glazed Low-E	North	7.5	83.57	22.396	-	105.966
Triple Glazed	North	12.5	84.12	18.653	-	102.773
Composite Climate						
Double Glazed	South	12.5	60.87	76.125	14.25	143.545
Double Glazed Low-E	South	15	60.71	62.249	11.25	134.209
Triple Glazed	South	15	61.34	52.267	10.51	124.117
Moderate Climate						
Double Glazed	North	25	36.92	23.688	3.563	64.171
Double Glazed Low-E	North	27.5	36.87	22.467	3.025	62.362
Triple Glazed	North	27.5	37.01	19.076	2.941	59.027
Cold & Cloudy Climate						
Double Glazed	South	17.5	55.08	9.813	94.75	159.643
Double Glazed Low-E	South	17.5	57.48	7.858	87.92	153.258
Triple Glazed	South	22.5	56.47	6.411	67.37	130.251
Cold & Sunny Climate						
Double Glazed	South	42.5	31.52	12.125	325.188	367.833
Double Glazed Low-E	South	42.5	33.18	10.954	297.143	341.277
Triple Glazed	South	42.5	34.56	8.995	247.27	290.825

Thus the final suggested glazing orientation in new buildings in different Indian climatic zones may be:

1. Hot & Dry [North & South]
2. Warm & Humid [North & South]
3. Composite [South]
4. Moderate [North]
5. Cold & Cloudy [South]
6. Cold & Sunny [East & South]

4.3 Efficient air-conditioners

In China, currently the residential air conditioner market is undergoing a rapid expansion. Thus, a similar phenomenon is to be expected in India when economic growth continues on its path. Greater use of available, cost-effective technologies to increase energy efficiency in air conditioners such as using a more efficient compressor can lead to sharp reductions in electricity use. High-efficiency units use only 50% of the electricity compared to the common ones, but cost about 2.5 times more. If 1 million air conditioners of the high efficiency type were introduced, 750 GWh could be saved per year.

4.4 Compact Fluorescent Lamps (CFLs) and Light Emitting Diodes (LEDs)

State of the art CFLs and LEDs have a huge potential to reduce the lighting energy demand. The other benefits include less damage to the environment due to longer life of these lamps leading to less landfills (disposal of bulbs) and simultaneously these bulbs reduce the amount of mercury by 70%, which is released to the atmosphere through a normal incandescent lamp.

A comparison of various parameters pertaining to the incandescent lamp and efficient lamps is given below in Table 12.

Table 12: Cost benefit analysis of CFLs versus Incandescent lamps

Comparison	Incandescent Lamps	Compact Florescent Lamps
Rated Watts	80	20
Lamp Life (Hours)	750	10000
Lamps needed for 10,000 hours	13	1
Cost per kWh (residential) $	0.08	0.08
Energy used over 10000 hours (kWh)	800	200
Electricity cost for 10,000 hours ($)	64	16
Cost per bulb ($)	0.4	8
Bulb cost per 10,000 hours	5.2	8
Total life cycle cost	69.2	24

Direct saving US$:	45.2
Reduction in energy demand:	600 kWh
Average GHG emission for power sector:	800 g / kWh
Saving of GHG emissions with one bulb replaced by CFL:	480 kg

The CFLs are available in various capacities ranging from 5 up to 40 W that are equal in output to incandescent lamps of four times their capacity.

Despite the superior characteristics of the CFLs, still over 1 billion incandescent lamps are sold in India every year. The CFL penetration in India is a meager 3% compared to 33% in Singapore and 40% in Korea. The market analysis and the consultations conducted by Indian Institute of Technology Delhi (IIT) indicated that the main reasons for still relatively low interests of consumers to purchase CFLs are the low awareness about benefits and their high price as compared to standard incandescent lamps. A specific campaign in cooperation with the lamp manufacturers, state owned power utilities and retail marketing chains, would improve penetration and lead to a price reduction. If 10% of Indian lamp sales would be CFLs, about 50 million tonnes CO2 reduction would be achieved. This would still only mean that about one room per urban dwelling would be lighted by a CFL.

A new lighting technology in the form of Light Emitting Diodes is also available nowadays. These are solid light bulbs, which are extremely energy efficient. An LED lamp generally lasts about 10 times longer than CFLs and about 130 times more than an ordinary Incandescent lamp. Since LEDs do not have a filament, they are not damaged under circumstances when a regular incandescent bulb would be broken. Because they are solid, LED bulbs hold up well to jarring and bumping. These bulbs do not cause heat build-up; LED's produce 3.6 kJ/hour, compared to 90 for incandescent bulbs. A possible reduction of more than 80% can be expected from usage of LEDs for lighting. These lamps have started replacing the traffic lights in many countries (including India) because of extensive energy saving potential and longer working life.

5. Combined programs in commercial buildings: case studies

The commercial sector includes a diverse range of buildings in the public and private sectors. Energy saving experience worldwide suggests that the best targets for energy saving activity in the commercial sector tend to be hospitals, hotels, office buildings, schools and other institutional buildings including airports and ports. These segments are characterized by relatively large individual facilities or a large number of facilities with similar energy usage patterns that are at least large enough to make their energy savings potential measurable.

In India commercial buildings are a major source of high electricity consumption because of lack of awareness and careless usage of electricity compounded by old buildings not designed for air-conditioning purposes.

In government buildings alone, the investment potential has been estimated at 76 million $ for energy efficiency projects (having over 500 kW connected load for individual facility) in 36 cities. Overall energy savings potential has been estimated at 760 GWh. At 15% capital recovery factor, cost for every kWh avoided works out to about $ 0.12 while unit cost of supply from new generating facility would be about $ 0.12. It has also been estimated that air conditioner facility improvement will require about 80% of the total investments whereas light will require 10% of the investments.

With its new Energy Conservation Act in force, the Indian Government has taken some initiatives towards reduction in energy consumption in the Government-owned commercial buildings by carrying out energy audits and selecting the methods to check energy leaks and efficient use of electricity in buildings. In pursuance of government policy the Bureau of Energy Efficiency has initiated identification of buildings consuming a huge amount of electricity annually to carry out energy audits through a team of experts.

Nine government buildings and establishments - Rail Bhawan, Sanchar Bhawan, Shram Shakti Bhawan, Transport Bhawan, Research & Referral Hospital, Terminal I, II and cargo section of Delhi Airport, Prime Minister Office, Ministry of Defense Blocks, Rashtrapathi Bhawan and All India Institute of Medical Sciences have been identified for the project. A consortium was formed with National Productivity Council, DSCL Energy Services, Thermax EPS, Energy Audit Services, Central Power Research Institute and The Energy Research Institute. The results of the energy audit and suggested ways and means for their implementation in the various government buildings are summarized below.

5.1. All India Institute of Medical Sciences

Established in 1956, it is a medical institute of national importance which has comprehensive facilities for teaching, research and patient-care and has proved to be the best in patient care for last 4 decades. The connected load of the institute is 5800 kW and the annual average consumption reaches 39.2 GWh. The institute is divided into seven complexes having a total built up area of 0.1 million sq. m. The institute is supplied with 11 kV power supply and single part tariff of 0.13 $/ kWh is applicable for energy consumption. The current energy efficient features installed in the building includes:

- Installation of CFLs & 36 W FTLs
- Installation of electronic chokes in administrative blocks
- Installation of centrifugal chillers
- Installation of Variable Frequency Drives and Air Handling Units in CN centre.

About 15% of electricity is used for lighting, of which over 90% are fluorescent tubes of 40 W. Here, design improvement and use of energy efficient fixtures were suggested that would yield an energy saving potential of 777 kW with an initial outlay of 244,000 $.

50% of the electricity use goes into air conditioning. Alterations to the air-conditioning system installed at the institute were suggested as follows:

Table 13: Proposed savings in AIIMS Air Conditioning system

	Operating	**Proposed**	**Savings (US$)**	**Investment (US$)**
Chiller	Centrifugal Chillers (500 TR * 4)	Automation for optimizing system efficiency due to load variation	123,067	311,111
Chilled Water Pump	25 kW * 5	Automation to improve the system efficiency	71,089	311,11
C T Fan	19 kW * 5	Removal of one CT fan and change of MOC with automation	22,311	29,333
Total			**216,467**	**371,555**

Total estimated savings through air-conditioning and lighting improvement are 4.9 GWh per annum. At the average carbon intensity of the Northern grid of 796 g CO_2/kWh GHG emissions would be reduced by 3900 tonnes.

5.2 Rail Bhawan

Rail Bhawan is the headquarter of Indian Railways with a built-up area of 2,910 m^2 and about 4,850 employees. The building has a connected load of 2187 kW and a total electricity consumption of around 1.4 GWh per annum. The present annual energy consumption in the lighting system at Rail Bhavan is 456 MWh (19% of total consumption) which costs 64,500 $, air conditioning uses 936 MWh (32% of total consumption) at costs of 132,500 $. The anticipated annual energy saving due to lighting energy efficiency measures are 150 MWh (replacement with electronic ballast & high lumen tubes and de-lamping), saving 21,300 $

annually, leading to a pay-back period of 2.6 years. Concerning air conditioning, recommended measures yield 416 MWh, a saving of 58,900 $ with a pay-back period of 4.9 years. For the details of savings envisaged after carrying out energy audit of the buildings is see Appendix 1. The total possible electricity saving in air conditioning and lighting energy demand envisaged is 566 MWh which would lead to 450 tonnes of GHG reduction.

5.3 Shram Shakti Bhawan

Shram Shakti Bhawan (SSB) is located in central Delhi under New Delhi Municipal Council (NDMC) administered area. The metering of Shram Shakti Bhawan includes the electrical supply to Transport Bhawan (TB) hence the Transport Bhawan is also included under the project. Shram Shakti Bhawan is a six-storied building with a total floor area of 2356 m^2, Transport Bhawan is a five-storied building with a total floor area of 2280 m^2. The buildings have a connected load of 1.8 MW; annual average consumption is 2.1 GWh. In the current load pattern, lighting consumes 28% and air conditioning 44% of the total electrical energy.

Table 14: Proposed savings in Shram Shakti Bhawan

Area	Brief Description	Savings, US$	Investment, US$
Lighting	Retrofit based on Design and Technology for task lighting	18,533	26,222
Air Conditioning	Replacement of Window and Split ACs with Centrifugal Chiller based Central AC System	59,556	271,111
Total		78,089	297,333

The expected reduction in electrical consumption is 558 MWh, i.e. 26% and translates into 444 t CO_2.

5.4 Palam Airport

The domestic airport located in Delhi is having a connected load of 16.14 MW. The electricity is supplied at a variable unit cost of 0.1 $/kWh. The average annual consumption of electricity is 71.28 GWh. The average power factor of the connected load is 0.917. The connected load for terminal 1 is 6.78 MW (42%), whereas that for terminal 2 is 6.62 MW (41%) and the cargo section 1.45 MW (9%). Other connected loads are 1.29 MW (8%). The further distribution of load on the basis of activities carried out in the buildings under consideration:

Table 15: Distribution of connected load on various terminals

Terminal	Lighting	HVAC	Others
Terminal – 1	9%	83%	8%
Terminal – 2	12%	81%	7%
Cargo terminal	45%	48%	7%

The following energy efficiency measures are suggested for reducing the energy demand of the domestic airport.

Table 16: Proposed savings at Palam Airport

Terminal	Measure	Details	Annual savings US$	Investment required US$
All locations	Power Factor improvement from 0.917 to 0.999	Capacitor requirement 4765 kVAR	573,333	335,556
Terminal – 1	Efficient use of transformers	Cyclic switching off of transformers	4822	Nil
Terminal – 1	Load shifting from 11 kV to 33 kV	Reduction in transformer and cable losses	5378	Nil
Terminal – 1	Supply voltage reduction from 247 to 220 V		29,444	51,379
Terminal – 1	Application of Electronic Ballast	Change of ballast of 6912 tube lights	65,244	68,667
Terminal – 2 & Cargo	Efficient use of transformers	Cyclic switching off of transformers	9400	Nil
Terminal – 2	Supply voltage reduction from 247 to 220 V		13,089	38,622
Cargo	Supply voltage reduction from 247 to 220 V		34,889	48,333
Terminal – 2	Application of Electronic Ballast & high lumen tube lights		65,667	67,378
Terminal – 2	Replacement of lamps	HPMV lamps by MH lamps	8667	8444
Cargo	Application of Electronic Ballast & high lumen tube lights		4778	8622
Cargo	Replacement of lamps	HPMV lamps by MH lamps	764,44	81,333

The installed air conditioning system at all the terminals was analyzed and following observations were made:

1. Provision of projected roof and limited sun facing wall area limits the heat penetration in the terminal and cargo buildings.
2. Walls and windows of terminal buildings have adequate insulations, which reduces the building-heating load.
3. Air changes (Infiltration) and auxiliary loads have major contribution in total heat load, which does not justify further strengthening of insulation.

The water pumping system is under performing with most of the pumps operating at less than 75% efficiency. In some cases the efficiency levels are as low as 12%. Air Handling Units are running at an efficiency level below 30%. It is estimated that the air conditioning system can be optimized for power consumption and an annual saving of 332,000 $ can be achieved by investing 1.09 million $. The total possible savings from all energy efficiency measures comes out to be 12.2 GWh (around 17% saving). The expected reduction in GHG emissions from these measures can be of the order of 9710 tonnes.

6. Barriers in executing building energy efficiency CDM projects:

Despite the relatively favorable general policy framework to support energy efficiency, there are several barriers to the actual implementation of these measures. The identified barriers range from the still inadequate legal and regulatory framework that limits the role of Energy Service Companies (ESCOs) and the lack of a coherent system of energy planning to different information, “capacity” and financial barriers.

6.1 Higher initial costs

All energy efficiency technologies have a higher cost of investment than the standard technology. Short-sighted consumers and cash-strapped bureaucrats do not value the lower operational costs during the lifetime of the equipment but want to minimize their initial outlay. Some of the key barriers to the implementation of economically feasible energy efficiency measures in buildings are related to the costs and the associated risks of the project preparation stage. Firstly, the owners of the buildings, who are not even aware of the specific energy efficiency technologies and their costs *vis-à-vis* their cost saving potential are not often ready to invest even in preliminary energy audits. Secondly, should a preliminary energy audit give an incentive to the end user to proceed towards full feasibility studies, this is still perceived as a very risky investment as the study might never lead to the actual financing decision. This explains the puzzle of extremely short payback periods but no uptake of the more efficient equipment. This barrier can be removed by ESCOs but only if the legal system allows them to have sufficient securities such as continued ownership of the equipment until the end of the contract.

6.2 Technological and awareness barriers

Most building managers are overloaded with daily routines and therefore do not have the time to think about an integrated energy management system. They are hesitant to employ a new, unknown technology that may require skills beyond their qualification. Again, ESCOs can overcome this barrier.

6.3 Technological and awareness barriers

A trivial, but often overlooked barrier is the transaction cost accruing if one has to address many different owners /operators of buildings. This essentially limits CDM projects to large-scale commercial buildings. But even here, the annual emission reduction lies between 500 and 10,000 t, which may not be enough to cover the CDM-related transaction costs (Michaelowa et al. 2003). Programs for appliance dissemination such as airconditioners, windows and CFLs may overcome this barrier if they are large enough; monitoring of the equipment use may however be challenging. So far, no large-scale project of this type has an approved baseline and monitoring methodology.

7. Conclusions

The Indian building sector offers a huge potential for greenhouse gas reduction, but only a small part can realistically be tapped by the CDM. This is due to the fact that transaction costs may be prohibitive for all but the biggest commercial buildings or large-scale appliance diffusion programs.

The initial focus of the CDM projects should be on service sector buildings such as hotels, headquarters of banks and large companies with high specific energy consumption and with large potential for energy savings. The first of such projects has been approved by the Indian National CDM Authority.

Although the cumulative energy saving potential of the hospitals, schools and other public buildings in India is considerably bigger, the problem is that their energy bills are currently paid directly by the Government through the respective ministries that are supervising their operations. Such a situation completely discourages the operators of these buildings to introduce any energy saving initiatives. However, a large-scale unilateral CDM program of the Government could change the picture.

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Appendix 1

Table A 1: Saving in lighting energy demand in Rail Bhawan

S. No.	Parameter	Value	Unit
(A)	Present status		
1	Present rate of electricity/kWh	0.14	$
2	Consumption for existing tube light	46.4	W
3	Total no. of 40 Watts tube lights in rooms	3516	No.
4	Operating hours/year	2500	hour
5	40 Watts tube light in staircase	34	No.
6	Operating hours/year	8760	hour
(B)	Proposed Modification:		
1	Replacing each FTL with high lumen TL & Electronic ballast	30	W
2	Delamping the single FTL which illuminates the ceiling	19	No.
(C)	Savings:		
1	Savings on account of replacing FTL in rooms	148,280	kWh/year
2	Savings due to delamping	2204	kWh/year
3	Total energy saved due to lighting modification	150484	kWh/year
4	Total amount saved due to lighting modification	21,311	US$
(D)	Investment:		
1	Cost per high lumen TL with electronic ballast	15.5	US$
2	Total Investment	55222	US$
(E)	Payback	2.6	Years

Table A 2: Saving in Air conditioning in Rail Bhawan

Cooling	Average SPC of existing air conditioners	1.42	kW/TR
	Present condensing temp. (winter season)	15	deg. C
	Average condensing temp. during summer	35	deg. C
	Increase in SPC of compressor due to higher condensing temp. (Taking that for every 1 deg. C rise in condensing temp. there is 2 % increase in SPC of compressor)	40	%
	Expected SPC of air conditioners during summer	1.99	kW/TR
	Presently installed capacity of AC with a diversity of 25%	400	TR
	Capacity of central AC system required	400	TR
	Installed window AC	358	No
	Installed AC load	751.8	kW
	Present AC running load from Energy bill	600	KW
	Presently delivered TR	301.81	TR
	Loading with Central AC plant with 75%	300	TR
	Power required by central plant/TR	1.10	kW
	KW consumption of central AC plant with 75% loading	330	kW
	Power Saving	270	kW
	Working Hrs /day	10	
	Working days /year	125	
	Working Hrs /Yr	1250	
	Energy cost / kWh	0.14	US$
	Energy saving kWh /year	337,500	kWh
	Annual energy saving	47,775	US$
Heating	Room heating load for two months/year	400	kW
	Energy consumed for room heating /Year	168,000	kWh
	Energy cost / yr	23,778	US$
	Equivalent kcal (capacity of hot water generator)	344,000	kcal
	Hot water flow required to carry the above heat (35/40 deg. C)	72	m^3/h
	Calorific value of Light Diesel Oil (LDO)	10000	kcal/kg
	Thermal efficiency of hot water generator	85	%
	Annual LDO requirement	16998	Kg
	Cost of LDO/Kg	0.445	US$
	Running energy cost for pump & FCUs / year	5111	US$
	LDO cost / year	7556	US$
	Annual savings	11111	US$
Total system	Total saving	58,889	US$
	Investment		
	Central AC plant	277,778	US$
	Hot Water generator	11,111	US$
	Total	28,889	US$
	Payback period	4.9	Years