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Report 47

Lighting and Energy in Buildings

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Contents

1. Background

Energy is an essential commodity of our life and the use of energy is increasing with human advancement and industrial development. Energy security and environmental impacts of the use of energy are two important issues of concern worldwide.

The acceleration of increase in the concentration of greenhouse gas in the atmosphere have caused the world to warm by more than half a degree Celsius in last century and it will lead to at least a further half degree warming over the next few decades [Stern 2006]. Energy is the main factor in the climate change, contributing to the major portion of the greenhouse gas emissions [IPCC 2007]. Industrialized nations are the source of most of the greenhouse gas emissions but it might change in future as the developing countries pursue industrialization. United States and Europe together consume almost 40 % of world's energy supply although they produce only 23 % of it. Europe is dependent on imports for about half of its total energy needs. With the current trend of energy use, the EU expects 65 % of its energy needs to be dependent on import by 2030, which poses critical challenge on the energy security [Belkin 2007].

One of the most effective means to solve these problems is energy efficiency, which can save energy while reducing the greenhouse gas emissions. The EU has been the leader in the field of energy efficiency and is taking new measures to promote it. These measures include minimum efficiency requirements for energy using equipments, stronger actions on energy use in buildings, transport and energy generation. The EU have committed on its new energy policy to improve energy efficiency by 20% by 2020[COM 2007]. This report summarises current trends in energy use for lighting in buildings, available technologies and practices, and various possibilities and potentials for energy efficient lighting in buildings.

2. Worldwide Energy and Lighting scenario

2.1 Worldwide Energy consumption

The amount of energy consumption in the world is in the continuous rise every year. Total global primary energy consumption in 2004 was 446.442 quadrillion (10^{15}) British thermal units (BTUs) (1 BTU = 1055.1 joules), which is equivalent to 130,839 TWh [EIA 2007]. The increase in the consumption between 1994 and 2004 continued at an average annual rate of 2.2 percent. In 2004, Petroleum, Coal, and Natural gas were the three major important

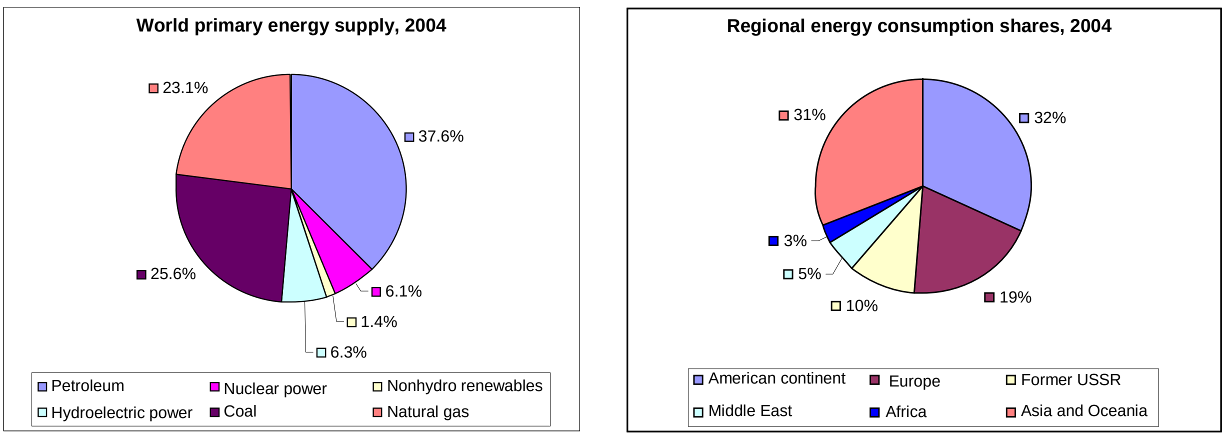

Figure 1 World primary energy supply and regional consumption shares in 2004 [EIA 2007]

energy supply sources accounting 37.6 percent, 25.6 percent, and 23.1 percent of total primary energy production (figure 1). More than half of the energy is consumed in America and Europe together and the rest is consumed in other regions.

2.2 Energy consumption in Buildings

The buildings, consisting of residential, commercial, and institutional buildings account for more than one-third of primary global energy demand. Building sector is the highest energy user among the three energy-using sectors: transportation, industry, and building. In the EU, the building sector represents more than 40% of total energy demand [COM 2001]. The global energy demand in building has been increasing at an average of 3.5% per year since 1970 [DOE 2006(b)]. The urban buildings usually have higher level of energy consumption per unit area than the buildings in rural areas. According to the projection by United Nations, the percentage of world's population living in urban areas will increase from 49 percent in 2005 to 61 percent by 2030 [UN 2005]. So the growth of energy use in building is expected to continue over the long term due to the growth in population, and also due to the urbanization.

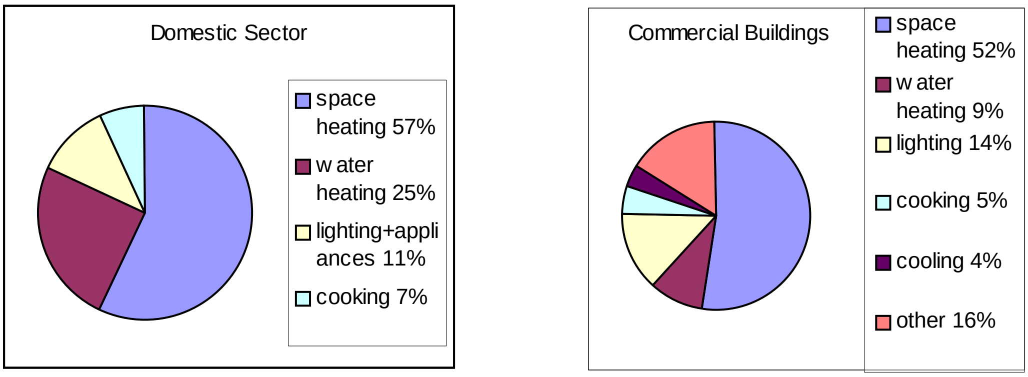

Figure 2 Energy consumption by end use in the EU domestic and commercial buildings [EC 2007]

Energy is consumed in buildings by different end users: space heating, water heating, ventilation, lighting, cooling, cooking, and other appliances. Heating (space and water) is the leading energy consumer in EU domestic and commercial building sectors followed by lighting (Figure 2). Other main consumers are cooking, cooling and other appliances. Lighting is the leading energy consumer (24%) in US commercial buildings ahead of space heating (13%), while its share is less than that of spacing heating and water heating in residential buildings [DOE 2006 (a)].

2.3 Worldwide Electricity consumption

The use of electricity in the world has been increasing at a faster rate than overall energy because of its versatile nature in production as well as in the consumption [EIA 2006]. Worldwide electricity consumption in 2004 was 15441 TWh, which is 11.8 percent of total primary energy consumption [EIA 2007]. Since large amount of energy is lost during the process of generation of useful electrical energy, the amount of input energy for the electricity generation is far greater than the amount of electricity at its point of use. Worldwide electricity generation uses 40 percent of the world's primary energy supply [Hore-Lacy 2003]. According to the International Energy Outlook 2006 [EIA 2006], the world's total net electricity consumption is expected to double from 2003 value of 14,781 TWh to 30,116 TWh in 2030 at an average of 2.7 percent per year. The growth of primary energy consumption for the same period will be 71 percent, expanding from 421 quadrillion British thermal units (Btu) in 2003 to 722 quadrillion Btu in 2030.

2.4 Electricity Consumption for Lighting

Lighting was the first service offered by electric utilities and it continues to be a major source of electricity consumption [IEA 2006]. Globally, almost one fifth of total electricity generated is consumed in lighting. According to the IEA study [IEA 2006], global grid based electricity consumed about 2650 TWh of electricity in 2005; an equivalent of 19 percent of total global electricity consumption. So the total electricity consumption for lighting is more than the global electricity produced by hydro or nuclear power plants, and almost same amount of electricity produced from natural gas. More than 50% of this lighting electricity is consumed in IEA member countries, but this case will not be the same in few years due to the increasing growth rate of lighting electricity use in non IEA countries.

Almost half of the global lighting electricity (48%) is consumed by the service sector. The rest is distributed between the residential sector (28%), industrial sector (16%), and street and other lighting (8%). The share of electricity use for lighting over total electricity use varies from 5 % to 15% for the industrialized countries, while the share is up to 86% (Tanzania) in developing countries. [Mills 2002]

2.5 Fuel-based Lighting and Vehicle Lighting

Despite the dominance of lighting energy use by electric lighting, there is also significant amount of energy used in vehicle lighting and off-grid fuel-based lighting. More than one quarter of the world's population still do not have access to electrical network and use fuel based lighting to fulfil their lighting needs [Mills 2002]. IEA [IEA 2006] estimates that the annual energy consumed in fuel based lighting is equivalent to 65.6 Mtoe (Million Tons of Oil Equivalent) of final energy use. The estimated amount of global primary energy used for lighting is 650 Mtoe. The fuel based light sources include candles, oil lamps, ordinary kerosene lamps, pressurized kerosene lamps, biogas lamps, propane lamps, and resin soaked twigs as used in remote Nepali villages [Bhusal 2007]. But the most widely used are ordinary wick-based kerosene lamps as fuel-based lighting in developing countries. For example, nearly 80 million people in India alone light their houses using kerosene as the primary lighting media [Shailesh 2006].

An estimated 750 million light-duty vehicles (cars, light trucks, and minivans), 50 million trucks, 14 million buses and minibuses, and 230 million two-three wheelers used in 2005 worldwide consumed the vehicle fuel for external lighting applications to provide illumination for driving and security needs. Although the amount of fuel used for lighting is small portion (3.2%) of all road vehicle energy use, 55 billions litres of petroleum, amounting to 47.1 Mtoe of final energy was used to operate vehicle lights in 2002. Vehicle lighting power demand for individual vehicle is increasing to improve the driving safety and comfort. On the other hand, increasing number of countries are introducing policy actions to promote greater use of daytime vehicle lighting through regulation or incentives. This will further increase the amount of global vehicle-lighting energy use. [IEA 2006]

2.6 Consumption of Light

The amount of light consumption in the world has been increasing everyday with the increase in the per capita light consumption and the increase in the population of the world. According to IEA estimation [IEA 2006], the amount of global light consumption in 2005 was 134.7 petalumen hours (Plmh). The electric lighting accounted for 99% of the total light consumption while vehicle lighting accounted for 0.9%, and fuel based lighting accounted for only 0.1%. The light consumed by the people who use fuel based lighting is very low compared to the light consumption by the people who have access to electricity. The average per capita light consumption by people with access to electricity is 27.6 Mlmh per annum, while the people without access to electricity use just 50 Kilolumen-hours (klmh) per person per annum. This shows that the people with electricity access are using more than 500 times more light compared to the light used by people without access to electricity. Even within the electrified places, there exist large variations in the use of light. The variation in light consumption among the different region of the world can be seen in Figure 3.

Although there is large inequality in the use of lighting among the different parts of world, there has been remarkable increase in the amount of light used all over the world in past century. The annual growth of artificial lighting demand in IEA countries was 1.8% in last decade, which is lower than the previous decades. This could be the indication of the start of demand saturation. But the growth of lighting demand on the developing countries is in the rise due to the rising average illuminance levels on those countries and also due to the new construction. The demand in developing countries is expected to rise more in the future due to the new electrification in the region where electric light doesn't exist at the moment.

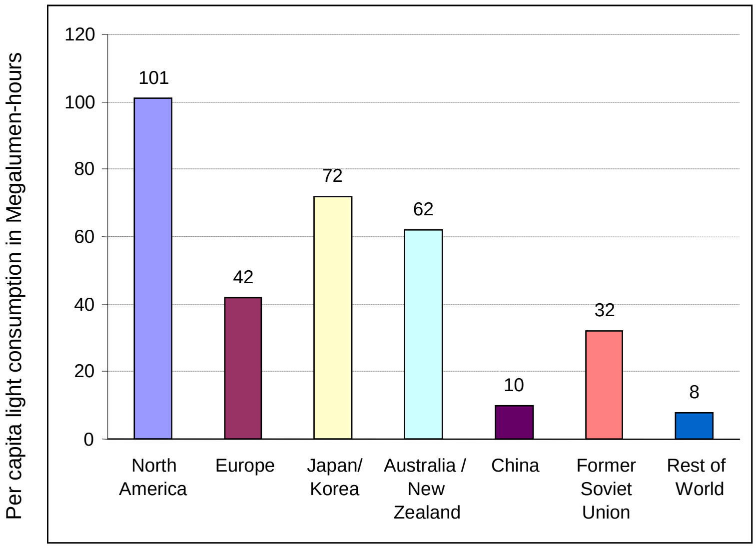

Figure 3 Estimated per-capita consumption of electric light in 2005 [IEA 2006]

2.7 Impacts of Lighting Energy use on the Environment

Lighting impacts the environment as a result of lighting energy use, material used to produce lighting equipment, and disposal of used equipment. Most of the greenhouse gas emissions occur due to the use of energy. Emissions in production of electricity, and also due to the burning of fuel in vehicle lighting and in fuel based lighting are responsible for lighting related greenhouse gas emissions. Hazardous materials (e.g. Lead, Mercury, etc.) used in the lamps and in ballasts, if not disposed properly, can cause serious impact on the environment. Lighting also affects the environment due to wastefully escaped light into the night sky.

Energy related environmental impacts in the electric lighting depend on the electricity generation method. Thermal power generation system has the highest impact on the environment due to combustion fuel, gas emissions, solid waste generation, water consumption, and thermal pollution. Electricity generated from renewable energy sources has the least effect on the environment. Lighting is one of the biggest causes of energy-related greenhouse gas emissions. Total lighting-related carbon dioxide (CO_2) emissions were estimated to be 1900 million tones (Mt) in 2005, which is equivalent to 83% of all emissions from the countries of the Former Soviet Union, or those of those from France, Germany, Italy and the United Kingdom combined [IEA 2006]. Energy efficient lighting reduces the lighting energy consumption and is a means to reduce CO_2 emissions. Fuel based lighting used in developing countries is not only inefficient and expensive, but also results in 244 million metric tones of carbon dioxide to the atmosphere every year, which is 58% of the CO_2 emissions from residential electric lighting globally [Mills 2002]. Replacing fuel based lighting with white LED lighting systems will help greatly reduce greenhouse gas emissions associated with lighting energy use.

3 Lighting Energy Use in Buildings

3.1 Overview

Lighting accounts a significant part of electricity consumption in buildings. Over 10% of all U.S. energy is used for lighting in buildings [Loftness 2004]. The amount of electricity used for lighting in buildings differs according to the type of buildings. In some buildings, lighting is the biggest single category of electricity use. In average, office buildings use the largest share of their total electricity use in lighting. European office buildings use 50% of their electricity for lighting, while the share of electricity for lighting is 20-30 % in hospitals, 15% in factories, 10-15% in schools and 10% in residential buildings [EC 2007(a)]. Furthermore, the heat produced by lighting represents great percentage of cooling load in many offices contributing in the consumption of electricity indirectly. On the other hand, heat produced by lighting can reduce the heating load in cold climate areas. The share of electricity for lighting over total electricity use is quite low compared to the commercial buildings. But in the developing countries, especially in electrified rural areas, almost all the electricity consumed in home is used for lighting. However, residential buildings use the most inefficient lighting technology compared to the commercial and industrial buildings. The share of different kind of lighting technology used in the US building sector for year 2001 is shown in the figure 4, where the annual energy consumption by each building sector is also illustrated.

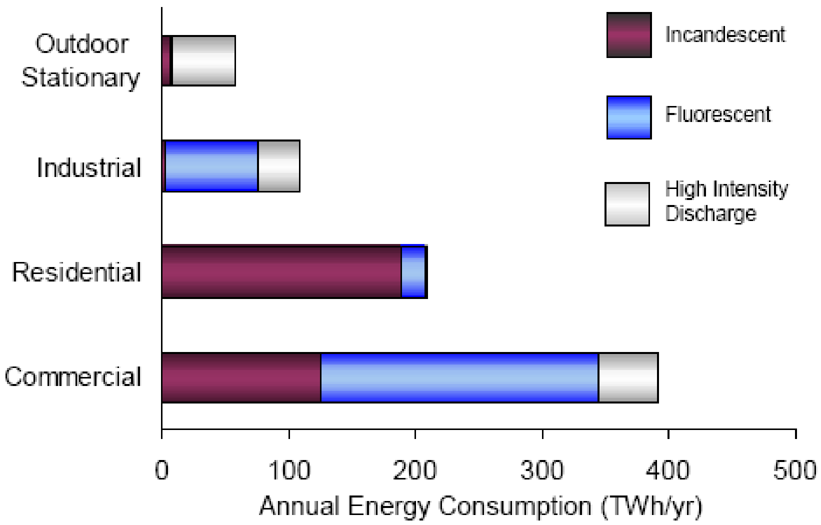

Figure 4 Shares of US Sectoral Energy use by Lighting Technology [Navigant 2002]

3.2 Residential Buildings

3.2.1 Energy Usage

The global residential lighting electricity consumption for year 2005 was estimated by IEA [IEA 2006] to be 811 TWh, which accounts to about 31% of total lighting electricity consumption and about 18.3% of residential electricity consumption. The estimate for the electricity consumption in residential lighting in IEA member countries was 372 TWh, which accounts for about 14.2% of total residential electricity consumption. Electric lighting is used in practically all households throughout Europe and represents a key component of peak electricity demand in many countries. According to the DELight [Environmental Change Unit 1998] study, lighting in the residential sector consumed 86 TWh (17% of all residential electricity use) per year in the EU-15 in year 1995. A recent study carried out by European Commission's institute of environment and sustainability through the questionnaires with national energy efficiency experts reported the consumption of electricity for lighting to be 77 TWh for the EU-15 , 13.6 TWh for the 10 new Member states, and 4.9 TWh for the newest 3 Member states (Table 1) [Bertoldi 2006].

There is very significant variation in the per household energy use for lighting among the EU member states. The lowest consumption is for Germany, where average household consumption is 310 kWh of electricity per year, and the highest consumption per year is in Malta with the value 1172 kWh per household. In the EU-15 Member states the lighting consumption as a share of total residential electricity consumption ranges between 6% and 18%, but the share is as high as 35% in one of the newest member state (Romania).

Table 1 National residential lighting energy characteristics of EU-28 countries [Bertoldi 2006]

Countries	Number of Households [millions]	Residential electricity consumption [TWh]	Lighting electricity consumption [TWh]	Lighting consumption as share of total electricity consumption[%]	Average lighting consumption per household [kWh]
Austria	3.08	16	1.1	6.875	357.14
Belgium	3.90	18.20	2.23	12.23	343.22
Denmark	2.31	9.71	1.36	14.00	589.00
Finland	2.30	12.20	1.7	13.93	739
France	22.20	141.06	9.07	6.43	409
Greece	3.66	18.89	3.4	18	1012
Germany	39.10	140.00	11.38	8.13	310
Ireland	1.44	7.33	1.32	18	1000
Italy	22.50	66.67	8	12	370
Luxembourg	0.20	0.75	0.098	13	487.5
Netherlands	6.73	23.75	3.8	16	524
Portugal	4.20	11.40	1.6	14.04	427
Spain	17.20	56.11	10.1	18	684
Sweden	3.90	43.50	4.6	10.57	1143
United Kingdom	22.80	111.88	17.9	16	785
Czech Republic	3.83	14.53	1.74	12	455.37
Cyprus	0.32	1.32	0.33	25	1040.7
Estonia	0.60	1.62	0.45	28	753.81
Hungary	3.75	11.10	2.775	25	740.48
Latvia	0.97	1.47	0.41	28	424.16
Lithuania	1.29	2.07	0.62	30	479.72

Malta	0.13	0.60	0.15	25	1172.15
Poland	11.95	22.80	6.38	28	534.4
Slovakia	1.67	4.82	0.4	8.3	240.05
Slovenia	0.68	3.01	0.43	14.3	628.9
Bulgaria	2.9	8.77	0.9	10	420
Romania	8.13	8.04	2.911	35.18	356.75
Hungary	1.42	6.07	1.1	18.11	773.76

US Lighting Market Characterization study [Navigant 2002] calculated from the survey of 4832 households that the average US household used 1946 kWh of electricity for lighting in 2001. According to the IEA assessment [IEA 2006], the average European household lighting electricity consumption is about 561 kWh, which is very close to that for the average Australian household of 577 kWh per annum. Compared to the European and Australian/New Zealand households, Japanese households use a bit higher electricity for lighting per year. Average Japanese residential electricity consumption for lighting is 939 kWh per annum.

Consumption of residential light in Russia, China, and other non OECD (Organisation for Economic Co-operation and Development) countries is quite low compared to the OECD countries. Russian households consumed 394 kWh electricity per household that provided 2 Mlmh electric light per annum per person in 2000 [IEA 2006]. With the rising income of households, there has been very rapid increase in the residential lighting electricity consumption. The Chinese average residential per capita consumption of light in 2003 was 1.4 Mlmh, which accounted for 181 kWh of electricity per household [IEA 2006]. The share of lighting electricity consumption over total electricity consumption of households was 28%, which is quite high and it can be explained by the fact that large majority of Chinese population live in rural areas and the electricity in rural houses is manly used for lighting.

The quantity of electric light used in household is poorer in rest of non OECD countries. In most of these countries the amount of electricity consumption for lighting in rural areas is quite low compared to the urban homes. In overall, the average consumption of electricity for residential lighting in those countries is estimated to be 84 kWh/ year per capita [IEA 2006]. The share of lighting electricity consumption in overall electricity consumption of homes is very high (up to 86%) compared to OECD countries [Mills 2002]. Apart from electric lighting, there are still 1.6 billion (1 billion= 10^9) people in the world who use fuel based light source for lighting due to the lack of electricity. Almost all the people without electricity live in the developing countries [IEA 2002]. As of the year 2000, roughly 14% of urban households and 49% of rural households in developing countries were without electricity, and in the least privileged parts of Africa, e.g., Ethiopia and Uganda, only 1% of rural households were electrified [Mills 2005].

3.2.2 Light sources and lighting characteristics

Residential lighting has still been continuing to be dominated by the use of incandescent lamps but compact fluorescent lamps (CFLs) are taking its share gradually. Fluorescent lamps are much more efficient than incandescent lamps of an equivalent brightness because more of the consumed energy is converted to usable light and less is converted to heat. The high purchase price compared to the incandescent lamp has been the major barrier to the penetration of compact fluorescent lamps in the residential market, even though they last much longer, save energy, and have short payback periods. While the

CFLs have now become cheaper due to the increased competition and they are available in more varieties, there is still lack of awareness in the public about the benefits.

The majority of an estimated 372 TWh of electricity used for domestic lighting in 2005 in IEA countries was used by low-efficient incandescent lamps. The average of 27.5 lamps per household was shared by 19.9 incandescent lamps, 5.2 LFLs (Linear fluorescent lamps), 0.8 halogen lamps and 1.7 CFLs. These values are average values of IEA countries and there are significant differences from country to country. Example of the few IEA countries in Table 2 shows that the average number of lamps per house holds varies from 10.4 of Greece to as high as 43 of USA. The average lamp efficiency is quite poor in those countries dominated by incandescent lamp (USA) compared to the countries where fluorescent lamps occupy larger share (Japan). Some of the practices of using the particular type of lamp are quite similar in European, American, and Australian/New Zealand households. For example, in all those countries the use of LFLs is mostly confined to the kitchen and bathrooms, while in the rest part of house the choice is divided among incandescent lamps, CFLs, and halogen lamps. [IEA 2006]

Table 2 Estimated national average residential lighting characteristics for some IEA member countries [IEA 2006]

Countries	Lighting electricity (kWh/ household per year)	No. of lamps per household	Average lamp efficacy (lm/W)	Light consumption (Mlmh/m^2 per year)	Lighting electricity consumption (kWh/m^2 per year)	Lamp operating hours per day
UK	720	20.1	25	0.21	8.6	1.60
Sweden	760	40.4	24	0.16	6.9	1.35
Germany	775	30.3	27	0.22	9.3	1.48
Denmark	426	23.7	32	0.10	3.3	1.59
Greece	381	10.4	26	0.09	3.7	1.30
Italy	375	14.0	27	0.09	4.0	1.03
France	465	18.5	18	0.22	5.7	0.97
USA	1946	43.0	18	0.27	15.1	1.92
Japan	939	17.0	49	0.49	10.0	3.38

Table 3 United States Residential lighting characteristics for different lamp type in 2001 [Navigant 2002]

Lamp type	Lighting electricity consumption (TWh/year)	Percentage of installed lamps	Average operating hours per day	Percentage of electricity consumption	Percentage of lumen output by source type
Incandescent	187.6	86%	1.9	90%	69%
Fluorescent	19.9	14%	2.2	10%	30%
HID	0.7	0%	2.8	0.3%	1%
Total	**208.2**	**100%**	**2.0**	**100%**	**100%**

Incandescent lamps of different variety constituted 86% of 4.6 billon lamps used in the United States residential buildings in 2001 [Navigant 2002]. Although the incandescent lamps were responsible for the 90% of the total lighting electricity consumption, their share for the total available lumen output was only 69% (Table 3) due to their comparatively poor efficacy. Australian/New Zealand households have the similar trend of the dominance of incandescent lamps. But, the dominating light source in the Japanese residential sector is the fluorescent lamps with 65% share (LFSs 57% and CFLs 8%). The rest is distributed between incandescent lamps 22%, halogen lamps 2%, and other lamps 11% [IEA 2006]. While most of the lamps used are fluorescent lamps, the average efficacy of the lamps is quite high but on the contrary the Japanese residential electricity consumption is high compared to European and Australian/New Zealand households due to the high average illuminance levels and relatively long average operating times (table 2).

Russia, on the other hand gets almost all of its residential light from incandescent lamps, where 98% of total installed lamps are incandescent lamps. This is not very common for other non OECD country's residential lighting. The share of fluorescent lamps over other types of lamps is relatively higher in those countries. The share of fluorescent lamps was 43% in Chinese residential lighting already in 2003. Similarly most of the Indian electrified homes have at least four LFLs and national LFL sales are about one-third of total incandescent lamp sales. [IEA 2006]

3.3 Commercial Buildings

3.3.1 Energy Usage

Lighting is one of the single largest users of electricity in most of the commercial buildings. The IEA [IEA 2006] estimates that 1133 TWh of final electricity was consumed in the world by commercial lighting in 2005. This is equivalent to 43% of total lighting electricity consumption and over 30% of total electricity consumption in the commercial buildings, which was used to produce 59.5 Plmh of light at an average source lumens efficacy of 52.5lm/W, a very high efficacy compared to the residential lighting. The total consumption of 1133 TWh of electricity used for commercial buildings is distributed between different types of buildings, in which Retail, Offices, Warehouses and educational buildings are the largest users (Figure 5).

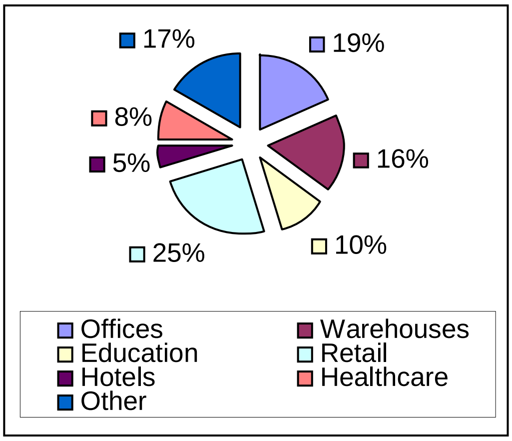

Figure 5 Global Commercial Lighting Energy Use by Building Type [IEA 2006]

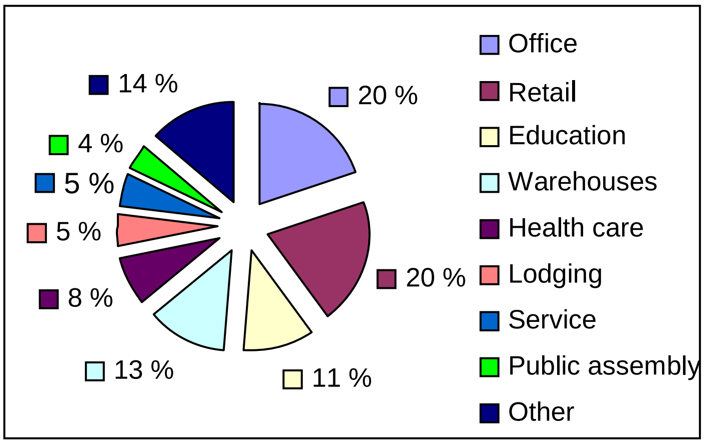

Figure 6 U.S. Commercial Lighting Energy Use by Building Type [Navigant 2002]

The lighting energy consumption in commercial buildings of IEA countries comprises 63% of world's total electricity consumption for lighting in this sector and 28.3% of total OECD commercial-building electricity consumption [IEA 2006]. OECD lighting energy intensities are higher than the world average for all commercial building sectors. The United States commercial lighting accounted more than 40% of commercial sector electricity consumption, a total of 391 TWh per year in 2001 [Navigant 2002]. Commercial buildings use more then half (51%) of the total lighting consumption. Offices, retail, and warehouses are the largest contributors to U.S. commercial lighting energy use (Figure 6).

Consumption for commercial sector lighting electricity in the European member states is estimated by IEA to be 185 TWh in 2005. There has been large number of estimates for European commercial-lighting energy use in the past, but there is large variation in the each other's estimated lighting energy intensity. The IEA analysis has taken into consideration of previous studies and has clamed to be reliable and consistent estimates of commercial-sector lighting energy consumption. In non-OECD countries, the trend of using lighting electricity for commercial buildings is growing with the increased economic growth and increased construction growth. In 2005, it was estimated that the 41% of electricity of non-OECD commercial buildings was consumed in lighting providing illumination for 17.5 billion square metres of floor area. [IEA 2006]

3.3.2 Light sources and lighting characteristics

The most of the light delivered to in the commercial buildings comes from the fluorescent lamps. It is common to use the fluorescent lamps in the open space facilities such as open space for work or shopping. Another reason for the increased use of fluorescent lamps in commercial sector is due to the implementation of different energy efficiency improvement

Table 4 Lamp types used for few European country's office lighting, in particular task areas[Tichelen 2007]

Existing office lighting			
	Belgium	**Germany**	**Spain**
Fluorescent lamps	80%	99%	70%
CFL	10%	5%	15%
T8 LFL	80%	90%	75%
T5 LFL	10%	5%	10%
Other types	20%	1%	30%
New office lighting			
Fluorescent lamps	95%	100%	85%
CFL	16%	10%	20%
T8 LFL	52%	45%	50%
T5 LFL	32%	45%	30%
Other types	5%	0%	15%

programmes. Fluorescent lamps provided most of the light to the OECD commercial buildings in 2005. The linear fluorescent lamps were producing the 76.5% of the light output and the rest 23.5% of light was provided by a mixture of incandescent, compact fluorescent, and HID lamps [IEA 2006]. Similarly, fluorescent lamps were the major consumer of US commercial lighting electricity in 2001 [Navigant 2002], accounting for 56% of lighting energy use. Incandescent lamps consumed 32% and HID lamps used 12% of US commercial lighting energy. Share of fluorescent lamps on total lumens output was 78%, while the incandescent and HID lamp provided only 8% and 14% respectively. In European office buildings, fluorescent lamps are the dominant users in which LFL (linear fluorescent lamp) is the most commonly used lamp [Tichelen 2007]. In the comparison of existing office lighting with new installation in three European countries (Belgium, Germany, and Spain), it is found that existing installations in Belgium and Spain still have sizeable number of other luminaries than Fluorescent type (Table 4). In non-OECD commercial sector, the share of incandescent lamps is even lower than that of OECD commercial sector. The estimated share of incandescent and halogen lamp in non-OECD commercial lighting was mere 4.8% in 2005 [IEA 2006].

Table 5 Estimated average lighting characteristics of commercial buildings in 2000 [IEA 2006]

Region	Average lighting power density (W/m^2)	Specific energy use (kWh/m^2)	Average annual operating period (hours)	Lighting system efficacy (lm/W)	Commercial building floor area (billion m^2)	Total electricity consumption (TWh/year)
Japan/Korea	12.6	33.0	2583	62.7	1.7	54.6
Australia/NZ	16.5	31.7	1924	43.5	0.4	12.7
North America	17.4	59.4	3928	50.1	7.3	435.1
OECD Europe	15.5	27.7	1781	46.1	6.7	185.8
OECD	15.6	43.1	2867	49.6	16.1	688.2

The intensity of lighting energy use by different types of commercial buildings has large variation (Figure 7). This variation is due to the different occupancy levels of different types of buildings. The average electricity consumption for lighting per square metre in healthcare buildings is highest of all types of buildings because of the lengthy operating periods. In addition to the efficacy of the lighting systems, lighting practices of each country and regions have great effect on the lighting intensity of buildings, e.g., the length of operating period and the average illuminance provided. European buildings have quite short operating hours, while the operating hours of North American commercial buildings are higher than that of Europe, Japan/Korea, and Oceania (Table 5). The average lighting electricity intensity of United States commercial buildings was 60.9 kWh/m^2 in 2001 [Navigant 2002]. Canadian commercial buildings had further high intensity values, consuming electricity at an average of 80.2 kWh/m^2 in 2003 [IEA 2006]. The non-OECD commercial buildings consume electricity at the lowest average among all the regions, consuming at an average of 24.1 kWh/m^2 in 2005 [IEA 2006].

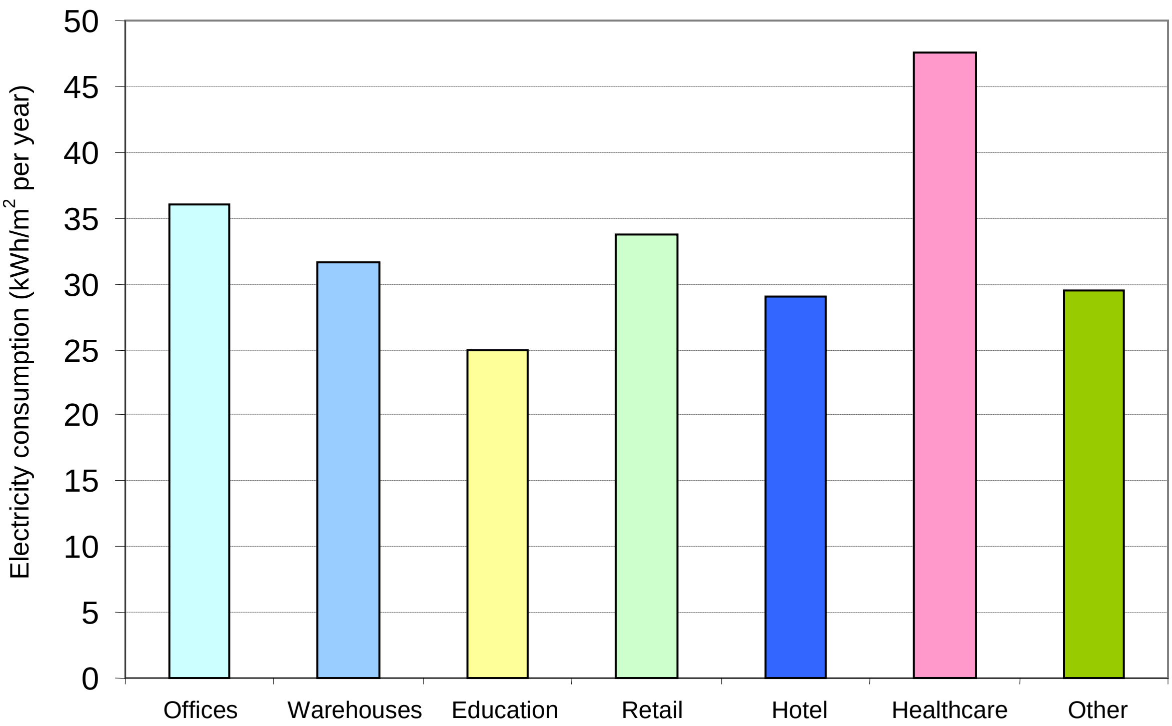

Figure 7 Estimated global lighting intensity by commercial building type in 2005

3.4 Industrial Buildings

3.4.1 Energy Usage

Most of the electricity in industrial buildings is used in industrial processes. Although the share of lighting electricity over total electricity consumption in industrial buildings was just over 8.7%, it accounted about 18% of total lighting electricity consumption in 2005 [IEA 2006]. Compared to the residential and commercial sector, there have been very few surveys and studies about the industrial building lighting energy use.

The IEA estimation of industrial lighting consumption for 2005 in OECD Europe was 100.3 TWh, amounting to 8.7% of total industrial electricity use, the same share as estimated for the global average. The estimation for Japanese industrial lighting electricity consumption is 34.9 TWh, accounting for about 7.8% of all industrial electricity consumption. Australian industrial lighting electricity consumption has the similar trend with the rest, accounting 7.6% of all industrial electricity use. The broad survey and study of industrial lighting energy use was done for United States under US Department of Energy in 2001 [Navigant 2002] which estimated total US industrial lighting energy use of 108 TWh, accounting for 10.6% of industrial electricity consumption.

Similarly, industrial lighting accounts for about 7.6% of all industrial electricity use in Australia. In Russia, Combination of industry and agriculture was estimated to have consumed about 56.3 TWh of electricity for lighting in 2000, of which 12.3 TWh was for agriculture (52% of agricultural electricity consumption) and 42 TWh for other industry (13.9% of industrial electricity consumption). [IEA 2006]

3.4.2 Light sources and lighting characteristics

Industrial lighting has the highest source-lumen efficacy among the three sectors: residential, commercial, and industrial. The total 490 TWH of electricity consumed to produce 38.5 Plmh of global industrial lighting in 2005 was produced at an average source-lumen efficacy of 79 lm/W [IEA 2006]. This is due to the fact that most of light in industrial buildings come from efficient fluorescent lamps and HID lamps.

Most of the industrial lighting electricity in US is consumed by Fluorescent lamp and HIDs, accounting for 67% and 31% of industrial lighting electricity (Table 6). Only 2% of total lamps installed in the industrial buildings are incandescent. The duty cycles of lamps in the US industrial sector is very much longer than other sectors, operating at an average of 13.5 hours per day. The average intensity of lighting energy varies according to the different industry buildings, ranging from 37 to 107 kWh/m^2. The IEA estimated that US and Canadian industrial sector together had average source-lumen efficacy of 80.4 lm/W in 2005 [IEA 2006].

The IEA analysed the lamp sales time-series data and estimated an average source-lumen efficacy of 81.6 lm/W for Japanese industrial-sector lighting. The IEA estimation for OECD Europe industrial sector average efficacy is 81.9 lm/W. Fluorescent lamps contribute for about 62% of OECD industrial illumination, HIDs for 37% and the others contribute for 1%. Similar to other countries, the Australian industrial lighting is dominated by fluorescent lamps, accounting for 55%, and the majority of remaining 45% is attributed to HIDs.

Table 6 US industrial lighting characteristics for different lamp types in 2001 [Navigant 2002]

Lamp type	Lighting electricity consumption (TWh/year)	Percentage of installed lamps	Average operating hours per day	Percentage of electricity consumption	Percentage of lumen output by source type
Incandescent	2.6	2%	16.7	2%	0%
Fluorescent	72.3	93%	13.4	67%	71%
HID	33.0	5%	13.9	31%	29%
Total	**107.9**	**100%**	**13.5**	**100%**	**100%**

Outside OECD countries, the Chinese industrial lighting have similar mixture of lamps like Europe. The penetration of efficient T5 fluorescent lamps in Chinese industrial sector is higher than that of European industrial sector. But the HID lamps are dominant in Russian industrial lighting. Only 36.5% of light in Russian industrial buildings comes from LFLs, while 56.3% from mercury-vapour HID lamps and the rest from other HID lamps and incandescent lamps. Due to the poor quality of lamps used, the Russian industrial sector source-lumen efficacy averaged 61 lm/W in 2000, which is far behind the European and American average. [IEA 2006]

4 Evaluation of lighting energy use for buildings

4.1 Codes and criteria for evaluating energy use for buildings

Different codes and legislations providing guidelines for designing and installing lighting systems in buildings evaluate the energy efficiency criteria in terms of energy use. The most common codes set the maximum allowable installed lighting power density. American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and the Illuminating engineering Society of North America (IESNA) develop the voluntary building code in the United States [ASHRAE 2004]. This code applies to all the buildings except low rise residential buildings and has a lighting section which specifies maximum “lighting power density” limits, in units of watts per square metre (W/m^2). Lighting codes in most of US states are usually based on ASHRAE or IEC, but California has its own code and is called Title 24 [Title24 2007]. The Title 24 code of 2001 for residential buildings recommended energy efficient lighting as having the installed lighting system efficacy greater than 40 lm/W. The 2005 version of the code defines the efficient lighting based on the wattage of lamps, according to which the efficacy has to be greater than 40 lm/W for lamps rated lass than 15 W, 50 lm/W for 15–40 W lamps, and 60 lm/W for lamps rated more than 40 W.

Before the adoption of the European Union’s Energy Performance in Building Directive (2002/91/EC), very few European countries had provisions addressing lighting in their codes [ENPER-TEBUC 2003]. In Denmark, some voluntary standards did recommend maximum lighting power density (LPD) levels in watts per square metre. The French regulation RT2000 (The Réglementation Thermique 2000) specifies minimum lighting energy performance requirements for new buildings and new extensions to existing buildings [IEA 2006]. The regulation specifies the efficiency requirements in three different ways: whole building LPD levels, space-by-space LPD levels or lighting flux limits. The lighting flux limits are given as: 4 W/m^2 per 100 lx for spaces of less than 30 m^2, and 3 W/m^2 per 100 lx for spaces of more than 30 m^2. The United Kingdom building codes for domestic as well as commercial lighting evaluate the efficiency as a luminous efficacy of the installed lighting system. The 2002 edition of the UK building code requires that the office, industrial and storage area luminaire should have average efficacy not less than 45 lm/W [IEA 2006].

Similarly, the Australian energy-efficiency provisions in Australian commercial and residential buildings have LPD limits for different areas. For large areas, the requirements include time switching or occupancy sensors [IEA 2006]. Mexico and China also apply building code standards for the energy performance of lighting in buildings, where the requirements are LPD limits expressed in watts per square metre. Maximum LPD threshold in Chinese households is 7W/m^2, and for normal offices it is 11 W/m^2 [IEA 2006].

Lighting power density level limits are only one part that influences lighting energy use. The other important part is the control of time of use and application of daylight. The metric which includes all these elements and represents the lighting system's performance is the annual energy intensity, expressed in annual energy consumption per unit area (kWh/m^2 per year). This metric would promote the use of efficient light source, effective control system taking consideration of the occupancy, and the exploitation of daylight. There are also limitations about this metric as all the other things being equal, a building with high occupancy rates will use more lighting energy than one with a lower occupancy because of the longer operating periods. So the buildings with different occupancy behaviour have to be grouped and different requirements have to be set while making the lighting energy codes.

International Energy Conservation Code (IECC) 2003 specifies that the lighting controls are required for each area, and each area must have light-reduction controls and automatic lighting scheduling [DOE 2005]. The most recent versions of the ASHRAE and IEC codes which are followed by most of US states have also started placing control and daylighting provisions in their standards. Four European countries (Flanders-Belgium, France, Greece, and Netherlands) used a detailed calculation procedure for lighting even before the adoption of new European Directive (EPBD), each calculation procedure estimating the overall average energy consumption for the lighting in the buildings [ENPER-TEBUC 2003]. The EPBD, which is under implementation in the European Union, directs the member countries to use a comprehensive method to calculate the energy consumption of buildings and incorporate mandatory minimum energy efficiency requirements for all building types [EC 2002].

4.2 Lighting impacts on HVAC systems

In every lighting system, the larger part of their input electrical energy is dissipated as heat. Hence, changes in the lighting energy use in buildings also changes the energy requirements for space heating and cooling. Generally, reduction in the lighting energy increases heating requirements during cold periods but it will lower the cooling requirements in the summer. However, the net energy balance would differ from place to place depending on the building characteristics, operating conditions, and local climatic conditions.

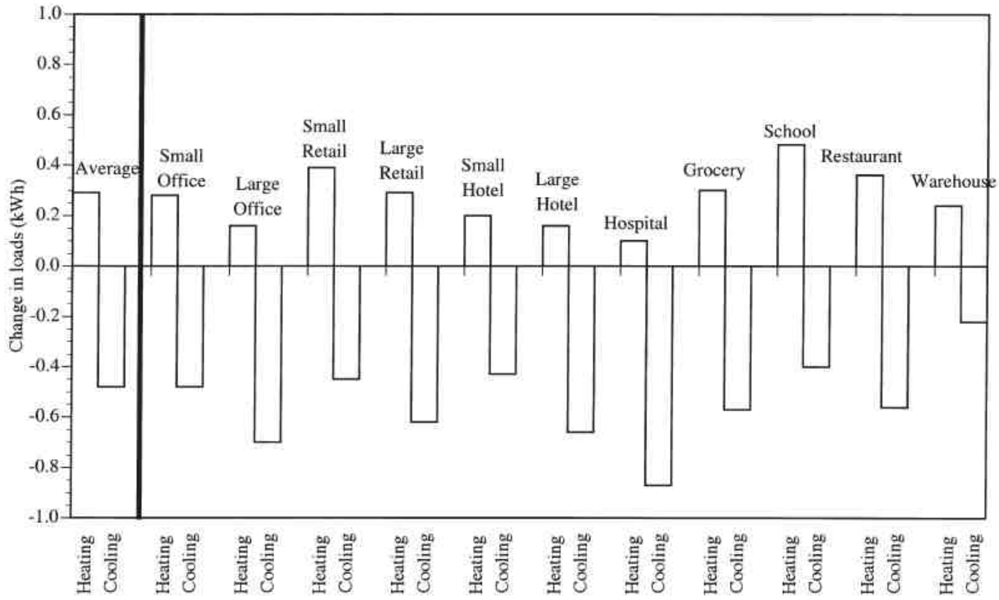

Figure 8 Change in heating and cooling loads caused by a 1 kWh decline in lighting loads in existing US commercial buildings [Sezgan 2000]

The change in the heating/cooling load due to the change in lighting load for different type of prototype US commercial buildings is shown in the figure 8. An analysis of the impact of lighting energy use on heating/cooling requirements on different types of commercial buildings showed that the large savings are possible in hospitals, large offices, and large hotels by the reduction of lighting energy use [Sezgan 2000]. But on the schools and warehouses, increase in heating load are greater than the reduction in cooling load due to the reduction of lighting energy use.

Monitoring a sample of existing commercial buildings in different areas of US, it is found that the warmest states have the biggest reduction (30% or more) in cooling loads with a reduction in lighting energy use. The cooler states can have about a 20% increase in net heating load for smaller buildings that are dominated by heat losses. But net cost savings for lighting reductions are expected even in the cooler climates due to the higher cost of electricity for cooling compared to the cost of heating fuels, and the short heating seasons. [Weigand 2003]

4.3 Lighting impacts on peak electric loads

The peak electricity use period varies from place to place. The development stage of the country, geographical location, season of the year has great effect on the time of peak electricity. For example, the electricity peak of most of the developing countries occurs during evening due to the use of electricity for residential lighting and cooking. For many utilities in industrialized countries, peak electricity use period occurs during the afternoon when commercial and industrial electricity demands are high.

The peak demand for residential lighting always occurs in the evenings, anytime between 6 to 10 pm depending on the countries. From the metering campaign of sample of households across four EU countries, it was found that lighting accounted for between 10% (Portugal) and 19 % (Italy) of residential peak power demand [Sidler 2002]. For developing countries where the lighting has up to 86% share on total electricity consumption, lighting accounts majority of the peak power demand. In industrialized countries, commercial-sector lighting peak coincides with the system peak. Also the indirect influence of lighting on air-conditioning loads will make a combined impact on the peak. The reduction in peak demand is very important aspects of lighting energy efficiency.

5 Energy saving in the future

5.1 Possibilities

Saving of electricity used for lighting without compromising on the quality of the lighting service is the main idea of energy efficient lighting. Savings can be achieved by making the lighting system components energy efficient, and also by using the right amount of light when it is needed and where it is needed. There is a large range of technological options available to achieve the energy saving in lighting. These include the more efficient lamps, more efficient ballasts, better luminaries, improved controls, and greater use of daylight. The improvement is the efficiency of lamps and the introduction of new innovative light sources is expected to accelerate the saving in lighting. The technological potential of saving can only be transformed into real saving if it is economically viable.

In residential sector, replacing the incandescent lamps with fluorescent lamps (LFL or CFL) has the largest potential for energy saving. Figure 9 shows the results from an end-use metering campaign conducted in a sample of French households. The results of the measurement showed that the consumption of electricity for lighting was reduced by an average of 74% when the majority of incandescent lamps of the households were replaced with CFLs [ECODROME 1998]. The saving in non residential buildings can be achieved by new efficient designs compared to standard practice in the new buildings, and through the retrofit of an existing building. In the office buildings, the most substantial saving can be achieved by substituting halophosphate lamps with triphosphor lamps and implementing the highest energy efficient level ballast with dimming control [Tichelen 2007]. The lighting upgrading done through the European GreenLight programme in wide range of buildings (schools, offices, airports, supermarkets, etc.) showed cost effective saving potentials in the existing buildings [EC 2007(b)]. It was observed in those example buildings that the use of more efficient lighting is generally cost-effective in almost all circumstances.

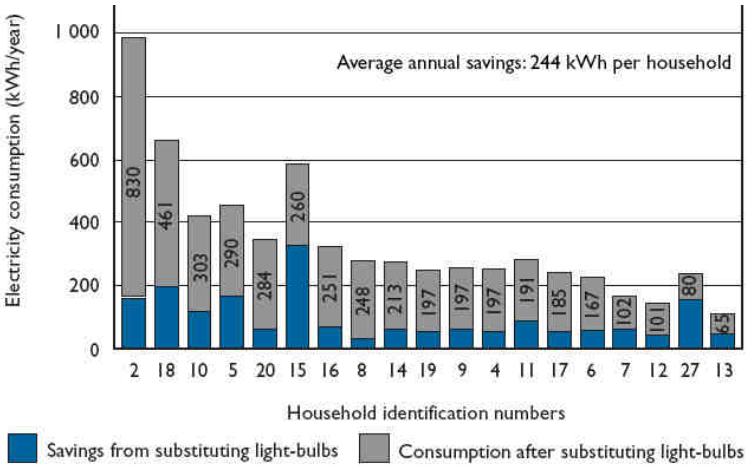

Figure 9 Annual lighting electricity consumption in a sample of French households before and after replacing incandescent lamps with CFLs [ECODROME 1998]

5.2 Saving Estimates

There have been many studies about the estimation of saving possibilities by the use of new lighting technologies. It was estimated in a study commissioned for the IEA that there exist 30-50% saving potential of total global lighting energy use [Mills 2002]. According to this study, the saving potential is as high as 92–99% in fuel based lighting. But his saving potential is obtained assuming substitution of electricity and no increase in light levels. The saving potential within residential sector is estimated to be 40–60%, commercial sector saving potential is estimated at 25–40%, and the industrial lighting is expected to have saving potential from 15–25%. These estimations represent a hypothetical policy pathway that assumed a combination of modest standards and aggressive voluntary programs promoting cost-effective lighting efficiency improvements using today's technologies. These estimates did not take account of potential for saving from the use of daylighting and it also didn't take account of the large variations of recommended illuminance levels across IEA countries. If these are taken into account, much larger saving potentials can be expected.

The IEA estimated the residential-lighting electricity consumption to decrease by 54% over the period 2005-2010 in IEA member countries under the scenario that imagined the outcome were the least life-cycle cost (LLCC) lighting systems to be installed under normal lighting-replacement cycles from 2005 onwards. In the LLCC scenario, 80% of all incandescent lamps, which are used for one hour or more a day, are replaced with CFLs between 2004 and 2007. The rest of the incandescent lamps were assumed not to be suitable for CFLs. [IEA 2006]

According to an EU SAVE project substantial amount energy can be saved in offices and schools by upgrading the lighting systems with existing best practice lighting technologies [Novem 1999]. The old lighting installations are replaced gradually as newer and efficient lighting systems come in the market, however much of the installations are left unchanged. Upgrading those unchanged part of current office-lighting stock to the standard for typical new installations would give a saving between 20% and 47% of the current energy used for lighting, and upgrading to current best practice would give a saving from 45% to 68% depending on the country. This would give a 55% saving across EU offices as a whole. In schools, the saving across the European Union of 30% would result from upgrading all existing lighting to typical current practice. The upgrade to the best practice installations would give the saving of 54%. It is estimated by European Commission in the proposal for the ballast Directive that replacing all the existing ballasts with electronic ballast would save 5TWh per year by 2010 and 12TWh by 2020.

Japanese Luminaire Association has made estimates of Japanese lighting energy consumption for the future under certain assumptions [IEA 2006]. The estimation projects the saving at 2010 from the implementation of various energy-saving measures. These measures include replacing incandescent lamps to LFLs and CFLs, switching of fluorescent lamps into high efficiency type, introduction of efficient lighting control systems into commercial building sector, introduction of CCFLs (Cold cathode fluorescent lamps) to "emergency exit" lamps, introduction of high-efficiency HID lamps for street lighting, etc. According to the estimates, if all these measures are fully implemented total lighting consumption in Japan would be reduced by 34% by 2010 and 48TWH of electricity consumption would be saved. These measures do not consider the possibility of greater use of daylight, which would result more saving.

The UK Market Transformation Programme have done recent assessments to examine the lighting saving potentials in UK residential, commercial, industrial and public lighting sectors [MTPROG 2007]. Due to the recent policy introductions (in particular Building Regulations 2006) energy usage in commercial lighting is expected to decrease by up to 7 TWh by 2020. The key policies include the removal of poor performing lamps, promotion light emitting diodes, setting of minimum standard for lighting efficiency, encouragement for the procurement of efficient lighting in public sector, minimum standard on daylight, and use of lighting controls. Figure 10 illustrates the estimated energy consumption of UK domestic lighting under different policy scenarios. The scenarios represent the likely energy usage by domestic lighting if no more policies are enacted (the reference scenario: Ref), the full economically viable potential from rapid adoption of best practice (the earliest best practice scenario: EBP), and a middle-group scenario based on the successful implementation of further group of policy measures (the policy scenario: P1). Under the reference scenario, the UK residential sector lighting is expected to consume 19 TWh in 2010. Adoption of earliest best practice, mainly the grater usage of CFLs, would reduce this consumption to just 9.5 TWh in 2010.

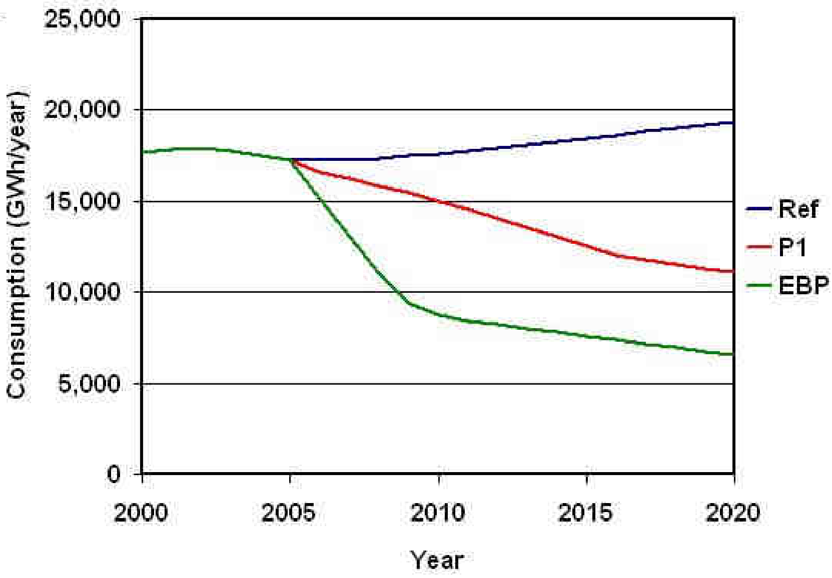

Figure 10 Estimation of UK energy consumption on domestic lighting under different policy scenarios [MTPROG 2007]

Consumption of lighting energy in China is growing very fast due to rapid growth of economy and urbanization. Throughout much of the 90s decade, there has been 15% growth of lighting energy per year compared to just 5% growths in national overall energy consumption [IEA 2006]. The China Greenlight programme estimates the possibility of saving up to 40% of lighting energy by the use of more efficient lighting technologies. China National Institute for Standardization estimates that the minimum energy performance standards applied for fluorescent lamp ballasts and LFLs alone will save over 27TWh of electricity in 2010 and over 59TWh in 2020.

5.3 Saving through Solid State Lighting

Solid state lighting technology which utilizes the light emitting diodes (LEDs) to produce light is expected to become the pivotal technology of future lighting. It has not only the potential to provide significant energy saving, but also offer new opportunities for applications that go well beyond the lighting provided by conventional lighting sources. According to US Department of Energy, no other technology offers so much potential to save energy and enhance the quality of lighting.

The US based optoelectronics industry development association (OIDA) estimated in 2002 that by 2027 solid-state lighting could reduce the global amount of electricity used for lighting by 50% [OIDA 2002]. The cumulative savings potential in the US alone over 2000 - 2020 could amount to 760 GW of electrical energy, alleviating the need for 133 new power stations (1000 MW each). An analysis conducted in South Korea estimated that the adoption of AC-LED technology could enable Korea to save up to 60 TWh per year by 2010 [IEA 2006]. Saving potential has also been estimated for UK, where LEDs could save up to 39.2 TWh of general lighting electricity demand by 2020 [Graves 2005].

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