

Chapter 2: Lighting energy in buildings

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2 Lighting energy in buildings

2.1 Holistic view of energy use in buildings

Introduction

Why are we designing and constructing buildings?

- to shield ourselves and various processes from weather and climatic conditions
- to create a good indoor environment
- to use resources as efficiently as possible during the construction phase
- to make buildings economical for the user and owner

Human needs as well as energy and environmental issues are essential in the building process. The International Energy Agency (IEA) has clearly shown in “Light’s Labour’s Lost” (IEA, 2006) that energy in buildings covers a large part of the energy consumption in the world and has therefore a significant impact on the environment. A more holistic view with focus in sustainability could help us to protect the environment.

Holistic view – Whole Building Design

The introduction above shows clearly that it is not possible to make a decision in one question without considering the others. A holistic view takes into account all energy flows in the building over time in order to reach a sustainable approach (Diemer, 2008). In order to build high performance buildings (WBDG, 2008) we have to consider all the different design processes and aspects of buildings (see figure 2-1) and all they show how buildings are used by owners and users.



Figure 2-1. Global objectives for High Performance Buildings. (WBDG, 2008)

Considering the façade as an energy filter should be the starting point of the building design process. A façade system, dynamic for the different seasons of a specific country, has possibilities for an overall energy reduction for heating, cooling and lighting. Preventing solar heat radiation from entering the building, when not needed, is a good start to keep the use of cooling system low.

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Useful daylight could be used in addition to electric lighting to fulfill lighting for visual tasks and to save energy.

The sustainability of the high performance building should be achieved by using as little energy resources as possible during the building process as well as during the life cycle of the building. Materials should be recycled as much as possible. The means and ways for reducing energy consumption should be achieved in an economical way for the building owner and user in order to motivate them to reduce energy consumption (SEA2007, STIL2007).

Design issues

The following issues in the building design phases should be taken into account:

- to carry out detailed analysis of solar shading, daylight linking, lighting and visual comfort needs
- to determine how the façade should be designed (e.g. thermal insulation, airtightness etc.)
- to study the design and operation of the ventilation system
- to study how much the internal heat gains from office equipment, lighting etc. can be minimized and whether this is enough to avoid installing mechanical cooling
- to carry out energy and indoor climate simulations, where secondary and primary energy consumption are determined
- to calculate lifecycle costs

Planning and Production process

The planning and production process is short in comparison to the lifetime of the building. In the decision process, lifetime of the building has to be considered together with the knowledge of building physics.

Environmental impact

In addition to moving the focus from investment issues to lifecycle analysis and calculations, it is necessary to consider a sustainable process. This means that environmental issues have to be taken into account at an early stage, such as:

- Energy use and peak load
- Materials used in luminaires, light sources, chemicals (for example mercury)
- Production of lighting equipment and transportation
- Light pollution
- Light trespass (unwanted light through neighbouring windows)
- Noise

Lifecycle analysis (LCA) and Lifecycle costs (LCC)

Initial investment in buildings covers only less than 20% of the long term costs. The main long term costs are related to operation and maintenance of the buildings. Energy consumption in the buildings contributes a large part of the operation cost. An example is given in Figure 2-2, where the use of energy, carbon dioxide (CO₂) emissions, solid wastes, and water use are studied in procurement, construction, operation and demolition phases of the building (Janssen 1999). We can see that the largest impact is caused by the energy use during the Operation & Maintenance phase of the building. This study was commissioned by Multiplex Construction and carried out with their assistance by the New South Wales Department of Public Works and Services and ERM Mitchell McCotter (DPWS NSW, 1998).

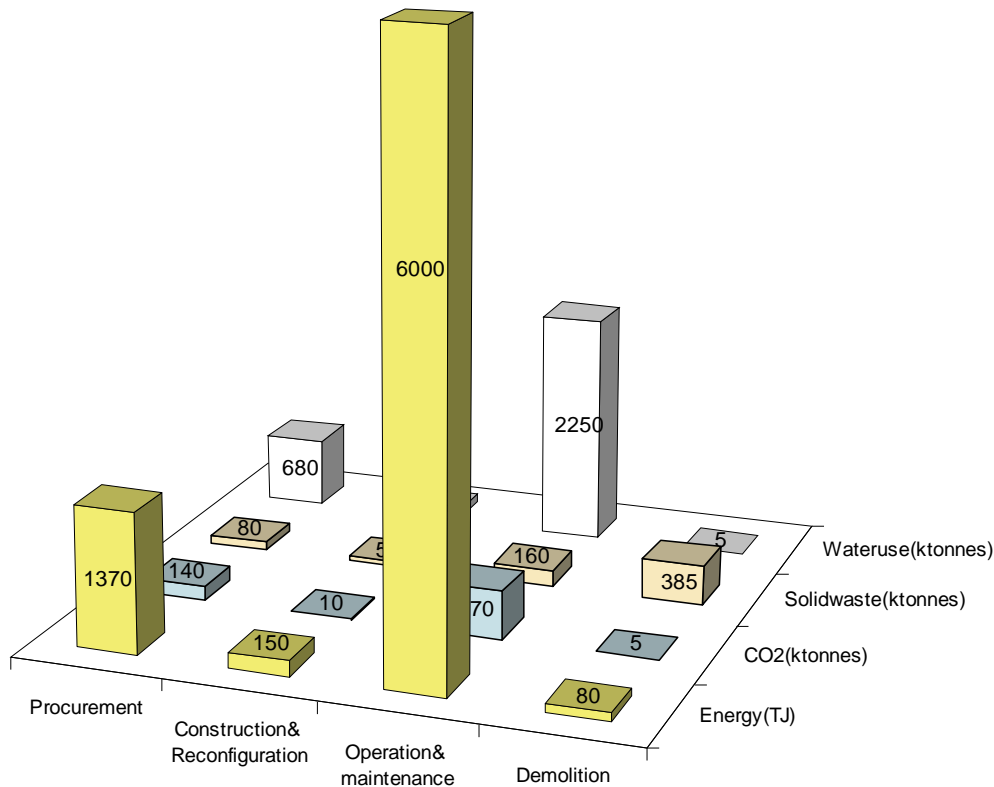


Figure 2-2. Stadium Australia LCA results. (Janssen, 1999)

Energy requirements

Lighting consumes about 19% of the total generated electricity (IEA 2006). It accounts for 30% to 40% of the total energy consumption in office buildings. The annual lighting electricity consumption per square meter of the building varies between 20 to 50 kWh/m², a (SEA 2007, STIL 2007).

There is a trend in the international community to reduce the electricity consumption of lighting with new technology to below 10 kWh/m² per year. The possible ways to reduce lighting energy consumption include: minimum possible power density, use of light sources with high luminous efficacy, use of lighting control systems and utilization of daylight.

The quality of light must be maintained when installed power for lighting is reduced. In this Guidebook different design concepts and new products, illustrated with case studies, show how lighting energy consumption can be reduced.

In the building sector, the potential for energy savings and improvements in indoor environment is often high. New buildings may have low energy consumption for heating, but on the other hand have higher electricity consumption than older ones. This is due to increased electricity use for ventilation, cooling, lighting and office equipment (Blomsterberg et al., 2007).

Daylight and solar radiation have a great influence on the energy flows in the building. Therefore the façade, and especially the glassed area of the façade could be seen as an energy filter. A way to reduce the energy flow through the façade is to use shades to block the solar radiation, utilize daylight to reduce the need of artificial lighting and therefore reduce the need of energy for cooling (Poirazis 2008, LEED 2009). But at the same time, the indoor environment has to be maintained to prevent discomfort for the users.

Energy consumption of buildings covers about 40% of the total energy consumption in Europe. In several European countries, there are initiatives for reducing energy consumption. These initiatives have time tables for implementation with a aim to reduce the energy related CO₂ emissions by 20% by 2020.

2.2 Facts and figures on lighting energy usage

2.2.1 Background

Energy is an essential commodity in our lives and the use of energy is increasing with industrial development. Energy security and the environmental impacts of energy use are major concerns worldwide.

The accelerating increase of greenhouse gases in the atmosphere has caused the world to warm by more than half a degree Celsius in the last century. It is expected that there will be at least a further warming of half a degree over the next few decades (Stern 2006). Use of energy is the main factor of the greenhouse gas emissions (IPCC 2007). Industrialized nations are currently the sources of most of the greenhouse gas emissions but this may change in the future as the developing countries pursue industrialization. The United States and Europe together consume almost 40% while producing only 23% of the total energy use of the world. Europe depends on imports for about half of its total energy needs. With the current trend of energy consumption, the EU expects 65% of its energy need to be fulfilled by import, which poses a critical challenge on the energy security (Belkin 2007).

Energy efficiency is one of the most effective means to solve these problems. It can both save energy and reduce 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 equipment, stronger action on energy use in buildings, transport and energy generation. The EU has committed to its new energy policy to improve energy efficiency by 20% by 2020 (COM 2007).

2.2.2 Worldwide Energy and Lighting Scenario

Worldwide energy consumption

Global energy consumption is rising continually every year. Total global primary energy consumption in 2006 was 472 quadrillion (10¹⁵) British Thermal Units (BTU) (1 BTU = 1055.1 joules), which is equivalent to 138330 TWh (EIA 2006).

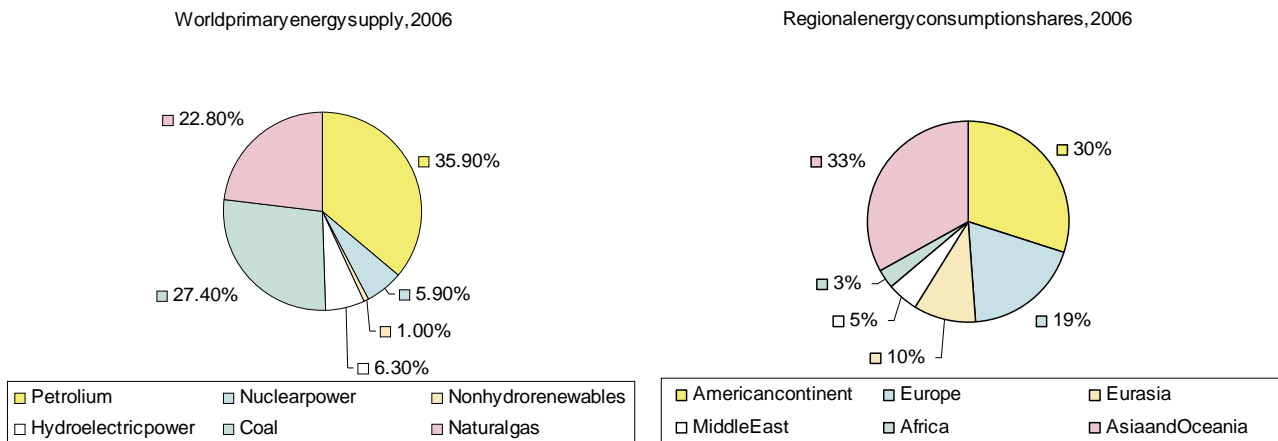


Figure 2-3. World primary energy supply and regional consumption shares in 2006 (EIA 2006).

The increase in the global energy consumption between 1996 and 2006 continued at an average annual rate of 2.3%. In 2006 the three most important energy sources were petroleum, coal and natural gas, accounting for 35.9%, 27.4%, and 22.8% of total primary energy production (Figure 2-3).

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Energy consumption in buildings

Buildings, including residential, commercial, and institutional buildings account for more than one third of primary global energy demand. The building sector is the biggest energy consumer among the three energy-using sectors: transportation, industry and buildings. Global energy demand in the building sector has been increasing at an average rate of 3.5% per year since 1970 (DOE 2006). Urban buildings usually have higher levels of energy consumption per unit of area than buildings in rural areas. According to a projection by the United Nations, the percentage of the world's population living in urban areas will increase from 49% (in 2005) to 61% by 2030 (UN 2005). Thus the growth of energy consumption in buildings is expected to continue in the long term as a result of population growth, and also as a result of urbanization.

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Energy is consumed in buildings for various end use purposes: space heating, water heating, ventilation, lighting, cooling, cooking, and other appliances. Lighting is the leading energy consumer (25%) in US commercial buildings ahead of space cooling (13%) while lighting energy consumption is less than that of space heating, space cooling and water heating in residential buildings (Figure 2-4). Heating (space and water) is the leading energy consumer in the EU domestic and commercial building sectors followed by lighting (Figure 2-5). Other main consumers are cooking, cooling and other appliances.

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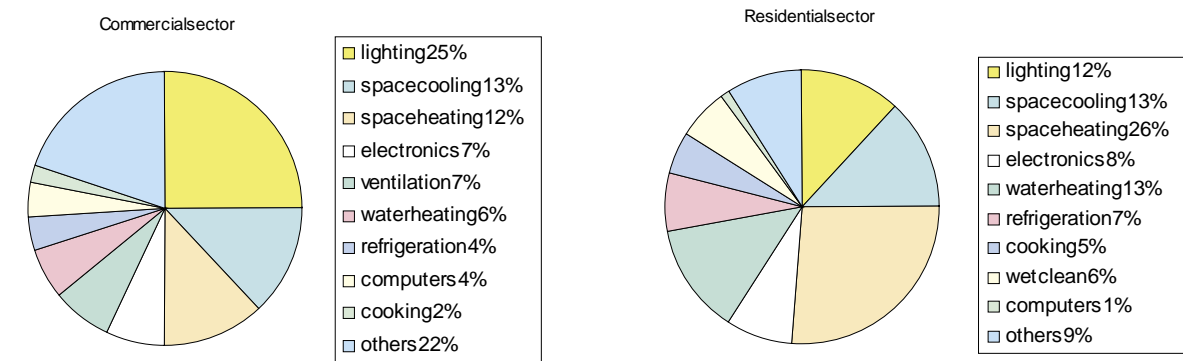


Figure 2-4. Energy consumption by end use in US commercial and residential buildings (DOE 2009).

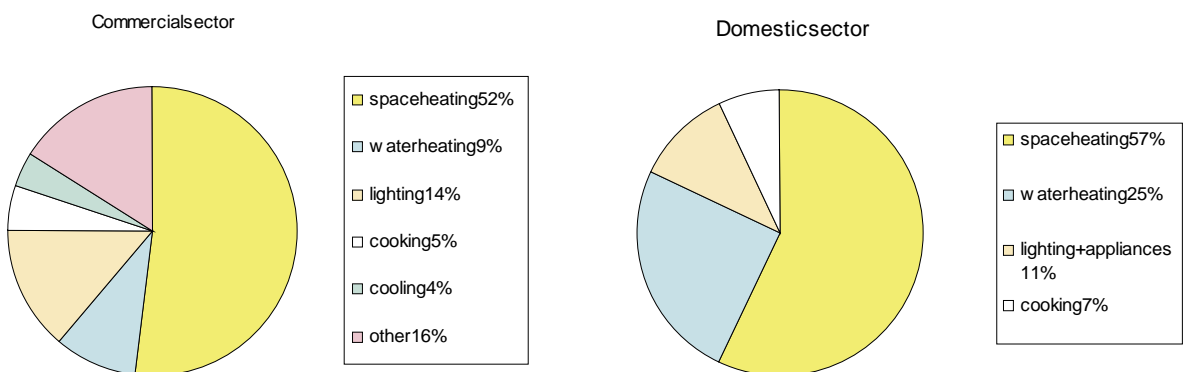


Figure 2-5. Energy consumption by end use in EU domestic and commercial buildings (EC 2007).

Worldwide electricity consumption

The global consumption of electricity has been increasing faster than the overall energy production of electricity, as well as its consumption in 2006 was 16378 TWh, which was 11.8% of the total primary energy consumption (EIA 2006). Because of losses in the generation process, the amount of input energy for electricity generation is much higher than the amount of electricity at its point of use. Worldwide electricity generation uses 40% of the world's primary energy supply (Hore-Lacy 2003). According to the International Energy Outlook 2009 (EIA 2009), the world's total net electricity generation in 2030 is expected to be increased by 77% from the 2006 level. The growth of the primary energy consumption for the same period will be 44%, expanding from 472 quadrillion BTU in 2006 to 678 quadrillion BTU in 2030.

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).

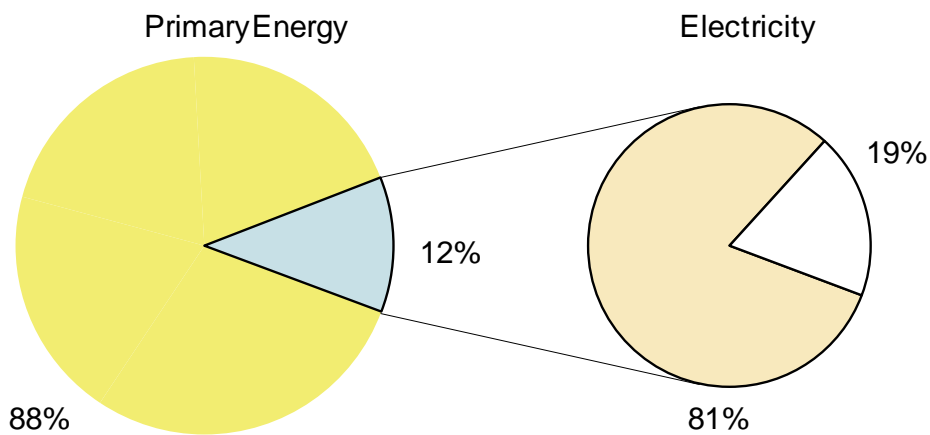


Figure 2-6. Global lighting energy use (EIA 2006, IEA 2006).

Globally, almost one fifth of the total amount of electricity generated is consumed by the lighting sector. The total electricity consumption of lighting is more than the global electricity produced by hydro or nuclear power plants, and almost the same as the electricity produced with natural gas. More than 50% of the electricity used by lighting is consumed in IEA member countries, but this is expected to change in the coming years because of 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 consumption of lighting of total electricity consumption varies from 5% to 15% in the industrialized countries, whereas the share is up to 86% (Tanzania) in developing countries (Mills 2002).

Fuel-based lighting and vehicle lighting

Despite the dominance of electric lighting, a significant amount of energy is also used in vehicle lighting and off-grid fuel-based lighting. More than one quarter of the world's population is still without access to electricity networks and uses fuel-based lighting to fulfill their lighting needs (Mills 2002). IEA (IEA 2006) estimates that the amount of energy consumed annually in fuel-based

lighting is equivalent to 65.6 million tons of oil. The estimated amount of global primary energy used for lighting sources include candles, oil lamps, ordinary kerosene lamps, propane lamps, and resin-soaked twigs as used in remote Nepali villages (Bhusal *et al.* 2007). In developing countries, the most widely used fuel-based lighting is ordinary wick-based kerosene lamps. For example, nearly 80 million people in India alone light their houses using kerosene as the primary fuel for lighting (Shailesh 2006).

equivalent (Mtoe) of final energy usage. The lighting is 650 Mtoe. The fuel-based lighting lamps, pressurized kerosene lamps, biogas and fuel-based lighting is ordinary wick-based kerosene lamps. For example, nearly 80 million people in India alone light their houses using kerosene as the primary fuel for lighting (Shailesh 2006).

An estimated 750 million light-duty vehicles (cars, 14 million buses and minibuses, and 230 million two-wheelers) were used in 2005 worldwide. They consume fuel to provide illumination for driving and security needs. Although the amount of fuel used for lighting accounts a small portion (3.2%) of all road vehicle energy usage, 55 billion litres of petroleum, amounting to 47.1 Mtoe of final energy, was used to operate vehicle lights in 2002. The power demand for lighting in the vehicle is increasing to improve the driving safety and comfort. Also, an increasing number of countries are introducing policy measures to promote greater use of daytime vehicle lighting through regulation or incentives. This will further increase the amount of global energy use of vehicle lighting (IEA 2006).

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Consumption of light

The amount of consumption of light in the world has increased with the increase in the population. According to IEA estimation (IEA 2006), the amount of global consumption of lighting in 2005 was 134.7 petalumen-hours (Plmh). The electric lighting accounted for 99% of the total light consumption while vehicle lighting accounted for only 0.1%. The average annual per capita light consumption of people with access to electric access to electricity use only 50 kilolumen-hours (klmh) per person per annum. Thus the light consumption of people with access to electricity is more than 500 times more compared to people without access to electricity. Even within the electrified places, there exist large variations in the consumption of light. The variation in light consumption among the different regions of the world is shown in Figure 2-7.

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Despite the inequality in the consumption of light, there has been a 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 was lower than during the previous decades. This might be an indication of the start of demand saturation. However, the growth of lighting demand in the developing countries is increasing due to the rising average illuminance levels in those countries and a

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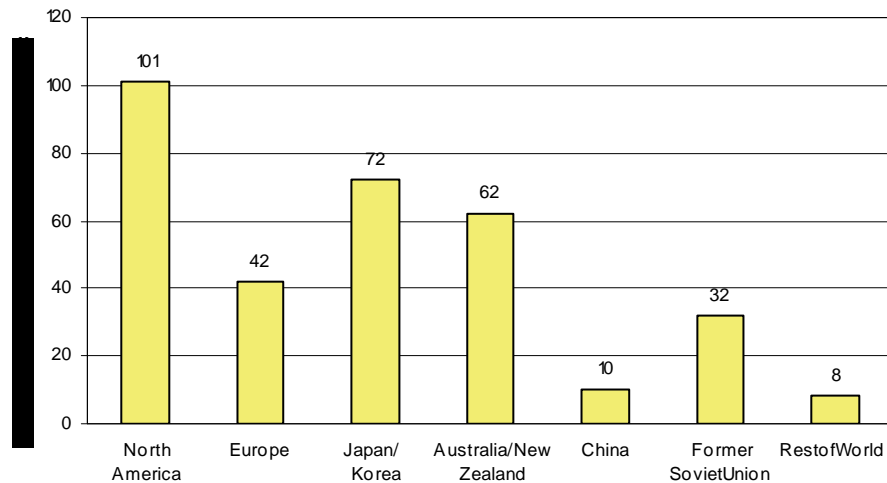


Figure 2-7. Estimated per capita consumption of electric light in 2005 (IEA 2006).

2.2.3 Impact of lighting energy consumption on the environment

The environmental impacts of lighting are caused by the energy consumption of lighting, the material used to produce lighting equipment, and the disposal of used equipment. Emissions during the production of electricity and also as a result of the burning of fuel in vehicle lighting and in fuel-based lighting are responsible for most of the lighting-related greenhouse gas emissions. Hazardous materials (e.g. lead, mercury, etc.) used in the lamps and ballasts, if not disposed properly, can cause harmful impacts on the environment. Lighting also affects the environment due to wastefully escaped light into the night sky (light pollution).

The environmental impacts of 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 production, water consumption, and thermal pollution. Electricity generated from renewable energy sources has the low effect on the environment. Lighting is one of the biggest causes of energy-related greenhouse gas emissions. The total lighting-related CO₂ emissions were estimated to be 1900 million tons (Mt) in 2005, which was about 7% of the total global CO₂ emissions from the consumption and flaring of fossil fuels (EIA 2007, IEA 2006). Energy efficient lighting reduces the lighting energy consumption and is thus a means to reduce CO₂ emissions. Fuel based lighting used in developing countries is not only inefficient and expensive, but also results in the release of 244 million tons of CO₂ to the atmosphere every year, which is 58% of the CO₂ emissions from residential electric lighting globally (Mills 2002). Replacing fuel based lighting with energy efficient electric lighting (based e.g. on LEDs) will provide a means to reduce greenhouse gas emissions associated with lighting energy consumption.

Primary energy and CO₂ emissions

Primary energy is the energy that has not been subjected to any conversion or transformation process. Primary energy is transformed in energy conversion processes to more convenient forms of energy, such as electricity. Electricity can be transformed from coal, oil, natural gas, wind, etc. The total primary energy factor is defined as the non-renewable and renewable primary energy divided by the delivered energy. Here the primary energy is the amount of energy that is required to supply one unit of delivered energy, taking into account the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary to deliver the energy to the place where it is used. The total primary energy factor for electricity is 2.5 in Europe. This value reflects a net efficiency of 40%, which is the average efficiency

of electricity production (Eurostat 2009).

The CO₂ intensity in power generation in different European countries is shown in Figure 2-8. The carbon footprint calculator takes CO₂ emission factor for electricity to be 527 g/kWh in the calculations (Carbon independent 2009).

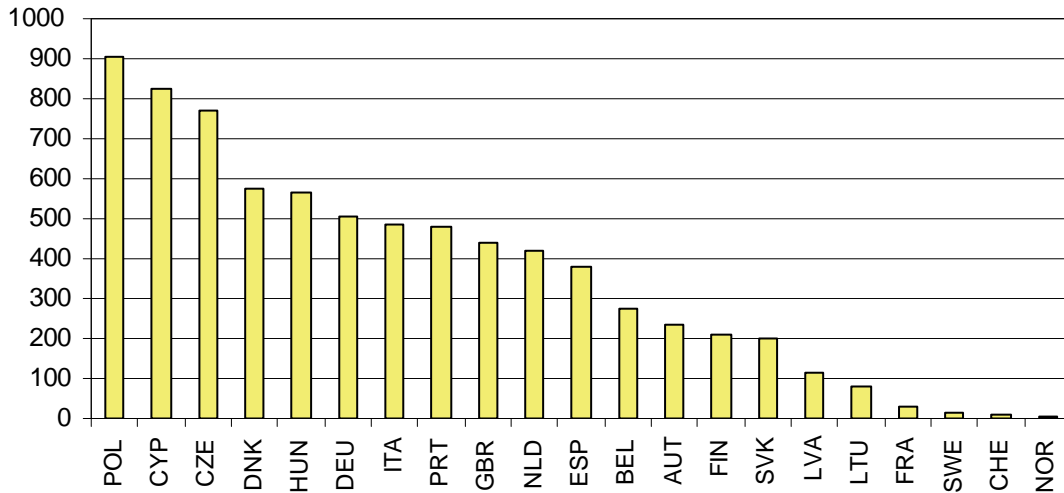


Figure 2-8. CO₂ intensity, gCO₂/kWh, in electricity generation in European countries for 2001. (Statistics Finland 2003)

Figure 2-9 presents the comparison of CO₂ emissions during lifetime of an incandescent lamp, CFL and a future LED light source. A 75W incandescent lamp with luminous efficacy of 12 lm/W, a 15W CFL with luminous efficacy of 60 lm/W and a 6W LED light source with luminous efficacy of 150 lm/W were compared to provide the same light output. The lifetime of future LED light source is assumed to be 25000h. The calculation was done for 25000 lamp burning hours. During this period one LED, 3 CFLs and 21 incandescent lamps were needed. Most of the energy consumption and CO₂ emissions were caused in the operating phase of the lamps. CO₂ emissions of the electricity production were considered to be 527 g/kWh. The CO₂ emissions during production of the lamps are also considered in the calculation.

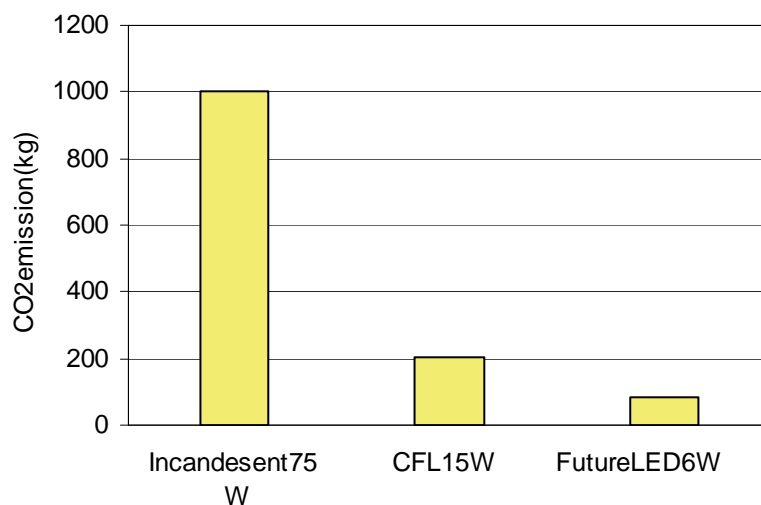


Figure 2-9. Comparison of CO₂ emissions during lifecycle (calculated for 25000 hours of time) of an incandescent lamp (12 lm/W), CFL (60 lm/W) and future LED light source (150 lm/W).

2.2.4 Lighting energy usage in buildings

Overview

Lighting accounts for a significant part of electricity consumption in buildings. For example, in the US, more than 10% of all 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 largest single category of electricity consumption; office buildings, on the average, use the largest share of their total electricity consumption in lighting.

European office buildings use 50% of their total electricity consumption 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). Furthermore, the heat produced by lighting represents a significant fraction of the cooling load in many of offices contributing to the further consumption of electricity indirectly. On the other hand, heat produced by lighting can reduce the heating load during winter in the areas with cold climate. In residential buildings, the share of electricity for lighting over total electricity use is quite low compared to the commercial buildings. However, in the developing countries, especially in electrified rural areas, almost all of the electricity consumed at homes is used for lighting. Residential buildings use the most inefficient lighting technology (incandescent lamps) compared to the commercial and industrial buildings. The share of different lighting technology used in the US building sector together with annual energy consumption by each building sector.

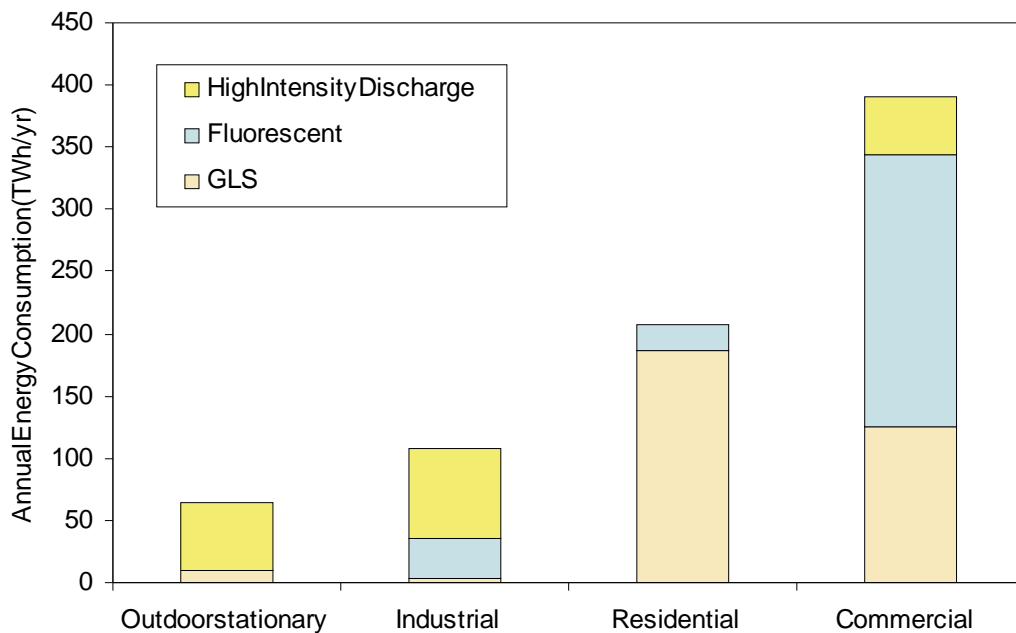


Figure 2-10. Shares of US sectoral electricity used by different light sources for lighting (Navigant 2002).

Residential buildings

Energy usage

The global residential lighting electricity consumption in 2005 was estimated by the IEA to be 811 TWh (IEA 2006), which accounts for about 31% of total lighting electricity consumption and about 18.3% of residential electricity consumption. The electricity used for lighting in IEA member countries was 372 TWh, which accounts for about 14.2% of total residential electricity consumption. Electricity used for lighting is used in practically all households throughout Europe and represents a key component of peak electricity demand in many countries. According to

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the DELight (Environmental Change Unit 1998) study, lighting in the residential sector consumed 86 TWh (17% of all residential electricity consumption) per year in the EU-15 in 1995. A recent study carried out by the European Commission's Institute of Environment and Sustainability 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 (Bertoldi and Atanasiu 2006).

The household energy consumption for lighting varies greatly among EU member states. The lowest consumption is in Germany where the average annual household lighting electricity consumption is 310 kWh, while the highest annual consumption 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 states.

The US Lighting Market Characterization study (Navigant 2002) calculated in 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 used 561 kWh of electricity for lighting, which is very close to the average annual lighting electricity consumption for an average Australian household, which is 577 kWh. The by an average Japanese household was 939 kWh in 2004.

Consumption of electricity for residential lighting in Russia, China, and other non OECD (Organisation for Economic Co-operation and Development) countries is lower compared to the OECD countries. The average electricity consumption for lighting in Russian households was 394 kWh per household, which provided 2 Mlmh electric light per annum per person in 2000 (IEA 2006). With the rising income of households, there has been a substantial increase in the residential lighting electricity consumption in Russia. 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 was quite high due to the fact that the majority of Chinese population lives in rural areas and the electricity in rural households is mainly used for lighting.

Table 2-1. National residential lighting energy characteristics of EU-28 countries (Bertoldi and Atanasiu 2006).

Countries	Number of Households (millions)	Residential electricity consumption (TWh/a)	Lighting electricity consumption (TWh/a)	Lighting consumption as share of total electricity consumption (%)	Average lighting electricity consumption per household (kWh/a)
Austria	3.08	16.00	1.10	6.88	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	1.70	13.93	739.00
France	22.20	141.06	9.07	6.43	409.00
Greece	3.66	18.89	3.40	18.00	1012.00
Germany	39.10	140.00	11.38	8.13	310.00
Ireland	1.44	7.33	1.32	18.00	1000.00
Italy	22.50	66.67	8.00	12.00	370.00
Luxembourg	0.20	0.75	0.01	13.00	487.50
Netherlands	6.73	23.75	3.80	16.00	524.00

Portugal	4.20	11.40	1.60	14.04	427.00
Spain	17.20	56.11	10.10	18.00	684.00
Sweden	3.90	43.50	4.60	10.57	1143.00
United Kingdom	22.80	111.88	17.90	16.00	785.00
Czech Republic	3.83	14.53	1.74	12.00	455.37
Cyprus	0.32	1.32	0.33	25.00	1040.70
Estonia	0.60	1.62	0.45	28.00	753.81
Hungary	3.75	11.10	2.775	25.00	740.48
Latvia	0.97	1.47	0.41	28.00	424.16
Lithuania	1.29	2.07	0.62	30.00	479.72
Malta	0.13	0.60	0.15	25.00	1172.15
Poland	11.95	22.80	6.38	28.00	534.40
Slovakia	1.67	4.82	0.40	8.30	240.05
Slovenia	0.68	3.01	0.43	14.30	628.90
Bulgaria	2.90	8.77	0.90	10.00	420.00
Romania	8.13	8.04	2.91	35.18	356.75
Hungary	1.42	6.07	1.10	18.11	773.76

In other non-OECD countries, the consumption of electric lighting in households is lower than in Russia and China. In most of these countries the consumption of lighting electricity in rural areas is quite low compared to the urban homes. Overall, the average annual consumption of electricity for residential lighting in these non-OECD countries (except Russia and China) is estimated to be 84 kWh per capita (IEA 2006). The share of electricity consumption of total electricity consumption in homes is very high (up to 86%) in developing countries, compared to OECD countries (Mills 2002). Apart from electric lighting, there are still 1.6 billion (1 billion = 10⁹) people in the world who use fuel-based light sources due to the lack of electricity. Almost all the people without electricity live in the developing countries (IEA 2002). In 2000 roughly 14% of urban households and 49% of rural households in developing countries were without electricity, and in some of the least privileged parts of Africa, e.g. Ethiopia and Uganda, only 1% of rural households were electrified (Mills 2005).

Light sources and lighting characteristics

Residential lighting is dominated by the use of incandescent lamps but compact fluorescent lamps (CFLs) are taking their share gradually and LED lamps will do so in the future. The high purchase price of CFLs compared to incandescent lamps has been a major barrier to their market penetration, even though they last much longer, save energy, and have short payback periods. Though the price of CFLs has decreased due to the increased competition and they are available in many varieties, there is still a lack of awareness in the public about their benefits.

The majority of the estimated 372 TWh of electricity used for domestic lighting in 2005 in IEA countries was used by inefficient incandescent lamps. The average of 27.5 lamps per household was shared by 19.9 incandescent lamps, 5.2 CFLs (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 some IEA countries is shown in Table 2-2 which shows that the average number of lamps per household varies from 10.4 (Greece) to 43 (USA). The average lamp luminous efficiency is low in the countries dominated by incandescent lamps (USA) compared to the countries where fluorescent lamps occupy a larger share (Japan).

type of lamp are quite similar in European, America 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 of the house the choice is divided among incandescent lamps, CFLs, and halogen lamps (IEA 2006).

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Table 2-2. Estimated national average residential lighting characteristics for some IEA member countries (IEA 2006).

Countries	Lighting electricity (kWh/household, a)	No. of lamps per household	Average lamp luminous efficacy (lm/W)	Light consumption (Mlmh/m ² , a)	Lighting electricity consumption (kWh/m ² , a)	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 2-3. United States Residential 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 household electricity consumption	Percentage of lumen output by source type
GLS	187.6	86%	1.9	90%	69%
Fluorescent	19.9	14%	2.2	10%	30%
HID (High Intensity Discharge)	0.7	0%	2.8	0.3%	1%
Total	208.2	100%	2.0	100%	100%

Incandescent lamps constituted 86% of 4.6 billion lamps used in the US residential buildings in 2001 (Navigant 2002). Although the incandescent lamps were responsible for 90% of the total lighting electricity consumption, their share of the total available lumen output was only 69% (Table 2-3) due to their poor luminous efficacy. However, in Australia and New Zealand households, a similar trend of the dominance of incandescent lamps is observed. In Japan, the dominating light source in the residential sector is the fluorescent lamp 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). Though most of the lamps used in the Japanese households are fluorescent lamps and their average luminous efficacy is quite high, the Japanese residential electricity consumption is high compared to those of the European and Australian/New Zealand households. This is due to the fact that Japanese households have high average illuminance levels and relatively long average operating times of lamps (Table 2-2).

In Russia, on the other hand, the incandescent lamp dominates in the residential sector, where 98% of total installed lamps are incandescent lamps. This is not very common for other non-OECD countries, where the share of fluorescent lamps is relatively higher. The share of fluorescent lamps was 43% in Chinese residential lighting already in 2003. Similarly, most of the

lamps used in the US residential buildings in 2001 (Navigant 2002). Although the incandescent lamps were responsible for 90% of the total lighting electricity consumption, their share of the total available lumen output was only 69% (Table 2-3) due to their poor luminous efficacy. However, in Australia and New Zealand households, a similar trend of the dominance of incandescent lamps is observed. In Japan, the dominating light source in the residential sector is the fluorescent lamp 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). Though most of the lamps used in the Japanese households are fluorescent lamps and their average luminous efficacy is quite high, the Japanese residential electricity consumption is high compared to those of the European and Australian/New Zealand households. This is due to the fact that Japanese households have high average illuminance levels and relatively long average operating times of lamps (Table 2-2).

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Indian electrified homes have at least four LFLs and total incandescent lamp sales (IEA 2006).

and the national LFL sales is about one third of

Commercial Buildings

Energy usage

Lighting is one of the single largest electricity users in most commercial buildings. The IEA (IEA 2006) estimated that 1133 TWh of electricity was consumed in the world by commercial lighting in 2005. This was equivalent to 43% of total lighting electricity consumption in the commercial buildings, which was used to produce 59.5 Plmh of light at an average source luminous efficacy of 52.5 lm/W. The total consumption of 1133 TWh of electricity is distributed among different types of buildings, in which retail, offices, warehouses and educational buildings were the largest users (Figure 2-11).

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The lighting electricity consumption in the commercial buildings of the IEA countries comprises 63% of the world's total electricity consumption for lighting in this sector and 28.3% of the total OECD electricity consumption in commercial buildings (IEA 2006). In the OECD countries the lighting energy intensities in commercial buildings are higher than the world average for all commercial building sectors. The US commercial lighting accounted for more than 40% of the commercial sector electricity consumption, a total of 391 TWh per year in 2001 (Navigant 2002). The US commercial buildings used more than half (51%) of the total lighting consumption. Offices, retail and warehouses are the largest contributors to US commercial lighting energy use (Figure 2-12).

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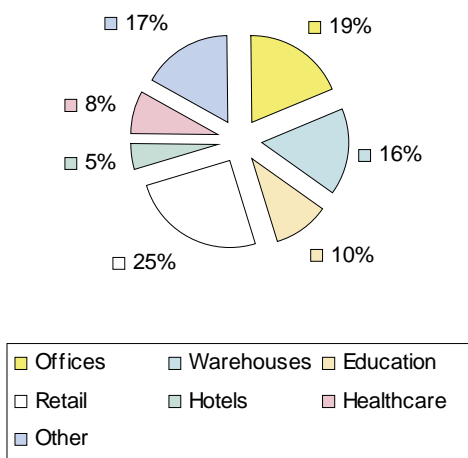


Figure 2-11. Global commercial lighting energy consumption by building type (IEA 2006).

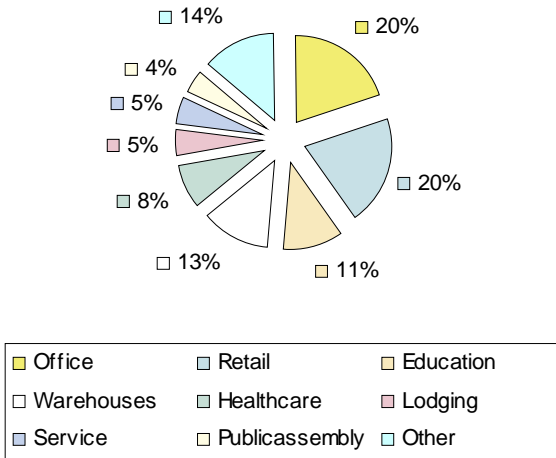


Figure 2-12. US commercial lighting energy consumption by building type (Navigant 2002).

The consumption of electricity for commercial sector lighting in the EU member states was previously estimated to be 185 TWh in 2005 (IEA 2006). There has been a large variation in the estimated lighting energy intensities. The IEA analysis has claimed to be reliable and consistent in its estimations of commercial lighting energy consumption. In the non-OECD countries, the trend of using lighting electricity for commercial buildings is growing with growths. In 2005, it was estimated that 41% of electricity was consumed by lighting providing illumination for 17.5 billion square metres of floor area (IEA 2006).

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Light sources and lighting characteristics

Most of the light delivered to commercial buildings is provided by fluorescent lamps. It is common to use 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 the implementation of different energy efficiency improvement programmes.

Fluorescent lamps provided most of the light to the OECD commercial buildings in 2005; linear fluorescent lamps provided 76.5% of the light output and the rest of the light output was provided by a mixture of incandescent, compact fluorescent, and HID lamps (IEA 2006). Similarly, fluorescent lamps were the major light sources in the US commercial lighting in 2001 (Navigant 2002), accounting for 56% of lighting energy consumption, while incandescent lamps consumed 32% and HID lamps 12% of the US commercial lighting energy. The share of fluorescent lamps was 78% on total lumen output, while the incandescent and HID lamps provided only 8% and 14% respectively. In European office buildings, fluorescent lamps are the dominant light sources, the LFL (linear fluorescent lamp) being most common lamp type (Tichelen *et al.* 2007). In a comparison between existing office lighting and new office lighting in three European countries (Belgium, Germany and Spain), it was found that existing office lighting in Belgium and Spain still has a large number of other lamps than fluorescent (Table 2-4). In the non-OECD commercial sector, the share of incandescent lamps is even lower than that in the OECD commercial sector. The estimated share of incandescent and halogen lamps in the non-OECD commercial lighting was 4.8% in 2005 (IEA 2006).

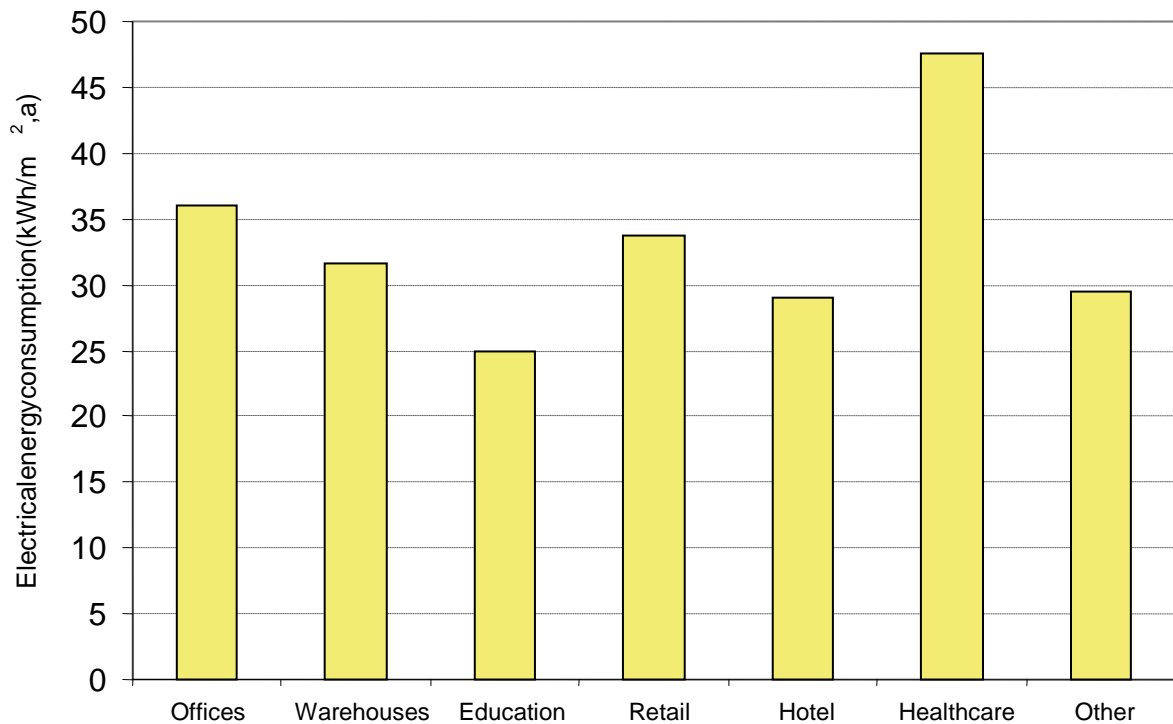
Table 2-4. Lamp types used for few European countries' office lighting (Tichelen *et al.* 2007).

Type of lamps	Belgium	Germany	Spain
<i>Existing office lighting</i>			
Fluorescent lamps	80%	99%	70%
CFL	10%	5%	15%
T8LFL	80%	90%	75%
T5LFL	10%	5%	10%
Other	20%	1%	30%
<i>New office lighting</i>			
Fluorescent lamps	95%	100%	85%
CFL	16%	10%	20%
T8LFL	52%	45%	50%
T5LFL	32%	45%	30%
Other	5%	0%	15%

There is a large variation in the annual lighting energy consumption per unit area between different types of commercial buildings (Figure 2-13). This is due to the different occupancy levels of the buildings. The average electricity consumption for lighting per square metre in healthcare buildings is the highest of all types of buildings because of the long operating periods. In addition to the efficacy of the lighting systems, lighting practice sine each country and region has significant effect on the annual lighting energy consumption per unit area of buildings, e.g. the length of operating hours, while the operating hours in North American European buildings have quite short operating periods. commercial buildings are longer than that of Europe, Japan/Korea, and Oceania (Table 2-5). The average annual lighting energy consumption per unit area in US commercial buildings was 60.9 kWh/m² in 2001 (Navigant 2002). In the Canadian commercial buildings this value was 80.2 kWh/m² 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/m² in 2005 (IEA 2006).

Table 2-5. Estimated average lighting characteristics of commercial buildings in 2000 (IEA 2006).

Region	Average lighting power density (W/m ²)	Annual lighting energy consumption per unit area (kWh/m ²)	Average operating period (h/a)	Lighting system efficacy (lm/W)	Commercial building floor area (billion m ²)	Total electricity consumption (TWh/a)
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

**Figure 2-13.** Estimated global lighting electricity consumption by commercial building type in 2005 (IEA 2006).

Industrial Buildings

Energy usage

Most of the electricity in industrial buildings is used for industrial processes. Although the share of lighting electricity of total electricity consumption in industrial buildings was only 8.7%, it accounted for about 18% of total global lighting electricity consumption in 2005 (IEA 2006). Compared to the residential and commercial sectors, there have been very few surveys and studies about the industrial building lighting energy consumption.

The IEA estimation of European OECD countries industrial lighting consumption in 2005 was 100.3 TWh per annum, amounting to 8.7% of total industrial electricity consumption in the

European OECD countries, the same share as estimated for the global average. The estimation of Japanese industrial lighting electricity consumption was 34.9 TWh, accounting for about 7.8% of all industrial electricity consumption. The Australian industrial lighting electricity consumption accounted for 7.6% of all industrial electricity consumption. A survey of industrial lighting energy use conducted by the US Department of Energy in 2001 (Navigant 2002) estimated that the total US industrial lighting energy use was 108 TWh, accounting for 10.6% of industrial electricity consumption.

In Russia, 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 industries (13.9% of industrial electricity consumption) (IEA 2006).

Light sources and lighting characteristics

Among the three sectors (residential, commercial and industrial), industrial sector has the highest source-lumen efficacy. The electricity consumption for global industrial lighting was 490 TWh in 2005, which produced 38.5 Plmh of industrial light with an average source-lumen efficacy of 79 lm/W (IEA 2006). This is due to the fact that most of the light in industrial buildings comes from efficient fluorescent lamps and HID lamps.

Most of the US industrial lighting electricity is consumed by fluorescent lamp and HID lamps, accounting for 67% and 31% of industrial lighting electricity (Table 2-6). Only 2% of all lamps installed in the US industrial buildings are incandescent lamps. The operating period of lamps is 13.5 hours per day in the US, which is much longer than in the other sectors. The average annual lighting energy consumption per unit area varies according to the different industry buildings, ranging from 37 to 107 kWh/m². The IEA estimated that the US and Canadian industrial sectors together had average source-lumen efficacy of 80.4 lm/W in 2005 (IEA 2006).

The IEA has estimated an average source-lumen efficacy of 81.6 lm/W for Japanese industrial sector lighting. According to the IEA estimation for OECD Europe, the average lamp luminous efficacy in industrial sector is 81.9 lm/W. Fluorescent lamps contribute for about 62% of OECD industrial illumination, HID for 37% and others 1%. Similarly, the Australian industrial lighting is dominated by fluorescent lamps, accounting for 55% of total lighting, and the majority of remaining 45% is attributed to HID lamps.

Table 2-6. US industrial lighting characteristics for different lamp types in 2001 (Navigant 2002).

Lamp type	Lighting electricity consumption (TWh/a)	Percentage of installed lamps	Average operating hours per day (h/day)	Percentage of electricity consumption	Percentage of lumen output by source type
Incandescent	2.6	2%	16.7	2%	-
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 the OECD countries, the Chinese industrial lighting has a mixture of lamps similar to Europe. The use of the efficient T5 fluorescent lamps in Chinese industrial sector is higher than in the European industrial sector. In Russia, the HID lamps are dominant in industrial lighting. Only

36.5% of light in Russian industrial buildings is provided by LFLs, while 56.3% is by mercury-vapour lamps and the rest from other HID lamps and incandescent lamps. The average Russian industrial lighting sector source-lumen efficacy was 61 lm/W in 2000, which was far behind the European and American average (IEA 2006).

2.2.5 Evaluation of lighting energy use for buildings

Codes and criteria for evaluating energy use for buildings

Various 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 (LPD). The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) and the Illuminating Engineering Society of North America (IESNA) have provided the recommended building code in the US (ASHRAE 2004). This code applies to all 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 the US states are usually based on ASHRAE or IEC while California has its own code named Title 24 (Title 24 2007). The Title 24 code of 2001 for residential buildings recommended energy efficient lighting with the installed lighting system efficacy greater than 40 lm/W. The 2005 version of the code defines efficient lighting based on the wattage of lamps, according to which the efficacy has to be greater than 40 lm/W for lamps rated less than 15 W, 50 lm/W for 15–40 W lamps, and 60 lm/W for lamps rated more than 40 W in power.

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 recommend maximum LPD levels in watts per square metre (ENPER-TEBUC 2003). The French regulation RT2000 (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, namely; whole building LPD levels, space-by-space LPD levels and normalized lighting power density limits. The normalized lighting power density 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 for 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 luminaires should have an average efficacy of at least 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 7 W/m^2 , and for normal offices 11 W/m^2 (IEA 2006).

Lighting power density limits are only one issue in influencing the lighting energy use. The other important issues are the control of time of use and the use of daylight. The metric which includes all these elements and represents the lighting system’s performance is the annual lighting energy consumption per unit area ($\text{kWh/m}^2, \text{a}$). This metric would promote the use of efficient light sources and effective control systems by considering the occupancy and the utilization of daylight. There are also limitations about this metric as a building with high occupancy rates will use more lighting energy than one with a lower occupancy rate.

because of the longer operating periods. Thus buildings with different requirements have to be set in different levels.

Buildings with different behaviour have to be grouped into different lighting energy codes.

The International Energy Conservation Code (IECC 2003) specifies that lighting control systems are required for each area, and each area must have lighting scheduling (DOE 2005). The most recent versions of the ASHRAE and IEC codes which are followed by most of the US states have also started placing control and daylighting options in their codes. Four European countries (Flanders-Belgium, France, Greece and the Netherlands) used a detailed calculation procedure for lighting already before the adoption of the new European Directive, Energy Performance of Buildings Directive (EPBD) (ENPER-TEBUC 2003). The 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).

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Lighting impact on HVAC systems

In every lighting system, a substantial proportion of the input electrical energy is dissipated as heat. Also, when the visible radiation meets the surface, part of it is absorbed and part of it is reflected. Through successive reflections, the visible radiation is also absorbed by room surfaces. Hence, variations in the lighting energy use in buildings changes the energy requirements for space heating and cooling. Generally, reducing the lighting energy increases heating requirements during cold periods while it lowers the cooling requirements in the summer. However, the net energy balance differs from place to place depending on the building characteristics, operating conditions, and local climatic conditions.

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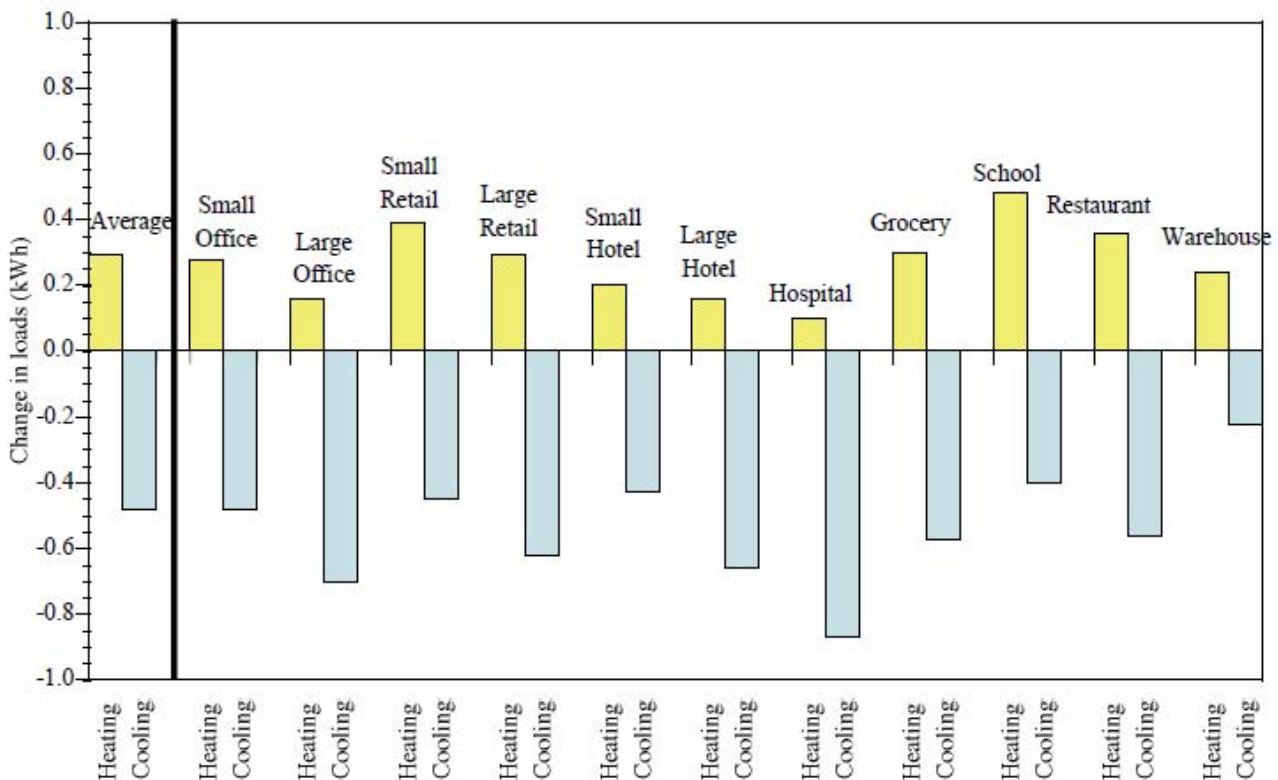


Figure 2-14. Changes in heating and cooling loads caused by a 1 kWh decline in lighting loads in existing US commercial buildings (Sezgan and Koomey 2000).

The change in the heating/cooling load due to the change in the lighting load for different types of US commercial buildings is shown in Figure 2-14. An

analysis of the impact of lighting energy

consumption on heating/cooling requirements in different commercial buildings showed that large savings are possible in hospitals, large offices, and large hotels by the reduction of lighting energy consumption (Sezgan and Koomey 2000). However, in schools and warehouses, increases in the heating load are greater than the reduction in the cooling load due to lower lighting energy consumption.

A study of existing commercial buildings in different parts of the US showed that the warmest states have the largest reduction (30% or more) in cooling loads with a reduction in lighting energy use. The cooler states can have an increase of about 20% in the net heating load in small buildings that are dominated by heat losses. However, net costs savings from reductions in lighting energy 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 shorter heating seasons (Weigand 2003).

Lighting impacts on peak electricity loads

The peak electricity consumption period varies from place to place. The development stage of the country, geographical location and the season of the year as well as building type (windows and shading types, etc.) have great impact on the time of peak electricity demand. For example, in most of the developing countries occurs during the evening due to the use of electricity for residential lighting and cooking. For many utilities in industrialized countries, peak electricity consumption period occurs during the afternoon when commercial and industrial electricity demands are high.

The peak demand for residential lighting always occurs in the evenings, at the time between 6 to 10 pm depending on the countries. In a metering campaign of sample of households across four EU countries it was found that lighting accounted for between 10% (Portugal) and 19% (Italy) of the residential peak power demand (Sidler 2002). In developing countries where the lighting has up to 86% share on the total electricity consumption, lighting accounts for the majority of the peak power demand. In industrialized countries, commercial sector lighting peak demands coincide with the overall electrical system peak demand. The indirect influence of lighting on air-conditioning loads affects the peak demand. The reduction in peak demand is a very important aspect of energy efficiency of lighting.

References

- ASHRAE, 2004. ANSI/ASHRAE/IESNA Standard 90.1.2004. *Energy Standard for Buildings Except low-rise residential buildings*. ISSN 1041-2336.
- BELKIN, P., 2007. The European Union's Energy Security Challenges. CRS Report for Congress, NCSE, Washington. (<http://www.cnie.org/NLE/CRSreports/08Feb/RL33636.pdf>)
- Bertoldi, P., Atanasiu, B., 2006. Residential Lighting Consumption and Saving Potential in the Enlarged EU. Proceedings of EDAL'06 Conference, London, UK.
- Bhusal, P., Zahnd, A., Eloholma, M., Halonen, L., 2007. Replacing Fuel Based Lighting with Light Emitting Diodes in Developing Countries: Energy and Lighting in Rural Nepali Homes. LEUKOS, The Journal of the Illuminating Engineering Society of North America, Vol 3, no. 4, pp. 277–291.
- Blomsterberg Et Al. University Of Lund. Best façade. 2004. EBD-R-07/15, www.bestfacade.com, EU-project.
- BOVERKET, National Board of Housing Building and Planning, Building/Living Project. Available from: www.byggabodialogen.se/templates/Page_3477.aspx
- Carbon Independent 2009. Available from: <http://www.carbonindependent.org/>

- COM, 2007 . An Energy Policy for Europe: Communication from the Commission to the European Council and the European Parliament. Commission of the European Communities, Brussels, 2007.
- Diemer, H.K., Diemer R.F.M. The Lighting Practice, Inc. Article: Sustainable building, PLDA Light Focus 2008.
- DOE (U.S. Department of Energy), 2005. Commercial Energy Code Compliance IECC 2000/2001/2003, Compliance Lighting Requirements, Chapter 8 IECC. Building Energy Codes Program, Washington, DC.
Available from: www.energycodes.gov
- DOE (U.S. Department of Energy) 2006. Strategic Plan . Climate Change Technology Program.
Available from: <http://www.climatechange.gov/stratplan/final/CCTP-StratPlan-Sep-2006.pdf>
- DOE (U.S. Department of Energy) 2009 . 2009 Building Energy Data Book.
Available from: <http://buildingsdatabook.eren.doe.gov/>
- DPWS NSW, 1998, Department of Public Works and Services, New South Wales: Stadium Australia Life Cycle Assessment (Inventory Results). Conducted for Multiplex Constructions (NSW) by DPWS and ERM Mitchell McCotter. Report prepared by DPWS Environmental and Energy Services.
- EC (European Commission), 2002. Energy Performance of Buildings Directive. 2002/91/EC
- EC (European Commission), 2007.
Available from: http://www.ec.europa.eu/comm/energy_transport/atlas/html/buildings.html
- EIA (Energy Information Administration), 2006. International Energy Annual 2006. Available from <http://www.eia.doe.gov>
- EIA (Energy Information Administration), 2009. International Energy Outlook 2009. DOE/IEA-0484(2009).
- EIA (Energy Information Administration), 2007. International emissions data: Energy Related Carbon Emissions. Available from <http://www.eia.doe.gov/environment.html>
- Environmental Change Unit 1998. Domestic Efficient Lighting (DELIGHT), University of Oxford (UK), 1998 . ISBN 1-874370-20-6.
- ENPER-TEBUC, 2003. Energy Performance of Buildings: Calculation Procedures Used in European Countries, for the Commission of the European Communities, DG-TREN SAV E Contract No. 4.1031/C/00018/2000 ENPER-TEBUC.
- Eurostat 2009. European Commission – Eurostat. Available from: <http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home/>
- HORE-LACY, I. 2003. Nuclear Electricity, 7th edition. Uranium Information Centre - Australia, and World Nuclear Association - UK. ISBN 0-9593829-8-4.
- IEA, 2006. International Energy Agency. Light's Labour's Lost. IEA Publications, France.
- IEA, 2002. International Energy Agency. World Energy Outlook. IEA Publications, France.
- IPCC, 2007. Climate Change 2007: Mitigation of Climate Change, Intergovernmental Panel on Climate Change Working Group III, Netherlands Environmental Assessment Agency.
- Janssen, M, 1999, <http://buildlca.rmit.edu.au/CaseStudy/Stadium/Stadium.html>
- Janssen, M. and Buckland, B. (2000). Stadium Australia Life Cycle Assessment – Energy Use and energy Efficient Design.
- LEED 2009. <http://www.usgbc.org/DisplayPage.aspx?CategoryId=19>

- LOFTNESS, V., 2004. Improving Building Energy Efficiency in the U.S.: Technologies and Policies for 2010 to 2050. Proceedings of the workshop *The 10-50 Solution: Technologies and Policies for a Low-Carbon Future*. The PEW Center on Global Climate Change and the National Commission on Energy Policy. Washington DC.
- Mills, E., 2002. Why we're here: The \$320-billion global lighting energy bill. *Proceedings of the 5th International Conference on Energy Efficient Lighting*, Nice, France 29-31 May 2002. pp.369-385.
- Mills, E., 2005. The Specter of Fuel based Lighting. *Science*, Vol.308, No.5726, pp.1263-1264
- MTPROG (UK Market Transformation Programme). 2007. Available from: <http://www.mtprog.com/>
- NAVIGANT (Navigant Consulting) 2002. U. S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate. Building Technologies Program, US Department of Energy, Washington DC.
- Poirazis H., 2008. Single and double skin glazed office buildings: Analyses of energy use and indoor climate. (Report EBD-T-08/8). Lund University.
- SEA (Swedish Energy Agency), 2007. Energy statistics for offices.
- STI, 2007. ER2007:34. STIL 1, (Förbättrad energistatistik för lokaler – Stegvis STIL – Rapport för år 1 – Inventering av kontor och förvaltningsbyggnader. Statens Energi myndighet).
- Sezgan, O., Koomey, J.G., 2000. Interactions between lighting and space conditioning energy use in US commercial buildings. *Energy*, Vol25, no.8, pp793-805.
- Shailesh, K.R. 2006. White LED Based Illumination Systems for Indian Villages. LEUKOS, The Journal of the Illuminating Engineering Society of North America, Vol3, no.2, pp167-173.
- Sidler, O., 2002. Demand side management. End-use metering campaign in 400 households of the European Community. SAVE Programme, Project EURECO France: Commission of the European Communities, 2002
- Statistics Finland. 2003. 15.8.4. Carbon Dioxide Intensity in Power Generation in Some European Countries, CO_2/kWh . http://pxweb2.stat.fi/sahkoiset_julkaisut/energiatilasto2003/html/suom0015.htm.
- Stern, N., 2006. Stern Review: The Economics of Climate Change. HM Treasury, UK.
- Tichelen, P.V., Jansen, B., Geerken, T., Vanden, B. M., Hoof, V.V., Vanhooydonck, L., Vercauteren, A. 2007. Preparatory Studies for Eco-design Requirements of EuPs Final Report Lot8: Office lighting. Study for the European Commission DG TREN unit D3. Available from: <http://www.eup-richtlinie.at/download/lot8/finalreport.pdf>
- TITLE24, 2007. California's Energy Efficiency Standards for Residential and Non-residential Buildings. Available from: <http://www.energy.ca.gov/title24/>
- UN (United Nations Population Division), 2005. World population prospects: the 2004 revision population database. Available from: <http://esa.un.org/unpp/>
- WBDG (Whole Building Design Guide). 2008. Whole Building Design. www.wbdg.org/wbdg_approach.php
- Weigand, D.E. 2003. Advanced Lighting Guidelines 2003. New Building Institute. White Salmon, WA 98672. Available from: <http://www.newbuildings.org>