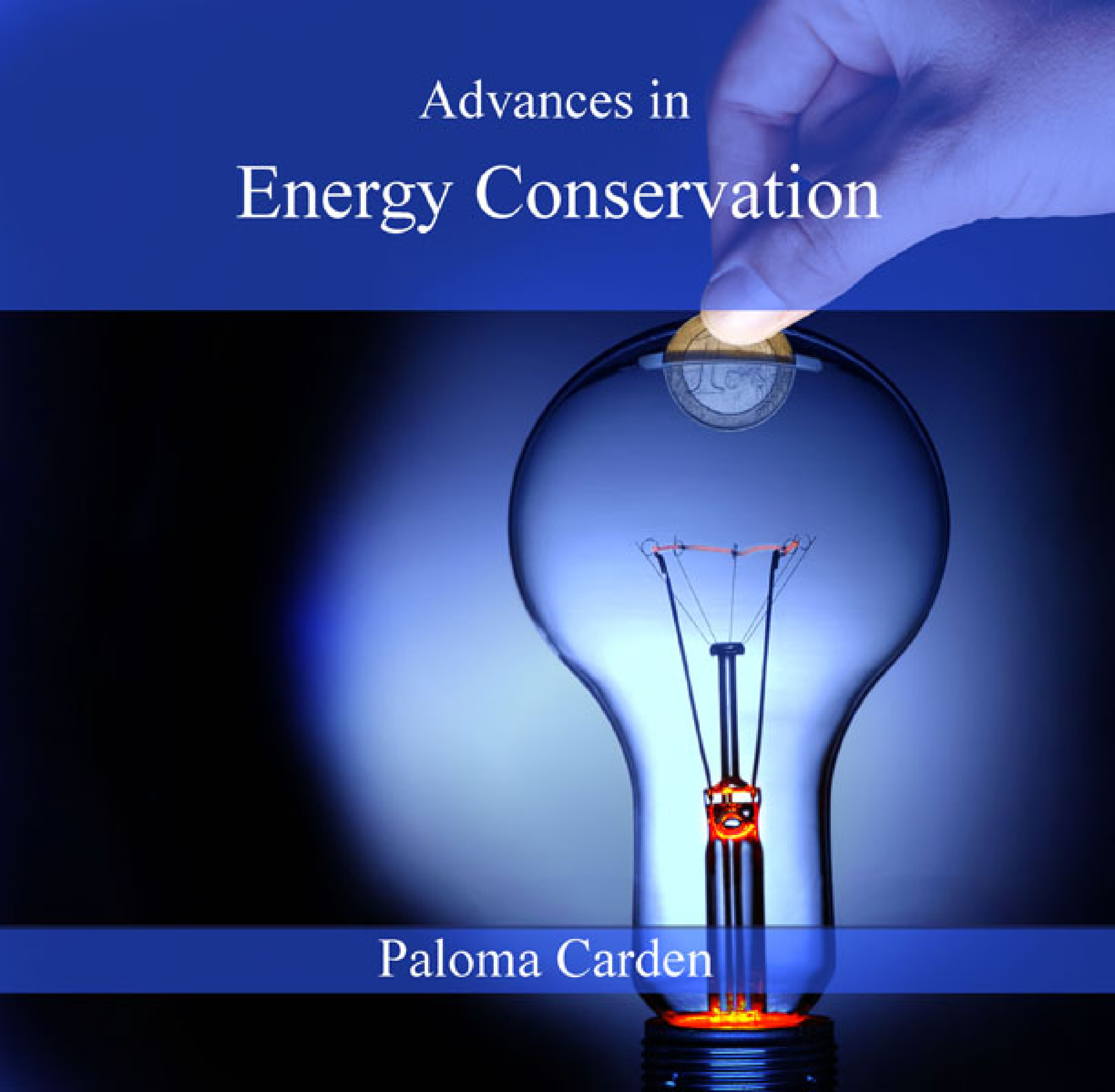
Advances in
Energy Conservation



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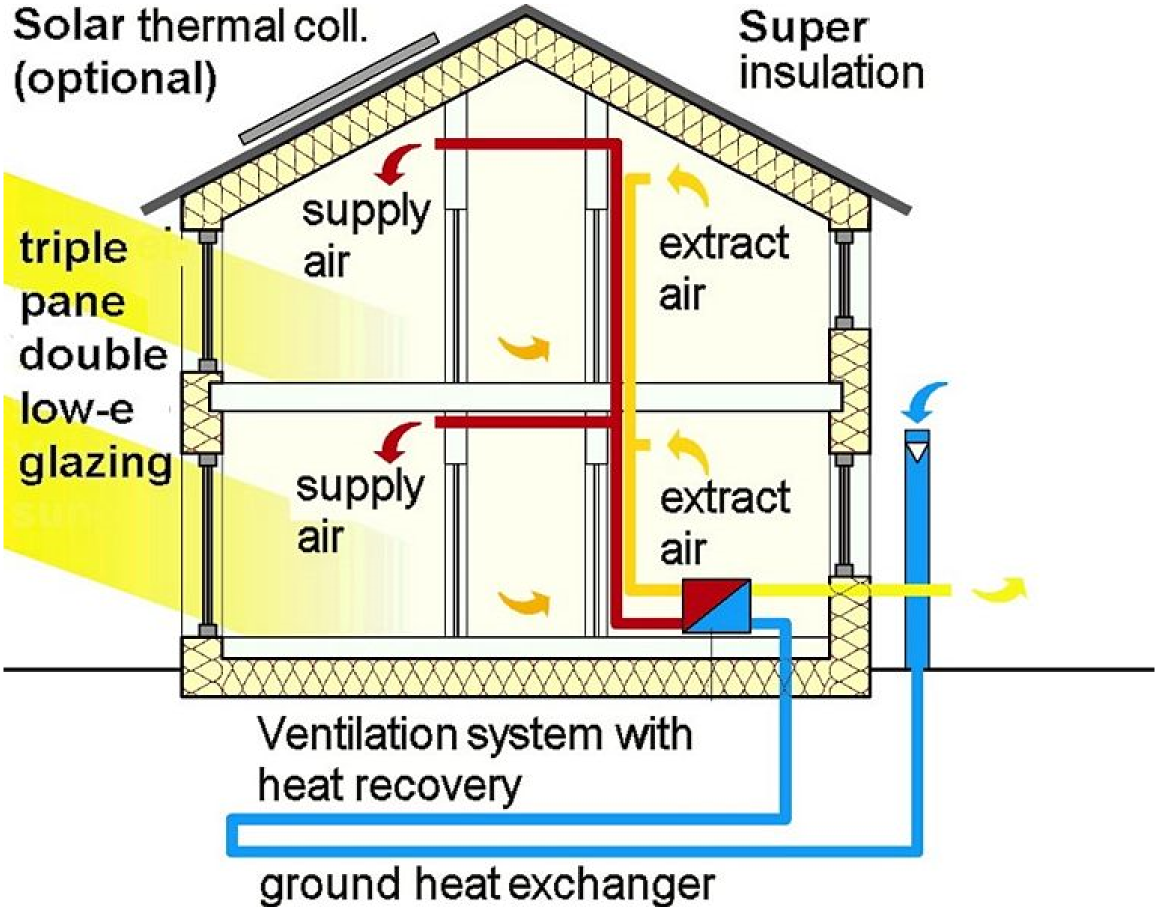
Chapter- 1

Introduction to Energy Conservation

Energy conservation refers to efforts made to reduce energy consumption. Energy conservation can be achieved through increased efficient energy use, in conjunction with decreased energy consumption and/or reduced consumption from conventional energy sources.

Energy conservation can result in increased financial capital, environmental quality, national security, personal security, and human comfort. Individuals and organizations that are direct consumers of energy choose to conserve energy to reduce energy costs and promote economic security. Industrial and commercial users can increase energy use efficiency to maximize profit.

Energy conservation policies



Low-energy building techniques and technologies in an Energy conserving building.

Electrical energy conservation is an important element of energy policy. Energy conservation reduces the energy consumption and energy demand per capita and thus offsets some of the growth in energy supply needed to keep up with population growth. This reduces the rise in energy costs, and can reduce the need for new power plants, and energy imports. The reduced energy demand can provide more flexibility in choosing the most preferred methods of energy production.

Climate change

By reducing emissions, energy conservation is an important part of lessening climate change. Energy conservation facilitates the replacement of non-renewable resources with renewable energy. Energy conservation is often the most economical solution to energy shortages, and is a more environmentally being alternative to increased energy production.

Energy conservation by country

India

Petroleum Conservation Research Association (PCRA) www.pcra.org is an Indian government body created in 1976 and engaged in promoting energy efficiency and conservation in every walk of life. In the recent past PCRA has done mass media campaigns in television, radio & print media. An impact assessment survey by a third party revealed that due to these mega campaigns by PCRA, overall awareness level have gone up leading to saving of fossil fuels worth crores of rupees besides reducing pollution.

Bureau of Energy Efficiency is an Indian governmental organization created in 2002 responsible for promoting energy efficiency and conservation.

Japan

Advertising with high energy in Shinjuku, Japan.

Since the 1973 oil crisis, energy conservation has been an issue in Japan. All oil based fuel is imported, so indigenous sustainable energy is being developed.

The Energy Conservation Center promotes energy efficiency in every aspect of Japan. Private entities are implementing the efficient use of energy for industries.

Lebanon

In Lebanon and since 2002 The Lebanese Center for Energy Conservation (LCEC) has been promoting the development of efficient and rational uses of energy and the use of renewable energy at the consumer level. It was created as a project financed by the Global Environment Facility (GEF) and the Ministry of Energy Water (MEW) under the management of the United Nations Development Programme (UNDP) and gradually established itself as an independent technical national center although it continues to be supported by the United Nations Development Programme (UNDP) as indicated in the Memorandum of Understanding (MoU) signed between MEW and UNDP on June 18, 2007.

New Zealand

In New Zealand the Energy Efficiency and Conservation Authority is responsible for promoting energy efficiency and conservation.

European Union

At the end of 2006, the European Union-EU pledged to cut its annual consumption of primary energy by 20% by 2020. The 'European Union Energy Efficiency Action Plan' is long awaited. As part of the EU's SAVE Programme, aimed at promoting energy efficiency and encouraging energy-saving behaviour, the Boiler Efficiency Directive specifies minimum levels of efficiency for boilers fired with liquid or gaseous fuels. The European Commission is funding large-scale research projects to learn about success factors for effective energy conservation programmes.

United Kingdom

Energy conservation in the United Kingdom has been receiving increased attention over recent years. Key factors behind this are the Government's commitment to reducing carbon emissions, the projected 'energy gap' in UK electricity generation, and the increasing reliance on imports to meet national energy needs. Domestic housing and road transport are currently the two biggest problem areas.

Responsibility for energy conservation fall between three Government departments although is led by the Department for Energy and Climate Change (DECC). The Department for Communities and Local Government (CLG) is still responsible for energy standards in buildings, and the Department for Environment, Food and Rural Affairs (Defra) retains a residual interest in energy insofar as it leads to emissions of

CO2, the main greenhouse gas. The Department for Transport retains many responsibilities for energy conservation in transport. At an operational level, there are two main non-departmental governmental bodies ("quangoes") - the Energy Saving Trust, working mainly in the domestic sector with some interest in transport, and the Carbon Trust, working with industry and innovative energy technologies. In addition there are many independent NGOs working in the sector such as the Centre for Sustainable Energy in Bristol or the National Energy Foundation in Milton Keynes, and directly helping consumers make informed choices on energy efficiency sust-it

United States

The United States is currently the largest single consumer of energy. The U.S. Department of Energy categorizes national energy use in four broad sectors: transportation, residential, commercial, and industrial.

Energy usage in transportation and residential sectors, about half of U.S. energy consumption, is largely controlled by individual consumers. Commercial and industrial energy expenditures are determined by businesses entities and other facility managers. National energy policy has a significant effect on energy usage across all four sectors, and its strengthening is part of the 2010 Presidential-Congressional legislative debate.

Issues with energy conservation

Advocates and critics of various forms and policies of **energy conservation** debate some issues, such as:

- Standard economic theory suggests that technological improvements increase energy efficiency, rather than reduce energy use. This is called the *Jevons Paradox* and it is said to occur in two ways. Firstly, increased energy efficiency makes the use of energy relatively cheaper, thus encouraging increased use. Secondly, increased energy efficiency leads to increased economic growth, which pulls up energy use in the whole economy. This does not imply that increased fuel efficiency is worthless, increased fuel efficiency enables greater production and a higher quality of life. However, in order to reduce energy consumption, efficiency gains must be paired with a government intervention that reduces demand (a green tax, cap and trade).

- Some retailers argue that bright lighting stimulates purchasing. However, health studies have demonstrated that headache, stress, blood pressure, fatigue and worker error all generally increase with the common over-illumination present in many workplace and retail settings. It has been shown that natural daylighting increases productivity levels of workers, while reducing energy consumption.

- The use of telecommuting by major corporations is a significant opportunity to conserve energy, as many Americans now work in service jobs that enable them to work from home instead of commuting to work each day.

- Electric motors consume more than 60% of all electrical energy generated and are responsible for the loss of 10 to 20% of all electricity converted into mechanical energy.

- Consumers are often poorly informed of the savings of energy efficient products. The research one must put into conserving energy often is too time consuming and costly when there are cheaper products and technology available using today's fossil fuels. Some governments and NGOs are attempting to reduce this complexity with ecolabels that make differences in energy efficiency easy to research while shopping.

- Technology needs to be able to change behavioral patterns, it can do this by allowing energy users, business and residential, to see graphically the impact their energy use can have in their workplace or homes. Advanced real-time energy metering is able to help people save energy by their actions. Rather than become wasteful automatic energy saving technologies, real-time energy monitors and meters such as the Energy Detective, Enigin Plc's Eniscope, Ecowizard, or solutions like EDSA'a Paladin Live are examples of such solutions

- It is frequently argued that effective energy conservation requires more than informing consumers about energy consumption, for example through smart meters at home or ecolabels while shopping. People need practical and tailored advice how to reduce energy consumption in order to make change easy and lasting. This applies to both efficiency investments, such as investment in building renovation, or behavioral change, for example turning down the heating. To provide the kind of information and support people need to invest money, time and effort in energy conservation, it is imprtant to understand and link to people's topical concerns.

- In deregulated states commercial utility customers have the ability to compare energy rates among available electricity and natural gas providers.

Chapter- 2

Rebound Effect (Conservation)

In conservation the **rebound effect** (or **take-back effect**) refers to the behavioral or other systemic responses to the introduction of new technologies, or other measures taken to reduce resource use. These responses tend to offset the beneficial effects of the new technology or other measures taken. While the literature on the rebound effect generally focuses on the effect of technological improvements on energy consumption, the theory can also be applied to the use of any natural resource. The rebound effect is generally expressed as a ratio of the lost benefit compared to the expected environmental benefit when holding consumption constant. For instance, if a 5% improvement in vehicle fuel efficiency results in only a 2% drop in fuel use, there is a 60% rebound effect. The 'missing' 3% might have been consumed by driving faster or further than before.

The existence of the rebound effect is uncontroversial. However, debate continues as to the size and importance of the effect in real world situations. There are three possible outcomes regarding the size of the rebound effect:

1. The actual resource savings are higher than expected – the rebound effect is negative. This is unusual, and can only occur in certain specific situations (e.g. if the government mandates the use of more resource efficient technologies that are also more costly to use).
2. The actual savings are less than expected savings – the rebound effect is between 0% and 100%. This is sometimes known as 'take-back', and is the most common result of empirical studies on individual markets.
3. The actual resource savings are negative – the rebound effect is higher than 100%. This situation is commonly known as the Jevons paradox, and is sometimes referred to as 'back-fire'.

Governments and environmental groups often advocate research into higher fuel efficiency as the primary means of energy conservation. Economists tend to believe that, for the economy as a whole, the long term rebound effect for more fuel-efficient technologies is higher than 100%; if this is the case, the invention of technologies that improve fuel efficiency may paradoxically increase energy use.

History

The rebound effect was first described by William Stanley Jevons in his 1865 book *The Coal Question*, where he observed that the invention in Britain of a more efficient steam engine meant that the use of coal became economically viable for many new uses. This ultimately led to increased coal demand and much increased coal consumption, even as the amount of coal required for any particular use fell. According to Jevons, "It is a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth."

However, most contemporary authors credit Daniel Khazzoom for the re-emergence of the rebound effect in the research literature. Although Khazzoom did not use the term, he raised the idea that there is a less than one-to-one correlation between gains in energy efficiency and reductions in energy use, because of a change in the 'price content' of energy in the provision of the final consumer product. His study was based on energy efficiency gains in home appliances, but the principle applies throughout the economy. A commonly studied example is that of a more fuel-efficient car. Since each kilometre of travel becomes cheaper, there will be an increase in driving speed and/or kilometres driven, as long as the price elasticity of demand for car travel is not zero. Other examples might include the growth in garden lighting after the introduction of energy-saving compact fluorescent lamps or the increasing size of houses driven partly by higher fuel efficiency in home heating technologies. If the rebound effect is larger than 100%, all gains from the increased fuel efficiency would be wiped out by increases in demand (the Jevons paradox).

Khazzoom's thesis was criticized heavily by Michael Grubb and Amory Lovins who dismissed any disconnection between energy efficiency improvements in an individual market, and an economy-wide reduction in energy consumption. Developing Khazzoom's idea further, and prompting heated debate in the Energy Policy journal at that time, Len Brookes wrote of the fallacies in the energy-efficiency solution to greenhouse gas emissions. His analysis showed that any economically justified improvements in energy efficiency would in fact stimulate economic growth and increase total energy use. For improvements in energy efficiency to contribute to a reduction in economy-wide energy consumption, the improvement must come at a greater economic cost. Commenting in regard to energy efficiency advocates, he concludes that, "the present high profile of the topic seems to owe more to the current tide of green fervor than to sober consideration of the facts, and the validity and cost of solutions."

Khazzoom-Brookes postulate

In 1992, economist Harry Saunders coined the phrase the ‘Khazzoom-Brookes Postulate’ to describe the idea that energy efficiency gains paradoxically result in increases in energy use (the modern day equivalent of the Jevons paradox). He modeled energy efficiency gains using a variety of neo-classical growth models, and showed that the postulate is true over a wide range of assumptions. In the conclusion of his paper, Saunders stated that:

In the absence of efficiency gains, energy use will grow in lock step with economic growth (energy intensity will stay fixed) when energy prices are fixed. … Energy efficiency gains can increase energy consumption by two means: by making energy appear effectively cheaper than other inputs; and by increasing economic growth, which pulls up energy use. … These results, while by no means proving the Khazzoom-Brookes postulate, call for prudent energy analysts and policy makers to pause a long moment before dismissing it.

This work provided a theoretical grounding for empirical studies and played an important role in framing the problem of the rebound effect. It also reinforced an emerging ideological divide between energy economists on the extent of the yet to be named effect. The two tightly held positions are:

- Technological improvements in energy efficiency enable economic growth that was otherwise impossible without the improvement; as such, energy efficiency improvements will usually back-fire in the long term.
- Technological improvements in energy efficiency may result in a small take-back. However, even in the long term, energy efficiency improvements usually result in large overall energy savings.

Even though many studies have been undertaken in this area, neither position has yet claimed a consensus view in the academic literature. Recent studies have demonstrated that direct rebound effects are significant (about 30% for energy), but that there is not enough information about indirect effects to know whether or how often back-fire occurs. Economists tend to the first position, but most governments, businesses, and environmental groups adhere to the second. Governments and environmental groups often advocate further research into fuel efficiency and radical increases in the efficient use of energy as the primary means for reducing energy use and reducing greenhouse gas emissions (to alleviate the impacts of climate change). However, if the first position more accurately reflects economic reality, current efforts to invent fuel-efficient technologies may not much reduce energy use, and may in fact paradoxically increase oil and coal consumption, and greenhouse gas emissions, over the long run.

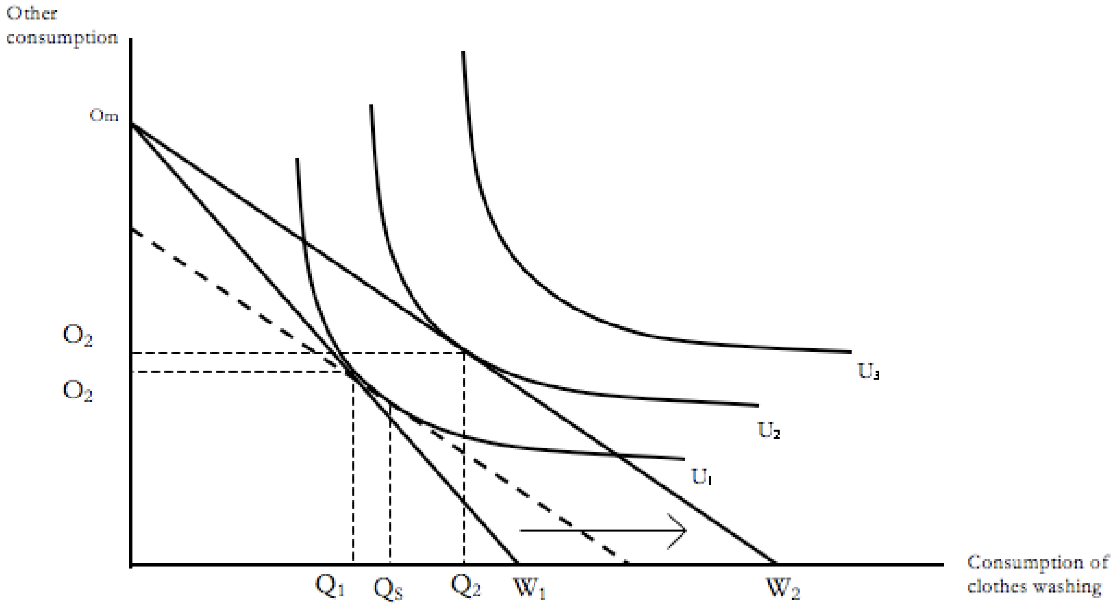
Types of effects

The full rebound effect can be distinguished into three different economic reactions:

1. Direct rebound effect: Increased fuel efficiency lowers the cost of consumption, and hence increases the consumption of that good because of the substitution effect.
2. Indirect rebound effect: Through the income effect, decreased cost of the good enables increased household consumption of other goods and services, increasing the consumption of the resource embodied in those goods and services.
3. Economy wide effects: New technology creates new production possibilities in and increases economic growth.

In the example of improved vehicle fuel efficiency, the direct effect would be the increased fuel use from more driving as driving becomes cheaper. The indirect effect would incorporate the increased consumption of other goods enabled by household cost savings from increased fuel efficiency. Since consumption of other goods increase, the embodied fuel used in the production of those goods would increase as well. Finally, the economy wide effect would include the long term effect of the increase in vehicle fuel efficiency on production and consumption possibilities throughout the economy, including any effects on economic growth rates.

Direct and indirect effects



Direct and Indirect Effects

For cost reducing resource efficiency, distinguishing between direct and indirect effects is shown in Figure 1 below. The horizontal axis shows units of consumption of the targets good (which could be for example clothes washing, and measured in terms of kilograms of clean clothes) with consumption of all other goods and services on the vertical axis. An economical technology change that enables each unit of washing to be produced with less electricity results in a reduction of the price per unit of washing. This shifts the household budget line rightwards. The result is a substitution effect because of the decreased relative price, but also an income effect due to the increased real income. The substitution effect increases consumption of washing from Q1 to QS, and the income effect from QS to Q2. The total increase in consumption of washing from Q1 to Q2 and the resulting increase in electricity consumption is the direct effect. The indirect effect comprises the increase in other consumption, from O1 to O2. The scale of each of these effects depends on the elasticity of demand for each of the goods, and the embodied resource or externality associated with each good. A parallel effect will happen for cost saving efficient technologies for producers, where output and substitution effects will occur.

The rebound effect can increase the difficulty of projecting the reduction in greenhouse emissions from an improvement in energy efficiency. Estimation of the scale of direct effects on residential electricity, heating and motor fuel consumption has been common motivation for research of rebound effects. Evaluation and econometric methods are the two approaches generally employed in estimating the size of this effect. Evaluation methods rely on quasi-experimental studies and measure the before and after changes to energy consumption from the implementation of energy efficient technology, while econometric methods utilize elasticity estimates to forecast the likely effects from changes in the effective price of energy services.

Research has found that in developed countries, the direct rebound effect is usually small to moderate, ranging from roughly 5% to 40%. However, the rebound effect may be more significant in the context of the undeveloped markets in developing economies.

Economy wide effects

Even if the direct and indirect rebound effects add up to less than 100%, technological improvements that increase efficiency may still result in economy wide effects that results in increased resource use for the economy as a whole. In particular, this would happen if resource efficiency enables an expansion of production in the economy, and an increase in the rate of economic growth. For example, for the case of energy use, more efficient technology is equivalent to a lower price for energy resources. It is well known that changes in energy costs have a large impact on economic growth rates. In the 1970s sharp increases in petroleum prices led to stagflation (recession and inflation) in the developed countries, whereas in the 1990s lower petroleum prices contributed to higher economic growth. An improvement in energy efficiency has the same effect as lower fuel prices, and leads to faster economic growth. Economists generally believe that especially for the case of energy use, more efficient technologies will lead to increased use, because of this growth effect.

To model the scale of this effect, economists use computational general equilibrium (CGE) models. While CGE methodology is by no means perfect, results indicate that economy wide rebound effects are likely to be very high, with estimates above 100% rather common. One simple CGE model has been made available online for use by economists.

Indirect effects from conservation

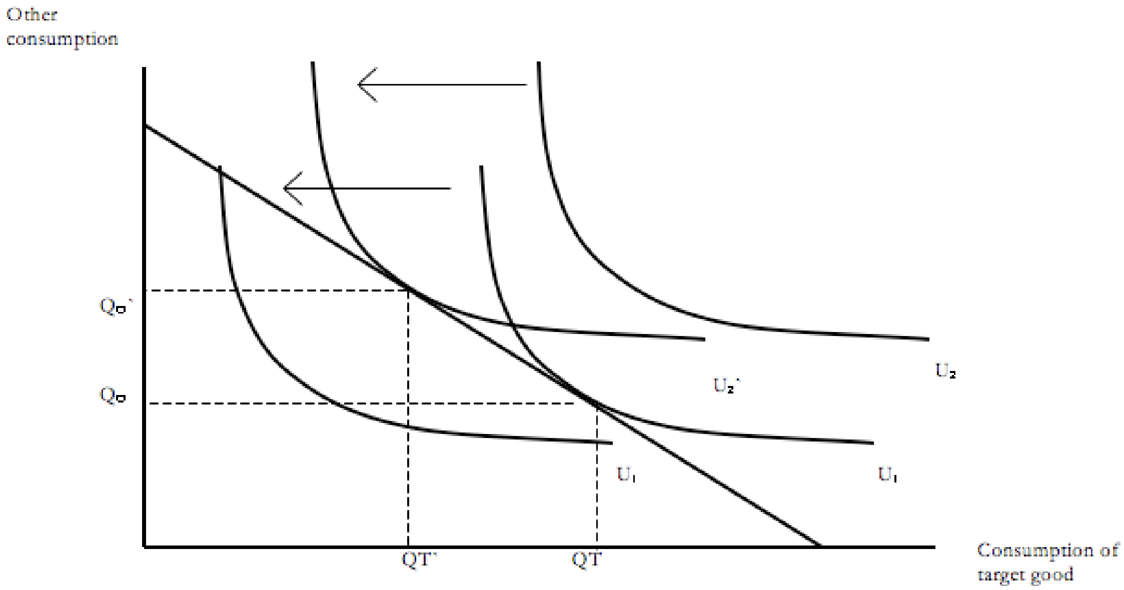


Figure2: change in preferences of a household revealing indirect effects from conservation

For conservation measures, indirect effects closely approximate the total economy wide effect. Conservation measures constitute a change in consumption patterns away from particular targeted goods towards other goods. Figure 2 below shows that a change in preference of a household results in a new consumption pattern that has less of the target good (QT to QT`), and more of all other goods (QO to QO`). The resource consumption or externalities embodied in this other consumption is the indirect effect.

Although a persuasive view has prevailed that indirect effects with respect to energy and greenhouse emissions should be very small due to energy directly comprising only a small component of household expenditure, this view is gradually being eroded. Many recent studies based on life-cycle analysis show the energy consumed indirectly by households is often higher than consumed directly through electricity, gas, and motor fuel, and is a growing proportion. This is evident in the results of recent studies that indicate indirect effects from household conservation can range from 10% to 200% depending on the scenario, with higher indirect rebounds from diet changes aiming to reduce food miles.

Income level variation

Research has shown that the direct rebound effects for energy services is lower at high income levels, due to less price sensitivity. Studies have found that own-price elasticity of gas consumption by UK households was two times greater for households in the lowest income decile when compared to the highest decile. Studies have also observed higher rebounds in low-income houses for improvements in heating technology. Evaluation methods have also been used to assess the scale of rebound effects from efficient heating installations in lower income homes in the United Kingdom. This research found that direct effects are close to 100% in many cases. High income households in developed countries are likely to set the temperature at the optimum comfort level, regardless of the cost – therefore any cost reduction does not result in increased heating, for it was already optimal. But low-income households are more price sensitive, and have made thermal sacrifices due to the cost of heating. In this case, a high direct rebound is likely. This analogy can be extended to most household energy consumption.

The size of the rebound effect is likely to be different in developing countries. A study was undertaken in rural India to evaluate the impact of an alternative energy scheme. Households where given solar powered lighting in an attempt to reduce the use of kerosene for lighting to zero except for seasons with insufficient sunshine. The scheme was also designed to encourage a future willingness to pay for efficient lighting. The results were surprising, with high direct rebounds between 50 and 80%, and total direct and indirect rebound above 100%. Because the new lighting source was essentially zero cost, operating hours for lighting went up from an average of 2 to 6 per day, with new lighting consisting of a combination of both the no-cost solar lamps and also kerosene lamps. Also, more cooking was undertaken which enabled an increased trade of food with neighboring villages.

Rebounds with respect to time

The individual opportunity cost of time is not often considered. Hence, often overlooked in the rebound effect literature is the rebound effect with respect to savings in time. Faster modes of transport are a classic example. Since the time cost forms a major part of the total cost of commuter transport, faster modes will reduce real costs, but will also encourage longer commuting distances. While important, it is almost impossible to estimate empirically the scale of such effects due to the subjective nature of the value of time. Time saved can either be directed towards work or leisure. Labour time saved at work due to the increased labour productivity is likely to be spent on further labour time at higher productive rates. For leisure time saving, this may simply encourage people to diversify their leisure interests to fill their generally fixed period of leisure time.

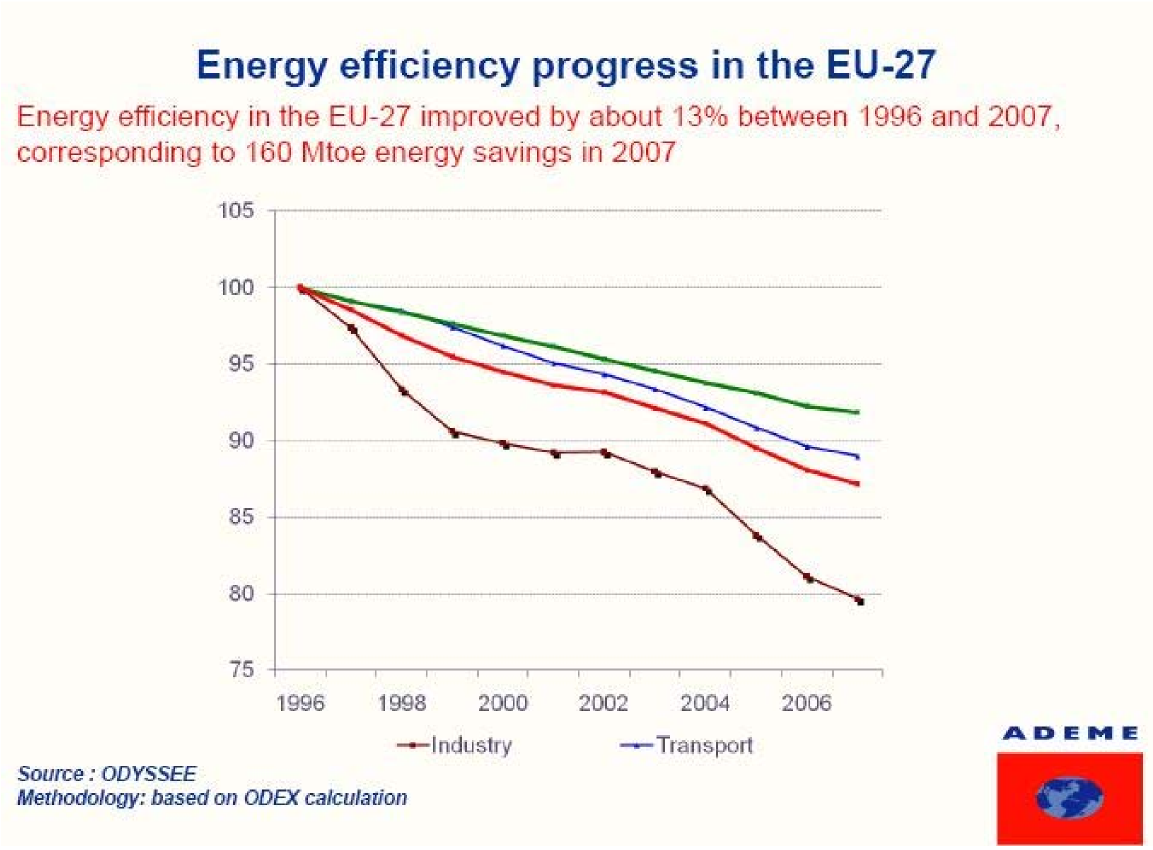
Suggested Solution

In order to ensure that efficiency enhancing technological improvements actually reduce fuel use, the ecological economists Mathis Wackernagel and William Rees have suggested that any cost savings from efficiency gains be "taxed away or otherwise removed from further economic circulation. Preferably they should be captured for reinvestment in natural capital rehabilitation." This can be achieved through, for example, the imposition of a green tax, a cap and trade program, or higher fuel taxes.

Chapter- 3

Efficient Energy Use

A spiral-type integrated compact fluorescent lamp, which has been popular among North American consumers since its introduction in the mid 1990s.



Energy efficiency progress in the EU-27

Energy efficiency in the EU-27 improved by about 13% between 1996 and 2007, corresponding to 160 Mtoe energy savings in 2007

Source : ODYSSEE
Methodology: based on ODEX calculation

Efficient energy use, sometimes simply called **energy efficiency**, is the goal of efforts to reduce the amount of energy required to provide products and services. For example, insulating a home allows a building to use less heating and cooling energy to achieve and maintain a comfortable temperature. Installing fluorescent lights or natural skylights reduces the amount of energy required to attain the same level of illumination compared to using traditional incandescent light bulbs. Compact fluorescent lights use two-thirds less energy and may last 6 to 10 times longer than incandescent lights. Improvements in energy efficiency are most often achieved by adopting a more efficient technology or production process.

There are various motivations to improve energy efficiency. Reducing energy use reduces energy costs and may result in a financial cost saving to consumers if the energy savings offset any additional costs of implementing an energy efficient technology. Reducing energy use is also seen as a key solution to the problem of reducing greenhouse gas emissions. According to the International Energy Agency, improved energy efficiency in buildings, industrial processes and transportation could reduce the world's energy needs in 2050 by one third, and help control global emissions of greenhouse gases.

Energy efficiency and renewable energy are said to be the *twin pillars* of sustainable energy policy. In many countries energy efficiency is also seen to have a national security benefit because it can be used to reduce the level of energy imports from foreign countries and may slow down the rate at which domestic energy resources are depleted.

Overview

Making homes, vehicles, and businesses more energy efficient is seen as a largely untapped solution to addressing the problems of pollution, global warming, energy security, and fossil fuel depletion. Many of these ideas have been discussed for years, since the 1973 oil crisis brought energy issues to the forefront. In the late 1970s, physicist Amory Lovins popularized the notion of a "soft energy path", with a strong focus on energy efficiency. Among other things, Lovins popularized the notion of negawatts—the idea of meeting energy needs by increasing efficiency instead of increasing energy production.

Energy efficiency has proved to be a cost-effective strategy for building economies without necessarily growing energy consumption. For example, the state of California began implementing energy-efficiency measures in the mid-1970s, including building code and appliance standards with strict efficiency requirements. During the following years, California's energy consumption has remained approximately flat on a per capita basis while national U.S. consumption doubled. As part of its strategy, California implemented a "loading order" for new energy resources that puts energy efficiency first, renewable electricity supplies second, and new fossil-fired power plants last.

Lovins' Rocky Mountain Institute points out that in industrial settings, "there are abundant opportunities to save 70% to 90% of the energy and cost for lighting, fan, and pump systems; 50% for electric motors; and 60% in areas such as heating, cooling, office equipment, and appliances." In general, up to 75% of the electricity used in the U.S. today could be saved with efficiency measures that cost less than the electricity itself. The same holds true for home-owners, leaky ducts have remained an invisible energy culprit for years. In fact, researchers at the US Department of Energy and their consortium, Residential Energy Efficient Distribution Systems (REEDS) have found that duct efficiency may be as low as 50-70%. The US Department of Energy has stated that there is potential for energy saving in the magnitude of 90 Billion kWh by increasing home energy efficiency.

Other studies have emphasized this. A report published in 2006 by the McKinsey Global Institute, asserted that "there are sufficient economically viable opportunities for energy-productivity improvements that could keep global energy-demand growth at less than 1 percent per annum"—less than half of the 2.2 percent average growth anticipated through 2020 in a business-as-usual scenario. Energy productivity, which measures the output and quality of goods and services per unit of energy input, can come from either reducing the amount of energy required to produce something, or from increasing the quantity or quality of goods and services from the same amount of energy.

The Vienna Climate Change Talks 2007 Report, under the auspices of the United Nations Framework Convention on Climate Change (UNFCCC), clearly shows "that energy efficiency can achieve real emission reductions at low cost."

Appliances

Energy

Washing machine

Manufacturer
Model

More efficient

A
B
C
D
E
F
G

Less efficient

B

Energy consumption kWh/cycle (based on standard test results for 60°C cotton cycle) Actual energy consumption will depend on how the appliance is used	1.75
Washing performance A: higher G: lower	A B C D E F G
Spin drying performance A: higher G: lower	A B C D E F G
Spin speed (rpm)	1400
Capacity (cotton) kg	5.0
Water consumption	5.5
Noise (dB(A) re 1 pW) Washing	5.2
Spinning	7.6

Further information contained in product brochure

Modern energy-efficient appliances, such as refrigerators, freezers, ovens, stoves, dishwashers, and clothes washers and dryers, use significantly less energy than older appliances. Current energy efficient refrigerators, for example, use 40 percent less energy than conventional models did in 2001. Following this, if all households in Europe changed their more than ten year old appliances into new ones, 20 billion kWh of electricity would be saved annually, hence reducing CO_2 emissions by almost 18 billion kg. In the US, the corresponding figures would be 17 billion kWh of electricity and 27,000,000,000 lb (1.2×10^{10} kg) CO_2. According to a 2009 study from McKinsey & Company the replacement of old appliances is one of the most efficient global measures to reduce emissions of greenhouse gases. Modern power management systems also reduce energy usage by idle appliances by turning them off or putting them into a low-energy mode after a certain time. Many countries identify energy-efficient appliances using energy input labeling.

The impact of energy efficiency on peak demand depends on when the appliance is used. For example, an air conditioner uses more energy during the afternoon when it is hot. Therefore, an energy efficient air conditioner will have a larger impact on peak demand than off-peak demand. An energy efficient dishwasher, on the other hand, uses more energy during the late evening when people do their dishes. This appliance may have little to no impact on peak demand.

Building design

A building's location and surroundings play a key role in regulating its temperature and illumination. For example, trees, landscaping, and hills can provide shade and block wind. In cooler climates, designing buildings with a south facing windows increases the amount of sun (ultimately heat energy) entering the building, minimizing energy use, by maximizing passive solar heating. Tight building design, including energy-efficient windows, well-sealed doors, and additional thermal insulation of walls, basement slabs, and foundations can reduce heat loss by 25 to 50 percent.

Dark roofs may become up to 39 C° (70 F°) hotter than the most reflective white surfaces, and they transmit some of this additional heat inside the building. US Studies have shown that lightly colored roofs use 40 percent less energy for cooling than buildings with darker roofs. White roof systems save more energy in sunnier climates. Advanced electronic heating and cooling systems can moderate energy consumption and improve the comfort of people in the building.

Proper placement of windows and skylights and use of architectural features that reflect light into a building, can reduce the need for artificial lighting. Increased use of natural and task lighting have been shown by one study to increase productivity in schools and offices. Compact fluorescent lights use two-thirds less energy and may last 6 to 10 times longer than incandescent light bulbs. Newer fluorescent lights produce a natural light, and in most applications they are cost effective, despite their higher initial cost, with payback periods as low as a few months.

Effective energy-efficient building design can include the use of low cost Passive Infra Reds (PIRs) to switch-off lighting when areas are unnoccupied such as toilets, corridors or even office areas out-of-hours. In addition, lux levels can be monitored using daylight sensors linked to the building's lighting scheme to switch on/off or dim the lighting to pre-defined levels to take into account the natural light and thus reduce consumption. Building Management Systems (BMS) link all of this together in one centralised computer to control the whole building's lighting and power requirements.

The choice of which space heating or cooling technology to use in buildings can have a significant impact on energy use and efficiency. For example, replacing an older 50%

efficient natural gas furnace with a new 95% one will dramatically reduce energy use, carbon emissions, and winter natural gas bills. Ground source heat pumps can be even more energy efficient and cost effective. These systems use pumps and compressors to move refrigerant fluid around a thermodynamic cycle in order to "pump" heat against its natural flow from hot to cold, for the purpose of transferring heat into a building from the large thermal reservoir contained within the nearby ground. The end result is that heat pumps typically use four times less electrical energy to deliver an equivalent amount of heat than a direct electrical heater does. Another advantage of a ground source heat pump is that it can be reversed in summertime and operate to cool the air by transferring heat from the building to the ground. The disadvantage of ground source heat pumps is their high initial capital cost, but this is typically recouped within 5 to 10 years as a result of lower energy use.

Smart meters are slowly being adopted by the commerial sector to highlight to staff and for internal monitoring purposes the building's energy usage in a dynamic presentable format. The use of Power Quality Analysers can be introduced into an existing building to assess usage, harmonic distortion, peaks, swells and interruptions amongst others to ultimately make the building more energy-efficient. Often such meters communicate by using wireless sensor networks.

A term relevant for efficient energy use is **energy use intensity**, which is defined as energy consumption per floor area.

Industry

Industry uses a large amount of energy to power a diverse range of manufacturing and resource extraction processes. Many industrial processes require large amounts of heat and mechanical power, most of which is delivered as natural gas, petroleum fuels and as electricity. In addition some industries generate fuel from waste products that can be used to provide additional energy.

Because industrial processes are so diverse it is impossible to describe the multitude of possible opportunities for energy efficiency in industry. Many depend on the specific technologies and processes in use at each industrial facility. However there are a number of processes and energy services that are widely used in many industries.

Various industries generate steam and electricity for subsequent use within their facilities. When electricity is generated, the heat that is produced as a by-product can be captured and used for process steam, heating or other industrial purposes. Conventional electricity generation is about 30 percent efficient, whereas combined heat and power (also called co-generation) converts up to 90 percent of the fuel into usable energy.

Advanced boilers and furnaces can operate at higher temperatures while burning less fuel. These technologies are more efficient and produce fewer pollutants.

Over 45 percent of the fuel used by US manufacturers is burnt to make steam. The typical industrial facility can reduce this energy usage 20 percent (according to the US Department of Energy) by insulating steam and condensate return lines, stopping steam leakage, and maintaining steam traps.

Electric motors usually run at a constant speed, but a variable speed drive allows the motor's energy output to match the required load. This achieves energy savings ranging from 3 to 60 percent, depending on how the motor is used. Motor coils made of superconducting materials can also reduce energy losses. Motors may also benefit from voltage optimisation.

Industry uses a large number of pumps and compressors of all shapes and sizes and in a wide variety of applications. The efficiency of pumps and compressors depends on many factors but often improvements can be made by implementing better process control and better maintenance practices. Compressors are commonly used to provide compressed air which is used for sand blasting, painting, and other power tools. According to the US Department of Energy, optimizing compressed air systems by installing variable speed drives, along with preventive maintenance to detect and fix air leaks, can improve energy efficiency 20 to 50 percent.

Vehicles

The estimated energy efficiency for an automobile is 280 Passenger-Mile/10^6 Btu. There are several ways to enhance a vehicle's energy efficiency. Using improved aerodynamics to minimize drag can increase vehicle fuel efficiency. Reducing vehicle weight can also improve fuel economy, which is why composite materials are widely used in car bodies.

More advanced tires, with decreased tire to road friction and rolling resistance, can save gasoline. Fuel economy can be improved by up to 3.3% by keeping tires inflated to the correct pressure. Replacing a clogged air filter can improve a cars fuel consumption by as much as 10 percent on older vehicles. On newer vehicles (1980's and up) with fuel-injected, computer-controlled engines, a clogged air filter has no effect on mpg but replacing it may improve acceleration by 6-11 percent.

Energy-efficient vehicles may reach twice the fuel efficiency of the average automobile. Cutting-edge designs, such as the diesel Mercedes-Benz Bionic concept vehicle have achieved a fuel efficiency as high as 84 miles per US gallon (2.8 L/100 km; 101 mpg$_{\text{-imp}}$), four times the current conventional automotive average.

The mainstream trend in automotive efficiency is the rise of electric vehicles (all@electric or hybrid electric). Hybrids, like the Toyota Prius, use regenerative braking to recapture energy that would dissipate in normal cars; the effect is especially pronounced in city driving. plug-in hybrids also have increased battery capacity, which makes it possible to drive for limited distances without burning any gasoline; in this case, energy efficiency is dictated by whatever process (such as coal-burning, hydroelectric, or renewable source) created the power. Plug-ins can typically drive for around 40 miles (64 km) purely on electricity without recharging; if the battery runs low, a gas engine kicks in allowing for extended range. Finally, all-electric cars are also growing in popularity; the Tesla Roadster sports car is the only high-performance all-electric car currently on the market, and others are in preproduction.

Energy conservation

Energy conservation is broader than energy efficiency in including active efforts to decrease energy consumption, for example through behavioural change, in addition to using energy more efficiently. Examples of conservation without efficiency improvements are heating a room less in winter, using the car less, or enabling energy saving modes on a computer. As with other definitions, the boundary between efficient energy use and energy conservation can be fuzzy, but both are important in environmental and economic terms. This is especially the case when actions are directed at the saving of fossil fuels. Energy conservation is a challenge requiring policy programmes, technological development and behavioral change to go hand in hand. Many energy intermediary organisations, for example governmental or non-governmental organisations on local, regional, or national level, are working on often publicly funded programmes or projects to meet this challenge.

Sustainable energy

Energy efficiency and renewable energy are said to be the “twin pillars” of a sustainable energy policy. Both strategies must be developed concurrently in order to stabilize and reduce carbon dioxide emissions. Efficient energy use is essential to slowing the energy demand growth so that rising clean energy supplies can make deep cuts in fossil fuel use. If energy use grows too rapidly, renewable energy development will chase a receding target. Likewise, unless clean energy supplies come online rapidly, slowing demand growth will only begin to reduce total carbon emissions; a reduction in the carbon content of energy sources is also needed. A sustainable energy economy thus requires major commitments to both efficiency and renewables.

Rebound effect

If the demand for energy services remains constant, improving energy efficiency will reduce energy consumption and carbon emissions. However, many efficiency improvements do not reduce energy consumption by the amount predicted by simple engineering models. This is because they make energy services cheaper, and so consumption of those services increases. For example, since fuel efficient vehicles make travel cheaper, consumers may choose to drive farther and/or faster, thereby offsetting some of the potential energy savings. This is an example of the direct rebound effect.

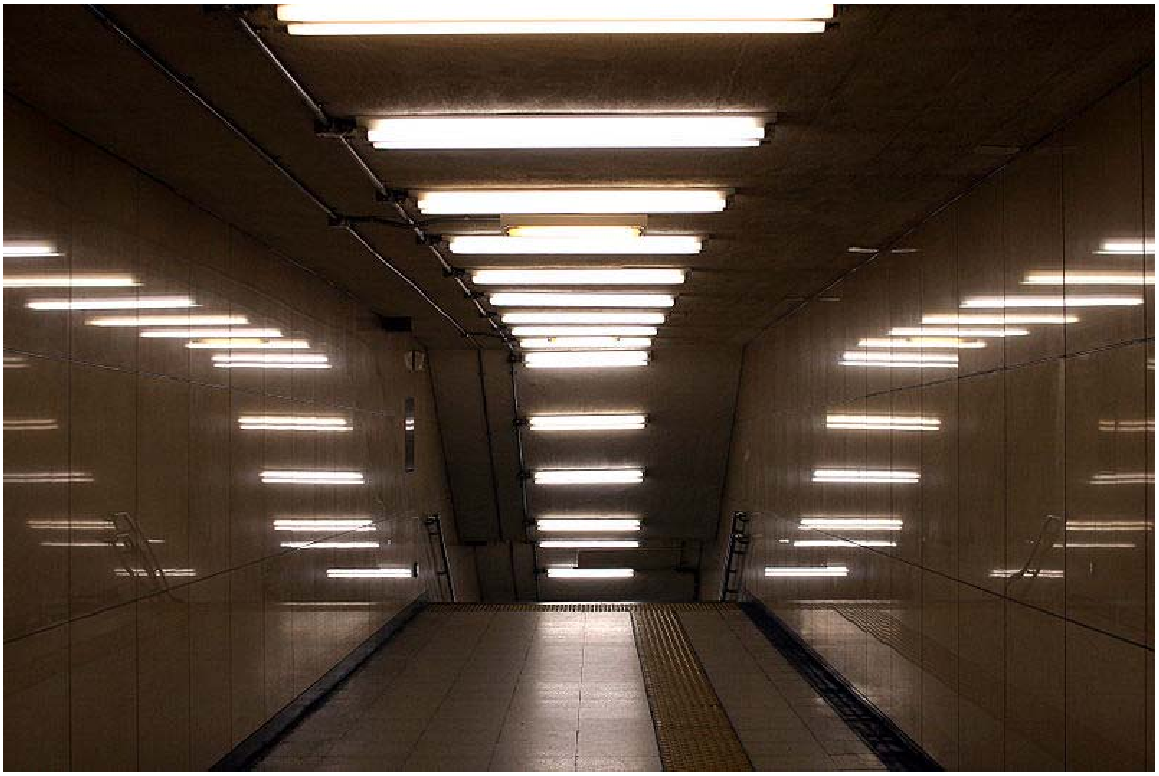
Estimates of the size of the rebound effect range from roughly 5% to 40%. The rebound effect is likely to be less than 30% at the household level and may be closer to 10% for transport. A rebound effect of 30% implies that improvements in energy efficiency should achieve 70% of the reduction in energy consumption projected using engineering models.

Since more efficient (and hence cheaper) energy will also lead to faster economic growth, there are suspicions that improvements in energy efficiency may eventually lead to even faster resource use. This was postulated by economists in the 1980s and remains a controversial hypothesis. Ecological economists have suggested that any cost savings from efficiency gains be taxed away by the government in order to avoid this outcome.

Chapter- 4

Use of Fluorescent Lamp for Energy Conservation

Fluorescent lamp



Fluorescent lamps

Assorted types of fluorescent lamps. Top, two compact fluorescent lamps. Bottom, two regular tubes. Left, matchstick shown for scale.

Typical F71T12 100 W bi-pin lamp used in tanning beds. Note the (Hg) symbol indicating it contains mercury. In the US this symbol is now required on all fluorescent bulbs that contain mercury.

A **fluorescent lamp** or **fluorescent tube** is a gas-discharge lamp that uses electricity to excite mercury vapor. The excited mercury atoms produce short-wave ultraviolet light that then causes a phosphor to fluoresce, producing visible light. A fluorescent lamp converts electrical power into useful light more efficiently than an incandescent lamp. Lower energy cost typically offsets the higher initial cost of the lamp. The lamp is more costly because it requires a ballast to regulate the current through the lamp.

While larger fluorescent lamps have been mostly used in commercial or institutional buildings, the compact fluorescent lamp is now available in the same popular sizes as incandescents and is used as an energy-saving alternative in homes.

History

Physical discoveries

Fluorescence of certain rocks and other substances had been observed for hundreds of years before its nature was understood. By the middle of the 19th century, experimenters had observed a radiant glow emanating from partially evacuated glass vessels through which an electrical current passed. One of the first to explain it was the Irish scientist Sir George Stokes from the University of Cambridge, who named the phenomenon "fluorescence" after fluorite, a mineral many of whose samples fluoresce strongly due to impurities. The explanation relied on the nature of electricity and light phenomena as developed by the British scientists Michael Faraday and James Clerk Maxwell in the 1840s.

Little more was done with this phenomenon until 1856 when a German glassblower named Heinrich Geissler created a mercury vacuum pump that evacuated a glass tube to an extent not previously possible. When an electrical current passed through a Geissler tube, a strong green glow on the walls of the tube at the cathode end could be observed. Because it produced some beautiful light effects, the Geissler tube was a popular source of amusement. More important, however, was its contribution to scientific research. One of the first scientists to experiment with a Geissler tube was Julius Plücker who systematically described in 1858 the luminescent effects that occurred in a Geissler tube. He also made the important observation that the glow in the tube shifted position when in proximity to an electromagnetic field. Alexandre Edmond Becquerel observed in 1859 that certain substances gave off light when they were placed in a Geissler tube. He went on to apply thin coatings of luminescent materials to the surfaces of these tubes. Fluorescence occurred, but the tubes were very inefficient and had a short operating life.

Inquiries that began with the Geissler tube continued as even better vacuums were produced. The most famous was the evacuated tube used for scientific research by William Crookes. That tube was evacuated by the highly effective mercury vacuum pump created by Hermann Sprengel. Research conducted by Crookes and others ultimately led to the discovery of the electron in 1897 by J. J. Thomson. But the Crookes tube, as it came to be known, produced little light because the vacuum in it was too good and thus lacked the trace amounts of gas that are needed for electrically stimulated luminescence.

Early discharge lamps

While Becquerel was primarily interested in conducting scientific research into fluorescence, Thomas Edison briefly pursued fluorescent lighting for its commercial potential. He invented a fluorescent lamp in 1896 that used a coating of calcium tungstate as the fluorescing substance, excited by X-rays, but although it received a patent in 1907, it was not put into production. As with a few other attempts to use Geissler tubes for illumination, it had a short operating life, and given the success of the incandescent light, Edison had little reason to pursue an alternative means of electrical illumination. Nikola Tesla made similar experiments in the 1890s, devising high frequency powered fluorescent bulbs that gave a bright greenish light, but as with Edison's devices, no commercial success was achieved.

Although Edison lost interest in fluorescent lighting, one of his former employees was able to create a gas-based lamp that achieved a measure of commercial success. In 1895 Daniel McFarlan Moore demonstrated lamps 2 to 3 meters (6.6 to 9.8 ft) in length that used carbon dioxide or nitrogen to emit white or pink light, respectively. As with future fluorescent lamps, they were considerably more complicated than an incandescent bulb.

After years of work, Moore was able to extend the operating life of the lamps by inventing an electromagnetically controlled valve that maintained a constant gas pressure within the tube. Although Moore’s lamp was complicated, expensive to install, and required very high voltages, it was considerably more efficient than incandescent lamps, and it produced a more natural light than incandescent lamps. From 1904 onwards Moore’s lighting system was installed in a number of stores and offices. Its success contributed to General Electric’s motivation to improve the incandescent lamp, especially its filament. GE’s efforts came to fruition with the invention of a tungsten-based filament. The extended lifespan of incandescent bulbs negated one of the key advantages of Moore’s lamp, but GE purchased the relevant patents in 1912. These patents and the inventive efforts that supported them were to be of considerable value when the firm took up fluorescent lighting more than two decades later.

At about the same time that Moore was developing his lighting system, another American was creating a means of illumination that also can be seen as a precursor to the modern fluorescent lamp. This was the mercury-vapor lamp, invented by Peter Cooper Hewitt and patented in 1901 (US 682692)(Note: This patent number is universally misquoted as US889,692). Hewitt’s lamp luminesced when an electric current was passed through mercury vapor at a low pressure. Unlike Moore’s lamps, Hewitt's were manufactured in standardized sizes and operated at low voltages. The mercury-vapor lamp was superior to the incandescent lamps of the time in terms of energy efficiency, but the blue-green light it produced limited its applications. It was, however, used for photography and some industrial processes.

Mercury vapor lamps continued to be developed at a slow pace, especially in Europe, and by the early 1930s they received limited use for large-scale illumination. Some of them employed fluorescent coatings, but these were primarily used for color correction and not for enhanced light output. Mercury vapor lamps also anticipated the fluorescent lamp in their incorporation of a ballast to maintain a constant current.

Cooper-Hewitt had not been the first to use mercury vapor for illumination, as earlier efforts had been mounted by Way, Rapieff, Arons, and Bastian and Salisbury. Of particular importance was the mercury vapor lamp invented by Küch in Germany. This lamp used quartz in place of glass to allow higher operating temperatures, and hence greater efficiency. Although its light output relative to electrical consumption was better than other sources of light, the light it produced was similar to that of the Cooper-Hewitt lamp in that it lacked the red portion of the spectrum, making it unsuitable for ordinary lighting.

Neon lamps

The next step in gas-based lighting took advantage of the luminescent qualities of neon, an inert gas that had been discovered in 1898 by isolation from the atmosphere. Neon glowed a brilliant red when used in Geissler tubes. By 1910, Georges Claude, a Frenchman who had developed a technology and a successful business for air liquefaction, was obtaining enough neon as a byproduct to support a neon lighting industry. While neon lighting was used around 1930 in France for general illumination, it was no more energy-efficient than conventional incandescent lighting. Neon tube lighting, which also includes the use of argon and mercury vapor as alternate gases, came to be used primarily for eye-catching signs and advertisements. Neon lighting was relevant to the development of fluorescent lighting, however, as Claude’s improved electrode (patented in 1915) overcame "sputtering", a major source of electrode degradation. Sputtering occurred when ionized particles struck an electrode and tore off bits of metal. Although Claude’s invention required electrodes with a lot of surface area, it showed that a major impediment to gas-based lighting could be overcome.

The development of the neon light also was significant for the last key element of the fluorescent lamp, its fluorescent coating. In 1926 Jacques Risler received a French patent for the application of fluorescent coatings to neon light tubes. The main use of these lamps, which can be considered the first commercially successful fluorescents, was for advertising, not general illumination. This, however, was not the first use of fluorescent coatings. As has been noted above, Edison used calcium tungstate for his unsuccessful lamp. Other efforts had been mounted, but all were plagued by low efficiency and various technical problems. Of particular importance was the invention in 1927 of a low-voltage “metal vapor lamp” by Friedrich Meyer, Hans-Joachim Spanner, and Edmund Germer, who were employees of a German firm in Berlin. A German patent was granted but the lamp never went into commercial production.

Commercialization of fluorescent lamps

All the major features of fluorescent lighting were in place at the end of the 1920s. Decades of invention and development had provided the key components of fluorescent lamps: economically manufactured glass tubing, inert gases for filling the tubes, electrical ballasts, long-lasting electrodes, mercury vapor as a source of luminescence, effective means of producing a reliable electrical discharge, and fluorescent coatings that could be energized by ultraviolet light. At this point, intensive development was more important than basic research.

In 1934, Arthur Compton, a renowned physicist and GE consultant, reported to the GE lamp department on successful experiments with fluorescent lighting at General Electric Co., Ltd. in Great Britain (unrelated to General Electric in the United States). Stimulated by this report, and with all of the key elements available, a team led by George E. Inman built a prototype fluorescent lamp in 1934 at General Electric’s Nela Park (Ohio) engineering laboratory. This was not a trivial exercise; as noted by Arthur A. Bright, "A great deal of experimentation had to be done on lamp sizes and shapes, cathode construction, gas pressures of both argon and mercury vapor, colors of fluorescent powders, methods of attaching them to the inside of the tube, and other details of the lamp and its auxiliaries before the new device was ready for the public."

In addition to having engineers and technicians along with facilities for R&D work on fluorescent lamps, General Electric controlled what it regarded as the key patents covering fluorescent lighting, including the patents originally issued to Hewitt, Moore, and Küch. More important than these was a patent covering an electrode that did not disintegrate at the gas pressures that ultimately were employed in fluorescent lamps. Albert W. Hull of GE's Schenectady Research Laboratory filed for a patent on this invention in 1927, which was issued in 1931.

While the Hull patent gave GE a basis for claiming legal rights over the fluorescent lamp, a few months after the lamp went into production the firm learned of a U.S. patent application that had been filed in 1927 for the aforementioned "metal vapor lamp" invented in Germany by Meyer, Spanner, and Germer. The patent application indicated that the lamp had been created as a superior means of producing ultraviolet light, but the application also contained a few statements referring to fluorescent illumination. Efforts to obtain a U.S. patent had met with numerous delays, but were it to be granted, the patent might have caused serious difficulties for GE. At first, GE sought to block the issuance of a patent by claiming that priority should go to one of their employees, Leroy J. Buttolph, who according to their claim had invented a fluorescent lamp in 1919 and whose patent application was still pending. GE also had filed a patent application in 1936 in Inman's name to cover the "improvements" wrought by his group. In 1939 GE decided that the claim of Meyer, Spanner, and Germer had some merit, and that in any event a long interference procedure was not in their best interest. They therefore dropped the Buttolph claim and paid $180,000 to acquire the Meyer, et al. application, which at that point was owned by a firm known as Electrons, Inc. The patent was duly awarded in December 1939. This patent, along with the Hull patent, put GE on what seemed to be firm legal ground, although it faced years of legal challenges from Sylvania Electric Products, Inc., which claimed infringement on patents that it held.

Even though the patent issue would not be completely resolved for many years, General Electric's strength in manufacturing and marketing the bulb gave it a pre-eminent position in the emerging fluorescent light market. Sales of "fluorescent lumiline lamps" commenced in 1938 when four different sizes of tubes were put on the market used in fixtures manufactured by three leading corporations, two based in New York City. During the following year GE and Westinghouse publicized the new lights through exhibitions at the New York World's Fair and the Golden Gate International Exposition in San Francisco. Fluorescent lighting systems spread rapidly during World War II as wartime manufacturing intensified lighting demand. By 1951 more light was produced in the United States by fluorescent lamps than by incandescent lamps.

Principles of operation

The fundamental means for conversion of electrical energy into radiant energy in a fluorescent lamp relies on inelastic scattering of electrons. An incident electron collides with an atom in the gas. If the free electron has enough kinetic energy, it transfers energy to the atom's outer electron, causing that electron to temporarily jump up to a higher energy level. The collision is 'inelastic' because a loss of energy occurs.

This higher energy state is unstable, and the atom will emit an ultraviolet photon as the atom's electron reverts to a lower, more stable, energy level. Most of the photons that are released from the mercury atoms have wavelengths in the ultraviolet (UV) region of the spectrum predominantly at wavelengths of 253.7 nm and 185 nm. These are not visible to the human eye, so they must be converted into visible light. This is done by making use of fluorescence. Ultraviolet photons are absorbed by electrons in the atoms of the lamp's interior fluorescent coating, causing a similar energy jump, then drop, with emission of a further photon. The photon that is emitted from this second interaction has a lower energy than the one that caused it. The chemicals that make up the phosphor are chosen so that these emitted photons are at wavelengths visible to the human eye. The difference in energy between the absorbed ultra-violet photon and the emitted visible light photon goes toward heating up the phosphor coating.

When the light is turned on, the electric power heats up the cathode enough for it to emit electrons. These electrons collide with and ionize noble gas atoms inside the bulb surrounding the filament to form a plasma by a process of impact ionization. As a result of avalanche ionization, the conductivity of the ionized gas rapidly rises, allowing higher currents to flow through the lamp.

Construction

Close-up of the cathodes of a germicidal lamp (an essentially similar design that uses no fluorescent phosphor, allowing the electrodes to be seen.)

A fluorescent lamp tube is filled with a gas containing low pressure mercury vapor and argon, xenon, neon, or krypton. The pressure inside the lamp is around 0.3% of atmospheric pressure. The inner surface of the bulb is coated with a fluorescent (and often slightly phosphorescent) coating made of varying blends of metallic and rare-earth phosphor salts. The bulb's electrodes are typically made of coiled tungsten and usually referred to as cathodes because of their prime function of emitting electrons. For this, they are coated with a mixture of barium, strontium and calcium oxides chosen to have a low thermionic emission temperature.

The unfiltered ultraviolet glow of a germicidal lamp is produced by a low pressure mercury vapor discharge (identical to that in a fluorescent lamp) in an uncoated fused quartz envelope.

Fluorescent lamp tubes are typically straight and range in length from about 100 millimeters (3.9 in) for miniature lamps, to 2.43 meters (8.0 ft) for high-output lamps. Some lamps have the tube bent into a circle, used for table lamps or other places where a more compact light source is desired. Larger U-shaped lamps are used to provide the same amount of light in a more compact area, and are used for special architectural purposes. Compact fluorescent lamps have several small-diameter tubes joined in a bundle of two, four, or six, or a small diameter tube coiled into a spiral, to provide a high amount of light output in little volume.

Light-emitting phosphors are applied as a paint-like coating to the inside of the tube. The organic solvents are allowed to evaporate, then the tube is heated to nearly the melting point of glass to drive off remaining organic compounds and fuse the coating to the lamp tube. Careful control of the grain size of the suspended phosphors is necessary; large grains, 35 micrometers or larger, lead to weak grainy coatings, whereas too many small particles 1 or 2 micrometers or smaller leads to poor light maintenance and efficiency. Most phosphors perform best with a particle size around 10 micrometers. The coating must be thick enough to capture all the ultraviolet light produced by the mercury arc, but not so thick that the phosphor coating absorbs too much visible light. The first phosphors were synthetic versions of naturally occurring fluorescent minerals, with small amounts of metals added as activators. Later other compounds were discovered, allowing differing colors of lamps to be made.

Electrical aspects of operation

Different ballasts for fluorescent and discharge lamps

Fluorescent lamps are negative differential resistance devices, so as more current flows through them, the electrical resistance of the fluorescent lamp drops, allowing even more current to flow. Connected directly to a constant-voltage power supply, a fluorescent lamp would rapidly self-destruct due to the uncontrolled current flow. To prevent this, fluorescent lamps must use an auxiliary device, a ballast, to regulate the current flow through the tube.

The terminal voltage across an operating lamp varies depending on the arc current, tube diameter, temperature, and fill gas. A fixed part of the voltage drop is due to the electrodes. A general lighting service T12 48 inch (1200 mm) lamp operates at 430 mA, with 100 volts drop. High output lamps operate at 800 mA, and some types operate up to 1500 mA. The power level varies from 10 watts per foot (33 watts per meter) to 25 watts per foot (82 watts per meter) of tube length for T12 lamps.

The simplest ballast for alternating current use is an inductor placed in series, consisting of a winding on a laminated magnetic core. The inductance of this winding limits the flow of AC current. This type is still used, for example, in 120 volt operated desk lamps using relatively short lamps. Ballasts are rated for the size of lamp and power frequency. Where the mains voltage is insufficient to start long fluorescent lamps, the ballast is often a step-up autotransformer with substantial leakage inductance (so as to limit the current flow). Either form of inductive ballast may also include a capacitor for power factor correction.

230 V ballast for 18–20 W

Many different circuits have been used to operate fluorescent lamps. The choice of circuit is based on mains voltage, tube length, initial cost, long term cost, instant versus non-instant starting, temperature ranges and parts availability, etc.

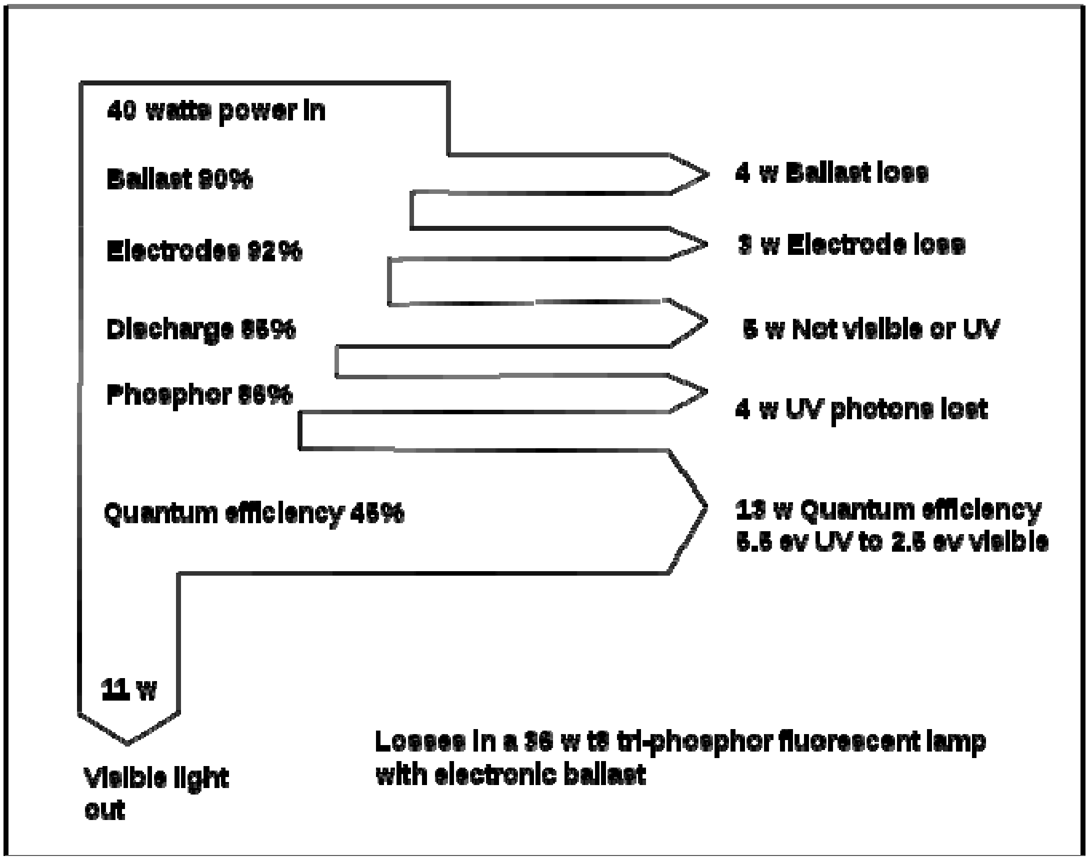
Fluorescent lamps can run directly from a DC supply of sufficient voltage to strike an arc. The ballast must be resistive, and would consume about as much power as the lamp. When operated from DC, the starting switch is often arranged to reverse the polarity of the supply to the lamp each time it is started; otherwise, the mercury accumulates at one end of the tube. Fluorescent lamps are (almost) never operated directly from DC for those reasons. Instead, an inverter converts the DC into AC and provides the current-limiting function as described below for electronic ballasts.

Effect of temperature

The light output and performance of fluorescent lamps is critically affected by the temperature of the bulb wall and its effect on the partial pressure of mercury vapor within the lamp. Each lamp contains a small amount of mercury, which must vaporize to support the lamp current and generate light. At low temperatures the mercury is in the form of dispersed liquid droplets. As the lamp warms, more of the mercury is in vapor form. At higher temperatures, self-absorption in the vapor reduces the yield of UV and visible light. Since mercury condenses at the coolest spot in the lamp, careful design is required to maintain that spot at the optimum temperature, around 40 °C.

By using an amalgam with some other metal, the vapor pressure is reduced and the optimum temperature range extended upward; however, the bulb wall "cold spot" temperature must still be controlled to prevent migration of the mercury out of the amalgam and condensing on the cold spot. Fluorescent lamps intended for higher output will have structural features such as a deformed tube or internal heat-sinks to control cold spot temperature and mercury distribution. Heavily loaded small lamps, such as compact fluorescent lamps, also include heat-sink areas in the tube to maintain mercury vapor pressure at the optimum value.

Losses



A Sankey diagram of energy losses in a fluorescent lamp. In modern designs, the biggest loss is the quantum efficiency of converting high-energy UV photons to lower-energy visible light photons.

The efficiency of fluorescent lighting owes much to the fact that low pressure mercury discharges emit about 65% of their total light in the 254 nm line (another 10–20% of the light is emitted in the 185 nm line). The UV light is absorbed by the bulb's fluorescent coating, which re-radiates the energy at longer wavelengths to emit visible light. The blend of phosphors controls the color of the light, and along with the bulb's glass prevents the harmful UV light from escaping.

Only a fraction of the electrical energy input into a lamp gets turned into useful light. The ballast dissipates some heat; electronic ballasts may be around 90% efficient. A fixed voltage drop occurs at the electrodes. Some of the energy in the mercury vapor column is also dissipated, but about 85% is turned into visible and ultraviolet light.

Not all the UV energy on the phosphor gets converted into visible light. In a modern lamp, for every 100 incident photons of UV impacting the phosphor, only 86 visible light photons are emitted (a quantum efficiency of 86%). The largest single loss in modern lamps is due to the lower energy of each photon of visible light, compared to the energy of the UV photons that generated them. Incident photons have an energy of 5.5 electron volts but produces visible light photons with energy around 2.5 electron volts, so only 45% of the UV energy is used. If a so-called "two-photon" phosphor could be developed, this would improve the efficiency but much research has not yet found such a system.

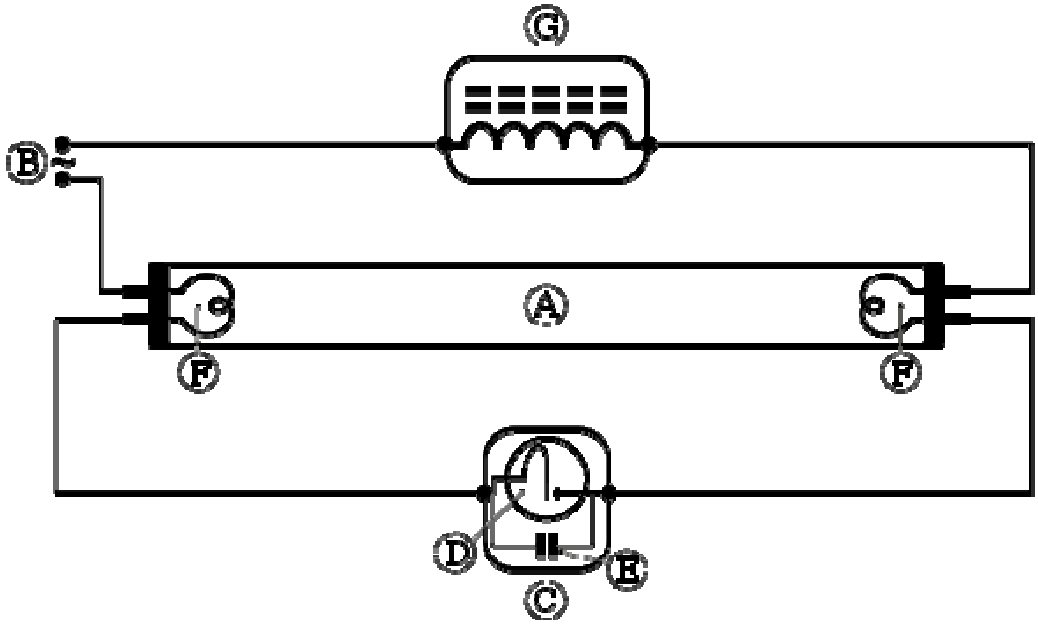
Cold cathode lamps

Most fluorescent lamps use electrodes that operate in thermionic emission mode, meaning they are operated at a high enough temperature for the chosen material (normally a special coating) to liberate electrons across to the gas-fill by heat.

However, there are also tubes that operate in cold cathode mode, whereby electrons are liberated only by the level of potential difference provided. This doesn't mean the electrodes are cold (and indeed, they can be very hot), but it does mean they are operating below their thermionic emission temperature. Because cold cathode lamps have no thermionic emission coating to wear out they can have much longer lives than is commonly available with thermionic emission tubes. This quality makes them desirable for maintenance-free long-life applications (such as LCD backlight displays). Sputtering of the electrode may still occur, but electrodes can be shaped (e.g. into an internal cylinder) to capture most of the sputtered material so it isn't lost from the electrode.

Cold cathode lamps are generally less efficient than thermionic emission lamps because the cathode fall voltage is much higher. The increased fall voltage results in more power dissipation at tube ends, which doesn't contribute to light output. However, this is less significant with longer tubes. The increased power dissipation at tube ends also usually means cold cathode tubes have to be run at a lower loading than their thermionic emission equivalents. Given the higher tube voltage required anyway, these tubes can easily be made long, and even run as series strings. They are better suited for bending into special shapes for lettering and signage, and can also be instantly switched on or off.

Starting



A *preheat* fluorescent lamp circuit using an automatic starting switch. A: Fluorescent tube, B: Power (+220 volts), C: Starter, D: Switch (bi-metallic thermostat), E: Capacitor, F: Filaments, G: Ballast

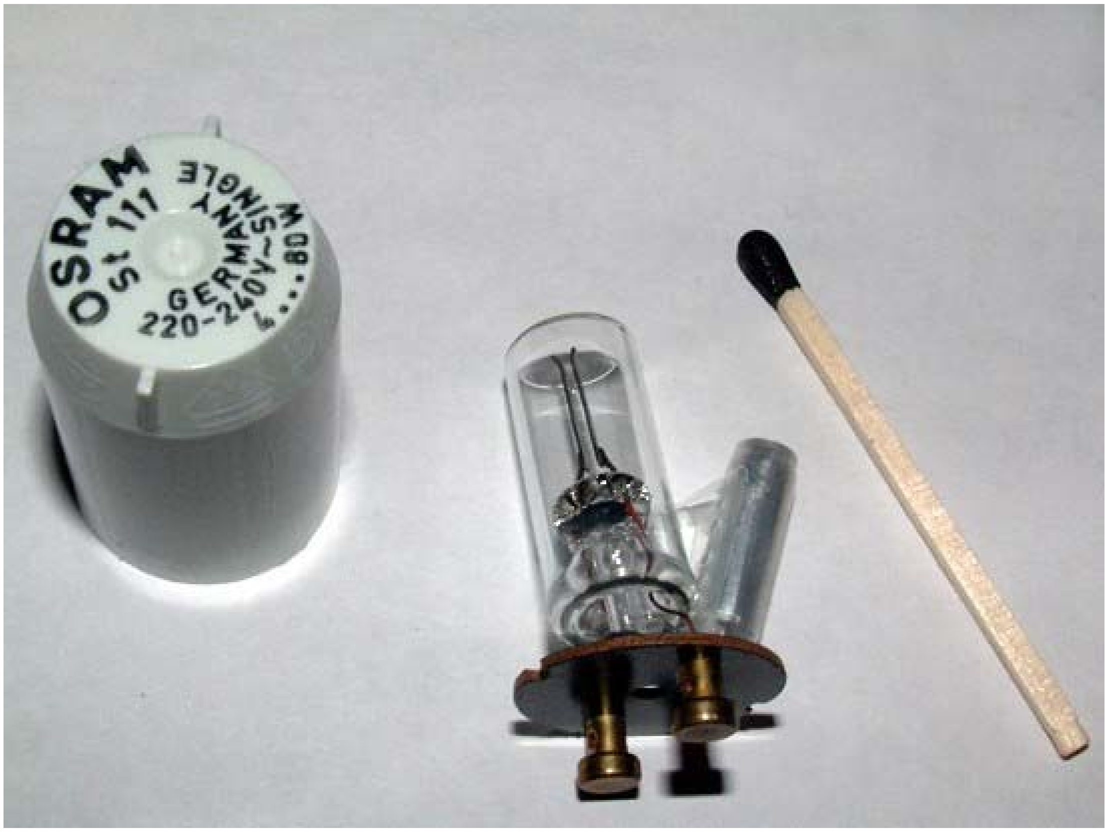
Starting a preheat lamp. The automatic starter switch flashes orange each time it attempts to start the lamp.

The mercury atoms in the fluorescent tube must be ionized before the arc can "strike" within the tube. For small lamps, it does not take much voltage to strike the arc and starting the lamp presents no problem, but larger tubes require a substantial voltage (in the range of a thousand volts).

Switchstart/preheat

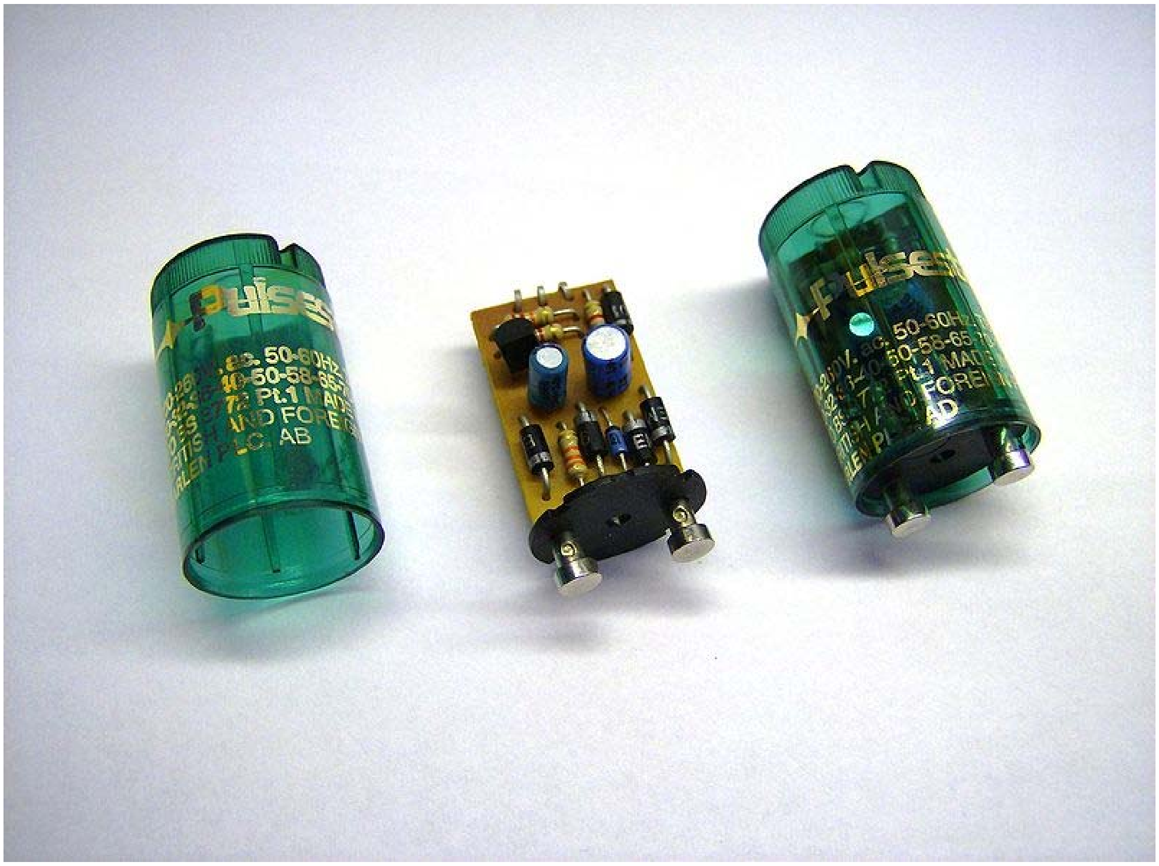
This technique uses a combination filament/cathode at each end of the lamp in conjunction with a mechanical or automatic switch that initially connect the filaments in series with the ballast and thereby preheat the filaments prior to striking the arc. Note that in North America, this is referred to as *Preheat*. Elsewhere this is referred to as *Switchstart*.

These systems are standard equipment in 200–240 V countries (and for 100–120 V lamps up to about 30 watts), and generally use a glow starter. Before the 1960s, four-pin thermal starters and manual switches were also used. Electronic starters are also sometimes used with these electromagnetic ballast lamp fittings.



A *preheat* fluorescent lamp "starter" (automatic starting switch)

The automatic glow starter shown in the photograph to the left consists of a small gas-discharge tube, containing neon and/or argon and fitted with a bi-metallic electrode. The special bi-metallic electrode is the key to the automatic starting mechanism.



Electronic fluorescent lamp starters

When power is first applied to the lamp circuit, a glow discharge will appear over the electrodes of the starter. This glow discharge will heat the gas in the starter and cause the bi-metallic electrode to bend towards the other electrode. When the electrodes touch, the two filaments of the fluorescent lamp and the ballast will effectively be switched in series to the supply voltage. This causes the filaments to glow and emit electrons into the gas column by thermionic emission. In the starter's tube, the touching electrodes have stopped the glow discharge, causing the gas to cool down again. The bi-metallic electrode also cools down and starts to move back. When the electrodes separate, the inductive kick from the ballast provides the high voltage to start the lamp. The starter additionally has a capacitor wired in parallel to its gas-discharge tube, in order to prolong the electrode life.

Once the tube is struck, the impinging main discharge then keeps the cathode hot, permitting continued emission without the need for the starter to close. The starter does not close again because the voltage across the lit tube is insufficient to start a glow discharge in the starter.

Tube strike is reliable in these systems, but glow starters will often cycle a few times before allowing the tube to stay lit, which causes undesirable flashing during starting. (The older thermal starters behaved better in this respect.)

If the tube fails to strike, or strikes but then extinguishes, the starting sequence is repeated. With automated starters such as glow starters, a failing tube will cycle endlessly, flashing as the lamp quickly goes out because emission is insufficient to keep the lamp current high enough to keep the glow starter open. This causes flickering, and runs the ballast at above design temperature. Some more advanced starters time out in this situation, and do not attempt repeated starts until power is reset. Some older systems used a thermal over-current trip to detect repeated starting attempts. These require manual reset.

Electronic starters use a more complex method to preheat the cathodes of a fluorescent lamp. They commonly use a specially designed semiconductor switch. They are programmed with a predefined preheat time to ensure that the cathodes are fully heated and reduce the amount of sputtered emission mix to prolong the life of the lamp. Electronic starters contain a series of capacitors that are capable of producing a high voltage pulse of electricity across the lamp to ensure that it strikes correctly. Electronic starters only attempt to start a lamp for a short time when power is initially applied and will not repeatedly attempt to restrike a lamp that is dead and cannot sustain an arc. This eliminates the re-striking of a lamp and the cycle of flashing that a failing lamp installed with a glow starter can produce. Electronic starters have also been developed that are capable of striking the fluorescent tube within 0.3 seconds, which gives a virtually instant start.

Instant start

In some cases, a high voltage is applied directly: *instant start* fluorescent tubes simply use a high enough voltage to break down the gas and mercury column and thereby start arc conduction. These tubes can be identified by a single pin at each end of the tube. The lamp holders have a "disconnect" socket at the low-voltage end to isolate the ballast and prevent electric shock. Low-cost lighting fixtures with an integrated electronic ballast use instant start on preheat lamps, even if it reduces the lamp lifespan.

Rapid start

Newer *rapid start* ballast designs provide filament power windings within the ballast; these rapidly and continuously warm the filaments/cathodes using low-voltage AC. No inductive voltage spike is produced for starting, so the lamps must be mounted near a grounded (earthed) reflector to allow the glow discharge to propagate through the tube and initiate the arc discharge. In some lamps a "starting aid" strip of grounded metal is attached to the outside of the lamp glass.

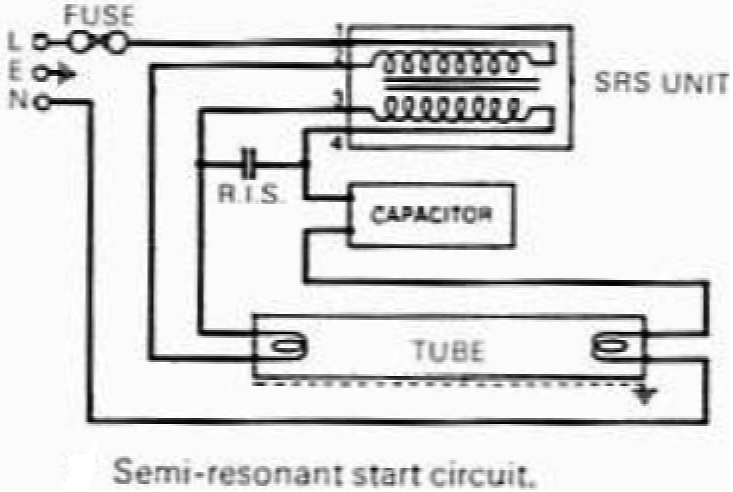
A rapid-start "iron" (magnetic) ballast continually heats the cathodes at the ends of the lamps. This ballast runs two F40T12 lamps in series.

Quick-start

Quick-start ballasts use a small auto-transformer to heat the filaments when power is first applied. When an arc strikes, the filament heating power is reduced and the tube will start within half a second. The auto-transformer is either combined with the ballast or may be a separate unit. Tubes need to be mounted near an earthed metal reflector in order for them to strike. Quick-start ballasts were more common in commercial installations because of lower maintenance as no starter switches need to be replaced. They are also used in domestic installations due to the virtually instant start. Quick-start ballasts are only used on 240 V circuits and are designed for use with the older, less-efficient T12 tubes, T8 retrofits will not start when used with quick-start ballasts.

Semi-resonant start

A 65 W semi-resonant lamp starting



A circuit diagram of a semi-resonant start fluorescent lamp

Semi-resonant start was invented by Thorn Lighting for use with T12 fluorescent tubes. This method uses a double wound transformer and a capacitor. With no arc current, the transformer and capacitor ring at mains frequency and generate about twice mains voltage across the tube, and a small electrode heating current. This tube voltage is too low to strike the arc with cold electrodes, but as the electrodes heat up to thermionic emission temperature, the tube striking voltage reduces below that of the ringing voltage, and the arc strikes. As the electrodes heat, the lamp slowly, over 3-5 seconds, reaches full brightness. As the arc current increases and tube voltage drops, the circuit provides current limiting.

Semi-resonant start was mainly used in commercial installations because of their higher initial cost. There are no starter switches to be replaced and cathode damage is reduced during starting. Due to the high open circuit tube voltage, this starting method was particularly good for starting tubes in cold locations. Additionally, the circuit power factor is almost 1.0, and no additional power factor correction is needed in the lighting installation. As the design requires that twice the mains voltage must be lower than the cold-cathode striking voltage (or the tubes would erroneously instant-start), this design can only be used with 5 ft and longer tubes on 240 V mains. Semi-resonant start fixtures are generally incompatible with energy saving T8 retrofit tubes, because such tubes have a higher starting voltage than T12 lamps and may not start reliably,especially in low temperatures. Recent proposals in some countries to phase out T12 tubes will reduce the application of this starting method.

Electronic ballasts

Electronic ballast for fluorescent lamp, 2x58W

Electronic ballasts and different compact fluorescent lamps

Starting a lamp that has an electronic ballast.

Electronic ballasts employ transistors to alter mains voltage frequency into high-frequency AC while also regulating the current flow in the lamp. These ballasts take advantage of the higher efficacy of lamps operated with higher-frequency current. Efficacy of a fluorescent lamp rises by almost 10% at a frequency of 10 kHz, compared to efficacy at normal power frequency. When the AC period is shorter than the relaxation time to de-ionize mercury atoms in the discharge column, the discharge stays closer to optimum operating condition. Electronic ballasts typically work in rapid start or instant start mode. Electronic ballasts are commonly supplied with AC power, which is internally converted to DC and then back to a variable frequency AC waveform. Depending upon the capacitance and the quality of constant-current pulse-width-modulation, this can largely eliminate modulation at 100 or 120 Hz.

Low cost ballasts mostly contain only a simple oscillator and series resonant LC circuit. When turned on, the oscillator starts, and the LC circuit charges. After a short time the voltage across the lamp reaches about 1 kV and the lamp ignites. The process is too fast to preheat the cathodes, so the lamp instant-starts in cold cathode mode. The cathode filaments are still used for protection of the ballast from overheating if the lamp does not ignite. A few manufacturers use positive temperature coefficient (PTC) thermistors to disable instant starting and give some time to preheat the filaments.

More complex electronic ballasts use programmed start. The output AC frequency is started above the resonance frequency of the output circuit of the ballast; and after the filaments are heated, the frequency is rapidly decreased. If the frequency approaches the resonant frequency of the ballast, the output voltage will increase so much that the lamp will ignite. If the lamp does not ignite, an electronic circuit stops the operation of the ballast.

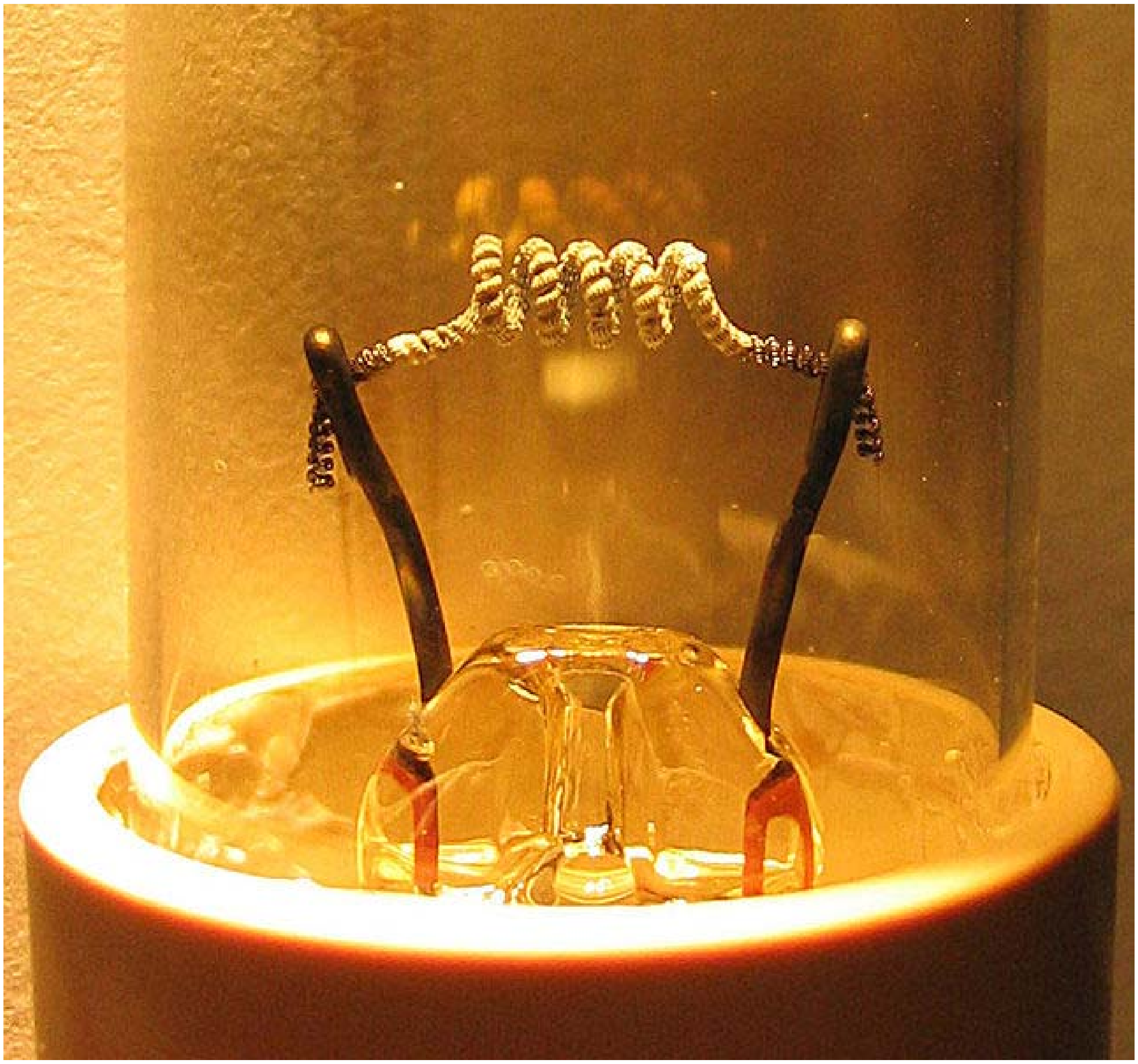
Many electronic ballasts are controlled by a PIC microcontroller or similar, and these are sometimes called digital ballasts. Digital ballasts can apply quite complex logic to lamp starting and operation. This enables functions such as testing for broken electrodes and missing tubes before attempting to start, auto detect tube replacement, and auto detection of tube type, such that a single ballast can be used with several different tubes, even those that operate at different arc currents, etc. Once such fine grained control over the starting and arc current is achievable, features such as dimming, and having the ballast maintain a constant light level against changing sunlight contribution are all easily included in the embedded microcontroller software, and can be found in various manufacturers' products.

Since introduction in the 1990s, high frequency ballasts have been used in general lighting fixtures with either rapid start or pre-heat lamps. These ballasts convert the incoming power to an output frequency in excess of 20 kHz. This increases lamp efficiency. These are used in several applications, including new generation tanning lamp systems, whereby a 100 watt lamp (e.g., F71T12BP) can be lit using 65 to 70 watts of actual power while obtaining the same luminous flux (measured in lumens) as magnetic ballasts. These ballasts operate with voltages that can be almost 600 volts, requiring some consideration in housing design, and can cause a minor limitation in the length of the wire leads from the ballast to the lamp ends.

End of life

The end of life failure mode for fluorescent lamps varies depending how they are used and their control gear type. Normal tube failure modes are as follows:

Emission mix



Closeup of the filament on a low pressure mercury gas discharge lamp showing white thermionic emission mix coating on the central portion of the coil acting as hot cathode. Typically made of a mixture of barium, strontium and calcium oxides, the coating is sputtered away through normal use, often eventually resulting in lamp failure.

The "emission mix" on the tube filaments/cathodes is necessary to enable electrons to pass into the gas via thermionic emission at the tube operating voltages used. The mix is slowly sputtered off by bombardment with electrons and mercury ions during operation, but a larger amount is sputtered off each time the tube is started with cold cathodes. The method of starting the lamp has a significant impact on this. Lamps operated for typically less than 3 hours each switch-on will normally run out of the emission mix before other parts of the lamp fail. The sputtered emission mix forms the dark marks at the tube ends seen in old tubes. When all the emission mix is gone, the cathode cannot pass sufficient electrons into the gas fill to maintain the discharge at the designed tube operating voltage. Ideally, the control gear should shut down the tube when this happens. However, some control gear will provide sufficient increased voltage to continue operating the tube in cold cathode mode, which will cause overheating of the tube end and rapid disintegration of the electrodes (filament goes open-circuit) and filament support wires until they are completely gone or the glass cracks, wrecking the low pressure gas fill and stopping the gas discharge.

Ballast electronics

This may occur in compact fluorescent lamps with integral electrical ballasts or in linear lamps. Ballast electronics failure is a somewhat random process that follows the standard failure profile for any electronic device. There is an initial small peak of early failures, followed by a drop and steady increase over lamp life. Life of electronics is heavily dependent on operating temperature—it typically halves for each 10 °C temperature rise. The quoted average life of a lamp is usually at 25 °C ambient (this may vary by country). The average life of the electronics at this temperature is normally greater than this, so at this temperature, not many lamps will fail due to failure of the electronics. In some fittings, the ambient temperature could be well above this, in which case failure of the electronics may become the predominant failure mechanism. Similarly, running a compact fluorescent lamp base-up will result in hotter electronics, which can cause shorter average life (particularly with higher power rated ones). Electronic ballasts should be designed to shut down the tube when the emission mix runs out as described above. In the case of integral electronic ballasts, since they never have to work again, this is sometimes done by having them deliberately burn out some component to permanently cease operation.

In most CFLs the filaments are connected in series, with a small capacitor between them. The discharge, once lit, is in parallel to the capacitor and presents a lower-resistance path, effectively shorting the capacitor out. One of the most common failure modes of cheap lamps is caused by underrating this capacitor (using lower-voltage, lower-cost part), which is very stressed during operation, leading to its premature failure.

Phosphor

The phosphor drops off in efficiency during use. By around 25,000 operating hours, it will typically be half the brightness of a new lamp (although some manufacturers claim much longer half-lives for their lamps). Lamps that do not suffer failures of the emission mix or integral ballast electronics will eventually develop this failure mode. They still work, but have become dim and inefficient. The process is slow, and often only becomes obvious when a new lamp is operating next to an old one.

Loss of mercury

Like in all mercury-based gas-filled tubes, mercury is slowly absorbed into glass, phosphor, and tube electrodes throughout the lamp life, where it can no longer function. Newer lamps now have just enough mercury to last the expected life of the lamp. Loss of mercury will take over from failure of the phosphor in some lamps. The failure symptoms are similar, except loss of mercury initially causes an extended run-up time to full light output, and finally causes the lamp to glow a dim pink when the mercury runs out and the argon base gas takes over as the primary discharge.

Subjecting the tube to asymmetric waveforms, where the total current flow through the tube does not cancel out and the tube effectively operates under a DC bias, causes asymmetric distribution of mercury ions along the tube due to cataphoresis. The localized depletion of mercury vapor pressure manifests as pink luminescence of the base gas in the vicinity of one of the electrodes, and the operating lifetime of the lamp may be dramatically shortened. This can be an issue with some poorly designed inverters.

The same effect can be observed with new tubes. Mercury is present in the form of an amalgam and takes some time to be liberated in sufficient amount. New lamps may initially glow pink for several seconds after startup. This period is minimized after about first 100 hours of operation.

Burned filaments

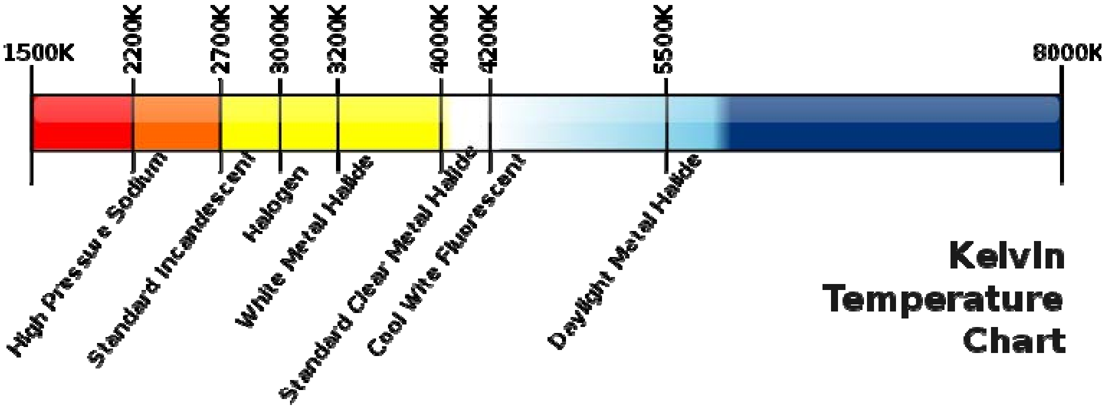
The filaments can burn at the end of the lamp's lifetime, opening the circuit and losing the capability to heat up. Both filaments lose function as they are connected in series, with just a simple switch start circuit a broken filament will render the lamp completely useless. Filaments rarely burn or fail open circuit unless the filament becomes depleted of emitter and the control gear is able to supply a high enough voltage across the tube to operate it in cold cathode mode. Some digital electronic ballasts are capable of detecting broken filaments and can still strike an arc with one or both filaments broken providing there is still sufficient emitter.

Phosphors and the spectrum of emitted light

Light from a fluorescent tube lamp diffracted by a CD shows the individual bands of color.

The spectrum of light emitted from a fluorescent lamp is the combination of light directly emitted by the mercury vapor, and light emitted by the phosphorescent coating. The spectral lines from the mercury emission and the phosphorescence effect give a combined spectral distribution of light that is different from those produced by incandescent sources. The relative intensity of light emitted in each narrow band of wavelengths over the visible spectrum is in different proportions compared to that of an incandescent source. Colored objects are perceived differently under light sources with differing spectral distributions. For example, some people find the color rendition produced by some fluorescent lamps to be harsh and displeasing. A healthy person can sometimes appear to have an unhealthy skin tone under fluorescent lighting. The extent to which this phenomenon occurs is related to the light's spectral composition, and may be gauged by its color rendering index (CRI).

Color temperature



The color temperature of different electric lamps

Correlated color temperature (CCT) is a measure of the "shade" of whiteness of a light source, again by comparison with a blackbody. Typical incandescent lighting is 2700 K, which is yellowish-white. Halogen lighting is 3000 K. Fluorescent lamps are manufactured to a chosen CCT by altering the mixture of phosphors inside the tube. Warm-white fluorescents have CCT of 2700 K and are popular for residential lighting. Neutral-white fluorescents have a CCT of 3000 K or 3500 K. Cool-white fluorescents have a CCT of 4100 K and are popular for office lighting. Daylight fluorescents have a CCT of 5000 K to 6500 K, which is bluish-white.

High CCT lighting generally requires higher light levels. At dimmer illumination levels, the human eye perceives lower color temperatures as more natural, as related through the Kruithof curve. So, a dim 2700 K incandescent lamp appears natural and a bright 5000 K lamp also appears natural, but a dim 5000 K fluorescent lamp appears too pale. Daylight-type fluorescents look natural only if they are very bright.

Color rendering index

Color rendering index (CRI) is a measure of how well colors can be perceived using light from a source, relative to light from a reference source such as daylight or a blackbody of the same color temperature. By definition, an incandescent lamp has a CRI of 100. Real-life fluorescent tubes achieve CRIs of anywhere from 50 to 99. Fluorescent lamps with low CRI have phosphors that emit too little red light. Skin appears less pink, and hence "unhealthy" compared with incandescent lighting. Colored objects appear muted. For example, a low CRI 6800 K halophosphate tube (an extreme example) will make reds appear dull red or even brown. Since the eye is relatively less efficient at detecting red light, an improvement in color rendering index, with increased energy in the red part of the spectrum, may reduce the overall luminous efficacy.

Lighting arrangements use fluorescent tubes in an assortment of tints of white. Sometimes this is because of the lack of appreciation for the difference or importance of differing tube types. Mixing tube types within fittings can improve the color reproduction of lower quality tubes.

Applications

Fluorescent light bulbs come in many shapes and sizes. The compact fluorescent light bulb (CFL) is becoming more popular. Many compact fluorescent lamps integrate the auxiliary electronics into the base of the lamp, allowing them to fit into a regular light bulb socket.

In US residences, fluorescent lamps are mostly found in kitchens, basements, or garages, but schools and businesses find the cost savings of fluorescent lamps to be significant and rarely use incandescent lights. Tax incentives and environmental awareness result in higher use in places such as California.

In other countries, residential use of fluorescent lighting varies depending on the price of energy, financial and environmental concerns of the local population, and acceptability of the light output. In East and Southeast Asia it is very rare to see incandescent bulbs in buildings anywhere.

Some countries are encouraging the phase-out of incandescent light bulbs and substitution of incandescent lamps with fluorescent lamps or other types of energy-efficient lamps.

The newest fluorescent lamps can be used to grow indoor plants to maturity. These lamps are marketed as High-Output T5 Fluorescents. The T8 and T12 predecessors can be used to rear seedlings, but are not powerful enough for mature plant growth.

In addition to general lighting, special fluorescent lights are often used in stage lighting for film and video production. They are cooler than traditional halogen light sources, and use high-frequency ballasts to prevent video flickering and high color-rendition index bulbs to approximate daylight color temperatures.

Advantages

Luminous efficacy

Fluorescent lamps convert more of the input power to visible light than incandescent lamps. A typical 100 watt tungsten filament incandescent lamp may convert only 2% of its power input to visible white light, whereas typical fluorescent lamps convert about 22% of the power input to visible white light.

The efficacy of fluorescent tubes ranges from about 16 lumens per watt for a 4 watt tube with an ordinary ballast to over 100 lumens per watt with modern electronic ballast, commonly averaging 50 to 67 lm/W overall. Most compact fluorescents above 13 watts with integral electronic ballasts achieve about 60 lm/W. Lamps are rated by lumens after 100 hours of operation. For a given fluorescent tube, a high-frequency electronic ballast gives about 10% efficacy improvement over an inductive ballast. It is necessary to include the ballast loss when evaluating the efficacy of a fluorescent lamp system; this can be about 25% of the lamp power with magnetic ballasts, and around 10% with electronic ballasts.

Fluorescent lamp efficacy is dependent on lamp temperature at the coldest part of the lamp. In T8 lamps this is in the center of the tube. In T5 lamps this is at the end of the tube with the text stamped on it. The ideal temperature for a T8 lamp is 25 °C (77 °F) while the T5 lamp is ideally at 35 °C (95 °F).

Life

Typically a fluorescent lamp will last between 10 to 20 times as long as an equivalent incandescent lamp when operated several hours at a time.

The higher initial cost of a fluorescent lamp is usually more than compensated for by lower energy consumption over its life. The longer life may also reduce lamp replacement costs, providing additional saving especially where labour is costly. Therefore they are widely used by businesses and institutions, but not as much by households.

Lower luminosity

Compared with an incandescent lamp, a fluorescent tube is a more diffuse and physically larger light source. In suitably designed lamps, light can be more evenly distributed without point source of glare such as seen from an undiffused incandescent filament; the lamp is large compared to the typical distance between lamp and illuminated surfaces.

Lower heat

About two-thirds to three-quarters less heat is given off by fluorescent lamps compared to an equivalent installation of incandescent lamps. This greatly reduces the size, cost, and energy consumption.

Chapter- 5

Compact Fluorescent Lamp

The tubular-type compact fluorescent lamp is one of the most popular types in Europe.

A spiral-type integrated CFL. This style has slightly reduced efficiency compared to tubular fluorescent lamps, due to the thicker layer of phosphor on the lower side of the twist. It has been the most popular type in North America since the mid 1990s, when the final expiration of patents allowed its manufacture.

A **compact fluorescent lamp** (**CFL**), also known as a **compact fluorescent light** or **energy saving light** (or less commonly as a **compact fluorescent tube**), is a type of fluorescent lamp. Many CFLs are designed to replace an incandescent lamp and can fit into most existing light fixtures formerly used for incandescents.

Compared to general service incandescent lamps giving the same amount of visible light, CFLs use less power and have a longer rated life. In the United States, a CFL has a higher purchase price than an incandescent lamp, but can save over US$40 in electricity costs over the lamp's lifetime. Like all fluorescent lamps, CFLs contain mercury, which complicates their disposal.

CFLs radiate a different light spectrum from that of incandescent lamps. Improved phosphor formulations have improved the perceived color of the light emitted by CFLs such that some sources rate the best 'soft white' CFLs as subjectively similar in color to standard incandescent lamps.

History

An early compact fluorescent lamp

The parent to the modern fluorescent lamp was invented in the late 1890s by Peter Cooper Hewitt. The Cooper Hewitt lamps were used for photographic studios and industries.

Edmund Germer, Friedrich Meyer, and Hans Spanner then patented a high pressure vapor lamp in 1927. George Inman later teamed with General Electric to create a practical fluorescent lamp, sold in 1938 and patented in 1941. Circular and U-shaped lamps were devised to reduce the length of fluorescent light fixtures. The first fluorescent bulb and fixture were displayed to the general public at the 1939 New York World's Fair.

The spiral tube CFL was invented in 1976 by Edward E. Hammer, an engineer with General Electric, in response to the 1973 oil crisis. The design met its goals, and it would have cost GE only about US$25 million to build new factories to produce them, but the invention was shelved. The design was eventually copied by others. It was not until 1995 that spiral lamps manufactured in China were commercially available; spiral lamps have steadily increased in sales volume.

In 1980, Philips introduced its model SL, which was a screw-in lamp with integral ballast. The lamp used a folded T4 tube, stable tri-color phosphors, and a mercury amalgam. This was the first successful screw-in replacement for an incandescent lamp. In 1985 Osram started selling their model EL lamp which was the first CFL to include an electronic ballast.

Development of fluorescent lamps that could fit in the same volume as comparable incandescent lamps required the development of new, high-efficacy phosphors that could withstand more power per unit area than the phosphors used in older, larger fluorescent tubes.

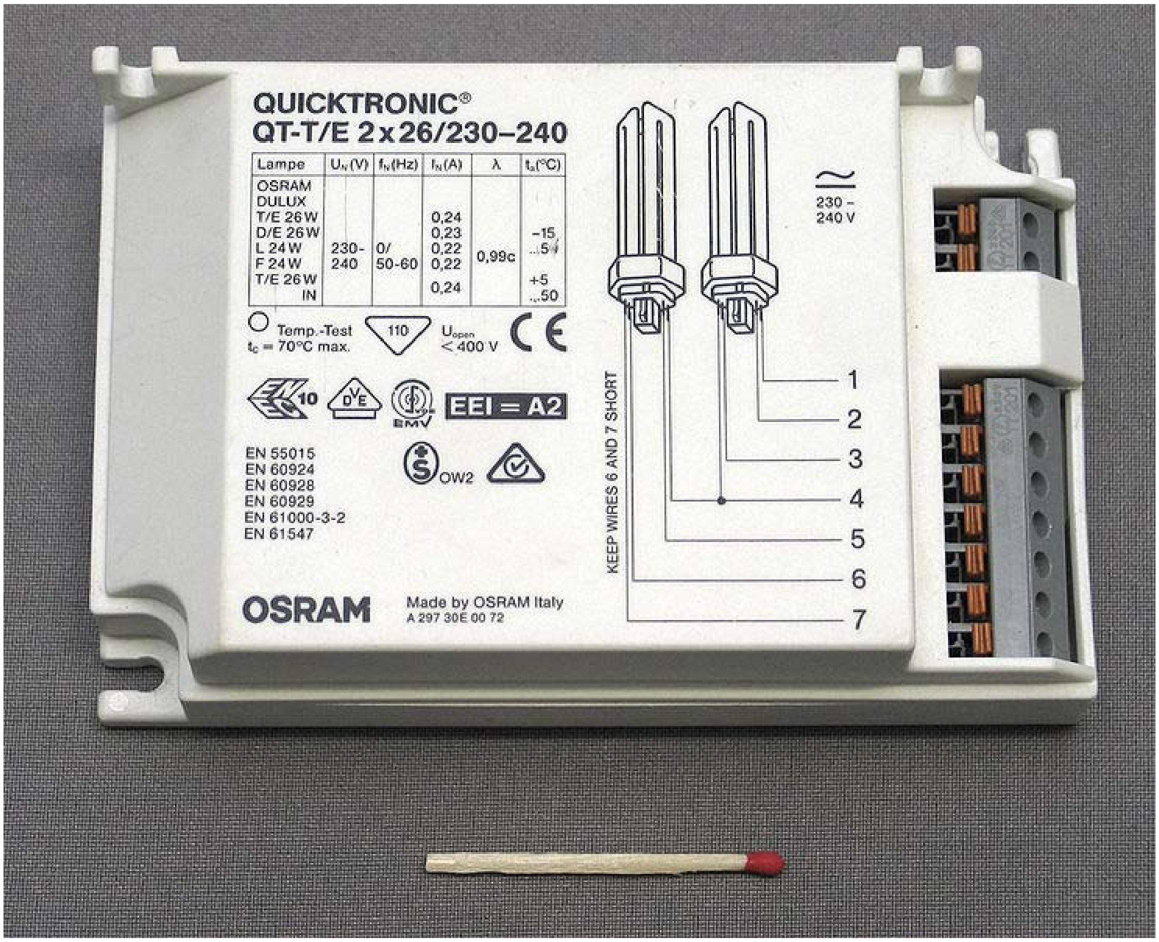
Construction

A compact fluorescent lamp used outside of a building.

The most important technical advance has been the replacement of electromagnetic ballasts with electronic ballasts; this has removed most of the flickering and slow starting traditionally associated with fluorescent lighting.

There are two types of CFLs: integrated and non-integrated lamps. Integrated lamps combine a tube, an electronic ballast and either an Edison screw or a bayonet fitting in a single unit. These lamps allow consumers to replace incandescent lamps easily with CFLs. Integrated CFLs work well in many standard incandescent light fixtures, reducing the cost of converting to fluorescent. Special 3-way models and dimmable models with standard bases are available.

Non-integrated bi-pin double-turn compact fluorescent lamp

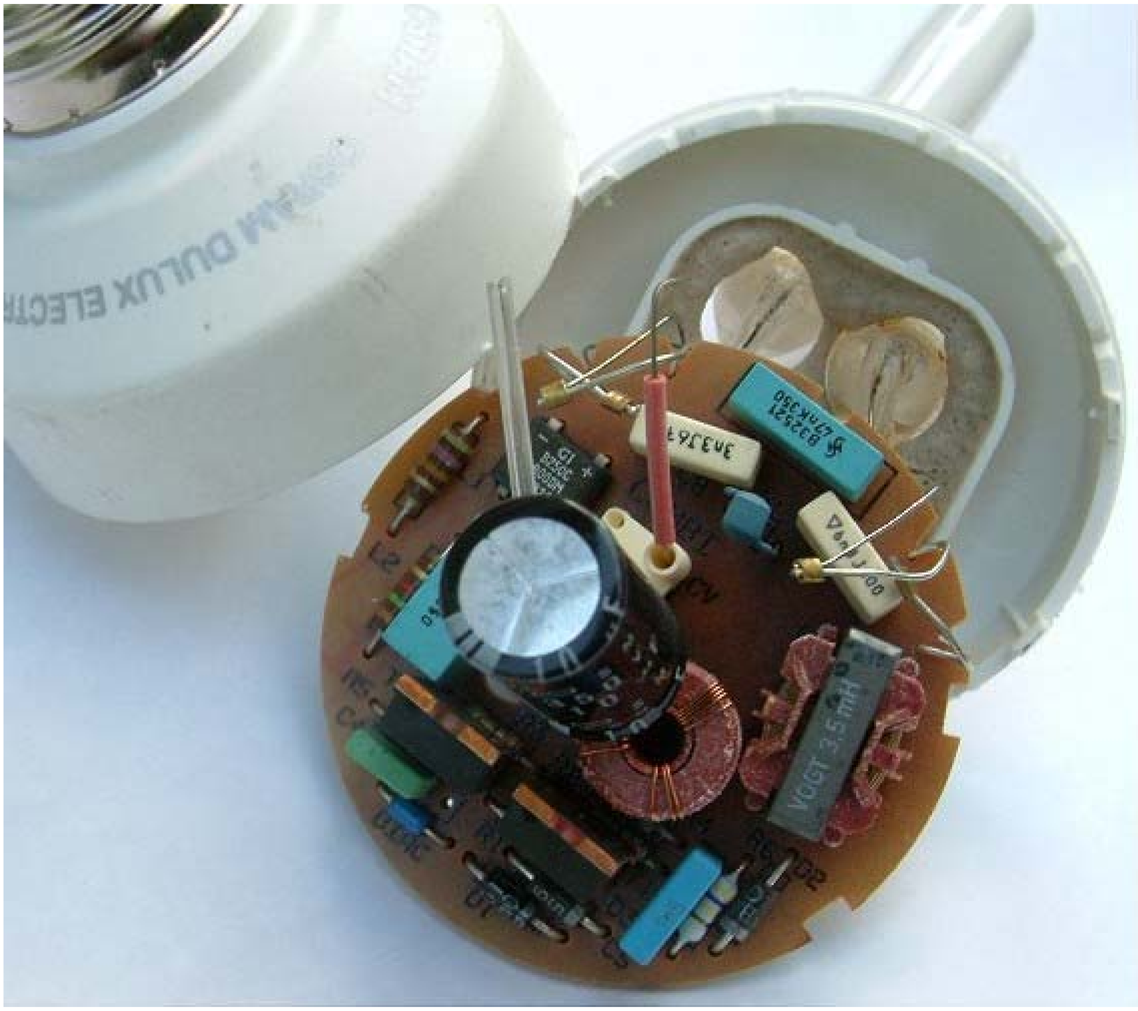


Non-integrated electronic ballast for compact fluorescent lamps

Non-integrated CFLs have the ballast permanently installed in the luminaire, and only the lamp bulb is usually changed at its end of life. Since the ballasts are placed in the light fixture they are larger and last longer compared to the integrated ones, and they don't need to be replaced when the bulb reaches its end-of-life. Non-integrated CFL housings can be both more expensive and sophisticated. They have two types of tubes: a bi-pin tube designed for a conventional ballast, and a quad-pin tube designed for an electronic ballast or a conventional ballast with an external starter. A bi-pin tube contains an integrated starter which obviates the need for external heating pins but causes incompatibility with electronic ballasts.

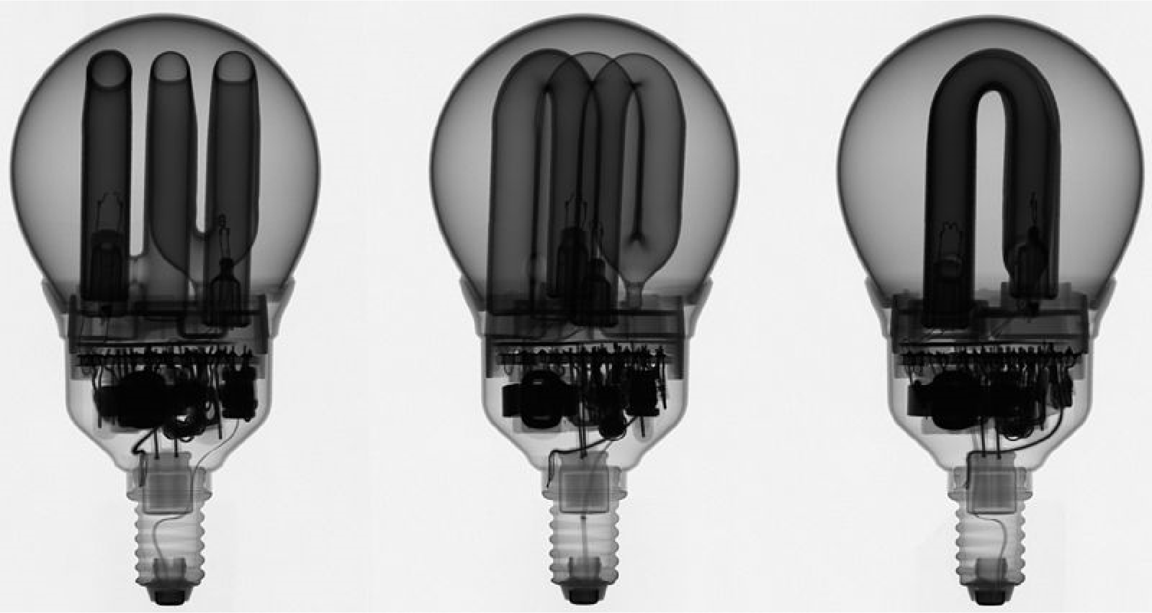
Components

CFLs have two main components: a gas-filled tube (also called bulb or burner) and a magnetic or electronic ballast.



An electronic ballast and permanently attached tube in an integrated CFL

Standard shapes of CFL tube are single-turn double helix, double-turn, triple-turn, quad-turn, circular, and butterfly.



Stitched X-ray image from three different angles (0°, 45°, 90°) of a defective IKEA compact fluorescent lamp. The burned through filament is visible in the left image.

Electronic ballasts contain a small circuit board with rectifiers, a filter capacitor and usually two switching transistors connected as a high-frequency resonant series DC to AC inverter. The resulting high frequency, around 40 kHz or higher, is applied to the lamp tube. Since the resonant converter tends to stabilize lamp current (and light produced) over a range of input voltages, standard CFLs do not respond well in dimming applications and special lamps are required for dimming service. CFLs that flicker when they start have magnetic ballasts; CFLs with electronic ballasts are now much more common.

CFL power sources

CFLs are produced for both alternating current (AC) and direct current (DC) input. DC CFLs are popular for use in recreational vehicles and off-the-grid housing. There are various aid agency led initiatives in developing countries to replace kerosene lanterns (with their associated health hazards) with DC CFLs (with car batteries and small solar panels or wind generators).

CFLs can also be operated with solar powered street lights, using solar panels located on the top or sides of a pole and light fixtures that are specially wired to use the lamps.

Comparison with incandescent lamps

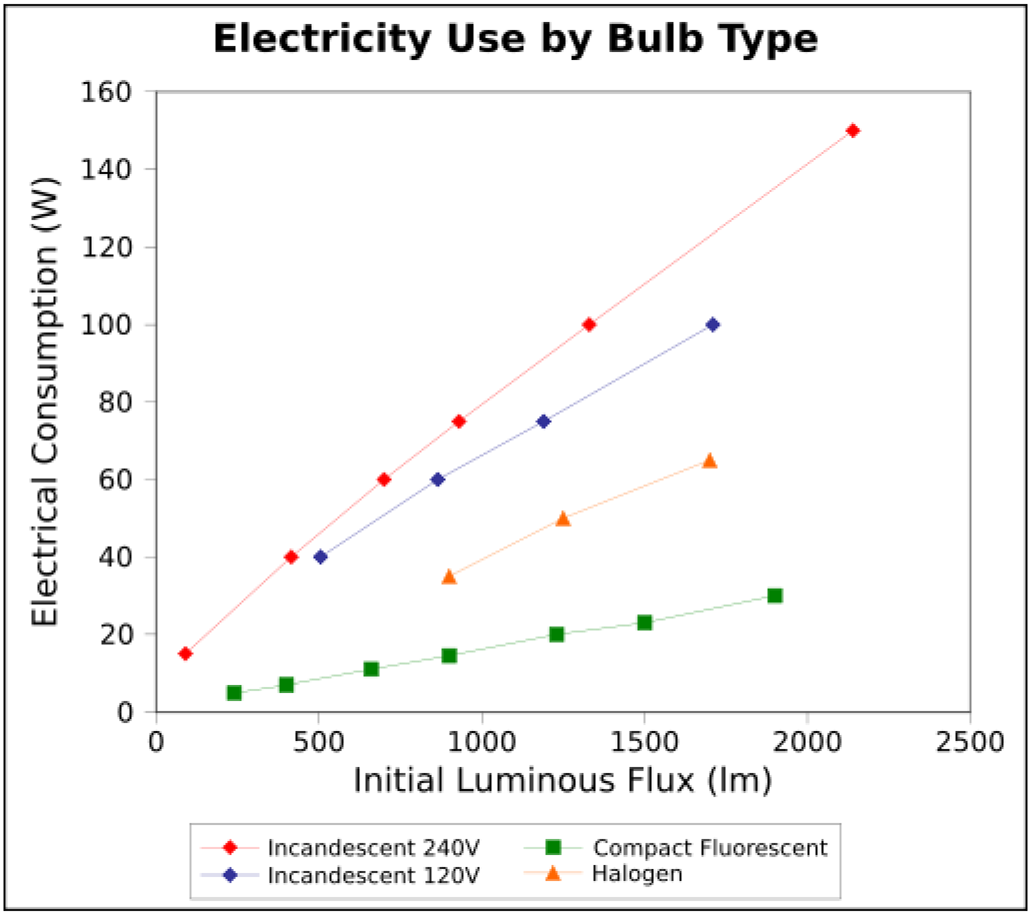
Lifespan

The average rated life of a CFL is between 8 and 15 times that of incandescents. CFLs typically have a rated lifespan of between 6,000 and 15,000 hours, whereas incandescent lamps are usually manufactured to have a lifespan of 750 hours or 1,000 hours.

The lifetime of any lamp depends on many factors including operating voltage, manufacturing defects, exposure to voltage spikes, mechanical shock, frequency of cycling on and off, lamp orientation, and ambient operating temperature, among other factors. The life of a CFL is significantly shorter if it is turned on and off frequently. In the case of a 5-minute on/off cycle the lifespan of a CFL can be reduced to "close to that of incandescent light bulbs". The US Energy Star program suggests that fluorescent lamps be left on when leaving a room for less than 15 minutes to mitigate this problem.

CFLs produce less light later in their lives than when they are new. The light output decay is exponential, with the fastest losses being soon after the lamp is first used. By the end of their lives, CFLs can be expected to produce 70–80% of their original light output. The response of the human eye to light is logarithmic (a photographic 'f-stop' reduction represents a halving in actual light, but is subjectively quite a small change). A 20–30% reduction over many thousands of hours represents a change of about half an f-stop. So, presuming the illumination provided by the lamp was ample at the beginning of its life, such a difference will be compensated for by the eyes, for most purposes.

Energy efficiency



The chart shows the energy usage for different types of light bulbs operating at different light outputs. Points lower on the graph correspond to lower energy use.

For a given light output, CFLs use 20 to 33 percent of the power of equivalent incandescent lamps. Since lighting accounted for approximately 9% of household electricity usage in the United States in 2001, widespread use of CFLs could save as much as 7% of total US household usage.

Electrical power equivalents for differing lamps

Electrical power consumption Watts (W)		**Minimum light output lumens (lm)**
Compact fluorescent	Incandescent	
8–9	40	450
9–15	60	800
15–20	75	1,100
20–25	100	1,600
25–45	150	2,600

Heating and cooling

If a building's indoor incandescent lamps are replaced by CFLs, the heat produced due to lighting is significantly reduced. In warm climates or in office or industrial buildings where air conditioning is often required, CFLs would reduce the load on the cooling system when compared to the use of incandescent lamps, resulting in savings in electricity, in addition to the energy efficiency savings of using CFLs instead of incandescent lamps. However, in cooler climates in which buildings require heating, the heating system will need to replace the inadvertently generated heat. While the CFLs are still saving electricity, total greenhouse gas emissions may increase in certain scenarios, such as the operation of a natural gas furnace to replace the unintended heating from CFLs running on low-GHG electricity. In Winnipeg, Canada, it is estimated that CFLs will only generate 17% savings in energy when switching from incandescent bulbs, as opposed to the 75% savings that can be expected if there were no heating or cooling considerations.

Efficacy and efficiency

Because the eye's sensitivity changes with the wavelength, the output of lamps is commonly measured in lumens, a measure of the power of light perceived by the human eye. The luminous efficacy of lamps refers to the number of lumens produced for each watt of electrical power used. A theoretically 100% efficient electric light source producing light only at the wavelength the human eye is most sensitive to would produce 680 lumens per watt.

The typical luminous efficacy of CFL lamps is 60 to 72 lumens per watt, and that of normal domestic incandescent lamps is 13 to 18 lm/W. Compared to the theoretical 100% efficient lamp, these figures are equivalent to lighting efficiency ranges of 9 to 11% for CFLs (60/680 and 72/680) and 1.9 to 2.6% for incandescents (13/680 and 18/680).

Embodied energy

While CFLs require more energy in manufacturing than incandescent lamps, this embodied energy is offset by their longer life and lower energy use than equivalent incandescent lamps.

Cost

While the purchase price of an integrated CFL is typically 3 to 10 times greater than that of an equivalent incandescent lamp, the extended lifetime and lower energy use will more than compensate for the higher initial cost. A US article stated "A household that invested $90 in changing 30 fixtures to CFLs would save $440 to $1,500 over the five-year life of the bulbs, depending on your cost of electricity. Look at your utility bill and imagine a 12% discount to estimate the savings."

CFLs are extremely cost-effective in commercial buildings when used to replace incandescent lamps. Using average U.S. commercial electricity and gas rates for 2006, a 2008 article found that replacing each 75 W incandescent lamp with a CFL resulted in yearly savings of $22 in energy usage, reduced HVAC cost, and reduced labor to change lamps. The incremental capital investment of $2 per fixture is typically paid back in about one month. Savings are greater and payback periods shorter in regions with higher electric rates and, to a lesser extent, also in regions with higher than U.S. average cooling requirements.

The current price of CFLs reflects the manufacturing of nearly all CFLs in China, where labor costs less. In September 2010, the Winchester, Virginia General Electric plant closed, leaving Osram Sylvania the last company to make standard incandescent bulbs in the United States. At that time, Ellis Yan, whose Chinese company made the majority of CFLs sold in the United States, was interested in building a United States factory to make CFL bulbs, but he needed $12.5 million to do so, and the U.S. government had not helped with this. Yan said stores wanted American-made bulbs, which would be 45 to 50 cents more each, but Yan said consumers were willing to pay this much.

General Electric had considered changing one of its bulb plants to make CFLs, but even after a $40 million investment, wage differences would mean the bulbs would cost one and a half times those made in China.

Comparison with alternative technologies

Solid-state lighting has already filled a few specialist niches such as traffic lights and may compete with CFLs for house lighting as well. LEDs providing over 200 lm/W have been demonstrated in laboratory tests and expected lifetimes of around 50,000 hours are typical. The luminous efficacy of available LED lamps does not typically exceed that of CFLs. DOE testing of commercial LED lamps designed to replace incandescent or CFL lamps showed that average efficacy was still about 31 lm/W in 2008 (tested performance ranged from 4 lm/W to 62 lm/W).

General Electric discontinued a 2007 development project intended to develop a high-efficiency incandescent bulb with the same lumens per watt as fluorescent lamps. Meanwhile other companies have developed and are selling halogen incandescents that use 70% of the energy of standard incandescents.

Other CFL technologies

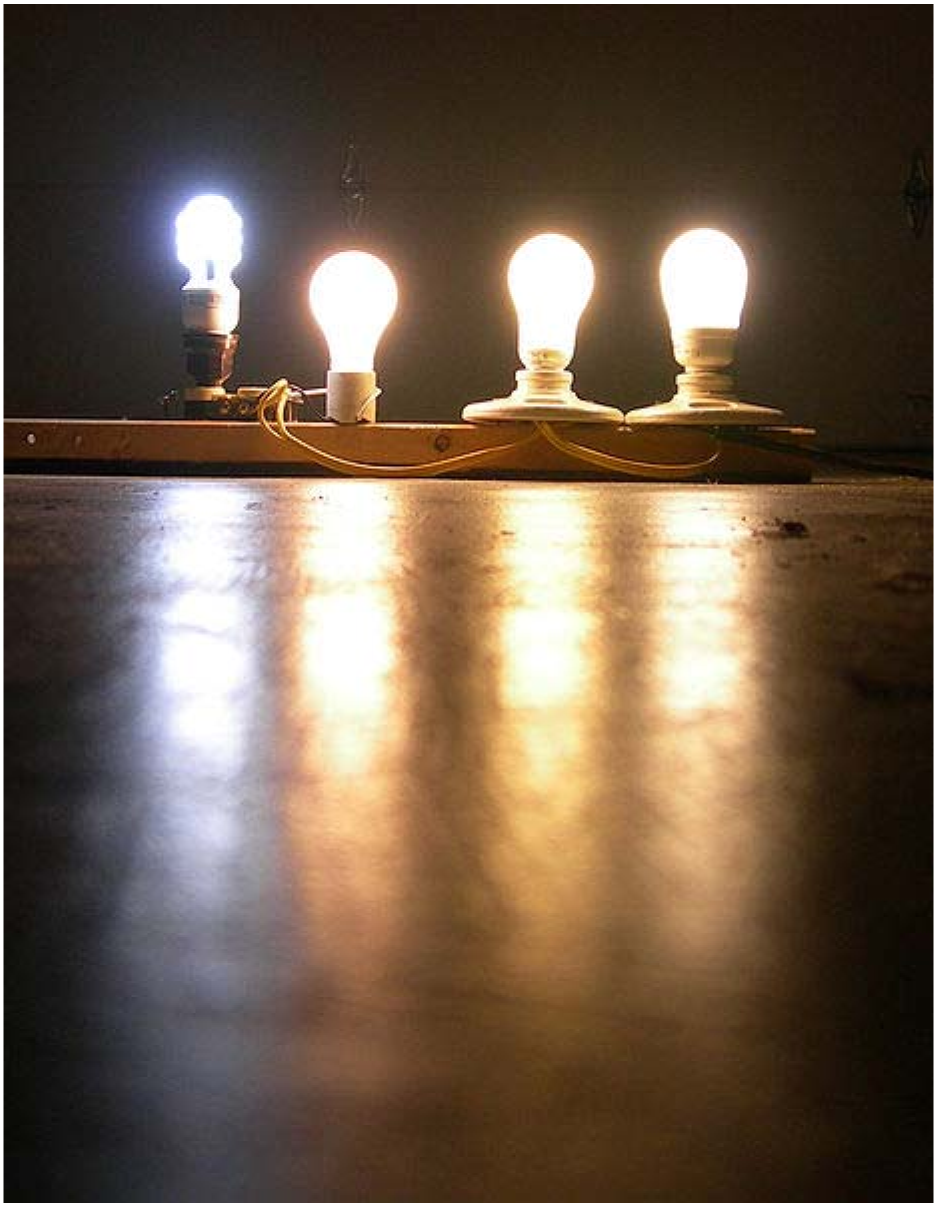
Another type of fluorescent lamp is the electrodeless lamp, known as magnetic induction lamp, radiofluorescent lamp or fluorescent induction lamp. These lamps have no wire conductors penetrating their envelopes, and instead excite mercury vapor using a radio-frequency oscillator. Currently, this type of light source is struggling with a high cost of production, stability of the products produced by domestic manufacturers in China, establishing an internationally recognized standard and problems with EMC and RFI.

Furthermore, induction lighting is excluded from Energy Star standard for 2007 by the EPA.

The cold cathode fluorescent lamp (CCFL) is one of the newest forms of CFL. CCFLs use electrodes without a filament. The voltage of CCFLs is about 5 times higher than CFLs, and the current is about 10 times lower. CCFLs have a diameter of about 3 millimeters. CCFLs were initially used for document scanners and also for backlighting LCD displays, but they are now also manufactured for use as lamps. The efficacy (lumens per watt) is about half that of CFLs. Their advantages are that they are instant-on, like incandescents, they are compatible with timers, photocells, and dimmers, and they have a long life of approximately 50,000 hours. CCFLs are a convenient transition technology for those who are not comfortable with the short lag time associated with the initial lighting of CFLs. They are also an effective and efficient replacement for lighting that is turned on and off frequently with little extended use (e.g. a bathroom or closet).

A few manufacturers make CFL-style bulbs with mogul Edison screw bases intended to replace 250 watt and 400 watt metal halide lamps, claiming a 50% energy reduction; however, these lamps require slight rewiring of the lamp fixtures to bypass the lamp ballast.

Spectrum of light

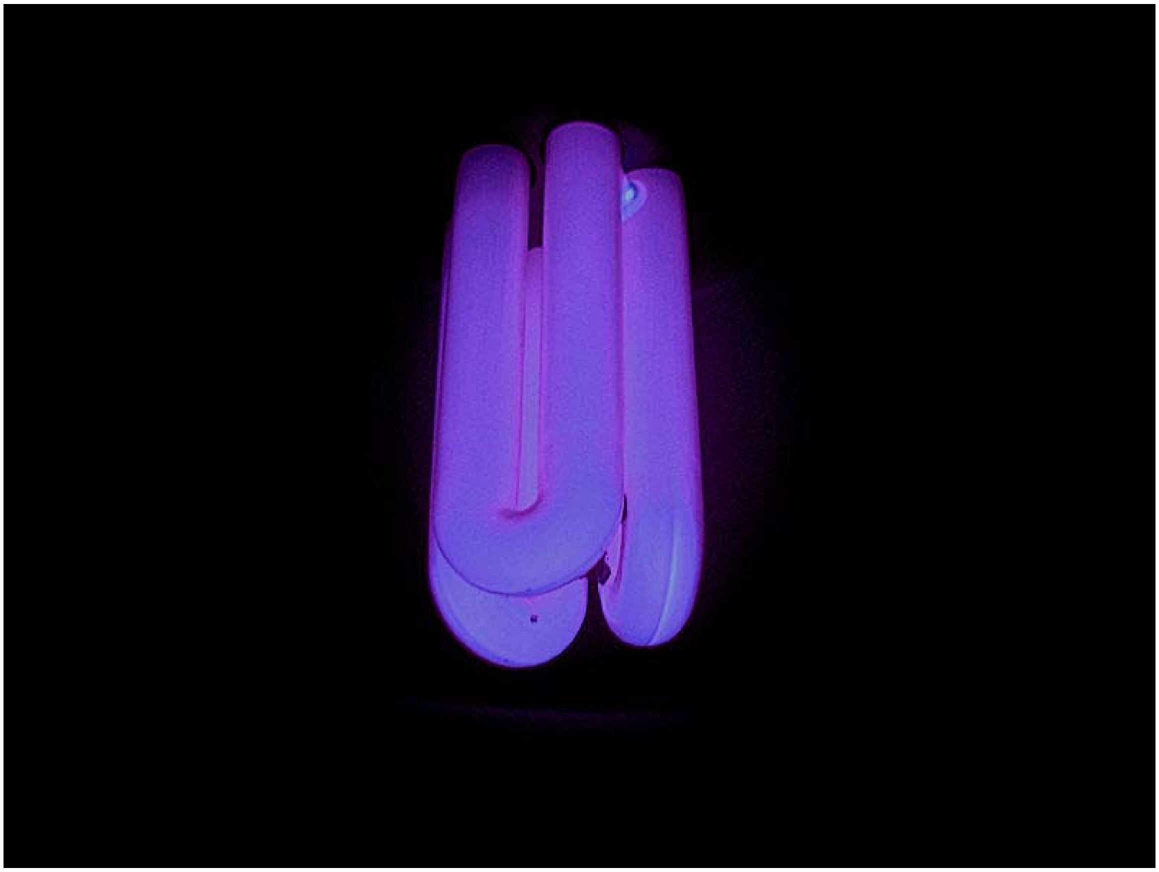


A photograph of various lamps illustrates the effect of color temperature differences (left to right):

1. Compact Fluorescent: General Electric, 13 W, 6,500 K
2. Incandescent: Sylvania 60 W Extra Soft White
3. Compact Fluorescent: Bright Effects, 15 W, 2,644 K
4. Compact Fluorescent: Sylvania, 14 W, 3,000 K

Color Temperature compared against a white ceiling.

Spectrum of a CFL bulb. The camera had a diffraction grating in front of the lens. The discrete images are produced by the different colors in the light, a line spectrum. An incandescent lamp would instead have a continuous band of color.



A blacklight CFL.

CFLs emit light from a mix of phosphors inside the bulb, each emitting one band of color. Modern phosphor designs are a compromise between the shade of the emitted light, energy efficiency, and cost. Every extra phosphor added to the coating mix causes a loss of efficiency and increased cost. Good quality consumer CFLs use three or four phosphors to achieve a 'white' light with a CRI (color rendering index) of around 80, where 100 represents the appearance of colors under daylight or a black-body (depending on the correlated color temperature).

Color temperature can be indicated in kelvins or mireds (1 million divided by the color temperature in kelvins).

Name	Color temperature	
	(K)	(Mired)
Warm/soft white	≤ 3,000	≥ 333
(Bright) white	3,500	286
Cool white	4,000	250

Daylight	≥ 5,000	≤ 200

Color temperature is a quantitative measure. The higher the number in kelvins, the more blue the shade. Color names associated with a particular color temperature are not standardized for modern CFLs and other triphosphor lamps like they were for the older-style halophosphate fluorescent lamps. Variations and inconsistencies exist among manufacturers. For example, Sylvania's Daylight CFLs have a color temperature of 3,500 K, while most other lamps with a *daylight* label have color temperatures of at least 5,000 K. Some vendors do not include the kelvin value on the package, but this is beginning to change now that the Energy Star criteria for CFLs is expected to require such labeling in its 4.0 revision.

Some manufacturers now label their CFLs with a 3 digit code to specify the color rendering index (CRI) and color temperature of the lamp. The first digit represents the CRI measured in tens of percent, while the second two digits represent the color temperature measured in hundreds of kelvins. For example, a CFL with a CRI of 83 and a color temperature of 2,700 K would be given a code of 827.

CFLs are also produced, less commonly, in other colors:

- Red, green, orange, blue, and pink, primarily for novelty purposes
- Blue for phototherapy
- Yellow, for outdoor lighting, because it does not attract insects
- Black light (UV light) for special effects

Black light CFLs, those with UVA generating phosphor, are much more efficient than incandescent black light lamps, since the amount of UV light that the filament of the incandescent lamp produces is only a fraction of the generated spectrum.

Efforts to encourage adoption

Due to the potential to reduce electric consumption and pollution, various organizations have encouraged the adoption of CFLs and other efficient lighting. Efforts range from publicity to encourage awareness, to direct handouts of CFLs to the public. Some electric utilities and local governments have subsidized CFLs or provided them free to customers as a means of reducing electric demand (and so delaying additional investments in generation).

More controversially, some governments are considering stronger measures to entirely displace incandescents. These measures include taxation, or bans on production of incandescent light bulbs that do not meet energy efficiency requirements.

In 2008, the European Union approved regulations progressively phasing out incandescent bulbs starting in 2009 and finishing at the end of 2012. By switching to energy saving bulbs, EU citizens will save almost 40 TW·h (almost the electricity consumption of 11 million European households), leading to a reduction of about 15 million metric tons of CO_2 emissions per year.

Australia, Canada, and the US have also announced plans for nationwide efficiency standards that would constitute an effective ban on most current incandescent bulbs.

Venezuela and Cuba have launched massive incandescent light bulbs replacement programs in order to save energy. In the case of Venezuela, the government was able to save 2000 MW of electricity in the first six months of the 2006 program called Mission Energy Revolution, which by 2007 replaced 20 million incandescent light bulbs with CFL from a total of an estimated 55 million light bulbs in the country. Cuba replaced all the 11 million light bulbs used in the island. Also, Venezuela signed an agreement with Vietnam, one of the large producers of CFLs in the world, to establish a factory to supply the future demand and hand-outs of government light bulbs.

The United States Department of Energy reports that sales of CFLs have dropped between 2007 and 2008, and estimated only 11% of suitable domestic light sockets use CFLs.

In the USA, a subjective program called the Program for the Evaluation and Analysis of Residential Lighting (PEARL) was created to be a watchdog program. PEARL has evaluated the performance and ENERGY STAR compliance of more than 150 models of CFL bulbs.

Labeling programs

In the United States and Canada, the Energy Star program labels compact fluorescent lamps that meet a set of standards for starting time, life expectancy, color, and consistency of performance. The intent of the program is to reduce consumer concerns due to variable quality of products. Those CFLs with a recent Energy Star certification start in less than one second and do not flicker. There is ongoing work in improving the 'quality' (color rendering index) of the light.

In the United Kingdom a similar program is run by the Energy Saving Trust to identify lighting products that meet energy conservation and performance guidelines.

Chapter- 6

Use of LED Lamp for Energy Conservation

A **light-emitting-diode lamp** is a solid-state lamp that uses light-emitting diodes (LEDs) as the source of light. The term "LED lightbulb" is also colloquially used. "LED lamp" may in general refer to conventional semiconductor light-emitting diodes, to organic LEDs (OLED), or polymer light-emitting diodes (PLED) devices, although OLED and PLED technologies are not commercially available in 2010.

Since the light output of individual light-emitting diodes is small compared to incandescent and compact fluorescent lamps, multiple diodes are often used together. In recent years, as diode technology has improved, high power light-emitting diodes with higher lumen output are making it possible to replace other lamps with LED lamps. One high power LED chip used in some commercial LED lights can emit 7527 lumens while using only 100 watts. LED lamps can be made interchangeable with other types of lamps.

Diodes use direct current (DC) electrical power, so LED lamps must also include internal circuits to operate from standard AC voltage. LEDs are damaged by being run at higher temperatures, so LED lamps typically include heat management elements such as heat sinks and cooling fins. LED lamps offer long service life and high energy efficiency, but initial costs are higher than those of fluorescent lamps.

An assortment of LED lightbulbs that are commercially available as of 2010 as replacements for screw-in bulbs, including floodlight fixtures (left), reading light (center), household lamps (center right and bottom), and low-power accent light (right) applications.

Technology overview

Dropped ceiling with LED lamps

General purpose lighting needs white light. LEDs emit light in a very small band of wavelengths, emitting strongly colored light. The color is characteristic of the energy bandgap of the semiconductor material used to make the LED. To emit white light from LEDs requires either mixing light from red, green, and blue LEDs, or using a phosphor to convert some of the light to other colors.

The first method (RGB-LEDs) uses multiple LED chips each emitting a different wavelength in close proximity, to form the broad white light spectrum. The advantage of this method is that the intensity of each LED can be adjusted to "tune" the character of the light emitted. The major disadvantage is high production cost.

The second method, phosphor converted LEDs (pcLEDs) uses one short wavelength LED (usually blue or ultraviolet) in combination with a phosphor, which absorbs a portion of the blue light and emits a broader spectrum of white light. (The mechanism is similar to the way a fluorescent lamp emits white light from a UV-illuminated phosphor.) The major advantage here is the low production cost, and high CRI (color rendering index), while the disadvantage is the inability to dynamically change the character of the light and the fact that phosphor conversion reduces the efficiency of the device. The low cost and adequate performance makes it the most widely used technology for general lighting today.

A single LED is a low-voltage solid state device and cannot be directly operated on standard AC current without some circuitry to control the voltage applied and the current flow through the lamp. A series diode and resistor could be used to control the voltage polarity and to limit the current, but this is inefficient since most of the applied voltage would be dropped as wasted heat in the resistor. A single series string of LEDs would minimize dropped-voltage losses, but one LED failure could extinguish the whole string. Paralleled strings increase reliability by providing redundancy. In practice, three strings or more are usually used. To be useful for illumination for home or work spaces, a number of LEDs must be placed close together in a lamp to combine their illuminating effects. This is because individual LEDs emit only a fraction of the light of traditional light sources. When using the color-mixing method, a uniform color distribution can be difficult to achieve, while the arrangement of white LEDs is not critical for color balance. Further, degradation of different LEDs at various times in a color-mixed lamp can lead to an uneven color output. LED lamps usually consist of clusters of LEDs in a housing with both driver electronics, a heat sink and optics.

Application

LED lamps are used for both general and special-purpose lighting. Where colored light is needed, LEDs come in multiple colors, which are emitted with no need for filters. This improves the energy efficiency over a white light source that generates all colors of light then discards some of the visible energy in a filter.

Compared to fluorescent bulbs, advantages claimed for LED light bulbs are that they contain no mercury (unlike compact fluorescent light bulbs), that they turn on instantly, and that lifetime is unaffected by cycling on and off, so that they are well suited for light fixtures where bulbs are often turned on and off. LED light bulbs are also less apt to break.

White-light light-emitting diode lamps have the traits of long life expectancy and relatively low energy use. The LED sources are compact, which gives flexibility in designing lighting fixtures and good control over the distribution of light with small reflectors or lenses. Due to the small size of LEDs, control of the spatial distribution of illumination is extremely flexible, and the light output and spatial distribution of a LED array can be controlled with no efficiency loss.

LED lamps have no glass tubes to break, and their internal parts are rigidly supported, making them resistant to vibration and impact. With proper driver electronics design, an LED lamp can be made dimmable over a wide range; there is no minimum current needed to sustain lamp operation.

LEDs using the color-mixing principle can emit a wide range of colors by changing the proportions of light generated in each primary color. This allows full color mixing in lamps with LEDs of different colors. In contrast to other lighting technologies, LED emission tends to be directional (or at least lambertian). This can be either an advantage or a disadvantage, depending on the requirements of the application. For applications where non-directional light is required, either a diffuser is used, or multiple individual LED emitters are used to cover different directions.

Household LED lamps

LED Lamp with E27 Edison screw, interchangeable with incandescent lamps

Lamp sizes and bases

LED lamps intended to be interchangeable with incandescent lamps are made in standard light bulb shapes, such as an Edison screw base, an MR16 shape with a bi-pin base, or a GU5.3 (Bipin cap) or GU10 (bayonet socket). LED lamps are made in low voltage (typically 12 V halogen-like) varieties, and as replacements for regular AC (e.g. 120 or 240 V AC) lighting. These lamps typically include circuitry to rectify the AC power and to convert the voltage to a level usable by the internal LED elements.

LED light bulbs

Many LED lamps have become available as replacements for screw-in incandescent or compact fluorescent light bulbs, ranging from low-power 5–40 watt incandescent bulbs, through conventional replacement bulbs for 60 watt incandescent bulbs (typically requiring about 7 watts of power), and as of 2010 a few lamps were available to replace higher wattage bulbs, e.g., a 13-watt LED bulb which is about as bright as a 100W incandescent. (A standard general purpose incandescent bulb emits light at an efficiency of about 14 to 17 lumens/W depending on its size and voltage. According to the European Union standard, an energy-efficient bulb that claims to be the equivalent of a 60W tungsten bulb must have a minimum light output of 806 lumens.)

Most LED bulbs are not designed to be dimmed (although some models are designed to work with dimmers), and are usually directional. The lamps have declined in cost to between US$30 to $50 each as of 2010. These bulbs are more power-efficient than compact fluorescent bulbs and offer lifespans of 30,000 or more hours, reduced operated at a higher temperature than specified. Incandescent bulbs have a typical life of 1,000 hours, compact fluorescents about 8,000 hours. A LED light bulb can be expected to last 25–30 years under normal use. The bulbs maintain output light intensity very well over their life-times. Energy Star specifications require the bulbs to typically drop less than 10% after 6000 or more hours of operation, and in the worst case not more than 15%. They are also mercury free, unlike fluorescent lamps. LED lamps are available with a variety of color properties. The higher purchase cost than other types may be more than offset by savings in energy and maintenance.

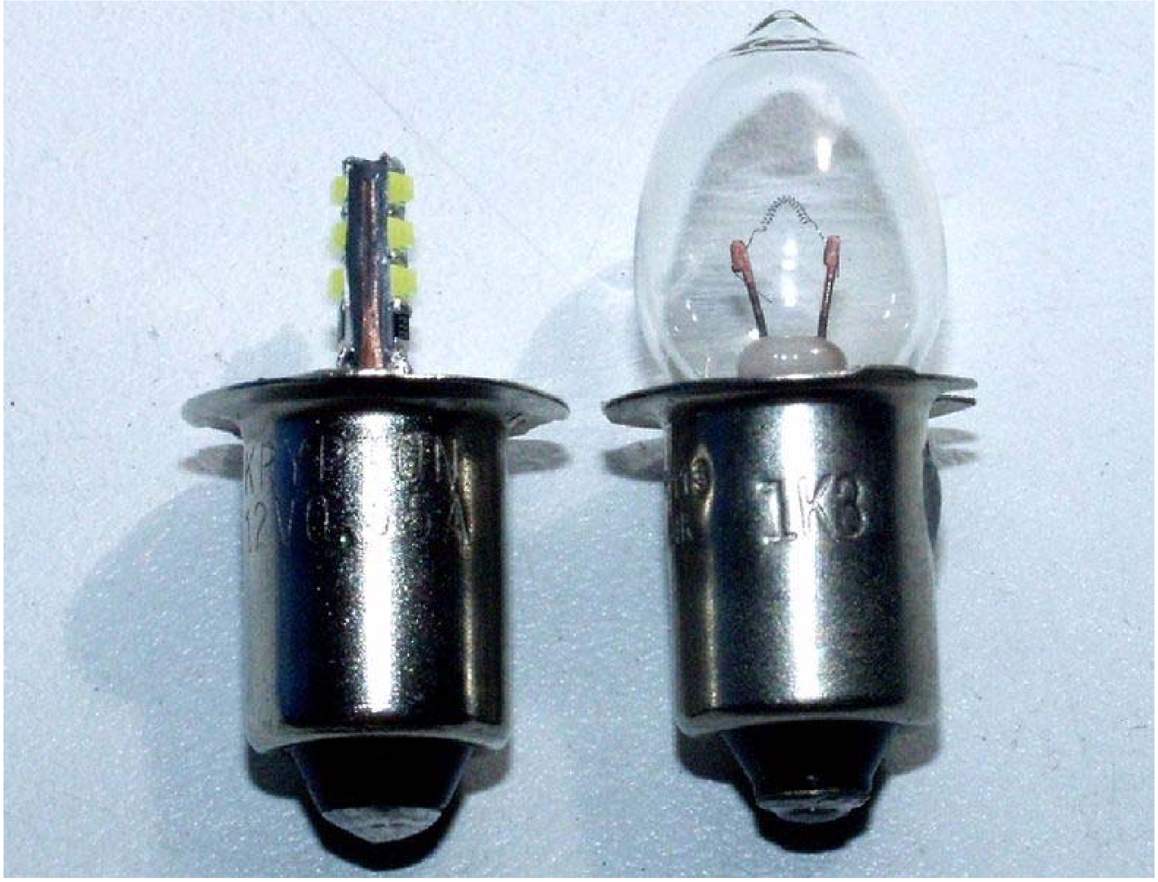
Several companies offer LED lamps for general lighting purposes. The C. Crane Company introduced a 7-watt replacement for a 60-watt bulb, the "Geobulb", with an efficiency of 59 lumens/W. The company also offers wedge-base lamps for replacement in low voltage fixtures. In the Netherlands, a company called Lemnis Lighting offers a dimmable LED lamp called Pharox. The company Eternleds Inc. offers a bulb called HydraLux-4 which uses liquid cooling of the LED chips. Philips makes a number of LED lamps which are commercially available in the United States and come with a six year warranty, and a number of smaller producers can be found that sell LED lights that are screw-in replacements for conventional bulbs, for example, the General LED Bulb from Arani

LED tubes in various length

The technology is improving rapidly, and new energy-efficient consumer LED lamps have been announced from three of the lighting industry's largest producers, Osram Sylvania, Philips, and General Electric, so these listings should be taken as not necessarily representative of what is currently available.

High power LED lamp with GU5.3 fitting and aluminum heat sink, intended to replace halogen reflector lamps.

Specialty uses



LED Flashlight replacement bulb (left), with tungsten equivalent (right)

White LED lamps have achieved market dominance in applications where high efficiency is important at low power levels. Some of these applications include flashlights, solar-powered garden or walkway lights, and bicycle lights. Monochromatic (colored) LED lamps are now commercially used for traffic signal lamps, where the ability to emit bright monochromatic light is a desired feature, and in strings of holiday lights.

LED lights have also become very popular in gardening and agriculture by 2010. First used by NASA to grow plants in space, LEDs came into use for home and commercial applications for indoor horticulture (aka grow lights). The wavelengths of light emitted from LED lamps have been specifically tailored to supply light in the spectral range needed for chlorophyll absorption in plants, promoting growth while reducing wastage of energy by emitting minimal light at wavelengths that plants do not require. The red and blue wavelengths of the visible light spectrum are used for photosynthesis, so these are the colors almost always used in LED grow light panels. These lights are attractive to indoor growers since they use less power than other types for the same light intensity, need no ballasts, and emit much less heat than HID lamps. The reduction in heat allows time between watering cycles to be extended because the plants transpire less under LED grow lights. Due to this change in growth conditions, users of LEDs are advised not to over-water the plants.

Pioneering mass use

In 2008 Sentry Equipment Corporation in Oconomowoc, Wisconsin, USA, was able to light its new factory interior and exterior almost solely with LEDs. Initial cost was three times more than a traditional mix of incandescent and fluorescent lamps, but the extra cost will be repaid within two years via electricity savings, and the lamps should not need replacing for 20 years. In 2009, the Manapakkam, Chennai office of the Indian IT company iGate spent 3,700,000 Indian rupees (U$80,000) to light 57,000 sq ft (5,300 m^2) of office space with LEDs. The firm expects the new lighting to pay for itself fully within 5 years.

LEDs on a big Christmas tree

In 2009 the exceptionally big Christmas tree standing in front of the Turku Cathedral in Finland was hung with 710 LED bulbs, each using 2 watts. It has been calculated that these LED lamps will pay for themselves in three and a half years, even though the lights run for only 48 days per year.

By 2010 mass installations of LED lighting for commercial and public uses were becoming common.

In 2010, on the reconstructed section of Bulevar Kralja Aleksandra (King Aleksandar Boulevard) in Belgrade, Serbia, LED lamps were introduced for new street lighting.

LED lamps have also been used for a number of demonstration projects for outdoor lighting and street lights. The United States Department of Energy has available several reports on the results of many pilot projects for municipal outdoor lighting. Many additional streetlight and municipal outdoor lighting projects have been announced.

Comparison to other lighting technologies

- Incandescent lamps (light bulbs) generate light by passing electric current through a resistive filament, thereby heating the filament to a very high temperature so that it glows and emits visible light. A broad range of visible frequencies are naturally produced, yielding a "warm" yellow or white color quality. Incandescent light is highly inefficient, as about 98% of the energy input is emitted as heat. A 100 W light bulb emits about 1,700 lumens, about 17 lumens/W. Incandescent lamps are relatively inexpensive to make. The typical lifespan of an AC incandescent lamp is around 1,000 hours. They work well with dimmers. Most older light fixtures are designed for the size and shape of these traditional bulbs.

- Fluorescent lamps (light bulbs) work by passing electricity through mercury vapor, which in turn emits ultraviolet light. The ultraviolet light is then absorbed by a phosphor coating inside the lamp, causing it to glow, or fluoresce. While the heat generated by a fluorescent lamp is much less than its incandescent counterpart, energy is still lost in generating the ultraviolet light and converting this light into visible light. If the lamp breaks, exposure to mercury can occur. Linear fluorescent lamps are typically five to six times the cost of equivalent incandescent lamps but have life spans around 10,000 and 20,000 hours. Lifetime varies from 1,200 hours to 20,000 hours for compact fluorescent lamps. Most fluorescent lamps are not compatible with dimmers. Those with "iron" ballasts flicker at 100 or 120 Hz, and are less efficient. The latest T8-sized triphosphate fluorescent lamps made by Osram, Philips, Crompton and others have a life expectancy greater than 50,000 hours, if coupled with a warm-start electronic ballast. The life expectancy depends on the number of on/off cycles, and is lower if the light is cycled often. The efficiency of these new lamps approaches 100 lumens/W. The efficiency of fluorescent tubes with modern electronic ballasts and compact fluorescents commonly ranges from 50 to 67 lumens/W. Most compact fluorescents rated at 13 W or more with integral electronic ballasts achieve about 60 lumens/W, comparable to the LED bulb.

Research and development

US Department of Energy

In May 2008, the U. S. Department of Energy (DOE) announced details of the Bright Tomorrow Lighting Prize competition. The L Prize is the first government-sponsored technology competition designed to spur lighting producers to develop high quality, high efficiency solid-state lighting products to replace the common light bulb. The competition will award cash prizes, and may also lead to opportunities for federal purchasing agreements, utility programs, and other incentives for winning products.

The Energy Independence and Security Act (EISA) of 2007 authorizes DOE to establish the Bright Tomorrow Lighting Prize competition. The legislation challenges industry to develop replacement technologies for the most commonly used and inefficient products, 60 W incandescent lamps and PAR 38 halogen lamps. The L Prize specifies technical requirements for these two competition categories. Lighting products meeting the competition requirements would use just 17% of the energy used by most incandescent lamps in use today. A future L Prize program announcement will call for developing a new “21st Century Lamp,” as authorized in the legislation.

The EISA legislation establishes basic requirements and prize amounts for each category. The legislation authorizes up to $20 million in cash prizes. On September 24, 2009 the DOE announced that Philips was the first to submit lamps in the category to replace the standard 60 W A-19 "Swan/Edison" light bulb.

National Institute of Standards and Technology

In June 2008, scientists at the National Institute of Standards and Technology (NIST) announced the first two standards for solid-state lighting in the United States. These standards detail the color specifications of LED lamps and LED light fixtures, and the test methods that producers should use when testing these solid-state lighting products for total light output, energy use, and chromaticity or color quality.

The Illuminating Engineering Society of North America (IESNA) published a documentary **standard LM-79**, which describes the methods for testing solid-state lighting products for their light output (lumens), energy efficiency (lumens per watt) and chromaticity.

The solid-state lights being studied are intended for general illumination, but white lights used today vary greatly in chromaticity, or specific shade of white. The American National Standards Institute (ANSI) published the **standard C78.377-2008**, which specifies the recommended color ranges for solid-state lighting products using cool to warm white LEDs with various correlated color temperatures.

DOE launched the Energy Star program for solid-state lighting products in 2008. NIST scientists assisted DOE by providing research, technical details and comments for the Energy Star specifications. Energy Star certification assures consumers that products save energy and are high quality and also serves as an incentive for producers to provide energy-saving products for consumers.

Other venues

Philips Lighting has ceased research on compact fluorescents, and is devoting the bulk of its research and development budget, 5 percent of the company's global lighting revenue, to solid-state lighting.

In January 2009, it was reported that researchers at Cambridge University had developed an LED bulb that costs £2 (about $3 U.S.), is 12 times as energy efficient as a tungsten bulb, and lasts for 100,000 hours.

Remaining problems

The production process of white LEDs is complex and many aspects have room for improvement. This means that the production price of volume products is still relatively high compared to traditional light sources. The process used to deposit the active semiconductor layers of the LED is constantly improved to increase yields and production throughput. The phosphors, which are needed for their ability to emit a broader wavelength spectrum of light, problems tuning the absorption and emission, and inflexibility of form have been issues.

More apparent to the end user, however, is the color rendering index (CRI) of low quality LEDs. CRI measures a light source's ability to render colors, with 100 being the maximum. LEDs with CRI below 75 are not recommended use in indoor lighting. Better CRI LEDs are more expensive, and more research and development is needed to reduce costs.

Variations of CCT (color correlated temperature) at different viewing angles present another obstacle against widespread use of white LED. It has been shown that CCT variations can exceed 500 K. This is clearly noticeable by human observers, who normally can distinguish CCT differences of 50 to 100 K in the range from 2000 K to 6000 K, which is the range of CCT variations of daylight.

LEDs also have limited temperature tolerance and falling efficiency as component temperature rises. This limits the total LED power that can practically be fitted into lamps that physically replace existing filament and compact fluorescent types. Much research and development is invested in improving thermal traits. Thermal management of high-power LEDs is a significant factor in design of solid state lighting equipment.

The long life of solid-state lighting products, expected to be about 50 times the most common incandescent bulbs, poses a problem for bulb makers, whose current customers buy frequent replacements.

Some critics suggest that producers may over-represent the efficiency and traits of their products to sell into a rapidly growing marketplace, suggesting that consumers still need to be wary of claims made about products in this market.

Applications

This garden light can use stored solar energy because of the low power use of its LED

- Automotive lighting
- Bicycle lighting
- Billboard displays
- Display lighting in art galleries to reduce heating on works to low values
- Domestic lighting
- Emergency lighting
- Flashlight (Electric torches)
- Floodlighting of buildings
- Grow lights for Plants
- Public transit vehicle route and destination signs
- Railway signals
- Stage lighting
- Traffic lights
- Train lights

Chapter- 7

Role of Green Building in Energy Conservation

Green building (also known as **green construction** or **sustainable building**) is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle: from siting to design, construction, operation, maintenance, renovation, and demolition. This practice expands and complements the classical building design concerns of economy, utility, durability, and comfort.

Although new technologies are constantly being developed to complement current practices in creating greener structures, the common objective is that green buildings are designed to reduce the overall impact of the built environment on human health and the natural environment by:

- Efficiently using energy, water, and other resources
- Protecting occupant health and improving employee productivity
- Reducing waste, pollution and environmental degradation

A similar concept is natural building, which is usually on a smaller scale and tends to focus on the use of natural materials that are available locally. Other related topics include sustainable design and green architecture. Green building does not specifically address the issue of the retrofitting existing homes.

Reducing environmental impact

Green building practices aim to reduce the environmental impact of new buildings. Buildings account for a large amount of land use, energy and water consumption, and air and atmosphere alteration. Considering the statistics, reducing the amount of natural resources buildings consume and the amount of pollution given off is seen as crucial for future sustainability, according to EPA. The building sector alone accounts for 30-40 percent of global energy use. Over 80 percent of the environmentally harmful emissions from buildings are due to energy consumption during the times when the buildings are in use . Green building does not typically include the concept of renovations although many of the 2050 homes are already built and UK homes account for 30% of UK Carbon Emissions. Domestic energy improvement targets of 20% between now and 2010, and again by a further 20% between 2010 and 2020 have been suggested by the UK government. The environmental impact of buildings is often underestimated, while the perceived costs of green buildings are overestimated. A recent survey by the World Business Council for Sustainable Development finds that green costs are overestimated by 300 percent, as key players in real estate and construction estimate the additional cost at 17 percent above conventional construction, more than triple the true average cost difference of about 5 percent. According to the UK Green Building Council, existing buildings account for 17% of the UK's total carbon emissions.

Goals of green building

The Blu Homes mkSolaire, a green building designed by Michelle Kaufmann.

The concept of sustainable development can be traced to the energy (especially fossil oil) crisis and the environment pollution concern in the 1970s. The green building movement in the U.S. originated from the need and desire for more energy efficient and environmentally friendly construction practices. There are a number of motives to building green, including environmental, economic, and social benefits. However, modern sustainability initiatives call for an integrated and synergistic design to both new construction and in the retrofitting of an existing structure. Also known as sustainable design, this approach integrates the building life-cycle with each green practice employed with a design-purpose to create a synergy amongst the practices used.

Green building brings together a vast array of practices and techniques to reduce and ultimately eliminate the impacts of new buildings on the environment and human health. It often emphasizes taking advantage of renewable resources, e.g., using sunlight through passive solar, active solar, and photovoltaic techniques and using plants and trees through green roofs, rain gardens, and for reduction of rainwater run-off. Many other techniques, such as using packed gravel or permeable concrete instead of conventional concrete or asphalt to enhance replenishment of ground water, are used as well.

While the practices, or technologies, employed in green building are constantly evolving and may differ from region to region, there are fundamental principles that persist from which the method is derived: Siting and Structure Design Efficiency, Energy Efficiency, Water Efficiency, Materials Efficiency, Indoor Environmental Quality Enhancement, Operations and Maintenance Optimization, and Waste and Toxics Reduction. The essence of green building is an optimization of one or more of these principles. Also, with the proper synergistic design, individual green building technologies may work together to produce a greater cumulative effect.

On the aesthetic side of green architecture or sustainable design is the philosophy of designing a building that is in harmony with the natural features and resources surrounding the site. There are several key steps in designing sustainable buildings: specify 'green' building materials from local sources, reduce loads, optimize systems, and generate on-site renewable energy.

Siting and structure design efficiency

The foundation of any construction project is rooted in the concept and design stages. The concept stage, in fact, is one of the major steps in a project life cycle, as it has the largest impact on cost and performance. In designing environmentally optimal buildings, the objective is to minimize the total environmental impact associated with all life-cycle stages of the building project. However, building as a process is not as streamlined as an industrial process, and varies from one building to the other, never repeating itself identically. In addition, buildings are much more complex products, composed of a multitude of materials and components each constituting various design variables to be decided at the design stage. A variation of every design variable may affect the environment during all the building's relevant life-cycle stages.

Energy efficiency

Green buildings often include measures to reduce energy use. To increase the efficiency of the building envelope, (the barrier between conditioned and unconditioned space), they may use high-efficiency windows and insulation in walls, ceilings, and floors. Another strategy, passive solar building design, is often implemented in low-energy homes. Designers orient windows and walls and place awnings, porches, and trees to shade windows and roofs during the summer while maximizing solar gain in the winter. In addition, effective window placement (daylighting) can provide more natural light and lessen the need for electric lighting during the day. Solar water heating further reduces energy loads.

Onsite generation of renewable energy through solar power, wind power, hydro power, or biomass can significantly reduce the environmental impact of the building. Power generation is generally the most expensive feature to add to a building.

Water efficiency

Reducing water consumption and protecting water quality are key objectives in sustainable building. One critical issue of water consumption is that in many areas, the demands on the supplying aquifer exceed its ability to replenish itself. To the maximum extent feasible, facilities should increase their dependence on water that is collected, used, purified, and reused on-site. The protection and conservation of water throughout the life of a building may be accomplished by designing for dual plumbing that recycles water in toilet flushing. Waste-water may be minimized by utilizing water conserving fixtures such as ultra-low flush toilets and low-flow shower heads. Bidets help eliminate the use of toilet paper, reducing sewer traffic and increasing possibilities of re-using water on-site. Point of use water treatment and heating improves both water quality and energy efficiency while reducing the amount of water in circulation. The use of non-sewage and greywater for on-site use such as site-irrigation will minimize demands on the local aquifer.

Materials efficiency

Building materials typically considered to be 'green' include rapidly renewable plant materials like bamboo (because bamboo grows quickly) and straw, lumber from forests certified to be sustainably managed, ecology blocks, dimension stone, recycled stone, recycled metal, and other products that are non-toxic, reusable, renewable, and/or recyclable (e.g. Trass, Linoleum, sheep wool, panels made from paper flakes, compressed earth block, adobe, baked earth, rammed earth, clay, vermiculite, flax linen, sisal, seagrass, cork, expanded clay grains, coconut, wood fibre plates, calcium sand stone, concrete (high and ultra high performance, roman self-healing concrete) , etc.) The EPA (Environmental Protection Agency) also suggests using recycled industrial goods, such as coal combustion products, foundry sand, and demolition debris in construction projects Building materials should be extracted and manufactured locally to the building site to minimize the energy embedded in their transportation. Where possible, building elements should be manufactured off-site and delivered to site, to maximise benefits of off-site manufacture including minimising waste, maximising recycling (because manufacture is in one location), high quality elements, better OHS management, less noise and dust.

Indoor environmental quality enhancement

The Indoor Environmental Quality (IEQ) category in LEED standards, one of the five environmental categories, was created to provide comfort, well-being, and productivity of occupants. The LEED IEQ category addresses design and construction guidelines especially: indoor air quality (IAQ), thermal quality, and lighting quality.

Indoor Air Quality seeks to reduce volatile organic compounds, or VOC's, and other air impurities such as microbial contaminants. Buildings rely on a properly designed HVAC system to provide adequate ventilation and air filtration as well as isolate operations (kitchens, dry cleaners, etc.) from other occupancies. During the design and construction process choosing construction materials and interior finish products with zero or low emissions will improve IAQ. Many building materials and cleaning/maintenance products emit toxic gases, such as VOC's and formaldehyde. These gases can have a detrimental impact on occupants' health and productivity as well. Avoiding these products will increase a building's IEQ.

Personal temperature and airflow control over the HVAC system coupled with a properly designed building envelope will also aid in increasing a building's thermal quality. Creating a high performance luminous environment through the careful integration of natural and artificial light sources will improve on the lighting quality of a structure.

Operations and maintenance optimization

No matter how sustainable a building may have been in its design and construction, it can only remain so if it is operated responsibly and maintained properly. Ensuring operations and maintenance(O&M) personnel are part of the project's planning and development process will help retain the green criteria designed at the onset of the project. Every aspect of green building is integrated into the O&M phase of a building's life. The addition of new green technologies also falls on the O&M staff. Although the goal of waste reduction may be applied during the design, construction and demolition phases of a building's life-cycle, it is in the O&M phase that green practices such as recycling and air quality enhancement take place.

Waste reduction

Green architecture also seeks to reduce waste of energy, water and materials used during construction. For example, in California nearly 60% of the state's waste comes from commercial buildings During the construction phase, one goal should be to reduce the amount of material going to landfills. Well-designed buildings also help reduce the amount of waste generated by the occupants as well, by providing on-site solutions such as compost bins to reduce matter going to landfills.

To reduce the impact on wells or water treatment plants, several options exist. "Greywater", wastewater from sources such as dishwashing or washing machines, can be used for subsurface irrigation, or if treated, for non-potable purposes, e.g., to flush toilets and wash cars. Rainwater collectors are used for similar purposes.

Centralized wastewater treatment systems can be costly and use a lot of energy. An alternative to this process is converting waste and wastewater into fertilizer, which avoids these costs and shows other benefits. By collecting human waste at the source and running it to a semi-centralized biogas plant with other biological waste, liquid fertilizer can be produced. This concept was demonstrated by a settlement in Lubeck Germany in the late 1990s. Practices like these provide soil with organic nutrients and create carbon sinks that remove carbon dioxide from the atmosphere, offsetting greenhouse gas emission. Producing artificial fertilizer is also more costly in energy than this process.

Cost and payoff

The most criticized issue about constructing environmentally friendly buildings is the price. Photo-voltaics, new appliances, and modern technologies tend to cost more money. Most green buildings cost a premium of <2%, but yield 10 times as much over the entire life of the building. The stigma is between the knowledge of up-front cost vs. life-cycle cost. The savings in money come from more efficient use of utilities which result in decreased energy bills. It is projected that different sectors could save $130 Billion on energy bills. Also, higher worker or student productivity can be factored into savings and cost deductions.

Studies have shown over a 20 year life period, some green buildings have yielded $53 to $71 per square foot back on investment. Confirming the rentability of green building investments, further studies of the commercial real estate market have found that LEED and Energy Star certified buildings achieve significantly higher rents, sale prices and occupancy rates as well as lower capitalization rates potentially reflecting lower investment risk.

Regulation and operation

Many countries have developed their own standards for green building or energy efficiency for buildings. Some of the major building environmental assessment tools currently in use include:

- Australia: Nabers / Green Star
- Brazil: AQUA / LEED Brasil
- Canada: LEED Canada / Green Globes
- China: GBAS
- Finland: PromisE
- France: HQE
- Germany: DGNB / CEPHEUS
- Hong Kong: HKBEAM
- India: Indian Green Building Council (IGBC) / GRIHA
- Italy: Protocollo Itaca / Green Building Counsil Italia
- Japan: CASBEE
- Malaysia: GBI Malaysia
- Mexico: LEED Mexico
- Netherlands: BREEAM Netherlands

- New Zealand: Green Star NZ
- Philippines: BERDE / Philippine Green Building Council
- Portugal: Lider A
- Singapore: Green Mark
- South Africa: Green Star SA
- Spain: VERDE
- Switzerland: Minergie
- United States: LEED / Living Building Challenge / Green Globes / Build it Green / NAHB NGBS / International Green Construction Code International Green Construction Code (IGCC)
- United Kingdom: BREEAM
- United Arab Emirates: Estidama
- IAPGSA Pakistan Institute of Architecture Pakistan Green Sustainable Architecture

International frameworks and assessment tools

IPCC Fourth Assessment Report

Climate Change 2007, the Fourth Assessment Report (AR4) of the United Nations Intergovernmental Panel on Climate Change (IPCC), is the fourth in a series of such reports. The IPCC was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) to assess scientific, technical and socio-economic information concerning climate change, its potential effects and options for adaptation and mitigation.

UNEP and Climate change

UNEP works to facilitate the transition to low-carbon societies, support climate proofing efforts, improve understanding of climate change science, and raise public awareness about this global challenge.

GHG Indicator

The GHG Indicator: UNEP Guidelines for Calculating Greenhouse Gas Emissions for Businesses and Non-Commercial Organizations

Agenda 21

Agenda 21 is a programme run by the United Nations (UN) related to sustainable development. It is a comprehensive blueprint of action to be taken globally, nationally and locally by organizations of the UN, governments, and major groups in every area in which humans impact on the environment. The number 21 refers to the 21st century.

FIDIC's PSM

FIDIC's Project Sustainability Management Guidelines were created in order to assist project engineers and other stakeholders in setting sustainable development goals for their projects that are recognized and accepted by as being in the interests of society as a whole. The process is also intended to allow the alignment of project goals with local conditions and priorities and to assist those involved in managing projects to measure and verify their progress.

The PSM Guidelines are structured with Themes and Sub-Themes under the three main sustainability headings of Social, Environmental and Economic. For each individual Sub-Theme a core project indicator is defined along with guidance as to the relevance of that issue in the context of an individual project.

The Sustainability Reporting Framework provides guidance for organizations to use as the basis for disclosure about their sustainability performance, and also provides stakeholders a universally applicable, comparable framework in which to understand disclosed information.

The Reporting Framework contains the core product of the Sustainability Reporting Guidelines, as well as Protocols and Sector Supplements. The Guidelines are used as the basis for all reporting. They are the foundation upon which all other reporting guidance is based, and outline core content for reporting that is broadly relevant to all organizations regardless of size, sector, or location. The Guidelines contain principles and guidance as well as standard disclosures – including indicators – to outline a disclosure framework that organizations can voluntarily, flexibly, and incrementally, adopt.

Protocols underpin each indicator in the Guidelines and include definitions for key terms in the indicator, compilation methodologies, intended scope of the indicator, and other technical references.

Sector Supplements respond to the limits of a one-size-fits-all approach. Sector Supplements complement the use of the core Guidelines by capturing the unique set of sustainability issues faced by different sectors such as mining, automotive, banking, public agencies and others.

IPD Environment Code

The IPD Environment Code was launched in February 2008. The Code is intended as a good practice global standard for measuring the environmental performance of corporate buildings. Its aim is to accurately measure and manage the environmental impacts of corporate buildings and enable property executives to generate high quality, comparable performance information about their buildings anywhere in the world. The Code covers a wide range of building types (from offices to airports) and aims to inform and support the following;

- Creating an environmental strategy
- Inputting to real estate strategy

- Communicating a commitment to environmental improvement
- Creating performance targets
- Environmental improvement plans
- Performance assessment and measurement
- Life cycle assessments
- Acquisition and disposal of buildings
- Supplier management
- Information systems and data population
- Compliance with regulations
- Team and personal objectives

IPD estimate that it will take approximately three years to gather significant data to develop a robust set of baseline data that could be used across a typical corporate estate.

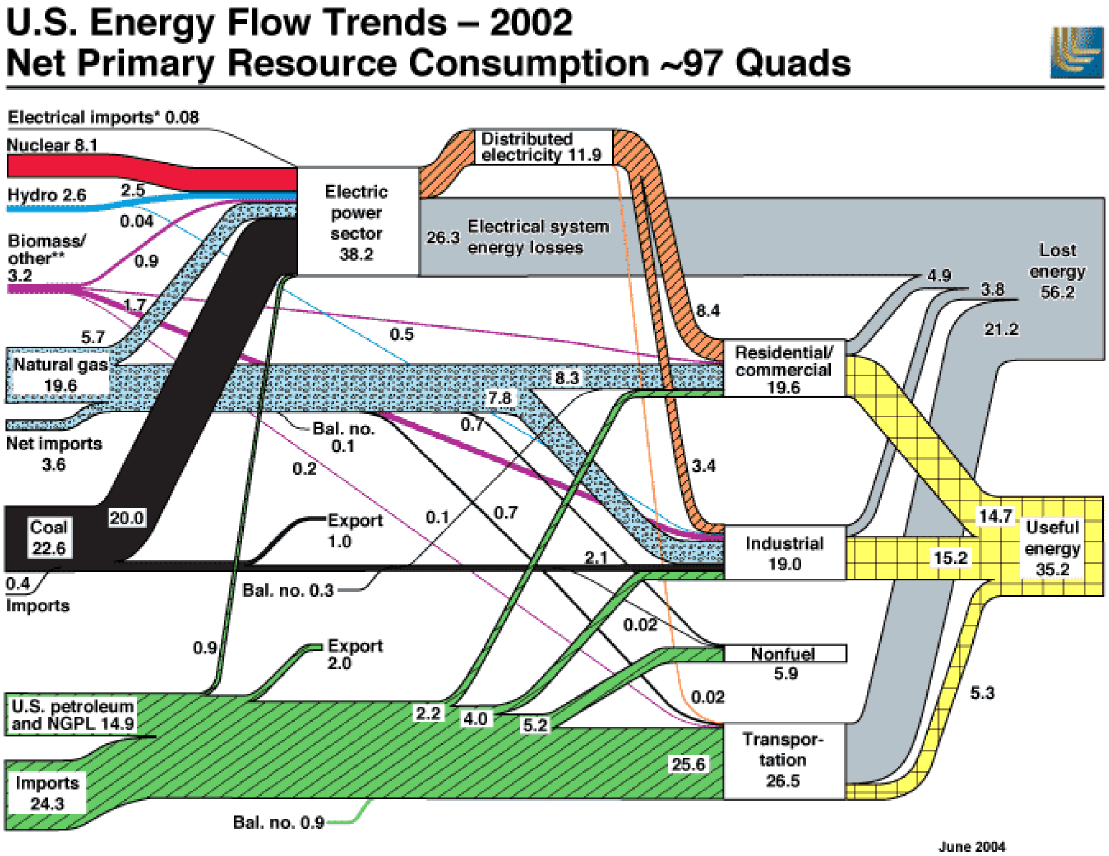
ISO 21931

ISO/TS 21931:2006, Sustainability in building construction—Framework for methods of assessment for environmental performance of construction works—Part 1: Buildings, is intended to provide a general framework for improving the quality and comparability of methods for assessing the environmental performance of buildings. It identifies and describes issues to be taken into account when using methods for the assessment of environmental performance for new or existing building properties in the design, construction, operation, refurbishment and deconstruction stages. It is not an assessment system in itself but is intended be used in conjunction with, and following the principles set out in, the ISO 14000 series of standards.

Chapter- 8

Energy Conservation in the United States

The United States is currently the second largest single consumer of energy. The U.S. Department of Energy categorizes national energy use in four broad sectors: transportation, residential, commercial, and industrial.

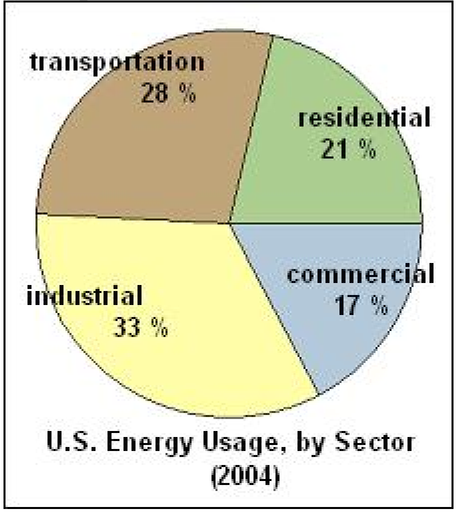


Source: Production and end-use data from Energy Information Administration, *Annual Energy Review 2002.*
*Net fossil-fuel electrical imports.
**Biomass/other includes wood, waste, alcohol, geothermal, solar, and wind.

June 2004
Lawrence Livermore
National Laboratory
http://eed.llnl.gov/flow

U.S. Energy Flow - 2002. Note that the breakdown of useful and waste energy in each sector (yellow vs. Grey) may be misleading since the 'lost' energy is largely unavoidable.

(Second law of thermodynamics: heat engines can not decrease total entropy, so they have to dump heat into a low temperature material.)



Energy usage in transportation and residential sectors (about half of U.S. energy consumption) is largely controlled by individual domestic consumers. Commercial and industrial energy expenditures are determined by businesses entities and other facility managers. National energy policy has a significant effect on energy usage across all four sectors.

Transportation

The transportation sector includes all vehicles used for personal or freight transportation. Of the energy used in this sector, approximately 65% is consumed by gasoline-powered vehicles, primarily personally owned. Diesel-powered transport (trains, merchant ships, heavy trucks, etc.) consumes about 20%, and air traffic consumes most of the remaining 15%. The two oil supply crisis of the 1970s spurred the creation, in 1975, of the federal Corporate Average Fuel Economy (CAFE) program, which required auto manufacturers to meet progressively higher fleet fuel economy targets. The next decade saw dramatic improvements in fuel economy, mostly the result of reductions in vehicle size and weight which originated in the late 1970s, along with the transition to front wheel drive. These gains eroded somewhat after 1990 due to the growing popularity of sport utility vehicles, pickup trucks and minivans, which fall under the more lenient "light truck" CAFE standard.

In addition to the CAFE program, the U.S. government has tried to encourage better vehicle efficiency through tax policy. Since 2002, taxpayers have been eligible for income tax credits for gas/electric hybrid vehicles. A "gas-guzzler" tax has been assessed on manufacturers since 1978 for cars with exceptionally poor fuel economy. While this tax remains in effect, it currently generates very little revenue as overall fuel economy has improved.

Another focus in gasoline conservation is reducing the number of miles driven. An estimated 40% of American automobile use is associated with daily commuting. Many urban areas offer subsidized public transportation to reduce commuting traffic, and encourage carpooling by providing designated high-occupancy vehicle lanes and lower tolls for cars with multiple riders. In recent years telecommuting has also become a viable alternative to commuting for some jobs, but in 2003 only 3.5% of workers were telecommuters. Ironically, hundreds of thousands of American and European workers have been replaced by workers in Asia who telecommute from thousands of miles away.

Fuel economy-maximizing behaviors also help reduce fuel consumption. Among the most effective are moderate (as opposed to aggressive) driving, driving at lower speeds, using cruise control, and turning off a vehicle's engine at stops rather than idling. A vehicle's gas mileage decreases rapidly highway speeds, normally above 55 miles per hour (though the exact number varies by vehicle). This is because aerodynamic forces are proportionally related to the square of an object's speed (when the speed is doubled, drag quadruples). According to the U.S. Department of Energy (DOE), as a rule of thumb, each 5 mph (8.0 km/h) you drive over 60 mph (97 km/h) is similar to paying an additional $0.30 per gallon for gas. The exact speed at which a vehicle achieves its highest efficiency varies based on the vehicle's drag coefficient, frontal area, surrounding air speed, and the efficiency and gearing of a vehicle's drive train and transmission.

Residential sector

The residential sector refers to all private residences, including single-family homes, apartments, manufactured homes and dormitories. Energy use in this sector varies significantly across the country, due to regional climate differences and different regulation. On average, about half of the energy used in U.S. homes is expended on space conditioning (i.e. heating and cooling).

The efficiency of furnaces and air conditioners has increased steadily since the energy crises of the 1970s. The 1987 National Appliance Energy Conservation Act authorized the Department of Energy to set minimum efficiency standards for space conditioning equipment and other appliances each year, based on what is "technologically feasible and economically justified". Beyond these minimum standards, the Environmental Protection Agency awards the Energy Star designation to appliances that exceed industry efficiency averages by an EPA-specified percentage.

Despite technological improvements, many American lifestyle changes have put higher demands on heating and cooling resources. The average size of homes built in the United States has increased significantly, from 1,500 sq ft (140 m^2) in 1970 to 2,300 sq ft (210 m^2) in 2005. The single-person household has become more common, as has central air conditioning: 23% of households had central air conditioning in 1978, that figure rose to 55% by 2001.

As furnace efficiency gets higher, there is limited room for improvement—efficiencies above 85% are now common. However, improving the building envelope through better or more insulation, advanced windows, etc., can allow larger improvements. The passive house approach produces superinsulated buildings that approach zero net energy consumption. Improving the building envelope can also be cheaper than replacing a furnace or air conditioner.

Even lower cost improvements include weatherization, which is frequently subsidized by utilities or state/federal tax credits, as are programmable thermostats. Consumers have also been urged to adopt a wider indoor temperature range (e.g. 65 °F (18 °C) in the winter, 80 °F (27 °C) in the summer).

One underutilized, but potentially very powerful means to reduce household energy consumption is to provide real-time feedback to homeowners so they can effectively alter their energy using behavior. Recently, low cost energy feedback displays, such as The Energy Detective or wattson, have become available. A study of a similar device deployed in 500 Ontario homes by *Hydro One* showed an average 6.5% drop in total electricity use when compared with a similarly sized control group.

Standby power used by consumer electronics and appliances while they are turned off accounts for an estimated 5 to 10% of household electricity consumption, adding an estimated $3 billion to annual energy costs in the USA. "In the average home, 75% of the electricity used to power home electronics is consumed while the products are turned off."

Home energy consumption averages

- Home heating systems, 30.7%
- Water heating, 13.5%
- Home cooling systems, 11.5%
- Lighting, 10.3%
- Refrigerators and freezers, 8.2%
- Home electronics, 7.2%
- Clothing and dish washers, 5.6% (includes clothes dryers, does not include hot water)
- Cooking, 4.7%
- Computers, 0.9%
- Other, 4.1% (includes small electrics, heating elements, motors, pool and hot tub heaters, outdoor grills, and natural gas outdoor lighting)
- Non end-user energy expenditure, 3.3%

Energy usage in some homes may vary widely from these averages. For example, milder regions such as the southern U.S. and Pacific coast of the USA need far less energy for space conditioning than New York City or Chicago. On the other hand, air conditioning energy use can be quite high in hot-arid regions (Southwest) and hot-humid zones (Southeast) In milder climates such as San Diego, lighting energy may easily consume up to 40% of total energy. Certain appliances such as a waterbed, hot tub, or pre-1990 refrigerator use significant amounts of electricity. However, recent trends in home entertainment equipment can make a large difference in household energy use. For instance a 50" LCD television (average on-time= 6 hours a day) may draw 300 Watts less than a similarly sized plasma system. In most residences no single appliance dominates, and any conservation efforts must be directed to numerous areas in order to achieve substantial energy savings. However, Ground, Air and Water Source Heat Pump systems, solar heating systems and evaporative coolers are among the more energy efficient, environmentally clean, and cost-effective space conditioning and domestic hot water systems available (Environmental Protection Agency), and can achieve reductions in energy consumptions of up to 69%.

Best building practices

Current best practices in building design, construction and retrofitting result in homes that are profoundly more energy conserving than average new homes. This includes insulation and energy-efficient windows and lighting.

Smart ways to construct homes such that minimal resources are used to cooling and heating the house in summer and winter respectively can significantly reduce energy costs.

Commercial sector

The commercial sector consists of retail stores, offices (business and government), restaurants, schools and other workplaces. Energy in this sector has the same basic end uses as the residential sector, in slightly different proportions. Space conditioning is again the single biggest consumption area, but it represents only about 30% of the energy use of commercial buildings. Lighting, at 25%, plays a much larger role than it does in the residential sector. Lighting is also generally the most wasteful component of commercial use. A number of case studies indicate that more efficient lighting and elimination of over-illumination can reduce lighting energy by approximately fifty percent in many commercial buildings.

Commercial buildings can greatly increase energy efficiency by thoughtful design, with today's building stock being very poor examples of the potential of systematic (not expensive) energy efficient design (Steffy, 1997). Commercial buildings often have professional management, allowing centralized control and coordination of energy conservation efforts. As a result, fluorescent lighting (about four times as efficient as incandescent) is the standard for most commercial space, although it may produce certain adverse health effects. Potential health concerns can be mitigated by using newer fixtures with electronic ballasts rather than older magenetic ballasts. As most buildings have consistent hours of operation, programmed thermostats and lighting controls are common. However, too many companies believe that merely having a computer controlled Building automation system guarantees energy efficiency. As an example one large company in Northern California boasted that it was confident its state of the art system had optimized space heating. A more careful analysis by Lumina Technologies showed the system had been given programming instructions to maintain constant 24 hour temperatures in the entire building complex. This instruction caused the injection of nighttime heat into vacant buildings when the daytime summer temperatures would often exceed 90 °F (32 °C). This mis-programming was costing the company over $130,000 per year in wasted energy (Lumina Technologies, 1997). Many corporations and governments also require the Energy Star rating for any new equipment purchased for their buildings.

Solar heat loading through standard window designs usually leads to high demand for air conditioning in summer months. An example of building design overcoming this excessive heat loading is the Dakin Building in Brisbane, California, where fenestration was designed to achieve an angle with respect to sun incidence to allow maximum reflection of solar heat; this design also assisted in reducing interior over-illumination to enhance worker efficiency and comfort.

Recent advances include use of occupancy sensors to turn off lights when spaces are unoccupied, and photosensors to dim or turn off electric lighting when natural light is available. In air conditioning systems, overall equipment efficiencies have increased as energy codes and consumer information have begun to emphasise year round performance rather than just efficiency ratings at maximum output. Controllers that automatically vary the speeds of fans, pumps, and compressors have radically improved part-load performance of those devices. For space or water heating, electric heat pumps consume roughly half the energy required by electric resistance heaters. Natural gas heating efficiencies have improved through use of condensing furnaces and boilers, in which the water vapor in the flue gas is cooled to liquid form before it is discharged, allowing the heat of condensation to be used. In buildings where high levels of outside air are required, heat exchangers can capture heat from the exhaust air to preheat incoming supply air.

A company in Florida tackled the issue of both energy-conservation and enhancing its workplace environment by implementing a conveyor system that is 40-60% quieter than traditional systems, emitting a noise level of only 55-50 decibels, equivalent to a soft-rock radio station. Lighting was addressed by not only programming the lighting console so that isolated lights could be switched on and off in designated areas of the warehouse, but also by enhancing natural lighting through the use of skylights and a high-gloss floor.

Industrial sector

The industrial sector represents all production and processing of goods, including manufacturing, construction, farming, water management and mining.

Increasing costs have forced energy-intensive industries to make substantial efficiency improvements in the past 30 years. For example, the energy used to produce steel and paper products has been cut 40% in that time frame, while petroleum/aluminum refining and cement production have reduced their usage by about 25%. These reductions are largely the result of recycling waste material and the use of cogeneration equipment for electricity and heating.

Another example for efficiency improvements is the use of products made of High temperature insulation wool (HTIW) which enables predominantly industrial users to operate thermal treatment plants at temperatures between 800 and 1400°C. In these high-temperature applications, the consumption of primary energy and the associated CO_2 emissions can be reduced by up to 50% compared with old fashioned industrial installations. The application of products made of High temperature insulation Wool is becoming increasingly important against the background of the currently dramatic rising cost of energy.

U.S. agriculture has doubled farm energy efficiency in the last 25 years.

The energy required for delivery and treatment of fresh water often constitutes a significant percentage of a region's electricity and natural gas usage (an estimated 20% of California's total energy use is water-related). In light of this, some local governments have worked toward a more integrated approach to energy and water conservation efforts.

To conserve energy, some industries have begun using solar panels to heat their water.

Unlike the other sectors, total energy use in the industrial sector has declined in the last decade. While this is partly due to conservation efforts, its is also a reflection of the growing trend for U.S. companies to move manufacturing operations overseas.

Government incentives and initiatives

The Energy Policy Act of 2005 included incentives which provide a tax credit of 30% of the cost of the new item with a $500 aggregate limit; the program was initially set to expire at the end of 2007 but was extended to 2010 and the aggregate limit increased to $1,500 by the The Energy Improvement and Extension Act of 2008 and the The American Recovery and Reinvestment Act of 2009, when it will expire.

The states and local areas (e.g., cities or counties) have various initiatives, and the U.S. Department of Energy funded a database known as DSIRE which provides information on these initatives. The state of Maryland has set a target of reducing its electricity usage by 15% from 2008 to 2015.

Chapter- 9

Energy Conservation in the United Kingdom

Various **energy conservation** measures are taken in the **United Kingdom**.

Much of the emphasis in energy debates tends to focus on the supply side of the issue, and ignore the demand. A number of commentators are concerned that this is being largely overlooked, partly due to the strength of the energy industry lobby. Energy conservation also has great potential, and may be able to significantly cut the size of the supposed energy gap, if early and concerted action is taken.

BedZED zero energy housing.

Housing

Along with road transport, domestic housing and energy use is currently one of the major obstacles to achieving carbon reduction targets. Housing currently accounts for just over 30% of all carbon dioxide emissions in the UK, and by 2010 the emissions from housing are expected to have risen 18.5% above 1990 levels. This rise is projected to continue beyond 2010. Action is being taken on new buildings through 2006 changes to the Building Regulations, and on existing housing through the Carbon Emission Reduction Target.

Domestic appliances

In the housing sector, consumer electronics and IT products are an area where energy use is expected to continue to rise rapidly. In the decade from the mid 1990s to the mid 2000s electricity consumed by such goods rose by 47%. By the early 2010s it is expected to have risen again by over 80%. It was estimated that, in 2004, at least 8% of domestic electricity was used by items in standby mode, representing 360 kW·h and 42 kg of carbon emissions for each household.

Consumption of electricity by all domestic appliances (including cooking and lighting) rose by 123% between 1970 and 2003, and by 223% when cooking and lighting are excluded.

Transport

Transport continues to grow as a significant user of fuel in the UK, and along with housing, this continues to be one of the major challenges to achieving the Government's carbon reduction targets.

By 2003 the amount of fuel used by transport had risen by around 60% since 1970. While oil is the main energy source, electricity and LPG make up a small percentage. Carbon emissions from transport have almost doubled over this period. Increasing car usage, increasing engine sizes, and levels of congestion are some of the problem areas, as is increasing air travel.

Road transport

Efforts to reduce emissions of nitrogen oxides, sulphur dioxide and particulates from diesel vehicles have actually led to an increase in fuel consumption and carbon dioxide emissions. Current technology should allow further reductions in emissions without increases in fuel consumption, and hopefully future technology will allow fuel consumption, and therefore CO_2 emissions, to reduce.

The basis of Vehicle Excise Duty (VED), also known as "road tax", was changed so that cars registered on or after March 1, 2001 are taxed according to the VED band that they fall into. VED bands are based on the results of a laboratory test, designed to calculate the theoretical potential emissions of the vehicle in grammes of CO_2 per kilometre travelled, under ideal conditions. This has encouraged a 21% increase in the ownership of diesel cars, which produce lower CO_2 emissions, but increase particulates. Company Car Tax was also revised to reflect both the list price and CO_2 emissions.

A voluntary scheme to display Fuel Economy Labels on new cars was introduced during July 2005, including information on Vehicle Excise Duty and likely fuel costs . The scheme brings the UK into line with European Directive 1999/94/EC, and aims to influence the behaviour of both consumers and manufacturers.

During the 1990s the Fuel Price Escalator was used to raise road fuel tax in an attempt to reduce vehicle usage and cut emissions. The mechanism was abandoned in the wake of the 2000 fuel protests. In the December 2006 Pre-Budget Report the Government announced a rise in fuel tax, and stated that fuel prices should rise each year 'at least in line with inflation'.

From 2008, a Renewable Transport Fuel Obligation is being introduced, under which petrol and diesel are likely to be blended with 5% biofuels by 2010. It is anticipated that this will cut carbon emissions in the transport sector by between 2% and 3%.

The 'Low Carbon Vehicle Partnership' is pursuing the goal that new cars should produce no more than 100 g/km of CO_2 by 2012. It also works in on reducing carbon emissions from commercial vehicles and in the area of alternative fuels.

Domestic shipping

Although 7.5% of freight within the UK is moved by coastal shipping and on inland waterways (in tonne kilometres, excluding crude oil from the North Sea), this is largely limited to stone, aggregates and refined petroleum. A series of reports have discussed the financial and environmental advantages of increasing this proportion. Compared to road transport, carbon emissions are around 80% less and nitrogen dioxide about 35% less.

As a result the issue is receiving more attention with, for example, British Waterways considering the potential for developing inland container ports. Blocks to the regular movement of containers include the lack of regular shipping services by reliable shippers of adequate size, and the additional handling costs involved.

In some areas, including London, investment is being made in the canal infrastructure in order to boost freight transport, and action is being taken to protect the remaining wharves on the Thames.

Air transport

Air transport is currently taxed through Air Passenger Duty.

Carbon emissions from international aviation are currently excluded from UK and international carbon reduction targets. Due to the current and projected rise in passenger numbers, the sector is expected to become a major source of emissions in the future. In 1998, 123.9 million international passengers were carried through UK airports (159.1 million in total, including domestic aviation). Due to the expansion of airport capacity envisaged by the Department for Transport's white paper *The Future of Air Transport*, it is forecast that 470 million passengers are likely to be carried by 2030.

Using the Department for Transport's 'best case' emission forecasts, in their August 2006 report the Environmental Audit Select Committee expect that the sector will account for 24% of the UK's emissions in 2050, compared to around 5% in 2006. In addition, due to a variety of altitude-related factors, carbon emissions from aviation are considered to be between 2 and 4 times as damaging as emissions at ground level. The Select Committee have called for a number of actions to combat this projected emissions increase, including the taxation of aviation fuel, the imposition of VAT on international air tickets, and a rise in Air Passenger Duty.

Industry

Compared to 1990, energy use by industry had fallen by over 5% by 2004.

The highest profile initiative to cut carbon emissions is the European Union Emission Trading Scheme, which is operated in the UK under the 'Greenhouse Gas Emissions Trading Scheme Regulations'. Under Phase I of the scheme, the UK was allocated an allowance of 736 million tonnes of CO_2 for the period 2005-2007 (i.e. an annual average of 245.3 million tonnes). An annual average of 246.2 million tonnes has been set for the Phase II period (2008–2012).

Other measures affecting industry include the Climate Change Levy.

Chapter- 10

Energy Efficiency in British Housing

Domestic housing in the United Kingdom presents a possible opportunity for achieving the 20% overall cut in UK carbon dioxide emissions targeted by the Government for 2010. However, the process of achieving that drop is proving problematic given the very wide range of age and condition of the UK housing stock.

Carbon emissions

Although carbon emissions from housing have remained fairly stable since 1990 (due to the increase in household energy use having been compensated for by the 'dash for gas'), housing accounted for around 30% of all the UK's carbon dioxide emissions in 2004 (40 million tonnes of carbon) up from 26.42% in 1990 as a proportion of the UK's total emissions. The Select Committee on Environmental Audit noted that emissions from housing could constitute over 55% of the UK's target for carbon emissions in 2050.

A 2006 report commissioned by British Gas estimated the average carbon emissions for housing in each of the local authorities in Great Britain, the first time that this had been done. This indicated that housing in Uttlesford (Essex) produced the highest emissions (8,092 kg of carbon dioxide per dwelling). This was 250% higher than housing in Camden (London) which produced the least (averaging 3,255 kg). Among the 23 towns included, Reading had the highest emissions (6,189 kg), with Hull the lowest (4,395 kg). The variations are due to a number of factors, including the age, size and type of the housing stock, together with the efficiency of heating systems, the mix of fuels used, the ownership of appliances, occupancy levels and the habits of the occupants.

Zero carbon ambition

In the December 2006 Pre-Budget Report, the Government announced their 'ambition' that all new homes will be 'zero-carbon' by 2016 (i.e. built to zero-carbon building standards). To encourage this, an exemption from Stamp duty land tax is to be granted, lasting until 2012, for all new zero-carbon homes up to £500,000 in value.

Whilst some organisations applauded the initial announcement of the scheme, in the pre-budget statement from the then UK Chancellor, Gordon Brown, others are concerned about the government's ability to deliver on the promise.

Domestic energy use

A tower block in Cwmbrân, South Wales

The housing stock in the United Kingdom is amongst the least energy efficient in Europe. In 2004, housing (including space heating, hot water, lighting, cooking, and appliances) accounted for 30.23% of all energy use in the UK (up from 27.70% in 1990). The figure for London is higher at approximately 37%.

In view of the progressive tightening of the Building Regulations' requirements for energy efficiency since the 1970s, it might be expected that a significant cut in domestic energy use would have occurred, however this has not yet been the case.

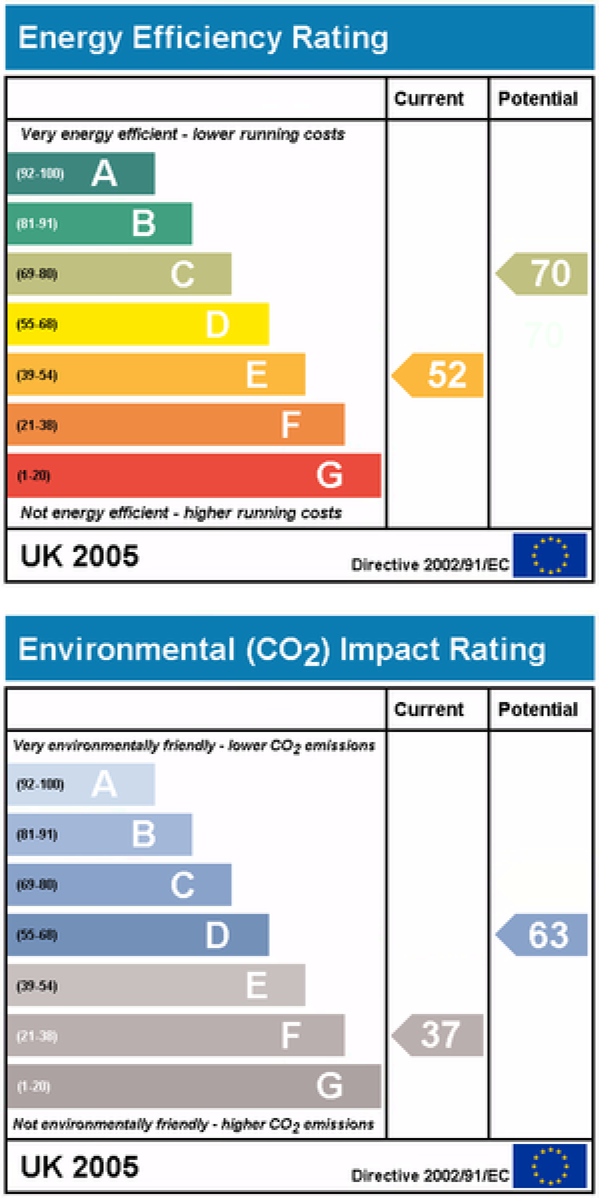
Although insulation standards have been increasing, so has the standard of home heating. In 1970, only 31% of homes had central heating. By 2003 it had been installed in 92% of British homes, leading in turn to a rise in the average temperature within them (from 12.1 °C to 18.20 °C). Even in homes with central heating, average temperatures rose 4.55 °C during this period.

At the same time, the increase in the number of households, increasing numbers of domestic electrical appliances, an increase in the number of light fittings, reduction in the average number of occupants per household, plus other factors, had led to an increase in total national domestic energy consumption from around 25% in 1970 to about 30% in 2001, and remained on an upward trend (BRE figures).

The figures for energy consumed by end use for 2003.

- Space heating - 60.51% (57.61% in 1990)
- Water heating - 25.23% (25.23% in 1990)
- Appliances and lighting - 13.15% (13.4% in 1990)
- Cooking - 2.74% (3.76%)

Building regulations



Home energy performance rating charts

The 1965 Building Regulations introduced the first limits on the amount of energy that could be lost through certain elements of the fabric of new houses. This was expressed as a u-value—the amount of heat lost per square metre, for each degree Celsius of temperature difference between inside and outside.

In effect, the Target Insulation is a ratio of 1.33 W/m²·K of wall area (Document L 2006). So to keep your square metre warm, you are limited as to how much energy you can use. This is slightly regressive in that richer people live in bigger houses which tend to have a lower surface area/floor area, although this is partially offset by them being detached, as opposed to, say, terraced.

These limits were tightened following the 1973 oil crisis, and on several subsequent occasions.

2006 changes

The energy policy of the United Kingdom through the 2003 Energy White Paper articulated directions for more energy efficient building construction. Hence, the year 2006 saw a significant tightening of energy efficiency requirements within the Building Regulations.

With the long term aim of cutting overall emissions by 60% by 2050, and by 80% by 2100, the intention of the 2006 changes was to cut energy use in new housing by 20% compared to a similar building constructed to the 2002 standards. The changes were the first to the regulations brought about by the desire to reduce emissions, though some have raised doubts about whether they will actually achieve the 20% cut.

In the 2006 regulations, the u-value was replaced as the primary measure of energy efficiency by the Dwelling Carbon Dioxide Emission Rate (DER), an estimate of carbon dioxide emissions per m^2 of floor area. This is calculated using the Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP 2005).

In addition to the levels of insulation provide by the structure of the building, the DER also takes into account the airtightness of the building, the efficiency of space and water heating, the efficiency of lighting, and any savings from solar power or other energy generation technologies employed, and other factors. For the first time, it also became compulsory to upgrade the energy efficiency in existing houses when extensions or certain other works are carried out.

Criticism

Some organisations have raised doubts over the claim that the changes will result in a 20% saving. Issues cited have included alleged problems with the calculation methods, the limitations of the modelling software, and the specification of the reference building used in the model. For example, a 2005 study sponsored by the Pilkington Energy Efficiency Trust indicated that the savings would only be in the region of 9%.

There are also concerns about enforcement, with a Building Research Establishment study in 2004 indicating that 60% of new homes do not conform to existing regulations. A 2006 survey for the Energy Saving Trust revealed that Building Control Officers considered energy efficiency 'a low priority' and that few would take any action over failure to comply with the Building Regulations because the matter 'seemed trivial'.

Despite the tightening of the requirements and previous loopholes, the regulations have been criticised by some for not going further. Criticisms include the exclusion of domestic appliances from the calculations, not requiring provision to be made for retrofitting of solar or other technologies, lack of remedial requirements if airtightness tests are failed, and for not requiring greater insulation standards.

A more fundamental criticism by some is that even if the expected 20% cut is achieved, this falls far short of achieving the long term goal of a 60% cut in carbon dioxide emissions by 2050. The London Sustainable Development Commission, for example, has calculated that to meet the 60% target, all new developments would have to be constructed to be carbon-neutral with immediate effect (using zero energy building techniques), in addition to cutting energy used in existing housing by 40%.

A further issue is the omission of the impact of domestic sector air conditioning in the projections. Air conditioning is beginning to gain acceptance in the domestic sector, driven in part by cheap self-install systems from the Pacific Rim, but with the established brands now also offering specifically targeted professionally installed ranges. Demand for cooling systems is rising mainly due to increased awareness, since air conditioning is standard on almost all new cars sold in the UK and also in the commercial sector, but also because of tight housing densities and long working hours, leading to problems with heat at night. The latter problem is compounded by the 'energy efficient' new build features such as tight insulation and small windows.

Older buildings often perform poorly under the government rules, but if they are listed buildings cannot easily be modified to meet the regulations. The regulations also neglect to allow for use of wood-burning stoves and similar highly efficient appliances.

Future changes

In December 2006, the government announced their ambition that all new housing should be build to zero-carbon standards from 2016; i.e., that the carbon emitted during a typical year should be balanced by renewable energy generation. Despite being the first country in the world to adopt such a policy the initiative was generally welcomed by the industry in principle, despite some subsequent concern over the practicalities.

In 2004, the Government indicated that the next revision to the energy performance standards of the Building Regulations would be in 2010. In the consultation document *Building a Greener Future: Towards Zero Carbon Development* it is proposed that the 2010 revision should require a further 25% improvement in the energy/carbon performance, in line with the 2004 proposals. It is further envisaged that there would be a 44% improvement in 2013, compared to 2006 levels. This would then be followed by the adoption of a zero carbon requirement in 2016, applied to all home energy use including appliances. These steps in performance would align the energy efficiency requirement of the Building Regulations with those of Levels 3, 4 and 6 of the Code for Sustainable Homes in 2010, 2013 and 2016 respectively.

Home energy labelling

Originally, from June 2007, all homes (and other buildings) in the UK would have to undergo Energy Performance Certification before they are sold or let, in order to meet the requirements of the European Energy Performance of Buildings Directive (Directive 2002/91/EC). The scheme provides the owner or landlord with an 'energy label' so that they can demonstrate the energy efficiency of the property, and is also included in the new Home Information Packs. The scheme has been criticized for its methodology and superficial approach, especially for old buildings. For example, it ignores thick walls with their low heat transmission, and its recommendations for compact fluorescent lamps, which can damage sensitive textiles and paintings.

It is hoped that energy labelling will raise awareness of energy efficiency, and encourage upgrading to make properties more marketable. Incentives may be available for carrying out energy conservation measures.

For new building, SAP 2005 calculations are to form the basis for the certification, while RDSAP (Reduced Data SAP) will be used to assess existing properties. It is estimated that only 10% of the nation's housing will score above 60 on the scale, although most will score above 40.

Other rating schemes

Another rating scheme of note is the Government sponsored EcoHomes rating, mostly used in public sector housing, and only applicable to new properties or major refurbishments. This actually measures a range of sustainability issues, of which energy efficiency is only one. EcoHomes is to be replaced by the Government's Code for Sustainable Homes in 2007.

The Energy Saving Trust set requirements for 'good practice' and 'advanced practice' for achieving lower energy buildings, while the Association for Environment Conscious Building's *CarbonLite* programme specifies Silver and Gold standards, the latter approaching a zero energy building.

In Wales where 'zero-carbon homes' are the aspiration for 2011 (although 2012 is more likely) the requirements are for Code for Sustainable Homes or equivalent. This has opened the doors for standards like Passiv Haus and the CarbonLite programme. Another lesser known building type that does not rely on airtightness in order to get its energy rating is Bio-Solar-Haus. This is not a well known type of house, but it has a range of positive advantages like it is built out of renewable resources and it is a breathable structure thus making it much healthier to live in.

Grants

rooftop turbine

The Government's low carbon buildings programme was launched in 2006 to replace the earlier *Clear Skies* and *Solar PV* programmes. It offers grants towards the costs of solar thermal heating, small wind turbine, micro hydro, ground source heat pump, and biomass installations. As of January 2007 funding for grants is proving insufficient to meet demand.

A similar scheme, the Scottish Community and Household Renewables Initiative operates in Scotland, which also offers grants towards the cost of air source heat pumps.

Local government

Under the Home Energy Conservation Act 1995, local authorities are required to consider measures to improve the energy efficiency of all residential accommodation in their areas, although they are not required to implement any measures. Most local authorities provide free advice on energy conservation and some also provide home visits, often targeting those in social housing and the fuel poor. Some also demand minimum levels of energy efficiency in newly constructed buildings. It was expected that the Act would result in a 30% cut in energy usage between 1996 and 2010. An overall cumulative improvement of 14.7% was reported to DEFRA for the year ending March 2004, but a large part of this would have happened without HECA.

In the South, most local authority housing was sold off in the 1980s-90s under RTB (Right to buy scheme), so the remaining stock is small. Much social housing has also been transferred to housing associations.

Demonstration and pioneering projects

BedZED zero energy housing

One of the most important energy efficiency demonstration projects was the 1986 Energy World exhibition in Milton Keynes, which attracted international interest. Fifty-one houses were built, designed to be at least 30% more efficient than the Building Regulations then in force. This was calculated using the Milton Keynes Energy Cost Index (MKECI), a test-bed for the subsequent SAP rating system and the National Home Energy Rating scheme.

The Beddington Zero Energy Development (BedZED), a non-traditional housing scheme of 82 dwellings near Beddington, London included zero energy usage as one of its key features. The project was completed in 2002 and is the UK's largest eco-development. The only energy used is generated from renewables on site. Due to their superinsulation, the properties use 88% less energy for space heating compared to those built to the 2002 Building Regulations, while the reduction for water heating is 57%.

The Green Building in Manchester City Centre and has been built to high energy efficiency standards and won a 2006 Civic Trust Award for its sustainable design. The cylindrical shape of the ten storey tower provides the smallest surface area related to the volume, ensuring less energy is lost through thermal dissipation. Other technologies including solar water heating, a wind turbine and triple glazing.

The South Yorkshire Energy Centre at Heeley City Farm in Sheffield is an example of refurbishing an existing property to show the options available.

The EcoHouse in Leicester incorporates products and materials selected for their green credentials, and operates as an advice centre with videos on products and suppliers, and refurbished computers for sale.

There are many owner occupied, existing home retrofits which achieve a 60% carbon saving which can be visited or viewed on the website www.superhomes.org.uk. Many of the homes have dramatically improved their energy efficiency to achieve these carbon savings, some have also installed renewable energy technologies.

International comparisons

International comparisons of particular note include:

- The 1977 Danish *BR77* standard (the first to set demanding energy efficiency requirements).
- The SBN-80 (Svensk Bygg Norm) 1980 Swedish Building Standards, which in 1983 was in advance of the UK 2002 standards.
- The voluntary Canadian R-2000 standard, to which around 14,000 houses had been built in the 10 years to 1992.

Since then many more have been built in Canada, in Japan, and in various other countries including a number in the UK. Currently energy savings of 30% to 40% are typically achieved in Canada.

- The voluntary German Passivhaus standard. Properties built to the standards use approximately 85% less energy and produce 95% less carbon dioxide compared to properties built to the UK's 2002 standards. Over 6,000 such houses have been built across several European countries.
- The voluntary Swiss Minergie standard which requires that general energy consumption must not to be higher than 75 % of that of average buildings and that fossil-fuel consumption must not be higher than 50 % of the consumption of such buildings, and the Minergie-P standard, requiring virtually zero energy consumption.

Research

In 2005, the Select Committee on Environmental Audit expressed their concern that there was a lack of significant funding for research and development of sustainable construction methods, with funding for the Building Research Establishment having been "drastically" cut in the previous 4 years. As a result, many of the sustainable building materials used in the UK are imported from Germany, Switzerland and Austria—some of the countries that have been prominent in research.

Existing housing stock

Even if all new housing does become zero carbon by 2016, the energy efficiency of the remainder of the housing stock would need to be addressed.

The 2006 *Review of the Sustainability of Existing Buildings* revealed that 6.1 million homes lacked an adequate thickness of loft insulation, 8.5 million homes had uninsulated cavity walls, and that there is a potential to insulate 7.5 million homes that have solid external walls. These three measures alone have the potential to save 8.5 million tonnes of carbon emissions each year. Despite this, 95% of home owners think that that the heating of their own home is currently effective.

Historic building regulations energy efficiency requirements

The u-value limits introduced in **1965** were:

- 1.7 for walls
- 1.4 for roofs

Following the 1973 oil crisis, these were tightened in **1976** to:

- 1.0 for exposed walls, floors and non-solid ground and exposed floors
- 1.7 for semi-exposed walls
- 1.8 average for walls and windows combined
- 0.6 for roofs

1985 saw the second tightening of these limits, to:

- 0.6 for exposed walls, floors and ground floors
- 1.0 for semi-exposed walls
- 0.35 for roofs

These limits were reduced again in **1990**:

- 0.45 for exposed walls, floors and ground floors
- 0.6 for semi-exposed walls
- 0.25 for roofs

- plus a requirement that the area of windows should not be more than 15% of the floor area.

Like the 2006 changes, it was predicted that the introduction of these limits would result in a 20% reduction in energy use for heating. A survey by Liverpool John Moores University predicted that the actual figure would be 6% *(Johnson, JA "Building Regulations Research Project")*.

In the **1995** Building Regulations, insulation standards were cut to the following U-values:

- 0.45 for exposed walls, floors and ground floors
- 0.6 for semi-exposed walls and floors
- 0.25 for roofs
- the limit on window area was raised to 22.5%

The **2002** regulations reduced the U-values, and made additional elements of the building fabric subject to control. Although there was in practice considerable flexibility and the ability to 'trade off' reductions in one are for increases in another, the 'target' limits became:

- 0.35 for walls
- 0.25 for floors
- 0.20 or 0.25 for pitched roofs (depending on the construction)
- 0.16 for flat roofs
- 2.2 for metal framed doors and windows
- 2.0 for other doors and windows
- the limit on window area was raised again to 25%

Similar limits were introduced into Scotland in 2002 & 2006, though with a lower limit of 0.3 or 0.27 for walls, and some other variations.

It was claimed by Government that these measures should cut the heating requirement by 25% compared to the 1995 Regulations. It was subsequently also claimed that they had achieved a 50% cut compared to the 1990 Regulations.

While the u-value ceased being the sole consideration in **2006**, u-value limits similar to those in the 2002 regulations still apply, but are no longer sufficient by themselves. The DER, and TER (Target Emission rate) calculated through either the UK Government's Standard Assessment Procedure for Energy Rating of Dwellings (SAP rating), 2005 edition, or the newer SEBM* (*Small Energy Building Model)which is aimed at non-dwellings, became the only acceptable calculation methods. Several commercial energy modeling software packages have now also been verified as producing acceptable evidence by the BRE Global & UK Government. Calculations using previous versions of SAP had been an optional way of demonstrating compliance since 1991(?). They are now a statutory requirement (B. Reg.17C et al.) for all building regulations applications, involving new dwelling/buildings and large extensions to existing non-domestic buildings.