UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

Sustainability Project: Incandescent, Fluorescent, and LED

Mark Tanaka

Zengxun Eddy Yang

Tuan Anh Trinh

Nick Matwyuk

Wilson Tran

Kevin McConville

University of British Columbia

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Mark Tanaka
Zengxun Eddy Yang
Tuan Anh Trinh
Nick Matwyuk
Wilson Tran
Kevin McConville

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Table of Contents

Abstract

This paper analyses environmental, economic, social aspects of Compact fluorescent Lights (CFLs), incandescent light bulbs and LEDs. The environmental aspect is evaluated by the life cycle for each bulb. In this analysis, the effect from each type of bulb to the environment and human due the manufacturing to disposal phase are taken into account. Finally, the environmental impact of these bulbs will be compared and evaluated based on the lighting quality and clean technology. LEDs were determined to be the most environmentally friendly choice because there were no harmful chemicals and provided the lowest greenhouse gas emissions over its lifetime.

The economic analysis will focus on the cost from the manufacturing and operation phase to the disposal phase of these bulbs. These bulbs will be compared based on their durability, the cost for each life cycle. Finally, each type of bulb will be evaluated to be the most efficient bulbs in term of the cost to produce and the ability to reduce energy consumption. LEDs were found to have the lowest operating costs at $1.51 per 10^6 Lumen-hours.

The social analysis will take human health social aspect into account. This analysis will evaluate people's opinion on different type of bulbs and their effort to reduce energy consumption and help the environment. Through this analysis, LEDs were found to have no known ill effects or negative social impacts.

Introduction

The new Student Union Building (SUB) is a building which will be designed by the students, and for the students. For this reason it is being designed with a LEED Platinum rating, the highest sustainability rating a building can receive. The following report outlines 3 candidates which will be compared for their use as light bulbs in the new SUB. The candidates will be compared based on their environmental impact from dust to dust, their economic impact throughout their lifetime as well as social impacts that arise from the various light bulbs. The 3 types of light sources studied are incandescent, fluorescent and LED: all of which are explained below:

"Incandescence is the emission of light (visible electromagnetic radiation) from a hot body due to its temperature." (Wikipedia) This is how incandescent bulbs create their light, hence their name. This is a very inefficient way of creating light as it is just a by product of the heat generation. In fact, "...about 90% of the energy they emit is in the form of heat (also called infrared radiation)" (GE). Although this heat can be advantageous in colder climates, it still represents more electricity to generate light.

Compact fluorescent light bulbs (CFLs) are a type of energy-saving bulb that fits into a standard light bulb socket or plugs into a small lighting fixture. Today, CFLs seem to be gaining in popularity. However, these types of light bulbs can also be toxic to your home and the environment if they don't get recycled properly. According to Gydesen and Maimann: " CFLs contain many toxic chemicals such as neon, lead powder, mercury and fluorine, which can cause problems during the manufacturing and disposal process because mercury can be emitted to the air and pollutes the atmosphere and the water".

CFLs are filled with a gas that contains mercury vapour and argon. The inner surface of the bulb is coated with a fluorescent coating made of varying blends of metallic and earth phosphor salts. Although CFLs are more energy efficient than incandescent light bulbs of an equivalent brightness, they don't produce steady light and tend to burn out more frequently.

An LED, or light emitting diode, is what's called a "solid-state lighting" technology, or SSL. Instead of emitting light from a vacuum (as in an incandescent bulb) or a gas (as in a CFL), an SSL emits light from a piece of solid matter. In the case of a traditional LED, that piece of matter is a semiconductor. Stated very simply, an LED produces light when electrons move around within its semiconductor structure. A semiconductor is made of a positively charged and a negatively charged component. The positive layer has openings for electrons; the negative layer has free electrons floating around in it. When an electric charge strikes the semiconductor, it activates the flow of electrons from the negative to the positive layer. Those excited electrons emit light as they flow into the positively charged holes.

Environmental Aspects

Embodied Energy requirements

Energy for Manufacturing

The energy required to manufacture each of the three light bulb options are analyzed.

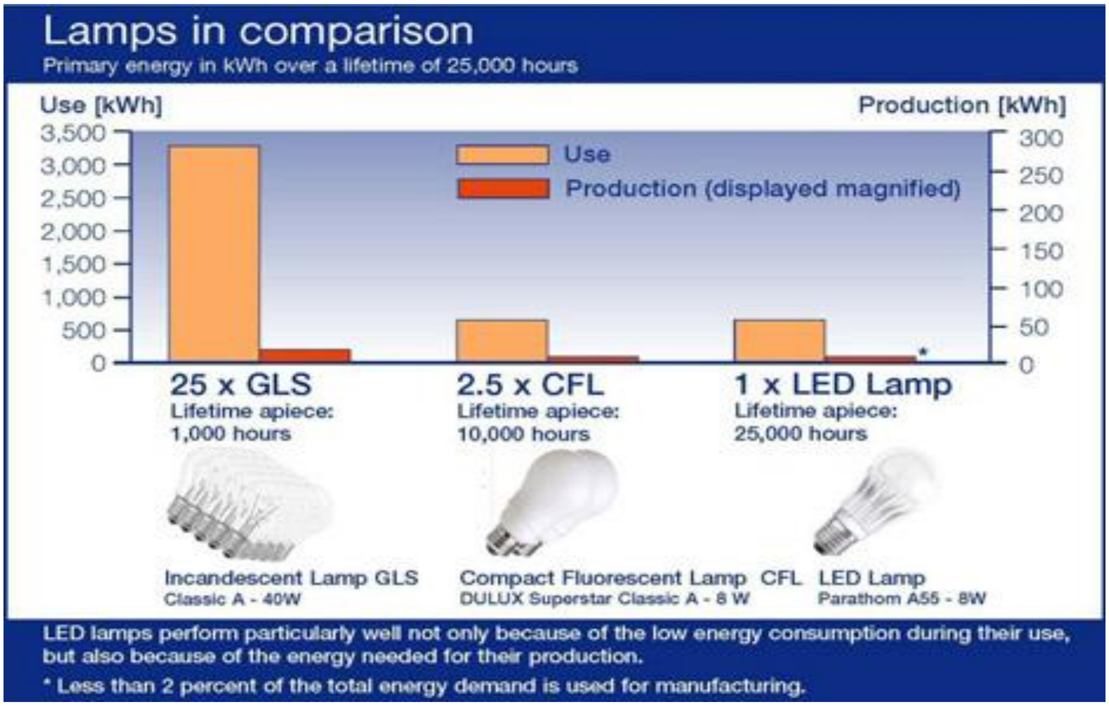

Figure 1 - Incandescent vs. CFL vs. LED

Incandescent

The process to manufacture an incandescent light bulb is quite simple. It requires a filament which creates the heat and light, a glass bulb, and aluminum and brass base for the connection piece. The energy required to produce this can be seen in the table below: (Ben)

	Energy Embodied (in kW-h)
Glass	0.17
Plastic	0
Electronics	0
Brass	0.18
Total	0.29 kW-h

Fluorescent

The amount of energy required to manufacture the various components of a 15W compact fluorescent light (CFL) bulb are as follows: (Ben)

	Energy Embodied (in kW-h)
Glass	0.17
Plastic	0.68
Electronics	0.66
Brass	0.18
Total	1.69 kW-h

It should be noted that because the typical compact fluorescent light bulb lasts, on average, about 10 times longer than an equivalent incandescent bulb (see Figure 1), for the purposes of comparison, we should be taking one-tenth of the value given. This gives us 0.169kW-h in equivalence to an incandescent bulb for the embodied energy of a CFL.

LED

The amount of energy required to manufacture an LED is broken down into the materials it is made out of and the energy required producing it.

	Materials Production Energy (kWh)
copper	0.26
aluminum	6.6
plastics	0.3
copper	1.1
aluminum	5.4
plastics	0.9
Total	14.56 kW-h

Creating a comparison with the incandescent bulb as the baseline, one can see from figure 1 that 1 LED lasts as long as 25 incandescent bulbs thus having an equivalent energy of only 0.582kW-h.

Conclusion

From these values we can see that based on energy for production, the LED requires the most at 0.582kW-h/bulb. The fluorescent and incandescent bulbs have an energy requirement of 0.169kW-h/bulb and 0.29kW-h/bulb respectively.

Energy during Operation

Incandescent

The current average lifespan of a 40W incandescent light bulb is approximately 1000 hours. This yields a lifetime consumption of 40kW-h of energy

Fluorescent

The current average lifespan of a 15W CFL bulb is approximately 10,000 hours. Given this, we can easily determine that over its lifetime, it will consume 120kW-h of energy. Again, we must keep in mind the difference in lifespan of this bulb relative to our benchmark, the incandescent bulb. This yields an equivalent energy of 12kW-h of energy. This requires about 3 times less energy than an equivalent incandescent bulb.

LED

According to Figure 1, an 8W LED Lamp is used to produced light for 25,000 hours. And the energy usage is about 200kW-h. With respect to our benchmark this yields an equivalent energy of only 8kW-h. This requires 5 times less energy than an equivalent incandescent bulb.

Conclusion

In summary, the operational energy consumption of LED bulbs rank the best with a energy usage of 8kW-h per 1000 hours followed by CFL's with 12kW-h per 1000 hours and finally incandescent with 40kW-h per 1000 hours of usage.

Energy for Disposal

Incandescent

There are currently no recycling methods for the incandescent light bulbs. The only energy that is used is the transportation costs to take them to the landfills. This energy will be the same as the transportation costs of the CFL's and LEDs during their respective transportation. Therefore, the transportation costs will not be reviewed and the benchmark incandescent bulbs will have a disposal value of 0.00 kW-h.

Fluorescent

There currently haven't been any studies done to determine the actual amount of energy consumed in order to properly recycle a compact fluorescent bulb, or any fluorescent light bulb, for that matter. Most studies which have conducted a life cycle analysis on CFL bulbs have made the qualitative estimate that the amount of energy to dismantle and recycle the bulb will be approximately the same as the amount of energy required to manufacture a bulb. Assuming this to be true, the energy to dispose each bulb will be 1.69kW-h. Considering the scale of this number relative to the amount of energy consumed during its use (1.69kW-h versus 120kW-h), even a large error in this assumption would make the number insignificant relative to the usage energy consumption. Even still, this is 1.69kW-hmore than an incandescent bulb.

LED

No recent studies have been done to determine the actual amount of energy consumed in order to properly recycle LEDs. Because there are no toxic materials used for manufacturing LED light bulbs, recycling LED light bulbs should be easier and use less energy than CFLs.

Conclusion

Due to the lack of harmful components and recycling facilities, incandescent light bulbs have the lowest energy for disposal. Since there have been few studies done on the energy for disposal of LED and CFL, we cannot determine which will requires less energy.

Embodied Greenhouse gases and Ecological footprint

In order to analyze the greenhouse gases and ecological footprints of CFL, LED and incandescent light bulbs, it is important to consider the emissions during their respective life cycles. Their emissions are calculated per 10 millions lumen hours. (Gydensen and Maimann)

Emissions	**CFL**	**Incandescent**	**Reduction**
Manufacturing and operation			
C02	14.4 kg	70.0 kg	52.6 kg
S02	0.11 kg	0.53 kg	0.42 kg
N0x	0.05 kg	0.35 kg	0.28 kg
CH4	0.05 g	0.25 g	0.20 g
Fly ash	0.82 kg	4.00 kg	3.18 kg
Mercury	1 mg	4.86 mg	3.86 mg
(gaseous/solid split)	0.4/0.6	1.94/2.92	1.54/2.32
Disposal			
Mercury	0.69 mg	none	-0.69 mg
Solid waste	0.015	0.02	0.027
Total mercury	1.69 mg	4,86 mg	3.17 mg
Total waste	0.83 kg	4.04 kg	3.21 kg

CFLs consume much less energy during operation than the incandescent lamps. According to the table above, in the long term, for a location that receives its energy from coal-powered power plants, the amount of chemicals released during the manufacturing and operation phase of CFLs are lower than those of incandescent light bulbs (1mg for CFL, 4.86mg for incandescent). In the disposal phase, the amount of solid waste in CFLs is less than incandescent light bulbs. However, the mercury amount of 0.69 mg in CFLs needs to be treated properly to avoid the possibility of mercury escaping into the environment, which is highly dangerous. Incandescent light bulbs don't harm the environment once disposed of in the landfill, thus is the more environmentally sound choice, especially taking into consideration that most of our province runs on emission-free hydroelectric power.

An OSRAM study of LED life-cycle analysis looked at how much energy and raw materials the lamps consume in terms of production, use and disposal and the environmental impact involved in the process. The study confirmed that LEDs accomplish the life-cycle analysis values of CFLs and are far superior to conventional incandescent lights. OSRAM (2008) states that, "The results allow for conclusions not only on resource consumption and primary energy input but also acidification, eutrophication, the greenhouse effect, ozone depletion and toxicity."

Conclusion

Life-cycle analysis studies conclude that LEDs and CFLs have far lower embodied greenhouse gases than incandescent. CFLs have environmental issues related to mercury contamination, but as better recycling practices are exercised these environmental risks could be mitigated. However there will still be no way to fully contain the mercury. Some CFLs will still inevitably break by accident, thus releasing the harmful chemicals into the environment. While incandescent have a higher greenhouse gases they have no disposal cost. Based on this information, LED's have the lowest combined greenhouse gases and disposal cost.

Economic Aspects

Manufacturing

Incandescent

Raw Materials

- Cardboard (packaging)
- White Glass
- Steel

Material Manufacture

5.25g Cardboard	0.171	MJ/bulb
20.00g White Glass	0.242	MJ/bulb
10.00g Steel	0.253	MJ/bulb
Total Energy For Production	0.666	MJ/bulb

Fluorescent

As there is little information available regarding the manufacturing costs of a CFL, we can only provide an estimate. The current average selling price per 15W CFL bulb is $5. If we assume that the profit from the retail selling price is 40%, then we get a manufacturing cost of about $3 per bulb, with variations depending on the type and output of the bulb.

LED

It seems difficult to get information about manufacturing cost of a LED light bulb. However, based on our research, the average selling price for a LED light bulb is about $40~$110. Assuming the profit for selling a LED light bulb is around 40% of selling price, then the manufacturing cost of LED is approximately $24-60 depend on the type of LED light bulb.

Operation

Incandescent

Light Output	1600	Lumens
Life	1125	Hours
Energy Use Rate	100	Watt
Purchase Cost	2.40	$/bulb
Energy Cost	0.0827	$/kWh
Disposal Cost	0.0	$/bulb
Light output over life	1.8 x 10^6	Lumen-Hours

Total Cost = Purchase Cost + (Energy Cost)x(Energy Use Rate)x(Life) + Disposal Cost

Total Cost = $2.40 + (($0.0827/kWh)x(0.1kW)x(1125h) + ($0.0)

Total Cost = $11.70/bulb

Total Cost per 10^6 Lumen-Hours = Total Cost / Light output over life x 10^6

Total Cost per 10^6 Lumen-Hours = $11.70 / (1.8 x 10^6) x 10^6 = $5.15 per 10^6 Lumen-Hours

Fluorescent

Light Output	900	Lumens
Life	10000	Hours
Energy Use Rate	15	Watt
Purchase Cost	5.00	$/bulb
Energy Cost	0.0827	$/kWh
Disposal Cost	3.00	$/bulb
Light output over life	9 x 10^6	Lumen-Hours

Total Cost = Purchase Cost + (Energy Cost)x(Energy Use Rate)x(Life) + Disposal Cost

Total Cost = $5.00 + (($0.0827/kWh)x(0.015kW)x(10000) + ($3.00)

Total Cost = $20.405/bulb

Total Cost per 10^6 Lumen-Hours = Total Cost / Light output over life x 10^6 Lumen-Hours

Total Cost per 10^6 Lumen-Hours = $20.405 / (9 x 10^6) x 10^6 = $2.27 per Lumen-Hours

For our analysis, we will continue to look at compact fluorescent light bulbs. A 15W CFL running for its 10000 hour lifetime will consume 150kW-h of energy. In BC, the current cost of electricity is $0.0827 per kW-h, so the usage cost will be $12.41 for each bulb. For continued usage of these bulbs, we need to also consider that CFLs will require 8 times fewer changes due to its life span than an incandescent light bulb. (Hydro)

LED

Light output	900	Lumens
Life	>50000	Hours
Energy Use Rate	8	Watt
Purchase Cost	35	$/bulb
Energy Cost	0.0827	$/kWh
Disposal Cost	0	$/bulb
Light output over life	45 x 10^6	Lumen-Hours

Total Cost = Purchase Cost + (Energy Cost)x(Energy Use Rate)x(Life) + Disposal Cost

Total Cost = $35.00 + (($0.0827/kWh)x(0.008kW)x(50000) + ($0.00)

Total Cost = $68.08/bulb

Total Cost per 10^6 Lumen-Hours = Total Cost / Light output over life x 10^6 Lumen-Hours

Total Cost per 10^6 Lumen-Hours = $68.08 / (4.5 x 10^7) x 10^6 = $1.512 per 10^6 Lumen-Hours

For our analysis, an LED light bulb can last up to 50,000 hours compared to 10,000 for compact fluorescent and 1,000 for an incandescent. In BC, the current cost of electricity is $0.0827 per kW-h, according to Figure 1, the cost of running 8 W LED for 50000 hours is $33.08 per bulb which the compact fluorescent will cost 2.5 times more. (Osram Opto Semiconductors)

Disposal

LED and incandescent bulbs will not be considered as their disposal cost is 0 as stated in the Energy for Disposal Section. The United States is a country with a large population, thus conserving energy and natural resources are critical issues. According to Ramroth: “For the period of 10,000 hour period, by using CFL instead of an incandescent can save 191 lbs of coal. So, if everyone if the United States replaces their 100W light bulb with a 23 W CFL, 29 million tons of coal can be saved” (Ramroth, 2008). By replacing incandescent light bulbs with CFLs will reduce the amount of total coal consumption in the United States by 2.6%.Clearly there are many benefit of using CFLs instead of incandescent light bulb. According to emission table above, the amount o mercury and total wasted are reduced significantly. However, at the disposal stage, there is a cost of 0.50 $ to recycle each CFL. In the United States for examples, 600 millions of CFLs are disposed each year and the cost to recycle these light bulbs can be very extremely expensive.

Conclusion

It is difficult to compare manufacturing costs due to the limited research done in this area. Instead the sales price of each can be compared to gauge the best product. Incandescent bulbs, being the most widely used have the lowest sales cost of $2.40, followed by CFL’s at $5.00 and finally LED at $35.95.

LED is a new technology which is still being advanced and developed. As seen with CFLs, the price will continually decrease with improving technology. These are baseline costs not taking into account the longevity of the bulbs. During operation the cost per 10^6 Lumen-hours were compared. LED were superior with a cost of $1.51, CFLs have a cost of $2.27, while Incandescent were the worst at $5.15. As stated in section Energy for Disposal, LED and Incandescent bulbs do not have a disposal cost, however due to the mercury contained in CFLs they have a disposal cost of $3 per bulb. Based on the economic analysis the LED is the optimum choice for the new SUB.

Social Aspects

Light Temperature

Every colour has a different temperature. This is important because each light bulb generates a different colour. Some examples of what colour temperatures are like are shown in the following table.

COLOUR TEMPERATURE	Kelvin	USE
Warm / Soft White	< or = to 3200K	Daily living, bedroom, rec room, living room, family room
Cool / Bright White	3200 – 4000K	Work, garage, hobby room, kitchen, bathroom
Daylight	> or = to 4000K	Detail, reading, or accurate colour rendition

http://www.economicallysound.com/lighting_basics_for_your_basic_bulb_purchase.html

Fluorescent bulbs range from 3000K to 7500K (Range). Incandescent bulbs range from 2700K to 2900K (Range). LED bulbs range from 2650K to 5400K (Sharp).

Incandescent light bulbs have the smallest range of colour temperature while fluorescents have the widest range and LED's are in the middle. This means that the new technologies have brought about a wider range of possibilities for colour temperatures. This gives another advantage for converting away from incandescent bulbs.

Health aspects

Another aspect to consider is the non-functional concerns related to these light bulbs. For instance, mercury is required in the manufacturing of fluorescent light bulbs. That is a harmful substance that needs to be properly disposed of. Anyway to avoid introducing more toxic chemicals should be implemented. There are also some health aspects related to fluorescent light bulbs that are of concern for "migraine suffers, epileptics and persons with autism and fetal alcohol spectrum disorder (FASD)" (Illness). The lights cycle at 60Hz and can cause ill effects such as migraines and seizures in epileptics and worsening skin rashes for people with dermatitis, eczema, lupus, photosensitivity, porphyria and xeroderma pigmentosum (Natural).

Human rights

It is imperative all people have their fundamental human rights without discrimination. Sustainability should not be strictly focused on the environmental issues. One could argue the social issues are just as important. We encourage UBC to make a commitment that the manufacturer of the lights for the new SUB is committed to the protection and advancement of human rights. The manufacturer should uphold a high standard of human rights policies concerning child labour, employee quality of life, safety, harassment and violence. At this point, we can not state a preference for a certain type of light as it applies to individual companies.

Resistance to change

Aside from the technical issues with regards to the different types of light bulbs, there is also a social aspect to be considered. While saving money and energy, as well as reducing our ecological footprint is important, there are some challenges to incorporating a new lighting system. Generally speaking, most people will prefer the incandescent light bulbs for their warmer indoors-suitable light. Also, an issue that arises with CFLs is their flickering during operation, which is widely regarded to cause potential headaches. The rate of flickering is at a frequency that the human brain cannot detect, however the widely accepted belief is that it does cause problems. Generally there aren't any current concerns with LED solid-state lighting, as the general public hasn't been widely exposed to the technology in a space-lighting application yet, but undoubtedly there will be social issues with attempting to implement such technologies as well.

Conclusion & Recommendations

After much research in the various areas under the broad sustainability scope there was a lot learned and even more to be explored. With consideration to the environmental, economic, and social aspects there was found to be a clear winner in most categories while others were too hard to pick one or the other.

First off, LEDs have the lowest environmental impact as they ranked second in manufacturing energy, tied for second for disposal, and ranked first in operation with the lowest energy required. The disposal and manufacturing energies make up a small fraction of the total energy required in the lifespan of a bulb so are considered negligible. In that case the LED is the clear winner.

Secondly, LEDs also came on top for economic aspects as well. As is the case for the environmental aspects, the cost of manufacturing and disposal is far less than that of the operating cost. In this case, with the LEDs superior life span it has the lowest operating cost.

Lastly, there are many subjective categories that go along with light bulbs. Light temperature is one such category and with advances in technology, LEDs and CFLs can be created with light temperatures equally that of incandescent light bulbs. Fluorescents have a unique capability to cause health concerns for people such as seizures for epileptics, this is not acceptable. Also, it is not right to force a person to do something that is not what they want to do. On the other hand, by educating people about the advantages of alternative lighting sources they might be swayed to think otherwise.

Through our analysis of these three lighting technologies, the LED bulbs stood out in most of the categories. The only downside for the use of LEDs is the initial cost which is offset by its longevity. The manufacturing, production, and disposal costs of bulbs is only a small fraction of the total cost. Operation costs make up around 99% of the total cost. Therefore, with the lowest operating cost and lack of harmful chemicals, LEDs are deemed the most economical and environmentally viable choice.

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