Economic and Environmental Cost Assessment of Lighting at UC Berkeley

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ABSTRACT

Improving lighting efficiencies is an attractive opportunity towards reducing the carbon footprint and operational costs on college campuses. However, it is difficult to quantify savings for a specific institution because of the effort it requires to perform a large-scale audit with many variables involved. In this cost-benefit analysis paper, I will focus on the UC Berkeley campus while using expedient methods in order to reduce the complexity of energy auditing a large institution. I will estimate the monetary and carbon costs of lighting under current lighting technologies and practices. After, I will extend the lighting cost calculations operating from better lighting technologies such as LEDs. The findings show that there are attractive benefits in the magnitude of millions of dollars and grams of CO2 saved over a few years. However, there are still notable barriers that prevent college campuses across the country to invest in lighting efficiency.

KEY WORDS

lighting, energy efficiency, carbon costs, climate change, savings

INTRODUCTION

Why is lighting important? We turn on a switch to light up a room, which allows us to see better. We turn off the switch when not in use to save energy and money. However, I believe it will be surprising to look at the costs when we move the conversation from a household level to the scope of lighting applied to a large area across a large time period. Advancing lighting efficiency is a worthwhile investment because lighting is crucial to driving human activity. Lighting bears a tremendous monetary and environmental cost to operate, accounting for "15 percent of global electricity consumption and 5 percent of worldwide greenhouse gas emissions" (Dreyfus). About 216 billion kwH was used for lighting alone in the U.S, which translates to an average cost of about $324 million dollars. In addition, lighting contributes to about 5% of global greenhouse gas emissions, which is still significant considering the many ways greenhouse gases are emitted through the transportation or agriculture sector. Hopefully, there is an understanding of the magnitude of the costs associated with something as simple but necessary like lighting. Implementing efficient lighting technologies and practices is an attractive way to reduce spending and further meet climate change goals on a global scale. Major energy organizations such as Clean Energy Ministerial have supported the movement as well as they created a lighting initiation to deploy 10 billion lighting solutions at the 2015 Paris Climate Conference. This cost analysis paper aims to apply this operation to a smaller scale on a college campus like UC Berkeley in hopes of finding insights and creating reproducibility with other college campuses.

It is critical to define the goals of an "efficient" lighting technology when approaching this paper in a comparison framework. The central goal is to compare the monetary and emissions cost, but there are many factors associated with lighting that need to be accounted for as well. Specifically, this paper will focus on the savings associated with light-emitting diode (LED) bulbs compared to fluorescent bulbs, which consume more wattage and have a shorter lifetime.

A central topic in this research paper is to evaluate the justification for transitioning to more efficient lighting technologies after evaluating the status quo of UC Berkeley's lighting costs. One way to look at this is to explore if it is economically attractive to invest in new lighting technologies by looking at the payback period of these technologies.

Incandescent bulbs vs LED bulbs

Attribute	Incandescent bulb	LED bulb
Product	GE 60-W, 4-pack, soft white	Philips 60-W equivalent, soft white, dimmable, 4-pack
Model number	41028	200952P
Price per bulb	$2.06	$3.25
Brightness (lumens)	840	800
Power (W)	60	10.5
Efficacy (lm/W)	14	76
Lifetime (h)	1000	25,000

[a] Data from amazon.com on 31 August 2016.

(Reference: CE 107: Climate Change Mitigation Lighting Comparison)

METHODS

Data Description

The lighting data used in my cost analysis is provided by the Cal Energy Office, a facility service that monitors and manages energy use of the UC Berkeley campus. Specifically, I was provided with a spreadsheet containing lighting data from Tan Hall, a recently LED retrofitted campus building. In addition, I was provided with a list of campus buildings that presently operates under linear fluorescent lighting. For my cost benefits analysis, I will focus on the economic and environmental savings of the LED retrofit in Tan Hall, and then extend my results on the fluorescent-lit buildings under the assumption that they will receive the same retrofit changes.

The primary variable of interest in this cost analysis will be the annual kilowatt-hour (kWh/year) consumption of a building, which represents the amount of energy required to sustain a bulb for an hour on an annual scale. Most importantly, the kWh is a convenient billing unit for electricity companies, which simplifies the monetary calculation of energy costs. Similarly, there are standard conversion units for a bulb's kWh expenditure to its carbon intensity (CO2/year) based on the type of energy source that the electricity was created from.

Calculating Costs

To complete an expedient energy audit, the variables of (1) wattage usage per fixture, (2) number of fixtures, and (3) operating hours per fixture need to be collected for each building. Using these three variables, I am able to calculate the annual kWh consumption for each building which allows me to further calculate the monetary and environmental costs of lighting. The annual kWh consumption is provided directly in the lighting data from the Energy Offices.

kWh Calculation of a 10.5 Wattage Bulb Operating Daily for 3 Hours

***10.5 W × 3 h d-1 × 365 d y-1 × 1 kWh/1000 Wh = 11.5 kWh/year**

Calculating the monetary costs associated with lighting will require a checkup with the electricity rates of the provider. For my cost analysis, I used $0.15/kWh because it was the standard residential rate in Berkeley. However, costs can vary drastically across tiers based on how much electricity a big institution such as UC Berkeley uses. Assessing the environmental costs also requires a checkup with the electricity provider's source of electricity generation. For the Pacific Gas & Electric Company, the electricity provider for UC Berkeley, natural gas was the only fossil fuel source which constituted 15% of the energy mix. The carbon intensity of natural gas is approximately 572g CO_2/kWh (Institute for Energy and Environmental Research), which I additionally multiplied by 15% in order to account for the mix percentage. In my final environmental cost analysis, I used a carbon intensity of 85.8g CO_2/kWH for the UC Berkeley campus.

RESULTS

Tan Hall Retrofit

Under linear fluorescent lighting before 2019, Tan Hall's annual operating costs came out to 535,994 kWh/year assuming continuous lighting throughout the school year. After the LED retrofit, the annual operating costs of Tan Hall reduced to 312,823 kWh/year, which is a savings of 223,171 kWh/year. The kWh difference after the retrofit translated to about $33,475 and 19,148 kg CO_2 in savings per year. The cost of the retrofit to fit 3208 LED lamps came out to $43,124, which means the payback period without taking into account the discount rate, emission reductions benefits, and installation costs is a little over a year.

Retrofitting Existing Buildings

There are about 63 campus buildings that still operate under linear fluorescent lighting such as Wheeler Hall and Pimentel Hall. Under a complete LED retrofit, there are a total of 155,546 lamps that need to be replaced. Under a similar savings portfolio per fixture under the Tan Hall Retrofit, there will be an annual savings of $1,621,863 and 927,720 kg CO2. However, this will require an upfront investment of about $2,090,538 with a similar payback rate of over a year.

DISCUSSION

The results of this cost analysis revealed attractive monetary and environmental benefits for a complete LED retrofit of the entire UC Berkeley campus. At an initial glance, a complete energy retrofit can certainly help balance campus budget and meet state energy goals in the long term. However, Tan Hall has been retrofitted only recently in Spring 2019 since the last energy audit of the building in 2008. The timeline for other building retrofits is unknown despite UC Berkeley's ambitious Carbon Neutrality goals. Ultimately, it is important to discuss some of the barriers as to why many college campuses across the United States do not invest in lighting efficiency. Although the results of this analysis are attractive, it will require an investment in the millions and many labor hours to retrofit an entire campus. Many campuses will require assistance from government grants as the upfront costs and payback period of LEDs do not make the investment attractive yet. In addition, the electricity generation source strongly influences how much monetary and environmental savings the LED retrofit will produce. The energy generation power mix of the Pacific Gas and Electric Company represents one of the more cleaner portfolios across the United States. However, in a state that uses less renewables and more coal to generate electricity, the environmental benefits and production costs decrease significantly. This can make investments in electricity generation efficiency more attractive over lighting efficiency since electricity generation is depended on by far more applications. Ultimately, the biggest barrier will be scientific exposure and education about lighting efficiency. Although it is known that better lighting practices and technologies will incur savings, it is unknown just how worthwhile the investment is on a more specific scale. It will make a significant difference if many institutions across campus can replicate the auditing methods in this analysis and present the savings results to policy makers in hopes of showing the large magnitude in potential savings.

Broader Implications and Future Directions

Although this cost analysis focused on LED retrofitting, there is a wide range of lighting practices that can be considered in order to perform more thorough energy audit. One consideration is to experiment with an added functionality to dim the lights to a more appropriate lighting level, which can make the lighting less straining to the eyes and will reduce energy use. In addition, the audit can take advantage of natural lighting, which entails identifying rooms that have a lot of natural sunlight coming in thus reducing the number of fixtures required for that room. Sensor technology is also available which will automatically turn the lights off when no one is in the room in order to reduce idle lighting. The reorganization of class time frames and sizes in order to maximize space used can affect lighting usage as well. Ultimately, these future directions of lighting practices aim at reducing the amount of hours of lighting and can assist in creating a more thorough audit.

Limitations

One main purpose of this cost analysis is to assess whether there is an expedient way to audit a large institution and get fairly accurate results. Although these methods are easily reproducible, it is undoubtedly not as accurate as a thorough standard audit that uses light meters to calculate wattage usage associated with lighting. It is recommended for a professional auditing team to analyze lighting usage statistics in person at the institution in order to get the most accurate numbers. In addition, the cost metrics of price per kWh and carbon intensity are estimates that are derived from dynamic properties. Specifically, the electricity cost can vary drastically with how the electricity provider manages their energy source. In addition, the life cycle assessment costs are not factored into these cost calculations. For example, nuclear power is not necessarily carbon free because there are economic and environmental costs to building that nuclear power plant. In order to improve my analysis, I would have liked to do an energy audit of a campus building myself and talk more in depth about the cost of electricity with the electricity provider of UC Berkeley.

REFERENCES

Alajmi, A. 2012. Energy audit of an educational building in a hot summer climate. Energy and Buildings 47:122–130.

E Source, Inc., Lighting, Technology Atlas Series, Volume 1, E Source, Boulder, CO, 1997.

Ganandran, G. S. B., T. M. I. Mahlia, H. C. Ong, B. Rismanchi, and W. T. Chong. 2014. Cost-Benefit Analysis and Emission Reduction of Energy Efficient Lighting at the Universiti Tenaga Nasional. The Scientific World Journal 2014:1–11.

Interlaboratory Working Group, 2000. Scenarios for a Clean Energy Future (Oak Ridge, TN: Oak Ridge National Laboratory; Berkeley, CA: Lawrence Berkeley National Laboratory; and Golden, CO: National Renewable Energy Laboratory), ORNL/CON-476, LBNL-44029, and NREL-TP-620-29379, November. (See http://www.ornl.gov/ORNL/Energy_Eff/CEF.htm.)

Kwong, Q. J., N. M. Adam, and B. Sahari. 2014. Thermal comfort assessment and potential for energy efficiency enhancement in modern tropical buildings: A review. Energy and Buildings 68:547–557.

Mills, E. (2005) The specter of fuel-based lighting, Science, 308, 1263-1264.

Roslizar, A., M. A. Alghoul, B. Bakhtyar, N. Asim, and K. Sopian. 2014. Annual Energy Usage Reduction and Cost Savings of a School: End-Use Energy Analysis. The Scientific World Journal 2014:1–8.

USDOE, 2012. 2011 Buildings Energy Data Book, US Department of Energy, Office of Energy Efficiency and Renewable Energy, March 2012 version, accessed at http://buildingsdatabook.eren.doe.gov/.

Zhou, X., D. Yan, T. Hong, and X. Ren. 2015. Data analysis and stochastic modeling of lighting energy use in large office buildings in China. Energy and Buildings 86:275–287.

APPENDIX

Table 1. Tan Hall Lighting Data. A section of the Energy Offices data detailing lighting operation variables after the LED retrofit.

					EXISTING		RETROFIT		SAVINGS
FXTR COD	FIXTURE DESCRIPTION	QTY	HR COD	HOURS/Y	DESCRIPTION	kWh/yr	DESCRIPTION	kWh/yr	kWh/yr
TT9C	2x2 2F31T8, 9 cell	19	H	8760	3F17T8L kit	7157	3LED10.5T8	5243	1914
TT9C	2x2 2F31T8, 9 cell	12	H	8760	3F17T8L kit	4520	3LED10.5T8	3311	1209
TT9C	2x2 2F31T8, 9 cell	7	H	8760	3F17T8L kit	2637	3LED10.5T8	1932	705
WW84L	8' wall wash 4F32T8 louvers	2	C	2000	4F32T8L	384	4LED12.5T8	200	184
WW84L	8' wall wash 4F32T8 louvers	2	C	2000	4F32T8L	384	4LED12.5T8	200	184
T2321	1x4 2F32 lensed troffer	2	C	2000	2F32T8L	192	2LED12.5T8	100	92
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
SM841L	1x8 surface mount 4F32T8 louvers	8	H	8760	4F32T8L	6728	4LED12.5T8	3504	3224
SM421L	1x4 surface mount 2F32T8 louvers	3	H	8760	2F32T8L	1261	2LED12.5T8	657	604
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
SM841L	1x8 surface mount 4F32T8 louvers	14	H	8760	4F32T8L	11773	4LED12.5T8	6132	5641
SM421L	1x4 surface mount 2F32T8 louvers	8	H	8760	2F32T8L	3364	2LED12.5T8	1752	1612
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
SM841L	1x8 surface mount 4F32T8 louvers	4	H	8760	4F32T8L	3364	4LED12.5T8	1752	1612
SM421L	1x4 surface mount 2F32T8 louvers	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	1	H	8760	2F32T8L	420	2LED12.5T8	219	201
SM841L	1x8 surface mount 4F32T8 louvers	6	H	8760	4F32T8L	5046	4LED12.5T8	2628	2418
SM421L	1x4 surface mount 2F32T8 louvers	3	H	8760	2F32T8L	1261	2LED12.5T8	657	604
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
T2321	1x4 2F32 lensed troffer	2	H	8760	2F32T8L	841	2LED12.5T8	438	403
SM841L	1x8 surface mount 4F32T8 louvers	10	H	8760	4F32T8L	8410	4LED12.5T8	4380	4030
SM421L	1x4 surface mount 2F32T8 louvers	6	H	8760	2F32T8L	2523	2LED12.5T8	1314	1209

Table 2. Fluorescent Campus Buildings. A section of the Energy offices data that listed the number of fixtures and lamps for campus buildings that operated under linear fluorescent lighting.

Year	Building	As-Built	ɪtrofit Complete	Building Type	uilding Annual Operating Hou	No. of Fixtures.	No of lamps
2008	Tan	Complete	Feb-08	L	8,736	968	1,936
2008	Gilman	Complete	Feb-08	L	8,736	202	404
2008	Koshland	Complete	Jun-08	L	8,736	1,108	2,216
2008	Hildebrand	Complete	Oct-08	L	8,736	1,480	2,960
2008	Latimer	Complete	Nov-08	L	8,736	3,089	6,178
2008	LSA	Complete	Dec-08	L	8,736	2,438	4,876
2009	Giauque	Complete	Dec-09	L	8,736	222	444
2010	Birge	Complete	Jan-10	L	8,736	1,577	3,154
2010	Hearst Mining	Complete	Oct-10	L	8,736	1,190	2,380
2011	Barker	Complete	Jun-11	L	8,736	1,634	3,268
2011	Etcheverry	Complete	Nov-11	L	8,736	3,037	6,074
2012	Giannini	Complete	Mar-12	L	8,736	799	1,598
2012	Le Conte Annex	Complete	Jul-12	L	8,736	932	1,864
2012	VLSB	Complete	Oct-12	L	8,736	7,365	14,730
2013	Donner Lab	Complete	Aug-13	L	8,736	702	1,404
2013	Davis	Complete	Sep-13	L	8,736	1,843	3,686
2013	Warren	Complete	Oct-13	L	8,736	1,050	2,100
2008	Wheeler	Complete	Oct-08	M	3,536	336	672
2008	Pimentel	Complete	Dec-08	M	3,536	184	368
2008	RSF	Complete	Dec-08	M	3,536	350	700
2009	Soda	Complete	Feb-09	M	3,536	580	1,160
2009	Hertz	Complete	Jun-09	M	3,536	86	172
2009	Kroeber	Complete	Jul-09	M	3,536	626	1,252
2009	Moses	Complete	Dec-09	M	3,536	611	1,222
2010	Wurster	Complete	Jan-10	M	3,536	2,302	4,604
2010	Morrison	Complete	Mar-10	M	3,536	319	638
2010	Stephens	Complete	Apr-10	M	3,536	871	1,742
2010	Barrows	Complete	Jun-10	M	3,536	2,480	4,960
2010	Hearst Gym	Complete	Nov-10	M	3,536	726	1,452
2010	ML King	Complete	Nov-10	M	3,536	2,002	4,004
2010	Minor Addition	Complete	Nov-10	M	3,536	1,132	2,264
2010	Dwinelle	Complete	Dec-10	M	3,536	2,475	4,950