Energy Demand and Utilization

39:611

Final Project

Scaife Hall Lighting Improvements

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Executive Summary

This project seeks to replace the current fluorescent lighting (FL) system in Scaife Hall with a light-emitting diode (LED) system, with the aim of simultaneously improving the lighting efficiency, limiting the effect of greenhouse gas emissions and decreasing the lighting costs of the building over the next 25 years. The intended lighting improvements also incorporate a hard-wired occupancy sensing system that functions as an incremental component that would increase the energy savings. The expected profitability of implementing the LED system in addition to the occupancy sensors over the intended period is $18,200, with projected energy savings of 900,000kWh, and CO_2 savings of 475 tons. If implemented, this project will be applicable to other buildings at Carnegie Mellon and will serve to provide similar benefits in lighting efficiency and system sustainability.

1 Introduction

1.1 Motivation and Context

Electricity in the U.S. commercial sector is used for a variety of functions including ventilation, cooling, refrigeration, powering equipment, and space and water heating. However, according to the U.S. Energy Information Administration (EIA), lighting accounts for the largest use of electricity in most retail, office, education, institutional, public, and government buildings. Outdoor and public street lighting also contribute to a large portion of the electricity use in the commercial sector. The EIA has conducted a study of the breakdown of various uses of electricity in this sector and the results are represented in Figure 1.

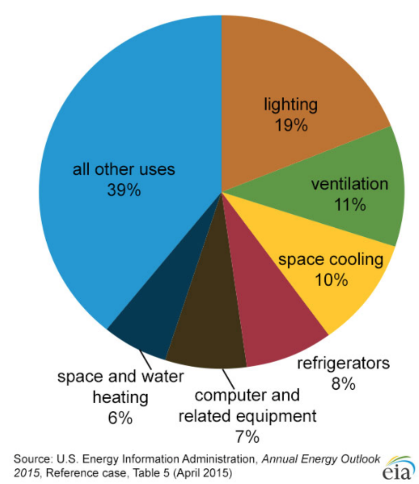

Figure 1: Breakdown of energy consumption

The study is based on the fact that U.S. electricity consumption totaled nearly 3,862 billion kWh in 2014 and that the commercial sectors share represented around 35% of this value. With the large portion of electricity consumption going to lighting in commercial buildings, it is crucial to ensure that the lighting systems operate effectively and efficiently. The focus of this project is on Scaife Hall in Carnegie Mellon University and will be centered on achieving lighting efficiency through the use of LED bulbs and occupancy sensors.

1.2 Background Information

Scaife Hall was built in 1962 by Altenhof J. Lewis and Bown B. Phillips. They tried to design Scaife Hall to be both practical and visually appealing [1]. The buildings notable features are its sun screen suspended from columns on the exterior of the building which block excess heat from the sun while letting gentle diffuse light and the shell shaped room 125 [2,6]. Scaife hall has 4 main floors plus one penthouse area and one basement for keeping mechanical systems. We did not explore the penthouse, but the basement is a lab area with graduate offices. Room 125 or the pringle is lecture hall and the rest of classrooms are on the second floor along with conference rooms. Classes take place between 9:30 am and 4:30 pm [5]. There also activity at night such as office hours for classes [5]. The offices which make up majority of Scaife Hall, are open intermittently between 8:30 am and past 5:00 pm [7]. Scaife currently uses fluorescent lights and has only a few motion sensor light for testing purposes [8,14]. It has even more sensors for energy use from different student projects over the years [7].

1.3 Related Work

During the past decade, researchers from the CenSCIR group at Carnegie Mellon implemented a campus wide testbed for new sensing technologies. The CenSCIR group consists of a multi disciplinary team from different departments at Carnegie Mellon. This group has multiple projects. A few of which are Sensor Andrew, Time Reversal Imaging, Trinetra - Assistive Technologies for the Blind, etc. Of the different project Sensor Andrew [17] is one, whose main goal is "to make CMU one of the most sensed campuses in the world". Sensor Andrew would infact, develop a sensor network in CMU, thus making it a living laboratory for real-world infrastructure problems. It is from this project that the electricity consumption at Scaife Hall is sensed.

2 Proposal

The goals for this project are as mentioned before, is to perform a baseline analysis of the existing lighting system followed by an incremental analysis of the system improvements. Based on our survey of Scaife Hall, most, if not all, of the lighting in Scaife Hall consists of FL strips. As seen in [16], LEDs produce the same amount of lighting with a lower amount of electricity consumption; hence, the baseline analysis would be to switch to LEDs and perform a cost-benefit analysis. The next step would be to add occupancy sensors to analyze the incremental benefits. The results are compared on Net-Present-Value (NPV) basis over a timeline of 25 years with a positive NPV indicating a viable project. Savings pertaining to energy usage and Carbon emissions have also been estimated.

2.1 Data

2.1.1 Scaife Hall Electricity Consumption (Inscope)

This Dataset consists of multiple csv files corresponding to different days. Each csv file consists of the following labels: BranchID, PhaseID, BranchName, BreakerPosition, PanelName, DateStamp, MinCurrent, MaxCurrent, MinVoltage, MaxVoltage, LocationID, AvgWatt, AvgVa. For the purposes of this analysis, the BranchName, BreakerPosition, DateStamp and AvgWatt were selected. Each row in the data-set consists of a single sensing point, which repeats every minute for the day. There are a total of 206 unique sensing points for each minute during the day. Of these points there are 44 that collectively measure lighting. The profile for a day can be seen in Figure 2.

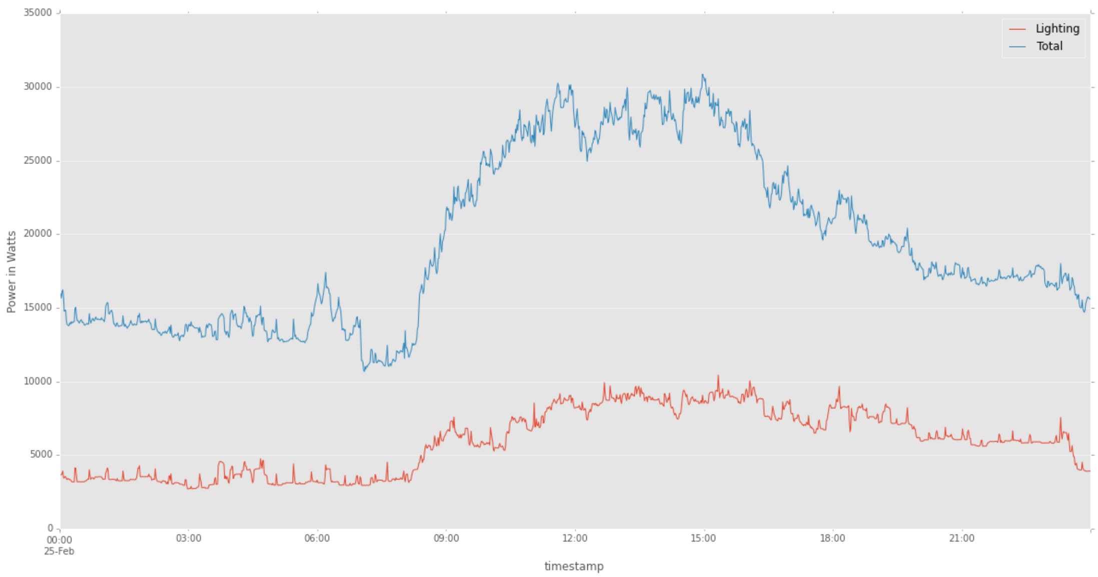

Figure 2: Profile for a day

2.1.2 Scaife Hall Survey

Our survey of Scaife Hall took multiple days and each type of room has differing levels of accuracy as far as number of lights is concerned. We decided to look at only the main floors and the basement. We looked at all of the classrooms and most of the conferences rooms. However, the data for the offices was limited. We had a sample of less than ten offices including both faculty rooms and staff rooms of both larger offices with 9 light strips and regular offices for 6 light strips. We found that most offices seemed to fit this pattern. Hence we extrapolated for other rooms based on their floor plans. Ending up with a total of 772 lights Appendix A Table 3 . See the No. of bulbs sheet in the attached Excel file for further details. We did not get a close look at many of the light fixture so we were not able to quantify which type of light they were beyond shape. Since over 90% of the lights were light tubes, we chose to look at a common type of light tube which is 32 watt Bi-Pin T8 linear tubes for both prices and wattage. We choose the 800 series over the more popular 700 series because of the 700 series was cancelled a few years ago [10]. We use the prices list at 1000bulbs.com as it consisted of a more comprehensive list of bulbs [11]. We also choose to use the plug and play LED lights because of their installation, cheaper cost and comparable efficiency to direct plug in LED[12]. In the end, we average the price and wattage across the different brands and temperature types including 3000K, 3500K, 4100K and 5000K [11]. Calculations Appendix A Table 4. can be viewed in the Cost per Bulb and in the No. of bulbs sheet.

3 Model and Assumptions

The model estimates the total electricity consumption (*Savings* $, *Average Hourly Usage*, *Occupancy Sensors*) for lighting and calculates the cost and net benefits (*Net-Present Value*) based on certain assumptions . The major assumptions for our model are as follows:

- Four representative weeks are chosen for analysis: one in February (Spring Semester), one in June (Summer Break), one in October (Fall Semester) and one in January (Winter Break). These four weeks capture the patterns for the whole year and other variances in consumption.
- Extrapolation of number of bulbs as mentioned in the previous section.
- The choice for LED and FL bulbs as explained in the previous section.
- Efficiency of sensors is a weighted average for different spaces based on the EPA study
- One sensor is required for a room and two per hallway.

The Following set of equations summarize our calculations:

$$\text{Savings per year} = \frac{\text{Total kWh}}{\text{day}} * 365 \text{ days} * \frac{\$}{\text{kWh}} * \%\text{Efficiency}_{\text{LED}} * \%\text{Efficiency}_{\text{Sensors}} \tag{1}$$

$$\text{Maintenance time per year} = \text{Lifetime in yrs} \div \left(\frac{\text{Avg. hrs}}{\text{day}} * 365 \text{ days}\right) \tag{2}$$

$$\text{Net-Present Value} = \sum_{i=1}^{25} \frac{Savings_i + Cost_i + Maintenance_i}{(1+r)^i} \tag{3}$$

The point estimates that we used for our analysis are as follows:

Based on the above equations and the point estimates :

- Total kWh calculations: This is just the total lighting consumption over all the filtered sensing points (44 of them) for the assumed period in our analyses [15].
- Average Hours calculations: This is calculated based on the per minute consumption for each sensing point. For example the average hours of usage for a particular sensing point is all the times there are

non-zero AvgWatt consumptions. This is averaged out for all the sensing points over all the days. The reason for this estimate is to find the replacement time for each of the bulbs [15].

- The $/CFL and $/LED are calculated based on different samples of both currently in the market (Refer Appendix A Table 4) The Lifetime of LEDs, CFLs and Sensors were again assumed (Appendix A Table 2). These are standard values [16].
- The Net Savings were calculated by finding the difference between the NPVs for each case, i.e. for the Base-line case, Savings = $\text{NPV}_{\text{LEDs}} - \text{NPV}_{\text{FLs}}$. (Appendix A Tables 5-7)

3.1 Occupancy Sensors

As a means to increment the savings offered by the LED system, the lighting improvements to Scaife Hall will incorporate hard-wired occupancy sensors to the buildings energy management systems. The optimal choice of sensors for installation are based on a hybrid design that combines the capabilities of two types of sensors, infrared and ultrasonic. CO_2 sensors were not considered for the purpose of this project as they are used to estimate the number of people in a specific area and thus do not contribute to the goals of the project. Infrared sensors detect heat and motion over a range of 15 feet and are most suitable for small rooms, such as offices and classrooms. Ultrasonic sensors are less reliable because they operate based on heat and sound detection, which could result in false triggering. Based on a study conducted by the EPA on the potential energy savings of occupancy sensors, it is predicted that their installation could save between 13 and 50% for offices, 40 and 46% for classrooms and up to 80% for corridors. As stated previously in our assumptions, a weighted average of these efficiencies based on the number of offices, classrooms and hallways surveyed and was calculated as 36.42%.

4 Evaluation

4.1 Net-Present Value Analysis

Based on our estimates, LEDs need to be replaced every 23 years whereas sensors need replacement every 12 years. The net savings expected for the baseline case is **$14, 357** and that for incremental case is **$18,154**. Figure 3 shows the comparison of Net-Present Value for the two analysis.

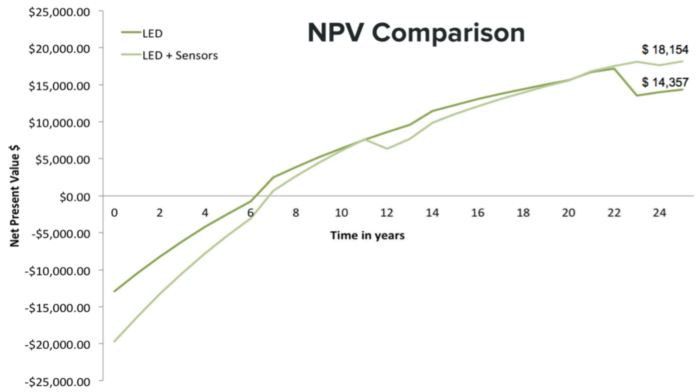

Figure 3: Net-Present Value Comparison

4.2 Sensitivity Analysis

In order to understand how each parameter affects our result, we performed a sensitivity analysis with the help of a Tornado plot in Figure 4. Baseline estimates have been obtained from the survey results as shown in Table 1. Sensitivity is carried out with 10% range of the baseline control variables except for electricity price, discount rate, lifetime for CFL and LEDs and the cost of sensor (Appendix A Table 8).

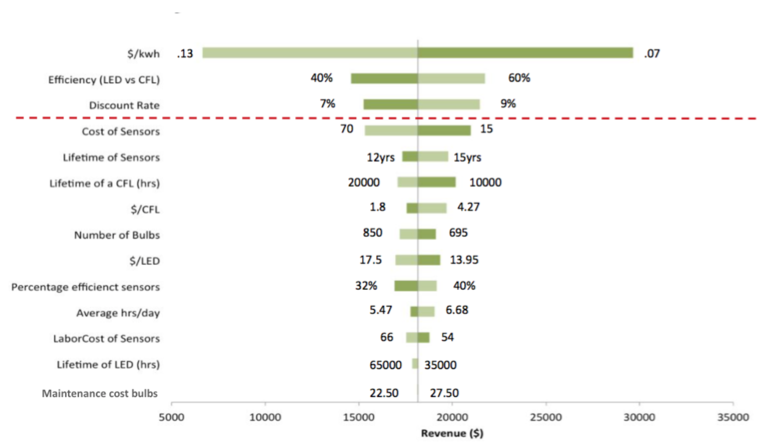

Figure 4: Tornado Plot for Sensitivity Analysis

The electricity price is the most sensitive parameter, followed by the efficiency of LEDs and then the discount rate. These three parameters most affect the Net Savings.

4.3 Environmental Impact

Switching from fluorescent light also offers energy saving and CO_2 emissions resulting from that reduction in energy use. The Energy Saving from LED lights is 660 MWh and the total CO_2 savings from switching is 347 tons [8]. Energy Savings from LED lights and Occupancy Sensors 900 MWh with total CO_2 savings being 474 tons [8]. (Refer to Environmental Savings, Appendix A Table 9). Energy usage and CO_2 emissions have been reduced by 50 percent from the baseline case when switching to LEDs. When switching to LEDs and Occupancy Sensors, energy usage and CO_2 emissions have been reduced to a fifth of the baseline case. These are huge reductions that will help improve the planet.

5 Limitations

Implementation of the intended lighting improvement systems is subject to a number of limitations derived from the initial assumptions made, extending throughout the data collected and the results generated by the model. A likely limitation would be, the effectiveness of the installed sensors. Considering that the cost analysis of the occupancy sensors was evaluated over a lifetime of 12 years, without taking the probability of any failures would be inaccurate. To simplify the effect of sensor failure over its lifetime, it can be assumed that 1% of the sensors will fail and be replaced every year, resulting in a reduction of efficiency from 36% to 35% and a 5% reduction in NPV (roughly $1,000). Discrepancies in the surveyed data are also regarded as a limitation when extended to the model. For example, the number of bulbs was extrapolated to fit an average value that was used for all the rooms and none of the restrooms were covered in the survey.

6 Deliverables, Schedule and Recommendations

Table 1: Deliverables

Deliverables	**Timeline**
Time to Replace LEDs	23 years
Time to Replace Sensors without Failure:	12 years
Time to Replace LEDs with an Addition of Sensors	35 years
Time to Replace Sensors with Failure	12 years
Payback Period for Baseline case	6 years
Payback Period for Incremental case	7 years

The above analyses was estimated based on a few major assumptions. Getting exact point estimates would result in a more robust analysis. Starting at the calculations for consumptions and hours of usage for every day instead of averaging over the period of four weeks. Once this has been implemented, an extension to the other buildings on the campus can be performed. Some form of predictive analysis can also be implemented in order to measure future consumptions and detect anomalies.

7 References

[1]: Cencer, S., Cole, A., Spitizer, M., Ding, G. (2010). Scaife Hall Build Audit Mechanical Systems 48421. Retrieved March 2, 2016, from
http://wise.ece.cmu.edu/redmine/attachments/download/146/scaife_hall_report.pdf

[2]: Katrini, Kolosky, Ranttila. (2014). Scaife Hall. Retrieved March 02, 2016, from
http://www.andrew.cmu.edu/user/aranttil/ScaifeOverview.php

[3]: Carnegie Mellon University. Connect with Us. (2015). Retrieved March 2, 2016, from
http://admission.enrollment.cmu.edu/pages/contact-us

[4]: Carnegie Mellon University. College of Engineering Office of Undergraduate Studies. (n.d.). Retrieved March 03, 2016, from
https://engineering.cmu.edu/current_students/contacts.html

[5]: Carnegie Mellon University. SpaceQuest (25Live)-The HUB - Carnegie Mellon University. (n.d.). Retrieved March 03, 2016, from
http://www.cmu.edu/hub/spacequest/

[6]: Shaw, M. (2014, June 02). Sunscreen Architecture: The Best Visor-Wearing Buildings. Retrieved March 03, 2016, from http://architizer.com/blog/suns-out-guns-out-the-best-visor-wearing-buildings/

[7]: G. Barry, personal communication, March 2, 2016

[8]: U.S. Energy Information Administration. (2015, July 8). State Electricity Profiles-Pennsylvania Electricity Profile 2013. Retrieved March 03, 2016, from https://www.eia.gov/electricity/state/Pennsylvania/ Carnegie Mellon University. (n.d.). Free, Fast, Easy

[9]: Life Cycle Assessment. Retrieved March 03, 2016, from http://www.eiolca.net/

[10]: F32T8 - 4100 Kelvin - T8 Linear Fluorescent Tubes. (2016). Retrieved February 15, 2016, from
https://www.1000bulbs.com/category/f32t8-fluorescent-tubes-4100k/

[11]: 1000Bulbs.com. (2016). Retrieved March 03, 2016, from https://www.1000bulbs.com/

[12]: Peters, L. (2014, July 22). How do plug-and-play T8s stack up against ballast-bypass LED lamps? (MAGAZINE). Retrieved March 03, 2016, from
http://www.ledsmagazine.com/articles/print/volume-11/issue-6/features/led-tubes/how-do-plug-and-play-t8s-stack-up-against-ballast-bypass-led-lamps.html

[13]: Carnegie Mellon University. (n.d.). Labor Rates-FMS Home. Retrieved March 03, 2016, from
https://www.cmu.edu/fms/SecLin_LaborRates/index.html

[14]: M. Bergs, personal communication, February, 2016

[15]: Jhabakh, Narendra. "Njhabakh/Energy-Demand." GitHub. GitHub.Inc, 03 Mar. 2016. Web. 03 Mar. 2016.
https://github.com/njhabakh/Energy-Demand/tree/master

[16]: "Compare: LED Lights vs CFL vs Incandescent Lighting Chart." Compare: LED Lights vs CFL vs Incandescent.

[17]: Rowe, Anthony, Mario Bergs, Gaurav Bhatia, Ethan Goldman, Ragunathan (Raj) Rajkumar, Lucio Soibelman, James Garrett, and Jos M. F. Moura. "Sensor Andrew: Large-Scale Campus-Wide Sensing and Actuation." (2008): n. pag. Web. 24 Feb. 2016.

[18]: Craig Dilouie (2013). Estimating Energy Savings with Lighting Controls. Lighting Controls Association. Web.

[19]: Environmental Protection Agency. (2002). Study: Potential Energy Savings from Occupancy Sensors. Web.

[20]: Light Guide: Occupant Sensors. (n.d.). Web. Retrieved from
http://www.lightsearch.com/resources/lightguides/sensors.html

[21]: Lighting Occupancy Sensors. (n.d.).Business Energy Advisor. Web. Retrieved from
https://fpl.bizenergyadvisor.com/BEA1/PA/PA_Lighting/PA-10

[22]: Michigan Department of Labor and Economic Growth. (2011).Occupancy Sensors for Lighting Control. The Energy Observer Quarterly: Energy Efficiency Information for the Facility Manager.

[23]: Waste Reduction Partners. (2004). Occupancy Sensors: Utility Savings Initiative- Fact Sheet. N.C. Department of Administration. Web.

8 Appendix A

Code : https://github.com/njhabakh/Energy-Demand

Excel Sheet : Attached with the submission

Tables:

Table 2: Point Estimates

Control Variables	**Baseline**
# of Bulbs	772
$/CFL	$2.50
$/LED	$15.50
Labor cost of Bulbs	$25.00
$/kwh	$0.10
Efficiency (LED vs CFL)	50%
Discount Rate	8%
Lifetime of a CFL (hrs)	15000
Lifetime of LED (hrs)	50000
Average hrs/day	6.073
Percentage efficienct sensors	36%
Cost of Sensors	42.5
Lifetime of Sensors	13.5
LaborCost of Sensors	60

Table 3 Number of Bulbs

Room Type	Average Lights Strips	Average Bulbs	Other light	Sample	Number of Rooms	Total Light Strips	Total Bulbs	Total Other	
1st Floor Main Hall	0	10	0		1	0	10	0	Notes:
Rm 129	16	3	2		1	16	3	2	Blue Boxes = sensos
2nd Floor Conference Rooms	12		0	206	5	60	0	0	Floresant Bulbs
2nd Floor Classroom	18	0	0	212, 220, 219, 212, 208	6	108	0	0	Confrence rooms might have occupancy sensing active
Stairwell per floor	2	4	0	both Starwells	8	16	32	0	
Main Hall(2, 3, 4, B)	14	0	0	3rd Floor, 2nd Floor	4	56	0	0	
Side Hall(2, 3, 4, B)	8	0	0	3rd Floor, 2nd Floor	4	32	0	0	
Lab	18	0	0			0	0	0	
110 Main Room	14	6	0		1	14	6	0	
1st Floor Women's Restroom	9	0	0		1	9	0	0	
4th Floor Regular Office	6	0	0	404, 413, 414	6	36	0	0	
4th Large Office	9	0	0		10	90	0	0	
3rd Large Office	16	0	0	301, 304, 422, 423, 424	8	128	0	0	
3rd Regular Office	12	0	0		12	144	0	0	
4th Floor Main Office	9	0	0		1	9	0	0	
2nd Floor Women's Restroom	1	0	0		1	1	0	0	**Total**
Total	164	23	2		69	719	51	2	**772**

Watts per Strip	Parameter	Average Cost	Sources
15	LED PP	$15.50	https://www.1000bulbs.com/category/led-tubes-retrofit/
32	FL	$2.50	https://www.1000bulbs.com/category/f32t8-fluorescent-tubes-4100k/
	Sensors	$42.50	
	Labor cost for installing sensors	$60.00	
	Labor cost changing 20 LED PP and FL	$25.00	
18	LED DW	$14.39	https://www.1000bulbs.com/category/led-tubes-retrofit/
	Installation FL and LED PP cost/unit	$2.50	
	Installation FL and LED PP cost/60 min	$15	http://www.payscale.com/research/US/Job=Custodian_Janitor/Hourly_Rate
	Installation FL and LED PP min/unit	10	http://work.chron.com/much-electricians-typically-charge-per-hour-6397.html
	Labor cost changing 20 DW bulbs	$137.50	
	Installation DW cost/unit	$13.75	https://www.redbeacon.com/hg/how-much-does-light-bulb-replacement-cost
	Installation DW cost/60 mintues	$55.00	http://work.chron.com/much-electricians-typically-charge-per-hour-6397.html
	Installation DW min/unit	20	http://www.ledsmagazine.com/articles/print/volume-11/issue-6/features/led-tubes/how-do-plug-and-play-t8s-stack-up-against-ballast-bypass-led-lamps.html

Table 4 Cost of Bulbs

FL cost	FL watt
1.84	32
1.85	32
2.08	32
2.53	32
2.73	32
2.74	32
1.83	32
1.99	32
2.28	32
2.44	32
2.49	32
3.48	32
1.83	32
2.19	32
2.25	32
2.28	32
2.49	32
2.86	32
4.23	32
1.81	32
1.9	32
1.99	32
2.02	32
2.16	32
2.22	32
2.33	32
2.49	32
3.39	32
3.75	32
4.27	32
2.491333333	**32**

PP cost	PP Watt
17.98	12
13.04	15
9.99	13
12.99	15
13.99	19
16.99	16.8
17.98	12
22.99	19.5
9.99	13
10.99	15
13.99	19
14.55	22
16.99	16.8
17.48	12
18.68	15
22.99	19.5
9.99	13
10.99	15
12.99	19
17.98	12
18.68	15
19.99	22
15.55590909	**15.93636364**

DW cost	DW watt
11.99	18
17.48	14.5
9.99	15
11.49	18
17.32	18
17.48	14.5
9.99	14.5
11.49	18
16.49	18
17.48	14.5
18.78	17.5
9.28	16
9.99	15
11.49	18
16.45	15
17.48	14.5
18.78	17.5
13.6	18
16.28	22
14.38578947	**16.65789474**

Table 5 NPV of CFL

Discount rate	8%				
CFL					
Lifetime	**Replacement after**			Cost of sensor	$2,805.00
15000	7			Cost of replacement for	$1,930.00
				Cost of replacement for	$11,966.00
				Cost of Janitor	$965.00
				Cost of Labor(Sensors)	$3,960.00
Year	**Investment**	**Labor Costs**	**Cost of electricit**	**Total Costs**	**Present value**
0	0	0	0	$0.00	$0.00
1	0	0	$5,267.39	$5,267.39	4877.214893
2	0	0	$5,267.39	$5,267.39	4515.939716
3	0	0	$5,267.39	$5,267.39	4181.425663
4	0	0	$5,267.39	$5,267.39	3871.690429
5	0	0	$5,267.39	$5,267.39	3584.898545
6	0	0	$5,267.39	$5,267.39	3319.350505
7	$1,930.00	$965.00	$5,267.39	$8,162.39	$4,762.68
8	0	0	$5,267.39	$5,267.39	2845.808046
9	0	0	$5,267.39	$5,267.39	2635.00745
10	0	0	$5,267.39	$5,267.39	2439.821713
11	0	0	$5,267.39	$5,267.39	2259.094178
12	0	0	$5,267.39	$5,267.39	2091.753869
13	0	0	$5,267.39	$5,267.39	1936.809138
14	$1,930.00	$965.00	$5,267.39	$8,162.39	$2,778.98
15	0	0	$5,267.39	$5,267.39	1660.501661
16	0	0	$5,267.39	$5,267.39	1537.501538
17	0	0	$5,267.39	$5,267.39	1423.612536
18	0	0	$5,267.39	$5,267.39	1318.159755
19	0	0	$5,267.39	$5,267.39	1220.518292
20	0	0	$5,267.39	$5,267.39	1130.109529
21	$1,930.00	$965.00	$5,267.39	$8,162.39	$1,621.51
22	0	0	$5,267.39	$5,267.39	968.8867708
23	0	0	$5,267.39	$5,267.39	897.1173803
24	0	0	$5,267.39	$5,267.39	830.6642411
25	0	0	$5,267.39	$5,267.39	769.1335565
				NPV	**$59,478.18**

Table 6 NPV of LED

LED					
Lifetime	Replacement after				
50000	23				
Year	Investment	Labor Costs	Cost of electricit	Total Costs	Present value
0	$11,966.00	$965.00	0	$12,931.00	$12,931.00
1	$ -	$ -	$2,633.70	$2,633.70	$2,438.61
2	$ -	$ -	$2,633.70	$2,633.70	$2,257.97
3	$ -	$ -	$2,633.70	$2,633.70	$2,090.71
4	$ -	$ -	$2,633.70	$2,633.70	$1,935.85
5	$ -	$ -	$2,633.70	$2,633.70	$1,792.45
6	$ -	$ -	$2,633.70	$2,633.70	$1,659.68
7	$ -	$ -	$2,633.70	$2,633.70	$1,536.74
8	$ -	$ -	$2,633.70	$2,633.70	$1,422.90
9	$ -	$ -	$2,633.70	$2,633.70	$1,317.50
10	$ -	$ -	$2,633.70	$2,633.70	$1,219.91
11	$ -	$ -	$2,633.70	$2,633.70	$1,129.55
12	$ -	$ -	$2,633.70	$2,633.70	$1,045.88
13	$ -	$ -	$2,633.70	$2,633.70	$968.40
14	$ -	$ -	$2,633.70	$2,633.70	$896.67
15	$ -	$ -	$2,633.70	$2,633.70	$830.25
16	$ -	$ -	$2,633.70	$2,633.70	$768.75
17	$ -	$ -	$2,633.70	$2,633.70	$711.81
18	$ -	$ -	$2,633.70	$2,633.70	$659.08
19	$ -	$ -	$2,633.70	$2,633.70	$610.26
20	$ -	$ -	$2,633.70	$2,633.70	$565.05
21	$ -	$ -	$2,633.70	$2,633.70	$523.20
22	$ -	$ -	$2,633.70	$2,633.70	$484.44
23	$ 11,966.00	$ 11,966.00	$2,633.70	$26,565.70	$4,524.54
24	$ -	$ -	$2,633.70	$2,633.70	$415.33
25	$ -	$ -	$2,633.70	$2,633.70	$384.57
				NPV	**$45,121.10**
					Net Savings
					$14,357.08

Table 7 NPV of LED + Sensors

LED + Sensors					
Lifetime hrs	Replacement after	Lifetime Sensors yrs			
50000	36	12			
Year	**Investment**	**Labor Costs**	**Cost of electricity**	**Total Costs**	**Present value**
0	$14,771.00	$4,925.00		$19,696.00	$19,696.00
1	$ -	$ -	$1,674.48	$1,674.48	$1,550.44
2	$ -	$ -	$1,674.48	$1,674.48	$1,435.59
3	$ -	$ -	$1,674.48	$1,674.48	$1,329.25
4	$ -	$ -	$1,674.48	$1,674.48	$1,230.79
5	$ -	$ -	$1,674.48	$1,674.48	$1,139.62
6	$ -	$ -	$1,674.48	$1,674.48	$1,055.20
7	$ -	$ -	$1,674.48	$1,674.48	$977.04
8	$ -	$ -	$1,674.48	$1,674.48	$904.67
9	$ -	$ -	$1,674.48	$1,674.48	$837.65
10	$ -	$ -	$1,674.48	$1,674.48	$775.61
11	$ -	$ -	$1,674.48	$1,674.48	$718.15
12	$ 2,805.00	$ 3,960.00	$1,674.48	$8,439.48	$3,351.43
13	$ -	$ -	$1,674.48	$1,674.48	$615.70
14	$ -	$ -	$1,674.48	$1,674.48	$570.09
15	$ -	$ -	$1,674.48	$1,674.48	$527.86
16	$ -	$ -	$1,674.48	$1,674.48	$488.76
17	$ -	$ -	$1,674.48	$1,674.48	$452.56
18	$ -	$ -	$1,674.48	$1,674.48	$419.04
19	$ -	$ -	$1,674.48	$1,674.48	$388.00
20	$ -	$ -	$1,674.48	$1,674.48	$359.26
21	$ -	$ -	$1,674.48	$1,674.48	$332.64
22	$ -	$ -	$1,674.48	$1,674.48	$308.00
23	$ -	$ -	$1,674.48	$1,674.48	$285.19
24	$ 2,805.00	$ 3,960.00	$1,674.48	$8,439.48	$1,330.90
25	$ -	$ -	$1,674.48	$1,674.48	$244.50
				NPV	**$41,323.97**
					Net Savings $18,154.21

Table 8 Sensitivity Ranges

Control Variables	Max	Min
# of Bulbs	850.00	695.00
$/CFL	4.27	1.8
$/LED	17.05	13.95
Labor cost of Bulbs	27.5	22.5
$/kwh	0.13	0.07
Efficiency (LED vs CFL)	0.6	0.4
Discount Rate	0.09	0.07
Lifetime of a CFL (hrs)	20000	10000
Lifetime of LED (hrs)	65000	35000
Average hrs/day	6.6803	5.4657
Percentage efficienct sensors	0.396	0.324
Cost of Sensors	70	15
Lifetime of Sensors	15	12
LaborCost of Sensors	66	54

Table 9 CO_2 Savings

$/kwh	0.1	$/kwh	0.1
SO2 tons/Mwh	0.0012	SO2 lb/Mwh	2.4
NOx tons/Mwh	0.00065	NOx lb/Mwh	1.3
CO2 tons/Mwh	0.5275	CO2 lb/Mwh	1055
	LED	**Sensors**	**FL**
$ per year	**$2,633.70**	**$1,674.48**	**$5,267.39**
$ total saved	65,842.40	89,822.90	0.00
total kwh Energy saved	658424.0106	898228.966	0
SO2 savings	0.7901088127	1.077874759	0
NOx savings	0.4279756069	0.5838488279	0
CO2 savings	347.3186656	473.8157796	0
CO2 savings from Manfacturi	27.8	37.9	0