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Energy Efficient Outdoor Lighting: Case Study, Economic Analysis, Model Development, and Application

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ENERGY EFFICIENT OUTDOOR LIGHTING:

CASE STUDY, ECONOMIC ANALYSIS, MODEL DEVELOPMENT, AND APPLICATION

ETM535 FINAL PROJECT

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INTRODUCTION

According to the Environmental Protection Agency, the vast majority (70%) of light bulbs in the United States are still inefficient [1]. More and more companies are converting outside lighting to state-of-the-art high efficient long lasting options such as Light-Emitting Diode (LED). Proponents of high efficiency lighting assert that upgrading older bulbs to new efficient ones will generate savings even though the installation costs may be high. Firms often compare upgrade costs and perceived benefits using different approaches and analysis methods. This project investigates one firm's upgrade economic model, provides critical analysis, and proposes an improved model which could be used for future upgrade projects at the firm. In addition to the proposed model, three (3) different use cases are examined in an effort to better understand under what conditions lighting upgrades make the most sense.

CASE BACKGROUND

In 2009 a Hillsboro, Oregon based high tech company upgraded all their outside parking and building lights to LED after estimating an annual savings of $23,853. This estimate was based on a spreadsheet model which accounted for the number of fixtures upgraded, wattage "savings" of the new LED bulbs, and current energy costs ($0.05837 per KWH). The firm's model and assumptions are discussed in subsequent sections. Table I below provides a summary of the existing lighting system and assumptions before the upgrade. As can be seen, the majority of the yearly costs were due to maintenance as **all** the bulbs were replaced each year in order to only call out bucket trucks and work crews one time per year versus every time a light bulb went out. Table II shows the LED upgrade model, with a yearly cost of electricity of $3,243.74. Since LEDs are much more reliable, which will be discussed later, the company calculated a huge savings in maintenance costs. Also, LED energy consumption was expected to be much less, resulting in much lower operating costs. During the upgrade process, some fixtures were considered were removed as is reflected in the difference of total fixture before and after the upgrade. The team set out to understand the firm's model, understand the inputs and assumptions, and potentially offer an improved model which would be more comprehensive and help with future decision making.

Table I: High Tech Company Pre-Upgrade Exterior Lighting Costs

250 watt MH and HPS Fixtures		
Number of fixtures		89
Wattage used per fixture		290
Total Wattage		25810
70 watt MH and HPS Wall pack Fixtures		
Number of fixtures		20
Wattage used per fixture		100
		2000
Total Electricity Usage (Watts)		**27810**
Annualized Costs Before Project		
Power Consumption		
Cal	0.05837 c/kWHr	
Usage	12 hrs/day	83430 kWHr
Maintenance costs	(Replacement parts, labor, lift rental)	$20,000
Power Cost		$4,870
Total Costs		**$24,870**

Table II: High Tech Company Upgrade Exterior Lighting Model

110 watt Fixtures	
Number of fixtures	77
Wattage used per fixture	110
Total Wattage	8470
24 watt LED Wall pack Fixtures	
Number of fixtures	20
Wattage used per fixture	24
Total Wattage	480
84 watt LED Flood Lights Added for N2 Plant	
Number of fixtures	4
Wattage used per fixture	84
Total Wattage	336
Total Replacement Wattage	9286
Total Wattage replaced	18524
Annual Replacement (kwHr)	$55,572
Cost of electricity	**$3,244**

Having the ability to provide light when the sun is not out has been important to the human race for a very long time. Outside lighting was the main reason for the beginning of the electrical grid. On September 4, 1882 the first electrical distribution network was initiated; it powered four hundred incandescent light bulbs [2]. Since that time in 1882 the electrical distribution system has become an integral part of society and outside lighting is still one of its main purposes.

Since 1882 the use of electricity progressed at a rapid pace until the early 1970's. At that time the United States experienced an energy crisis [3]. This crisis caused the United States to take a better look at how we use and produce energy. Studies show that the world population is growing at about 1% per year, but the energy use per person is growing a 2.2% per year [4]. At this rate, it is predicted that the planet will come to a point where it cannot sustain human life because it will run out of resources. For this reason, energy must be used in a more efficient way.

Conserving energy and using it efficiently is a multi-faceted endeavor that can be approached from many perspectives. This document will look at how reducing energy use in outside lighting through replacing lights and lighting fixtures with more efficient models. In 1997, electrical powered lighting consumed 2016 Terra Watt hours (TWh) [5]. It is estimated that the CO2 emissions generated from streetlights in the United States alone is over 150 million tons [6]. Technology has advanced and new models of light bulbs have been invented which greatly reduce energy used in outside lighting. With the technology we have available now we can increase the efficiency of outdoor lighting by 25%. If all outdoor lighting were replaced with LEDs, it would eliminate 765 TWh of electricity per year [7]. A brief description of the light bulb models used in this study is as follows:

- High Pressure sodium (HPS) lamps: HPS lamps were developed in 1968, and at that time they were considered the most high performance industrial style lighting discharge (HID) lamps yielding a strong yellow light. HPS lamps have dominated the outdoor lighting industry since then, but they do not come without their issues. One of the major problems about HPS lamps is that they do not instantly emit light once electricity is applied. Pressure has to build up and temperature has to rise in order for sodium metals to become vapor. When the vapor enters into the arc energy is released which causes the white light. If the power source is interrupted the HPS lamp has to cool down before it will emit light again [8]. This attribute about HPS lamps can cause major problems if a continues light is needed

- Ceramic metal halide (CMH): CMH lights started to become popular in the 1980's because of its high efficacy rating. Efficacy is the ratio of lumens to watts – Lumens being the unit of illumination; therefore, it takes less power to display more light. CMH's are also a type of high HID lamp and they have many of the same issues as HPS lamps [9]. The advantage CMH lamps have over HPS lamps is a higher color rendering index (CRI) of between 65 and 90, when HPS only offer a CRI between 20 and 25. CRI is a measure of accurate colors look under the light; a higher CRI indicates better color appearance [10]. CMH lamps are also known as 'metal arc' lamps. Their main applications are spot lighting where a high CRI is needed such as baseball and football fields, car lots and factory settings [11].

- Light emitting diodes (LED): The LED was created by Nick Holonyak, Jr. He crafted the first practical LED in 1962 [12]. LED's produce light through a process called electroluminescence. This process happens by recombination of the electron hole pairs in the p-n junction of semiconductors. The effect of recombination is a release of energy, but in form of light. Hence the name "light emitting" diodes. The process of luminance in LEDs is efficient, practical, and controllable. Therefore, it has many applications. LEDs are used for traffic signals, head lights, tail lights, television, and many more [13]. LEDs are the most efficient source of light that technology has to offer. Until recently, it was not possible to produce LEDs that had the capabilities of producing white light at the power levels needed for outdoor lighting, but in 2008 white LEDs had a recorded efficacy rating of 169 lumens per watt [13]. Now that the technology is available, if all incandescent light bulbs were replaced with LEDs the savings would be over 80 TWh annually [7].

HPS, CMH, and LED are the lamps used in this analysis. The site that is being studied replaced all of their HPS and CMH lamps with LEDs.

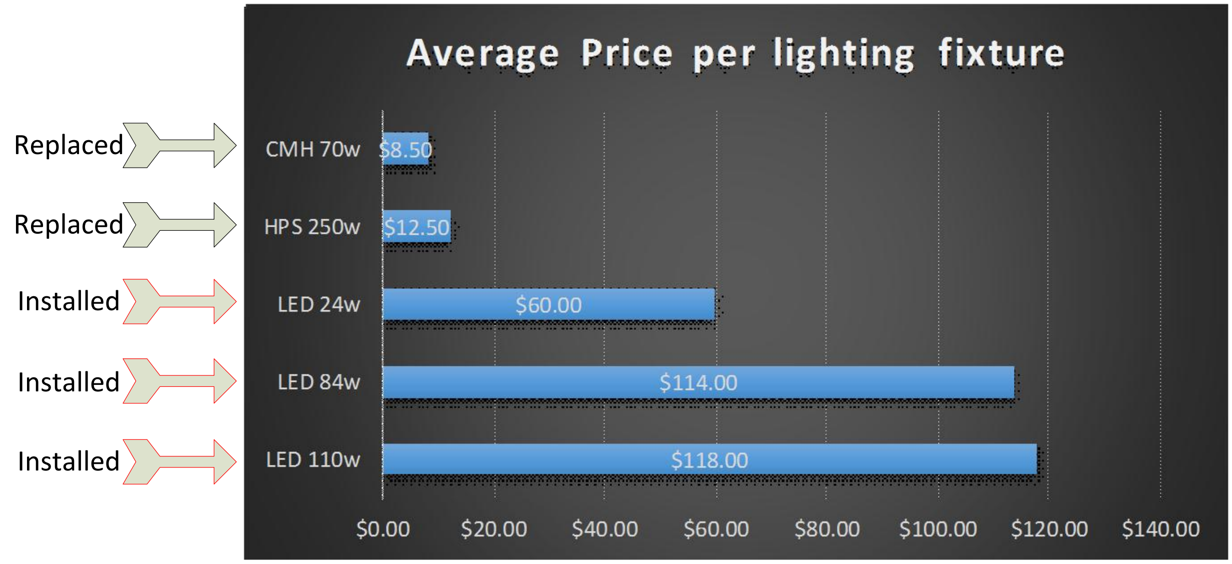


Fig 1: Average pricing for lighting options [14][15]

Fig 1 shows how much more LED bulb costs are as compared to CMH and HPS lighting. When comparing a HPS 250W lamp to an 110W LED it can be seen that there is over a one-hundred dollar difference in price, but these prices are deceiving. Through the economic analysis of the site that is being studied, it will be seen that LEDs are not only more beneficial to the environment, but they also cost less if energy cost and maintenance are considered.

Although LED lights seem to have only positive outcomes, the capital investment is a huge reason why they are not more popular; the market is showing evidence of a huge change. The McKinsey company states "The inflection point for LED retrofit bulbs in the residential segment, for example, is now likely to be around 2015"[16]. They also believe that almost 70% of the global lighting market will be held by LEDs in the year 2020.

The ever increasing population and energy use has caused energy efficiency and conservation to be a major priority of all human life. Solving the world energy crisis is a multi-faceted endeavor, and improving outside lighting with more efficient models such as LEDs is going to be an integral part of the solution.

ENERGY PRICING TRENDS

There are two predominant factors that drive the replacement of regular light bulbs with energy efficient ones. On the one hand, people are concerned with the effect of rising energy consumption on the environment. On the other hand, the price for energy is generally increasing, and very volatile

[17]. The price of energy has a monetarily measurable influence on economic models. It thus seems appropriate to take a closer look at energy cost prediction models must be taken.

In order to be able to evaluate the monetary significance of energy saving components, a reliable prediction of energy costs needs to be made. Different models already exist in the literature. One popular method is neural networks [18], which try to estimate long-time future energy prices. Energy prices can also be forecast on a daily basis. Common approaches to that are *real-time pricing* (RTP), *day-ahead pricing* (DAP), *time-of-use pricing* (TOUP), and *critical-peak pricing* (CPP) [18].

Pindyck [19] argues that the most reliable source to predict future energy trends is to take a look at past energy prices. From over 127 years of data, he derives complex mathematical models to predict the future price of energy. The approach of looking at past data to determine future trends seems appropriate for the application of this case. Hence, the price of energy (cents/kWh) in the United States during since 1990 [20] has been analyzed via linear regression. The results are summarized in Fig 2.

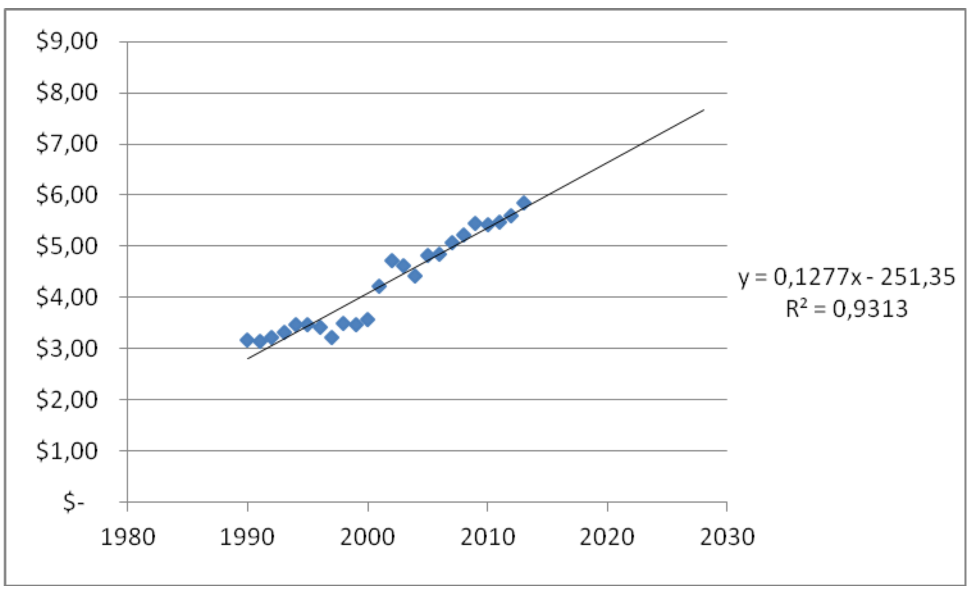


Fig 2: Energy Price [dollars/kWh] from 1990 to 2013 [21]

The fit of the model is very high (R^2>0.9). The assumption will be made that the models proposed by the literature exceed the needed complexity for the purpose of this paper. Accordingly, the results of Fig 2 will be used as a basis to determine likely prices of energy for the future.

The financial and monetary impacts of outdoor lighting projects and replacement decisions will be calculated by using the net present value (NPV). The NPV is an economic parameter in the dynamic investment appraisal. It is the sum of all present values of every cash flow of the investigated project or investment [22]. The cash flows are made comparable by discounting them to the beginning of the project. The calculated NPV is an actual amount of money that can be seen as the gain/loss of the project taking the companies MARR into account. This is one of the reasons why the NPV is used in this study. It is a computationally simple analysis which allows an easy interpretation because of the direct outcome of the expected monetary value of a project [23]. The pure decision making based on the NPV is therefore depended on the prefix:

NPV positive → acceptable project

NPV negative → non-acceptable project

The other reason for using the NPV is the fact that we determined the outdoor lighting projects as single projects. Every economic evaluation about the cost-effectiveness of these projects are seen as individual projects which either can be executed if being acceptable or neglected if being not cost beneficial.

Without funding constraints, the best projects are those with the highest NPV. However, in most of the real world cases there are budget constraint. This is why the project will also be evaluated by the ratio of the net benefits to the expenditures. The so called Benefit-Cost ratio (BCR) is calculated by dividing the benefits of a project by all its costs. It is important to discount all cash flows to the same point in time. Because the NPV will be used in the first economic analysis, the BCR is also calculated for the beginning of the project, using the present worth of the cost and benefits. The BCR must be greater than 1 for an acceptable project.

$BCR > 1$ → acceptable project

$BCR < 1$ → non-acceptable project

In general, the higher the BCR, the better and more cost-effective the project is. The same is valid for the NPV, the bigger the NPV is the more money can be earned. As already mentioned, all lighting projects are seen as individual and independent. So there will be no need to compare two or more projects with each other and the single economic methods described are sufficient for our project scope.

EXISTING MODEL & CRITICAL ANALYSIS

The firm in this study is a semiconductor manufacturing company with factories in Oregon, Texas and Florida. These manufacturing facilities are 24x7 operations and are spread over large campuses with parking for hundreds of people at any given time. Due to the large parking space areas and the 24x7 operation, there are occasions when lights go out and it can become unsafe for employees walking to their cars due to other cars not being able to see them in the parking lots as well as other safety concerns.

In 2008 at their Oregon headquarters and manufacturing site, their Facilities group put forward a proposal to overhaul their exterior lighting and replace all the building exterior and parking lot lights with LED lights with a comparable Lumens intensity. To get support for the project, the Facilities group came up with an ROI model that was approved by internal financial planners, and the project was implemented the next year.

The exterior lighting at the company was comprised of two different styles of light bulbs – 250 W light pole mounted fixtures and 70 W building mounted fixtures. Before replacement of the lights with LED lighting, the firm had to change a certain number of bulbs every year and hire equipment and manpower at an annual cost of $20,000 to do this maintenance work. Part of the rationale for replacement is elimination of these annual maintenance costs due to the 15 year effective life of the LED lighting.

The High Tech Case model assumes a simple replacement cost approach as shown in Appendix 1. The basic assumption for the model counted the number of lights and the wattage used on an annual basis – and calculated the annualized power consumption using the cost per kWh.

For clarity of analysis, the time per day the lights were supposed to be on was set at 12 hours per day. This gave an annualized power cost of $4870. Annual maintenance costs for this setup added an extra $20,000. These maintenance costs refer to the labor costs, cost of replacement lights, and specialized equipment used to install the lights. The company has a pre-defined MARR setting of 10% for maintenance projects, 15% for capital projects and 20 % for R&D projects.

In the replacement model shown in Appendix 2, the number of fixtures is roughly the same (101 to 109 prior). However, the wattage used in the large fixtures is significantly reduced from 290W and 100W to 110W, 24W and 84W. The total wattage replaced is 66% of the original wattage used (9.29 kW instead of 27.81 kW). This leads to a significantly lower annualized power cost as well ($1,626 instead of $4,870) – however, the bulk of any savings over the lifetime of the lights would come from NOT doing annual maintenance costs – considered indirect costs.

Issues needing more analysis:

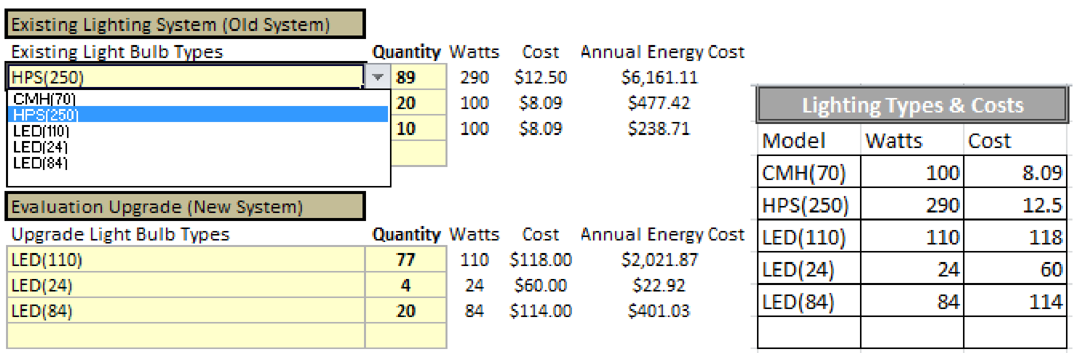
- Purchase costs of the LED lighting were not documented for purposes of the initial model.
- Installation Costs of the LED lighting fixtures – not enough information in the model to suggest whether there would be any conversion costs for converting one electrical fixture to a different one.
- Capital vs. Maintenance MARR: Rationale for using a lower MARR for a maintenance project vs a higher MARR for Capital projects
- Time Value of Money: What would have been the benefit of doing nothing and investing the outlay in a different project
- Energy Costs vs. Time: impact of higher energy costs over time
- Other Assumptions Not Documented

PROPOSED MODEL IMPROVEMENTS

Before deciding to create a new model, the team reviewed existing models in the body of knowledge [24]–[27]. The team was unable to locate any model in literature which was already available for application. The models available online were either primarily for lighting design purposes or were not fully featured economic models. The team found model, [24] which looked promising which the authors claimed included pay back analysis and time value of money, but the links to the model did not work and the screen shots showed the need to input luminaries for design purposes. Based on the available models, the team decided to propose a new model using the U.S. Department of Energy's Exterior Lighting Guide [28] as a basis.

This section will present a more comprehensive economic model and spreadsheet for energy efficient outdoor lighting upgrade projects. It is based on the High Tech Case spreadsheet presented and discussed above and it will include the criticized shortcomings of that model. Generally, the user of the model can perform the whole analysis on one master sheet. Three other worksheets are only used for background calculations and data storage. All the economic inputs and the calculated results are presented on the master sheet. The following paragraphs will explain and describe the inputs that are needed to monetary evaluate the lighting upgrade project.

The type and the quantity of the existing, old light bulbs and the upgraded, new ones are to be chosen in the top left sector of the spreadsheet. All these data and specifications are stored in a separate table in the workbook which can easily be modified by the user. The following excerpts of the spreadsheet show the drop down menu on the master sheet on the left side and the table for the input of the light bulb specifications on the right side, stored on the "Lighting Options" sheet.



Existing Lighting System (Old System)

Existing Light Bulb Types	Quantity	Watts	Cost	Annual Energy Cost
HPS(250)	89	290	$12.50	$6,161.11
CMH(70) / HPS(250) / LED(110) / LED(24) / LED(84)	20	100	$8.09	$477.42
	10	100	$8.09	$238.71

Evaluation Upgrade (New System)

Upgrade Light Bulb Types	Quantity	Watts	Cost	Annual Energy Cost
LED(110)	77	110	$118.00	$2,021.87
LED(24)	4	24	$60.00	$22.92
LED(84)	20	84	$114.00	$401.03

Lighting Types & Costs

Model	Watts	Cost
CMH(70)	100	8.09
HPS(250)	290	12.5
LED(110)	110	118
LED(24)	24	60
LED(84)	84	114

Fig 3: Drop down menu to choose light bulb (left); Table to enter light bulb specifications (right)

After choosing the light bulb models from the drop down menu, all needed data is automatically drawn from that database, using the Excel VLOOKUP function. This helps to improve the convenience and ease of use of the spreadsheet and the database can simply be extended if new light bulbs and technologies need to be included. The calculated annual energy cost for the first year of the project can be seen separately for each light bulb next to each lighting model. This number is calculated by multiplying the quantity of the bulbs, the consumed wattage of the light bulb and the later described hours of needed lighting and the energy cost.

Entry of other inputs relative to the existing system and the evaluation/upgrade system is done under the respective heading (e.g. "*Old System*", "*New System*"). The variable *Hours of Needed Lighting* is equal to the dark time duration of a day or, if the light is not needed the whole night, to the hours the lights are on per day.

In general, all cells that need manual input by the user of the model are marked with a yellow background. The grey background of the cells *Initial Energy Cost ($/kWh)* indicates that this input is automatically entered depending on the *Starting Year,* chosen in the last input cell.

The model uses the energy prices from year 1990 to 2012 according the U.S. Energy Administration Information [20] and assumes a linear energy price development, as explained and discussed in the previous "Energy Pricing Trends" section. The energy cost forecast calculation is done in the "*Model Output*" sheet. *The Minimum Attractive Rate of Return (MARR)* of 10% is chosen according to the High Tech Case setting and the inflation rate which is used in the model can be entered in the corresponding cell. There are three more model inputs related to the maintenance cost of the old (*Existing (Old) System Maintenance Cost*) and the new (*New System Maintenance Cost*) system as well as the one-time needed installation costs for the new light bulbs (*New System Installation Cost*).

The installation cost and especially the maintenance cost consist of the labor and the rental cost for the needed devices to install and replace the light bulbs and need to be adjusted over the project lifetime. Labor costs are mainly influenced by the wages and the development of it is highly associated to the inflation rate by the Oregon union labor laws. We assumed an average increase of the rental cost for lifts, etc., according to the inflation rate, too. So in total the maintenance cost is directly linked to the inflation rate. Fig 4 shows all the model inputs for the economic analysis of High Tech Case lighting upgrade project.

Existing Lighting System (Old System)	
Existing Light Bulb Types	Quantity
HPS(250)	89
CMH(70)	20
CMH(70)	10

Evaluation Upgrade (New System)	
Upgrade Light Bulb Types	Quantity
LED(110)	77
LED(24)	4
LED(84)	20

Model Inputs	
Hours of Needed Lighting	12
Initial Energy Cost ($/kWh)	0.0545
Minimum Attractive Rate of Return (MARR)	10.0%
Inflation	1.9%
Existing (Old) System Maintenance Cost	$10,000
New System Installation Cost (One-Time)	$18,500
New System Maintenance Cost	$0
Starting Year	2009

Model Outputs	
Breakeven Year	2011

Fig 4: Summary of the model inputs cut out of the spreadsheet

After the description of the needed model inputs, the next paragraphs will focus on the improvements of the proposed models in comparison to firm's spreadsheet. First, a closer look at the original model will be taken. Its shortcomings are very apparent and already listed in the previous section. The model is very static. Basically, it only takes two numbers into consideration: (1) the annual saved maintenance, and (2) the annual saved energy costs. This makes the model only valid for the given application, and it is not possible to use this model for other cases. Another big issue is that the existing model does not account for any changes in energy, labor, or other prices. This can have different implications. For example, it has already been established that the price for energy will rise in the future. Maintenance costs are also expected to rise because of an increase in labor costs. Lastly, the High Tech Case model only makes sense for one year. The time value of money is completely ignored. However, this is very important, especially when trying to evaluate a project that will produce costs (and benefits) over a longer period of time than one year.

All these mentioned shortcomings of the existing model are overcome by the proposed model. Two major benefits arise from the proposed model. First, it is universally applicable. In an organized manner, different inputs can be chosen. For example, the number of fixtures, as well as the preferred types can be chosen. Furthermore, appropriate numbers for the MARR and an inflation rate have been chosen. Should these numbers however change significantly over the next few years, they can be easily adjusted. Second, the proposed model makes possible alternatives easily comparable. By using the net present value (NPV) method, all costs expected over the entire lifetime of the new lighting fixtures are brought to one point in time. This makes it easy for the user to compare different options, like what impact changing the number of fixtures will have on the worth of the entire project. Another major improvement of the model is that it also accounts for the cost of the new light bulbs itself (hardware purchase cost). This represents the initial investment that must be made. Such an important input cannot be left out of any economic analysis. Furthermore, the proposed model includes a benefit cost ratio analysis. The outcome is one simple number that makes it easy for the user to determine whether or not the project should be undertaken.

Overall, the proposed model shows some promising advantages over the existing model. Mainly, the ability to universally apply this model to similar cases adds great value. It is also very easy for the user to determine the impact of every single input by seeing the direct change of the NPV. The use of a benefit cost ratio also allows for a simple and quick evaluation of whether or not the project should be undertaken. The presentation of the NPV and the B/C Ratio for different project life times also helps to further evaluate the lighting upgrade options. The model calculates and shows the values for a project life times of 3, 5, 10 and 15 years. Fig 5 shows the chart of the calculated NPV and B/C Ratio for the different periods.

NPV	
NPV Year	NPV
3	$6,778
5	$27,163
10	$66,328
15	$93,072

Benefit Cost Ratio	
BC Year	BC Ratio
3	1.23
5	1.90
10	3.20
15	4.09

Fig 5: Excerpt chart of the NPV and B/C Ratio for the High Tech Case

Another analysis that was added to the model is a break even analysis. The year in which the project will become profitable is shown in the section model output below the model inputs. In the specific case of the High Tech Case project, it only took less than two years to become net positive and so the projected started to pay off in the year 2011.

In addition to the comprehensive economic analysis, the model also displays the comparison of the yearly energy costs in the top right graph on the master sheet. This isolated view of the impact of the energy costs is another improvement of the model compared to the originally studied model. Therefore, the real energy savings caused by using more energy-efficient lighting technologies can be viewed separately. The next section will have a closer look at the results of the calculations and compare the results of the original model with the outcomes of the improved calculations.

The purpose of this section is to compare the results delivered by the existing model to those of the newly proposed model. The annual savings are summarized in Table 3. It can clearly be seen that the lightning exchange can be regarded as a full success, because great savings are evident. However, a closer number at the accuracy of the current model needs to be taken.

Table III: Comparison of Calculated Savings

Year	Annual Savings (Proposed model)	Annual Savings (High Tech Company model)
2009	$24,479	$23,853
2010	$24,826	$23,853
2011	$25,263	$23,853
2012	$25,756	$23,853
2013	$26,361	$23,853
2014	$26,786	$23,853
2015	$27,308	$23,853
2016	$27,838	$23,853
2017	$28,376	$23,853
2018	$28,922	$23,853
2019	$29,477	$23,853
2020	$30,040	$23,853
2021	$30,611	$23,853
2022	$31,192	$23,853
2023	$31,782	$23,853
2024	$32,381	$23,853
Present Worth	$179,337	$205,282

It can be seen that the proposed model actually shows higher savings that the existing one. This is because the proposed model accounts for an expected increase in energy prices over the next years. Accordingly, the proposed model appears more accurate than the existing one. Another interesting number is the present worth. Both present values are calculated with a MARR of 10%. Furthermore, an installation cost of $18,500 is taken into account for the proposed model, additionally to a purchase cost of $2,446. The current model does not take either of these numbers into account, as used light bulbs do not have any salvage value. This is the number that provides the most accurate insight on whether or not a project should be undertaken. As both values are greater than zero, the favorability of this project is further underlined.

It appears puzzling at first glance that the present worth of the existing model exceeds that of the proposed model, considering higher annual savings for the proposed model. This can be explained by the fact that no installation or purchasing costs are taken into account for the existing model.

Overall, the accuracy of the proposed model appears a lot better than that of the current one, because it takes a lot more variables into account. Given that such accuracy might not be necessary for the current case, the flexibility, adaptability and accuracy of the proposed model represent great advantages for future applications.

MODEL VALIDATION & ADDITIONAL CASES

This section will present three possible outdoor lighting scenarios. Each scenario is entered into the model and the results are analyzed to see if it is practical to upgrade the scenario with more efficient lights. The three different scenarios are a commercial restaurant parking lot, residential flood lights, and a 24 hour parking lot. The analysis for each is as follows:

Scenario #1: Commercial Restaurant parking lot. This scenario has a lot that is 150 by 250 feet with a restaurant in the middle of the lot. The existing outdoor lighting system consists of 6 poles with 10 400W HPS lamps that are on about 12 hours per day. The cost to replace an HPS lamp is $200 per lamp (parts and labor) [29]. In this scenario, using the existing system, three lamps a year would get replaced. Therefore the maintenance cost for the existing system is $600 per year. The MARR for this project is 15%, because it is a well-established restaurant that has been serving the community for years. The HPS lamps would get replace with 120W LED fixtures in the year 2013. At this time the cost of electricity is $0.05837 per kWh. The cost and labor to install each 120W LED fixture is $776 per fixture [14]. Fig 3 displays a graph of the analysis.

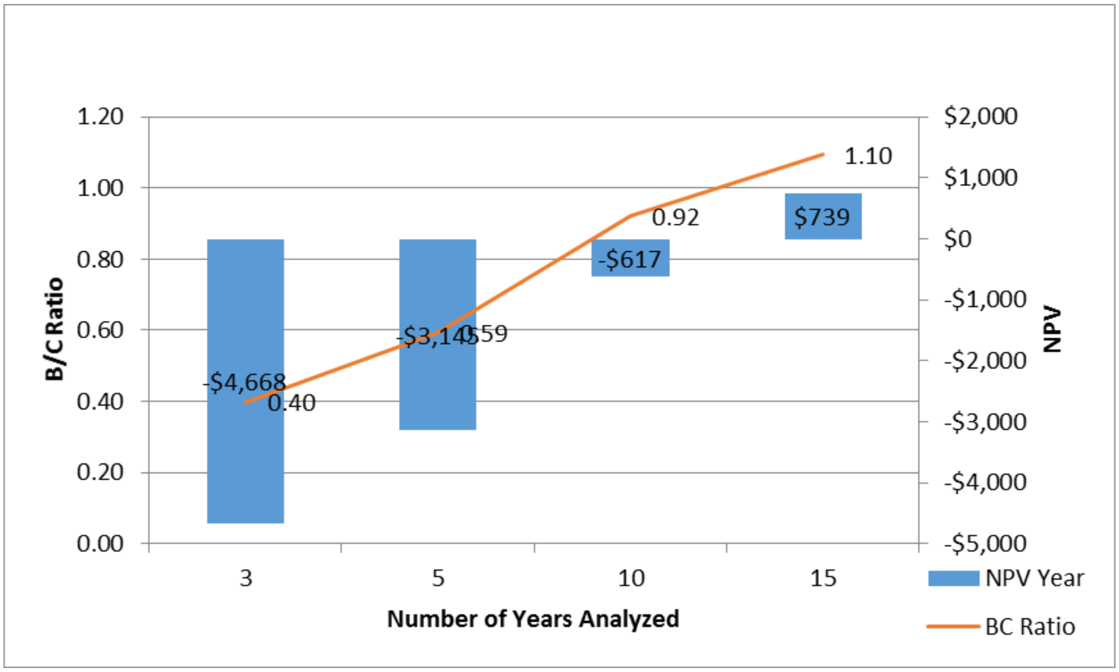


Fig 6: Commercial Restaurant NPV and B/C ratio

The initial cost for this project is $7,760. In Fig 6 it can be seen that this project could only be practical if it has a life time of 15 years. The breakeven year of this project is 2024. In the beginning of the project the difference in energy cost of the projects is the main source of revenue, but that quickly changes in the year 2015. The present worth of the energy saved in the first year of installation is $625, and the present worth of the energy saved in the last year of the project life time is $107. The cost saved on maintenance will always be $600 dollars or more per year. This project is much less lucrative then the high tech company project. If the cost of the LEDs were $6,000 the project would break even in 2020 and the decision to proceed might be easier for the property owner. As the years go on and technology advances, the cost of LEDs will decline and this project would be more practical. For now, the decision to follow through with this project would be probably be "no".

Scenario #2: Residential flood lights: This scenario consists of a residential dwelling that has eight 70W CMH flood lamps. The lights are turned on when the family goes to sleep and turned off when the first person wakes up. The time that the lights are on averages out to seven hours per day. The family replaces the lamps every four years. The cost for eight lamps is $64.72. Therefore the yearly maintenance cost is $16.18. The cost for eight (8) 24W LEDs is $480. As stated before, the LEDs have virtually no maintenance cost. The family has a MARR of 6% because they have a few loans they are paying off, and the cost of electricity is $0.09687 per kWh. Fig 7 displays a graph of the analysis.

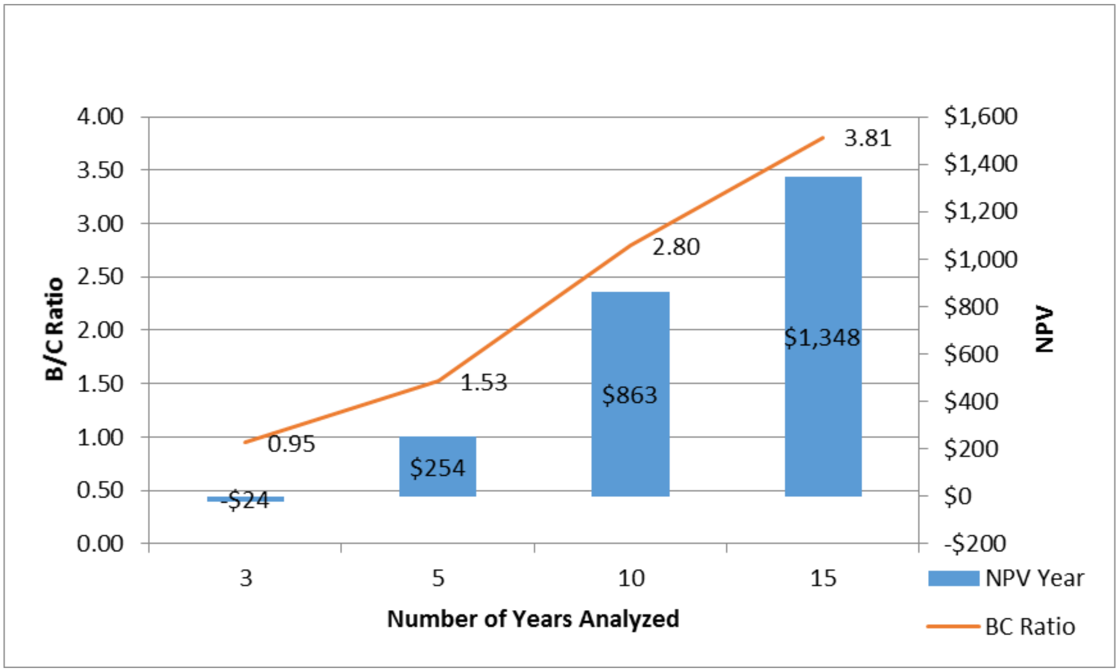


Fig 7: Residential flood lights NPV and B/C ratio

The initial cost for this project is $480. In Fig 7 it can be seen that this project will break even in year four (2016). This project is much more attractive than the commercial restaurant parking lot. This is a project where the main source of revenue comes from the energy cost. The present worth of the energy saved in the first year of installation is $142, and the present worth of the energy saved in the last year of the project life time is $78. The cost saved on maintenance will always be $16.16 dollars or more per year. The model shows that it would be a good decision to complete this project. The reason for this project being more practical then the commercial restaurant parking lot is due to the cost for installation not being part of the analysis, as the homeowner would do the installation themselves. It is also interesting to see that taking away 608 Watts of consumption can save over $1,000 in fifteen years in the residential market.

<u>**Scenario #3**</u>: Small 24 hour parking garage: This scenario has an enclosed parking garage that is 100' by 75'. The system runs 24 hours a day. The existing system consists of 4 400W HPS lamps. The cost to replace an HPS lamp is $200 per lamp (parts and labor) [29]. In this scenario, using the existing system, one lamp a year would get replaced. Therefore the maintenance cost for the existing system is $200 per year. The MARR for this project is 18%. The HPS lamps would get replace with 120W LED fixtures in the year 2013. At this time the cost of electricity is $0.05837 per kWh. The cost and labor to install each 120W LED fixture is $776 per fixture [30]. Fig 8 displays a graph of the analysis.

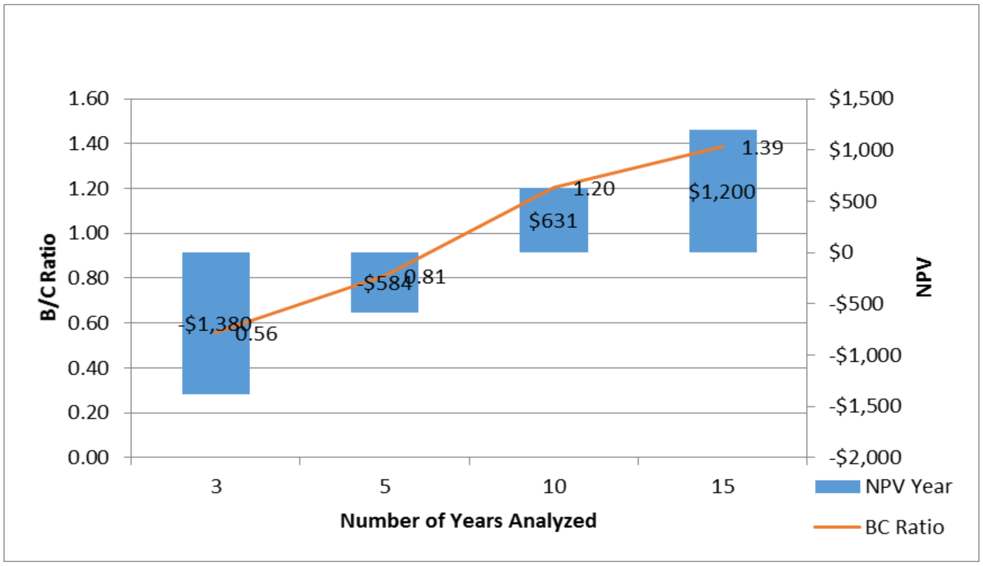


Fig 8: 24 hour parking garage NPV and B/C ratio

The initial cost for this project is $3,104. Fig 8 shows that this project is much more lucrative then the commercial restaurant project. The breakeven year of this project is 2019. The difference in energy cost of the projects is the main source of revenue. The present worth of the energy saved in the first year of installation is $487, and the present worth of the energy saved in the last year of the project life time is $58. The cost saved on maintenance will always be $200 dollars or more per year. This project is so energy intensive the lower wattage of the LEDs make a huge difference in energy cost and in turn, the cost of the LEDs do not make the project undoable. The decision to do this project would be a "yes".

The model developed was used to analyze three scenarios. The model showed that the commercial restaurant parking garage project was not practical, because the parts and installation cost of the LEDs did not justify the savings. The model showed that the residential flood lighting project was practical, because there is no installation cost when it comes to installing residential lights. Lastly, the model showed that 24 hour parking garage was also practical, because the project was so energy intensive. All of the results are logical when considering the scenarios. Therefore, the model is considered validated.

SUMMARY & FUTURE WORK

This paper presented a timely case study on potential replacement benefits of state-of-the-art LED lighting. An actual industry case was used for this study and a new model was proposed. Limitations with the case model were discussed as well as limitations existing models in the body of knowledge. A new more comprehensive model was developed which allows the user the flexibility to apply to different applications. Three (3) different scenarios were examined, showing different cases where new LED lighting may or may not make the most economic sense. This project used learning from ETM535, with specific application of TMV (Time Value of Money), NPV (Net Present Value), BC Ratio (Breakeven Ratio), and Payback Period. Linear regression was used to forecast future energy prices which were used by the model for predicting future energy costs.

Many further improvements could be made to the model. Inflation and energy prices could be modeled using non-deterministic methods. The model could include estimating installation costs including local labor, rental costs, insurance, etc. Additional lighting options could be added to model along with more input cells for the various options, the current model only has four (4) lighting input cells for each system. A web interface could be created so users could run the model without the need for specific computer software (i.e. MS-Excel).

This paper did not investigate how the replacement decision could be impacted by future technology changes or dramatic price reductions. In some cases, delaying an upgrade decision might make sense if a future technology, on the horizon, might be potentially a better solution. Additionally, it is expected that current technologies continue to experience reductions and efficiency improvements, which might impact upgrade decisions. The team did review the market s-curve for LED technology [31], which shows the technology is at the "mainstream" phase, so only gradual price reductions are expected (e.g. 5% per year).

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Existing Exterior Lighting Project

250 watt MH and HPS Fixtures		
	Number of fixtures	89
	Wattage used per fixture	290
	Total Wattage	25810
70 watt MH and HPS Wall pack Fixtures		
	Number of fixtures	20
	Wattage used per fixture	100
		2000
Total Electricity Usage (Watts)		**27810**

Annualized Costs Before Project

Power Consumption		
Cal	0.05837 c/kWHr	
Usage	12 hrs/day	83430 kWHr
Maintenance costs	(Replacement parts, labor, lift rental)	$20,000
Power Cost		$4,870
Total Costs		**$24,870**

New LED Fixtures Including Some Fixture Removal

110 watt Fixtures	
Number of fixtures	77
Wattage used per fixture	110
Total Wattage	8470
24 watt LED Wall pack Fixtures	
Number of fixtures	20
Wattage used per fixture	24
Total Wattage	480
84 watt LED Flood Lights Added for N2 Plant	
Number of fixtures	4
Wattage used per fixture	84
Total Wattage	336
Total Replacement Wattage	9286
Total Wattage replaced	18524
Annual Replacement (kwHr)	$55,572
Cost of electricity	**$3,244**

(12) 290 watt fixtures removed 3480 watts

Totals 5806 watts or 5.806 KW

Annualized Costs After Project

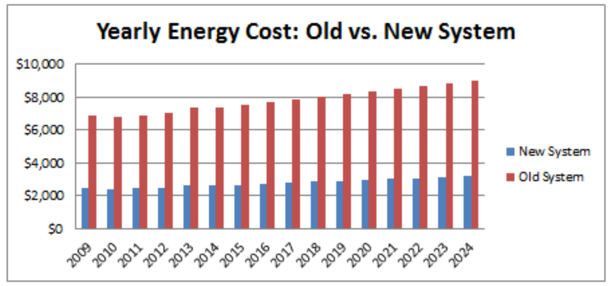
Power $1016.68 (17418 KWH x .05837 cents per KWH charged)

No annualized maintenance due to fixture life of 15 years

Total annual savings **$23,853.12**

Existing Lighting System (Old System)				
Existing Light Bulb Types	**Quantity**	Watts	Cost	Annual Energy Cost
HPS(250)	**89**	290	$12.50	$6,161.11
CMH(70)	**20**	100	$8.09	$477.42
CMH(70)	**10**	100	$8.09	$238.71

Evaluation Upgrade (New System)				
Upgrade Light Bulb Types	**Quantity**	Watts	Cost	Annual Energy Cost
LED(110)	**77**	110	$118.00	$2,021.87
LED(24)	**4**	24	$60.00	$22.92
LED(84)	**20**	84	$114.00	$401.03



Model Inputs	
Hours of Needed Lighting	**12**
Life Cycle for NPV and Benefit / Cost	**15**
Initial Energy Cost ($/kWh)	**0.0545**
Minimum Attractive Rate of Return (MARR	**10.0%**
Inflation	**1.9%**
Existing (Old) System Maintenance Cost	**$10,000**
New System Installation Cost (One-Time)	**$18,500**
New System Maintenance Cost	**$0**
Starting Year	**2009**

Model Outputs	
Breakeven Year	**2011**

NPV	
NPV Year	NPV
3	$6,778
5	$27,163
10	$66,328
15	$93,072

Benefit Cost Ratio	
BC Year	BC Ratio
3	1.23
5	1.90
10	3.20
15	4.09