AN INVESTIGATION OF WINDOW AND LIGHTING SYSTEMS USING LIFE CYCLE COST ANALYSIS FOR THE PURPOSE OF ENERGY CONSERVATION IN LANGFORD BUILDING A AT TEXAS A&M UNIVERSITY

A Thesis

by

HEA YEON HWANG

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Construction Management

An Investigation of Window and Lighting Systems using Life Cycle Cost Analysis for the Purpose of Energy Conservation in Langford Building A at Texas A&M University

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Approved by:

Co-Chairs of Committee,	John M. Nichols
	Zofia K. Rybkowski
Committee Member,	Weiling He
Head of Department,	Joseph P. Horlen

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ABSTRACT

An Investigation of Window and Lighting Systems Using Life Cycle Cost Analysis for the Purpose of Energy Conservation in Langford Building A at Texas A&M University. (May 2011)

Hea Yeon Hwang, B.E., Seoul National University of Technology

Co-Chairs of Advisory Committee: Dr. John M. Nichols
Dr. Zofia K. Rybkowski

Langford Building A forms part of the Langford Architectural Complex at Texas A&M University. Inefficient lighting fixtures and single pane windows in Langford Building A contribute to a considerable portion of the total cost of energy for this building. In the Southwestern United States, a building's windows can be responsible for a significant loss of energy. The windows and inefficient light bulbs can result in high utility costs and high labor charges from more frequent lighting maintenance than that required for efficient lighting. In Langford Building A, window system energy efficiency has not been improved since the building was constructed in 1977. This paper investigates the economic feasibility of using efficient lighting and window systems in Langford Building A. The cost for windows and new lighting tubes was analyzed and compared by using Life Cycle Cost Analysis. The payback periods, determined in this analysis, showed that more efficient lighting and window systems would reduce costs. As results of this analysis, the window film and LED lighting tube reduce building life cycle cost and short payback periods than other alternatives.

DEDICATION

I would like to dedicate the completion of this research to my parents. There is no doubt in my mind that without their continued support and counsel I could not have finished this course.

ACKNOWLEDGEMENTS

I would like to thank my committee co-chairs, Dr. John M. Nichols, and Dr. Zofia K. Rybkowski, and my committee member, Dr. Weiling He, for their guidance and support for the success of this paper.

Thanks also to my friends who helped me with this paper and the department faculty for making my time at Texas A&M University a great experience. Finally, thanks to my parents for their financial support and encouragement.

NOMENCLATURE

GBS	Green Building Studio
LED	Emitting Diodes Light
CFL	Compact Fluorescent Light
LCC	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
NPV	Net Present Value
MCS	Monte Carlo Simulation
LBA	Langford Building A of the Langford Architectural Complex at Texas A&M University College Station, Texas

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CHAPTER I

INTRODUCTION

Background

Excess energy consumption is a significant economic and political issue around the world. The concern arises from the depletion of fossil fuels, global warming, and the geopolitical issue related to the source locations for fossil fuels. Fossil fuel, which mainly includes coal, oil, and natural gas, provides nearly ninety-five percent of the world's total energy. These major energy sources are, however, being depleted and are non-renewable (Zoe, 1996).

Fossil fuel consumption contributes to global warming when electricity producing coal-fired power plants emit carbon dioxide and sulfur oxide (Shafiee & Topal, 2008; U.S. Department of Energy, 1995; Uri, 1980; von Hippel, Raskin, Subak, & Stavisky, 1993). Demand for fossil fuel will increase as the world's middle class develops, while fossil energy sources will deplete, therefore, costs for raw resources may rise, as they are at the present time (Dai & Chen, 2010; Shafiee & Topal, 2008, 2009).

Buildings are one of the major consumers of the world's energy. In the U.S., buildings consume thirty-nine percent of the country's total energy and sixty-eight percent of generated electricity (Baxter & Calandri, 1992; Edmonds & Smith, 2011; Nordell, 2003;WBDG., 2009).

This thesis follows the style of *Adult Education Quarterly*.

Although traffic and industry affect global warming by producing thirty-one percent and twenty-eight percent of greenhouse gases respectively, buildings produce forty percent (Brueckner & Zhang; Christie; Claes, 2001; Kanagawa, 2011; MacLean & Lave, 2003; Moriarty & Honnery, 2008; Uherek et al., 2010; Wade, Holman, & Fergusson, 1994; Zhang, Gudmundsson, & Oum, 2010). Green house gas emissions from buildings contribute thirty-eight percent of the carbon dioxide, forty-nine percent of the sulfur dioxide, and twenty-five percent of the nitrous oxides (Balaras et al., 2007; Cole, 1998; Georgopoulou et al., 2006; Huang & Haghighat, 2002; WBDG., 2009; H. Yan, Shen, Fan, Wang, & Zhang, 2010).

Buildings consume three main types of energy for lighting, heating, and cooling. Lighting accounts for twenty to twenty-five percent of all electricity use in the U.S, resulting in a significant cost to the community (U.S. Environmental Protection Agency, 1993) while heating and cooling systems consumption is forty percent. In a smaller domain, lighting alone typically represents about thirty to forty percent of a school's utility expenditures (Adkins, Eapen, Kaluwile, Nair, & Modi, 2010; Hirst, Cavanagh, & Miller, 1996; Johnson & Unterwurzacher, 1993; Lighting Controls Association, 2009).

This study presents energy saving alternatives for campus buildings and demonstrates the use of an Life Cycle Cost analysis to compare alternatives (Cople & Brick, 2010; Leckner & Zmeureanu, 2011; Mithraratne & Vale, 2004; Raman & Tiwari, 2008).

In this study, a framework has been established to study the methods to reduce the energy cost of an existing old campus building. To test the framework, Langford

Building A was selected for the case study as energy data for the building was available. A building's model was developed for the study using Revit architecture program (W. Yan, Culp, & Graf). This methodology can be applied to other old campus buildings.

Figure 1. Langford Building A Façade

Problem Statement

Langford Building A at Texas A&M University is wasting energy because of its inefficient lighting systems and old windows. This energy consumption can be shown to be economically reduced using Life Cycle Cost Methods.

Research Objective

The objectives of this research are:

1) to do a total cost analysis of the replacement of the lighting and windows of Langford Building A.

2) to calculate the life cycle cost (LCC) and payback periods.

Limitations

This paper focuses only on cooling and lighting energy usage in Langford A and suggests several ways to improve energy conservation on other aging campus buildings in Texas.

This research did not consider the maintenance cost in the buildings since it was difficult to collect data from the university. Only the initial cost and energy cost have been calculated for the study.

Only fluorescent tubes have been considered since most incandescent bulbs have been changed to CFL bulbs.

CHAPTER II

LITERATURE REVIEW

Introduction

The U.S. is the largest consumer of energy in the world but furnishes only about two percent of the world's production (O'Neill & Desai, 2005; Payne, 2009). Amory Lovins and colleagues at the Rocky Mountain Institute say that wasting unnecessary energy in the U.S. averages about $0.57 M per minute, and $820 M per day (Miller & Spoolman, 2010). In this respect, most of the campus buildings in the U.S. are wasting energy because of using outdated lighting systems and old windows. This research focuses on the inefficient energy usage of Langford A at TAMU since it unnecessarily increases the electric costs at the University.

Langford Energy Use

Inefficient energy usage by Langford A creates high utility fees as well as adverse effects on the environment. Charlie Shear, energy coordinator of the Utilities and Energy Management Department at TAMU, noted that an office building's lighting electricity usage is generally twenty-five to thirty percent (Shear, 2010) and cooling energy usage is about twenty-eight percent of the building's total electricity usage (Flex your Power, 2010). This observation applies to the lighting and cooling energy usage in Langford A is responsible for a large portion of its energy consumption.

In the past few years, the lighting fixtures in Langford have been changed from incandescent bulbs to compact fluorescent lamps (CFLs) and energy saving lighting fixtures for energy conservation. Therefore, the lighting energy cost of the building has been reduced. Brian Veteto, mechanical systems specialist at TAMU's physical plant, says that the 1970's-era ballast on the fixtures was changed to digital, solid-state ballast, which eliminates flickering when a fixture is turned on, providing more efficient operation (Rolfing, 2008).

Table 1 shows the relevant energy costs for TAMU.

Table 1.

Energy Costs TAMU

Date	Electricity (kWh)	Unit rate	Electricity cost	Chilled water (mBtu)	Unit rate	Chill cost
4/1/09	162,649	0.113	$18,379	576,885	0.0146	$8,423
5/1/09	153,618	0.113	$17,359	923,912	0.0146	$13,489
6/1/09	146,475	0.113	$16,552	1,182,110	0.0146	$17,259
7/1/09	155,245	0.113	$17,543	1,360,446	0.0146	$19,863
8/1/09	147,242	0.113	$16,638	1,277,437	0.0146	$18,651
9/1/09	152,989	0.113	$17,288	1,019,115	0.0146	$14,879
10/1/09	162,093	0.113	$18,317	760,251	0.0146	$11,100
11/1/09	162,255	0.113	$18,335	448,354	0.0146	$6,546
12/1/09	160,088	0.113	$18,090	177,834	0.0146	$2,596
1/1/10	143,116	0.113	$16,172	117,082	0.0146	$1,709
2/1/10	143,028	0.113	$16,162	56,029	0.0146	$818
3/1/10	143,283	0.113	$16,191	284,170	0.0146	$4,149
Total Energy Usage	1,832,081		$207,025	8,183,625		$119,481

The electricity costs are shown in Figure 2. The seasonal differences are evident in the data presented in the figure.

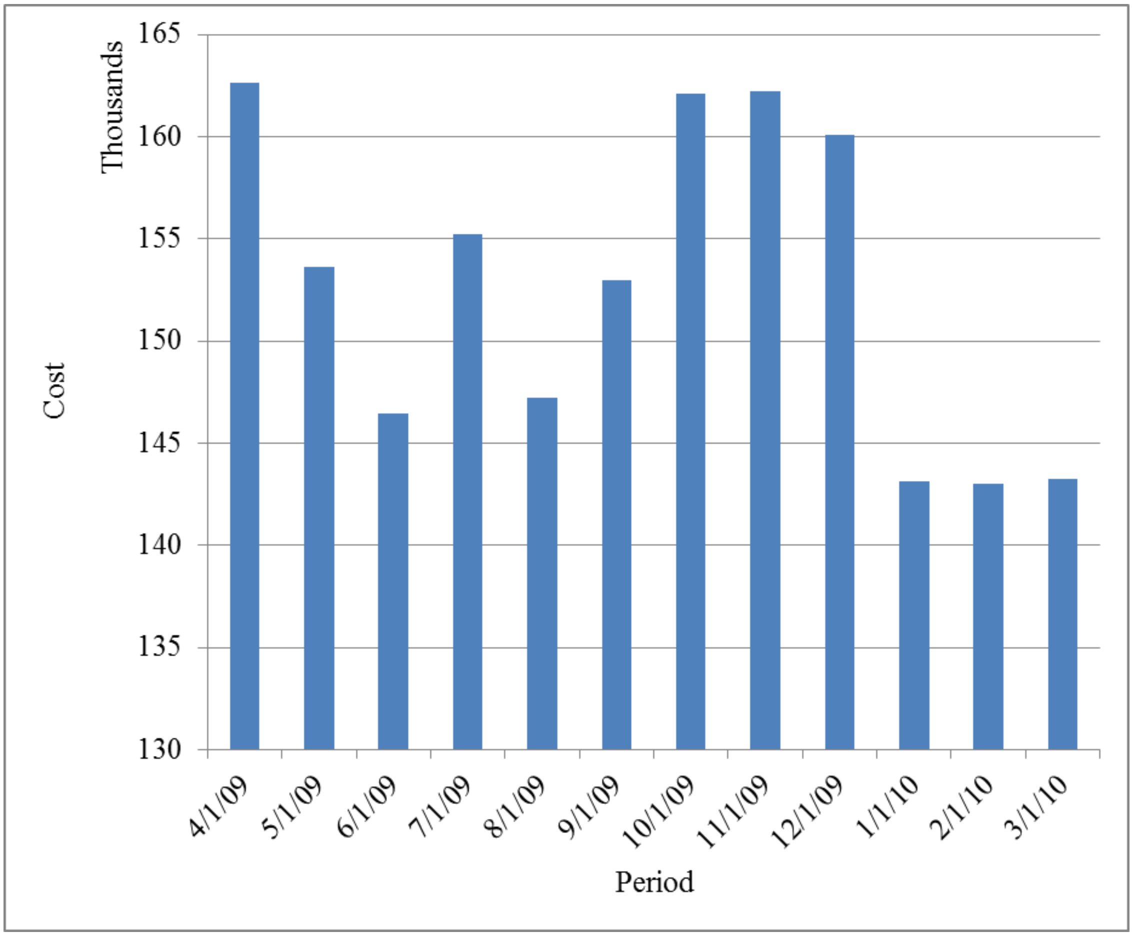

Figure 2. Electricity Costs TAMU

However, the remaining inefficient lighting fixtures and ordinary fluorescent lamps incur a high-energy cost. In addition, windows in Langford A have not been changed since the building was constructed due to the high replacement cost.

The cooling costs are measured in terms of the chilled water use as shown on Figure 3.

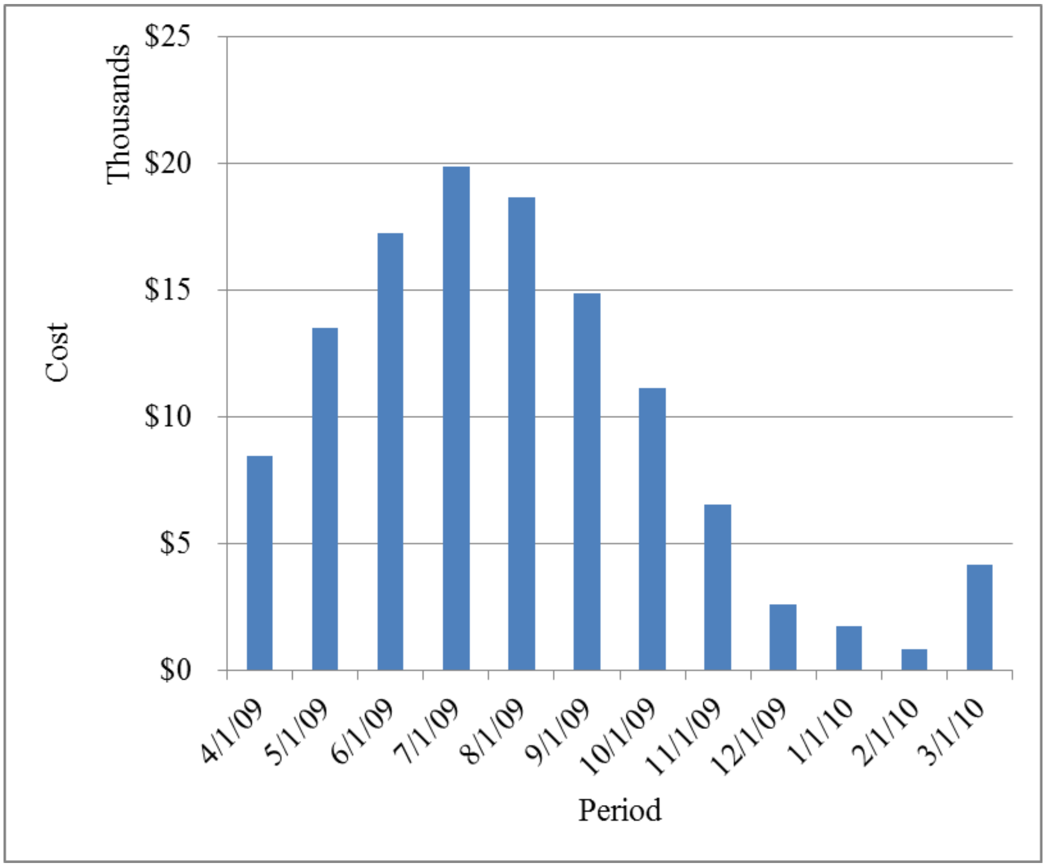

Figure 3. Chilled Water Costs TAMU

Figure 4 shows the TAMU utility rates of interest to this study.

Previous Studies

Many studies have been conducted to reduce lighting costs in certain buildings. Previous papers presented ways to save energy through studying daylight and converting to an effective lighting system (Guillemin & Morel, 2001; Holladay, 1929; Mahlia, Razak, & Nursahida, 2011; Yang & Nam, 2010; Zmeureanu & Peragine, 1999).

The key feature is the desire to reduce costs. The Department of Energy track energy costs in the USA Figure 5 and Figure 6 show sample of this type of available information (NIST, 2008).

PHYSICAL PLANT DEPARTMENT · TEXAS A&M UNIVERSITY

UTILITIES

Utility Rates

FY – 10 (September 1, 2009 – August 31, 2010)*

UTILITY SERVICE	UNIT RATE
Electricity	$ 0.113 / kwh
Domestic Cold Water	$ 1.567 / mgal
Domestic Hot Water	$ 13.822 / mgal
Waste Water Treatment	$ 4.277 / mgal
Solid Waste & Recycling	$ 92.870 / ton
Storm Drainage	$ 2.077 / msqft/month
Chilled Water	$ 14.582 / mmbtu
Heating Hot Water	$ 18.147 / mmbtu
Steam	$ 19.896 / mlbs
Natural Gas	Determined by Local Distribution Co.

Utility Rates are subject to change, beginning September 1st of each fiscal year.

*Be sure you are using the current utility rates for your project.

Utility Rates are posted at the following link:
http://energy.tamu.edu/

Figure 4. TAMU Utility Rates

Table Ca-3. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 3 (Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia)

Projected April 1 Fuel Price Indices (April 1, 2010 = 1.00)

Sector and Fuel	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Residential															
Electricity	0.96	0.98	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.01	1.01	1.02	1.02	1.02	1.03
Distillate Oil	1.00	1.05	1.11	1.15	1.18	1.23	1.28	1.31	1.34	1.36	1.38	1.39	1.40	1.42	1.43
LPG	0.99	1.03	1.07	1.11	1.14	1.16	1.18	1.21	1.22	1.23	1.24	1.24	1.25	1.26	1.27
Natural Gas	1.05	1.07	1.05	1.05	1.06	1.07	1.07	1.07	1.08	1.09	1.10	1.12	1.13	1.14	1.15
Commercial															
Electricity	0.94	0.95	0.96	0.96	0.95	0.96	0.98	0.98	0.98	0.98	0.99	0.99	0.99	1.00	1.01
Distillate Oil	1.00	1.06	1.14	1.19	1.23	1.29	1.34	1.38	1.42	1.44	1.46	1.48	1.49	1.51	1.52
Residual Oil	1.14	1.20	1.27	1.33	1.36	1.40	1.43	1.46	1.47	1.48	1.50	1.51	1.52	1.54	1.55
Natural Gas	1.08	1.14	1.14	1.14	1.16	1.17	1.17	1.18	1.18	1.20	1.21	1.23	1.25	1.26	1.27
Coal	0.96	0.93	0.92	0.91	0.88	0.87	0.86	0.86	0.85	0.85	0.84	0.84	0.84	0.83	0.83
Industrial															
Electricity	0.91	0.90	0.90	0.89	0.89	0.90	0.91	0.91	0.91	0.92	0.92	0.93	0.94	0.94	0.95
Distillate Oil	1.02	1.09	1.17	1.22	1.27	1.33	1.38	1.42	1.45	1.48	1.49	1.51	1.53	1.54	1.56
Residual Oil	1.10	1.16	1.23	1.29	1.33	1.36	1.39	1.42	1.44	1.44	1.46	1.47	1.49	1.50	1.52
Natural Gas	1.24	1.39	1.41	1.40	1.44	1.46	1.46	1.46	1.47	1.50	1.52	1.56	1.60	1.62	1.62
Coal	0.99	0.98	0.97	0.96	0.96	0.96	0.96	0.95	0.95	0.94	0.94	0.94	0.93	0.93	0.93
Transportation															
Motor Gasoline	1.02	1.07	1.15	1.21	1.24	1.27	1.30	1.32	1.34	1.36	1.37	1.39	1.40	1.41	1.42

Figure 5. Energy Cost Data from DOE

Table Ca-3, continued. Projected fuel price indices (excluding general inflation), by end-use sector and fuel type.

Census Region 3 (Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia)

Projected April 1 Fuel Price Indices (April 1, 2010 = 1.00)

Sector and Fuel	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Residential															
Electricity	1.03	1.03	1.04	1.05	1.07	1.08	1.09	1.10	1.10	1.11	1.12	1.13	1.13	1.14	1.15
Distillate Oil	1.45	1.46	1.48	1.50	1.51	1.54	1.56	1.58	1.61	1.63	1.65	1.67	1.69	1.71	1.73
LPG	1.28	1.29	1.30	1.31	1.32	1.33	1.35	1.36	1.37	1.39	1.40	1.41	1.43	1.44	1.45
Natural Gas	1.16	1.17	1.19	1.21	1.24	1.27	1.28	1.29	1.30	1.32	1.33	1.34	1.36	1.37	1.38
Commercial															
Electricity	1.01	1.02	1.03	1.04	1.06	1.07	1.09	1.10	1.11	1.12	1.12	1.13	1.14	1.15	1.16
Distillate Oil	1.54	1.56	1.58	1.61	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.83	1.85	1.87
Residual Oil	1.56	1.57	1.59	1.61	1.63	1.66	1.68	1.70	1.72	1.75	1.77	1.80	1.82	1.85	1.87
Natural Gas	1.28	1.29	1.32	1.35	1.38	1.42	1.44	1.44	1.46	1.47	1.49	1.51	1.52	1.54	1.56
Coal	0.83	0.83	0.83	0.83	0.84	0.84	0.84	0.84	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Industrial															
Electricity	0.95	0.96	0.97	0.99	1.01	1.03	1.04	1.05	1.06	1.07	1.08	1.09	1.11	1.12	1.13
Distillate Oil	1.58	1.59	1.61	1.64	1.66	1.68	1.71	1.74	1.76	1.79	1.82	1.84	1.86	1.89	1.91
Residual Oil	1.53	1.54	1.56	1.57	1.60	1.62	1.64	1.67	1.69	1.71	1.74	1.76	1.79	1.81	1.84
Natural Gas	1.64	1.67	1.71	1.77	1.83	1.91	1.94	1.94	1.97	2.01	2.04	2.08	2.12	2.16	2.20
Coal	0.93	0.93	0.93	0.94	0.94	0.94	0.94	0.95	0.95	0.95	0.95	0.96	0.96	0.96	0.96
Transportation															
Motor Gasoline	1.44	1.45	1.47	1.49	1.50	1.52	1.53	1.55	1.57	1.59	1.61	1.63	1.65	1.66	1.68

Figure 6. Energy Cost Data from DOE Continued

gbXML & Green Building Studio (GBS)

After completion of a model design, a Revit file is exported to the Green Building XML (gbXML) file, which is a textual schema that represents the building's information. All elements and their attributions of the buildings are specified in this file.

This information, which is contained in the gbXML, is then used for engineering analysis. The gbXML file has been used by architects due to the advantage of easy data exchange over the internet (NIST, 2008). The Autodesk Green Building Studio, (Autodesk, 2011) web based service to analyze building energy and efficiency, can import gbXML as an input and thus describing and inputting the building properties. This GBS web-based service (Autodesk, 2011) provides energy, water consumption data, and carbon emission analysis of the building. Through the data from GBS, architects can easily modify alternative designs to determine whether or not they are energy efficient and cost effective. The GBS uses accurate weather data within nine miles of the building location (Autodesk, 2011).

Presently, energy analysis software such as EnergyPlus (U.S. Department of Energy, 2011) and eQuest (Hirsch, 2011) can be used. However, unlike this other software, a GBS users can quickly learn and easily set a model's specifications for material, HVAC system, and U-value on the windows and walls even though the user does not have any significant knowledge of the GBS software. This is the main reason that the GBS was chosen for this research. To validate whether the simulation results are reliable, the actual energy usage data of Langford was compared with the simulated energy cost of the current lighting and window configurations. The actual electricity usage was obtained from the facility manager and the Utilities and Energy Management Department at TAMU as outlined in the previous section.

Cash Flow Diagram

In order to obtain more accurate comparison data, other costs such as labor, material, demolition, installation and operation have been estimated for the study. These costs were referenced from the RS Means Building Construction Cost Data Book 2009 (RSMeans, 2009). With this cost information, it was possible to obtain a rough estimate of the payback periods.

A cash flow diagram shows transactions that include initial cost, annual cost, and revenue. A cash flow depicts cash inflow and outflow based on a time line to summarize a financial cost problem and make a decision whether an investment in alternative projects is reasonable.

A typically constructed cash flow diagram is shown in Figure 7.

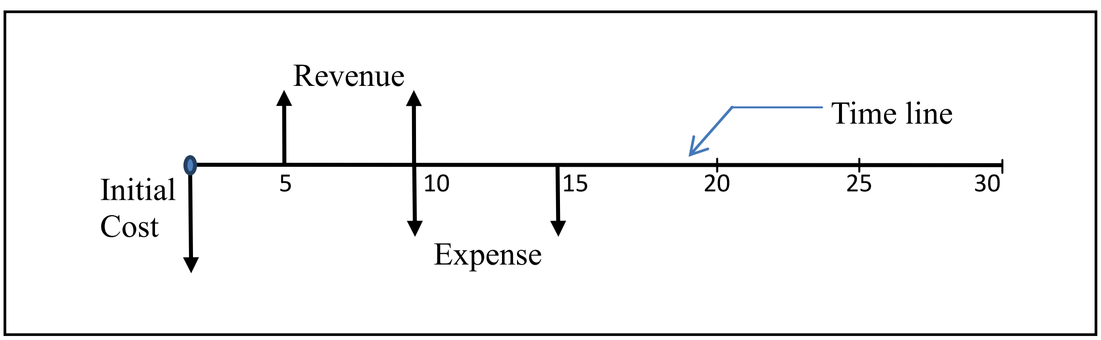

Figure 7. Constructing Cash Flow Diagram

On the figure, the horizontal line describes a time line that is divided into the same periods. Based on the time line, the first down arrow depicts initial costs for material, labor, and installation. After the first arrow, the up arrows represent annual revenue and the down arrows indicate expenses.

Life Cycle Cost Analysis

This study uses the building life cycle cost for a period of thirty years as the 'Life Cycle Costing for Design Professionals' recommends analysis periods from twenty five to forty years (Kirk & Dell'Isola, 1995). This is in line with normal economic analysis practice as illustrated on Figure 8.

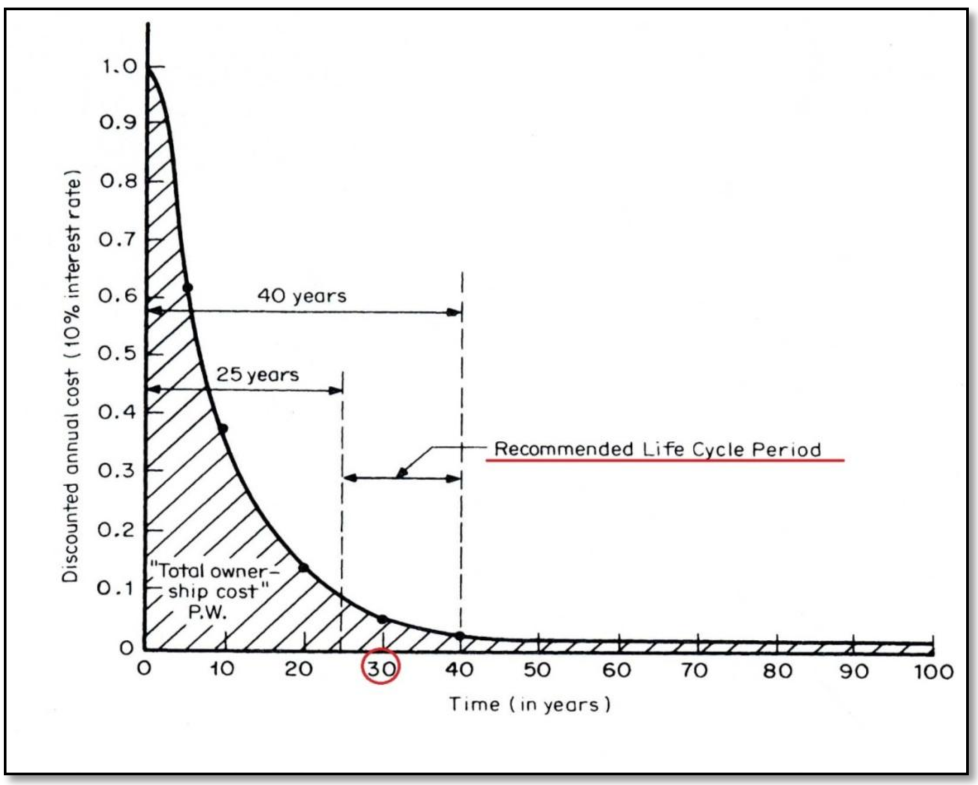

Figure 8. Recommended Life Cycle Cost Period (Kirk & Dell'Isola, 1995)

Using thecollectedeconomic data, a LCC study verifies by simulation which alternative will be the optimal strategy in this case provides the lowest building energy costs.

Energy conservation ratios are obtained by comparing:

1) the existing lamps in Langford A and the energy efficient lamps with ENERGY STAR LEDs,

2) between window replacement and low-e window film on the existing windows.

Based on these data, an applied LCC analysis with a cash flow diagram is used to determine the cost effective alternative. Life cycle cost analysis is a technique that uses simple principles of economics to estimate the total operation cost of a building across its life cycle (Muga, Mukherjee, & Mihelcic, 2008).

Life Cycle Cost Analysis (LCCA) has been used by the National Institute of Standards and Technology as a method to assess the total cost of facility ownership. "*It takes into account all costs of acquiring, owning, and disposing of a building or building system*"(Sieglinde, 2010). Total building cost can be estimated by a life cycle cost analysis to compare several alternatives and to select the most cost efficient option. Hence, stakeholders can make a better decision among alternatives by calculating expected annual costs throughout a building's lifespan. To analyze LCC, all expenditures for building items need to be assigned as the specific costs for each category, such as materials, installation, and replacement over a specified time period.

The life-cycle costs in this paper were calculated by using the formula:

$$\text{LCC} = \text{Initial cost} + \text{Replacement cost} + \text{Energy cost} \tag{1}$$

LCCA usually uses two methods, which are the Net Present Value (NPV) and the Uniform Annualized Cost (UAC) (Rahmen & Vanier, 2004). The NPV represents all costs such as future value, discounts, and inflation factors translated to present value, while the UAC method translates present value or future value into uniform annual costs. In this paper, the NPV method was used to forecast the total life cycle cost of Langford A over the study periods.

The Present Value (PV) decides future expenses by taking into account the predictable inflation of present dollars and discounting that amount by an anticipated rate over the period between the expected time of future and present time. Therefore, NPV represents total present value with expected future value, including discount and inflation factors. To calculate the NPV of Langford A in present value terms, the following formula was used:

$$PV = FV \times \frac{1}{(1+i)^{N}} \tag{2}$$

where PV is the total present money value, FV is the total future money value, N is the number of study periods and is the discount rate. To calculate LCC of the building, future value of each category such as energy cost, initial cost, and replacement cost was identified by applying the appropriate discount and inflation rate. The future value was then converted to present dollar value by using present value terms.

Payback Period

Simple Payback Period

Simple (undiscounted) payback period means the period of time needed to recover an initial investment. It is a vital measure in energy saving in life cycle cost analysis (LCCA). In other words, the payback period analysis is the easiest way to decide the feasibility of project alternatives. The following formula was used to calculate simple payback period:

$$\sum_{n=1}^{\theta} A - I \geq 0 \tag{3}$$

where, A is the annual cashflow, I is the Project Initial Cost and n is Years. Figure 9 illustrates the principles of this method.

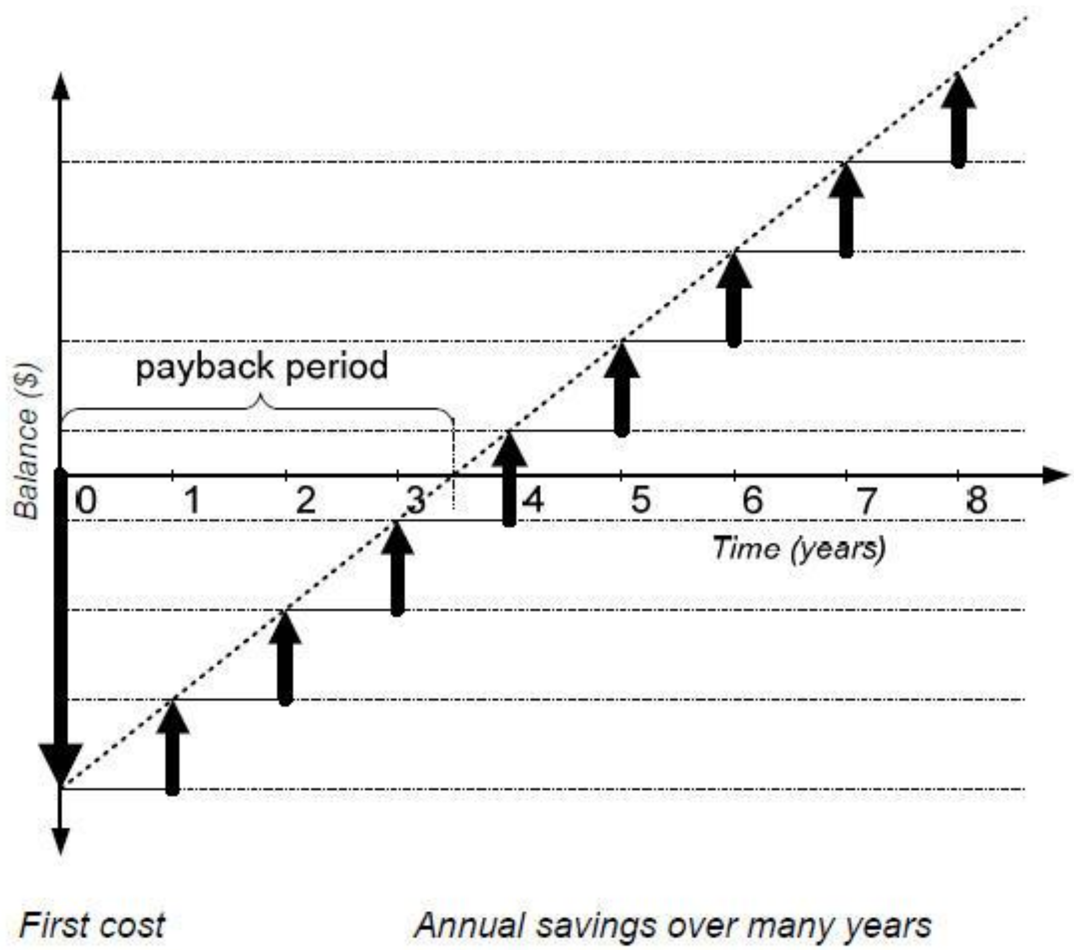

Figure 9. Simple Payback Periods (Rybkowski, 2009)

Discounted Payback Period

A discounted payback period takes into account the time value of money. Using this financial technology, the total present value of money can be calculated by applying discount rate. The discounted payback periods can be calculated by following formula:

$$\sum_{n=1}^{\theta'} \frac{A}{(1+i)^n} - I \geq 0 \tag{4}$$

where, A is the annual cashflow, I is the project initial cost, i is the discount rate θ is a dummy count variable, and n is years. Figure 10 illustrates this method.

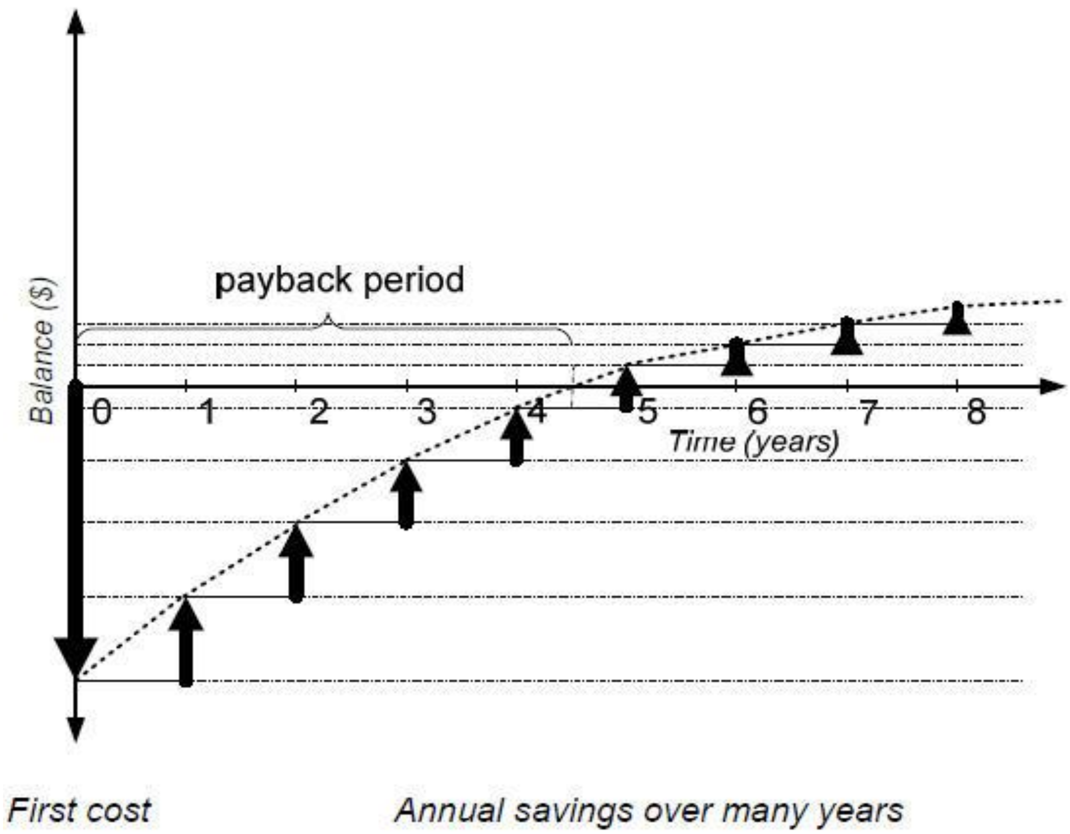

Figure 10. Discounted Payback Periods (Rybkowski, 2009)

Monte Carlo Simulation

Monte Carlo simulation in Microsoft Excel was used to evaluate financial values by using a sampling technique to help make a decision on the investments. Monte Carlo simulation is a useful method to analyze the feasibility of a project's predicted costs. Project risk and impact of uncertainty can be measured by using this simulation technique.

Monte Carlo simulation typically has two methods for LCCA, which are deterministic and probabilistic. The deterministic method uses fixed input variables such as time and cost from historical data and the cost book. Expected costs might be computed by simply using method, but the expected costs are untrustworthy since they do not consider any project uncertainty (Kumar, 2010).

To find a solution to this problem, the probabilistic method has been used to analyze LCC. Therefore, in this paper, the probabilistic method was used to obtain a more accurate value.

The Monte Carlo simulation uses a method for distribution of values to estimate variables and uncertain inputs. To evaluate the input, the simulation uses random numbers, normally over a ten thousand times for each input. The simulation is typically used for complex calculations (Lutz & Lutz. L., 2006). This simulation is especially useful in sensitive analysis and risk analysis.

Incentives

Despite the multiple advantages of LEDs, and with rapidly falling manufacturing costs, they remain expensive for commercial applications compared to other energy efficient lighting systems (Ross, 2000). The promised cost saving of LED lighting and advanced window systems can be successful by using federal and state incentives that encourage consumers to retrofit window and lighting systems where the governments provide financial resources to make these systems to affordable when compared to conventional systems using LCC. By having enough subsidies and consistent government regulation, there will be a significant development in a single market, job fields and economic.

The State Energy Conservation Office funds Texas Public School Districts by providing grants up to $30,000 for energy efficiency retrofits. One of the eligible projects is window treatments, such as a window film or upgrading to more efficient windows (Susan, 2010). Grants were awarded last year in the total amount of $885,269 to twenty-seven public school districts in Texas. The maximum award last year was $5,000 more than this year.

There is an another grant program, the 'Texas/Mexico Small Schools Grant Project' that offers a maximum amount of $50,000 to schools along the Texas/Mexico border to enable schools to install simple energy efficient equipment such as air conditioning and high energy efficient lighting. The success of this project not only improves air quality in classrooms and lighting systems but also provides students with a better learning environment. Twelve school districts in Texas have already received this award with annual savings around $78,275 (Susan, 2010).

ONCOR, Texas's largest regulated electric delivery business, has various incentive programs such as Educational Facilities Program, The State Energy Conservation Office, and School Matching Grant Program that provide electric energy efficiency and reduces energy costs for public schools and colleges (Price, 2010).

Table 2 presents the energy incentive systems in Texas. These grants may not be applicable to TAMU, but they demonstrate the commitment of the Texas government to energy efficiency and cost savings.

Table 2.

Incentive for Energy Saving

	Incentive Grant Programs	Incentive	Remark
1	The State Energy Conservation Office	$30,000	SECO
2	Texas/Mexico Small School Grant	$50,000	
3	Educational Facilities Program	$130 kW + $0.028 kWh	Oncor
4	School Matching Grant Program	$25,000	

Efficient Lighting

Moeck & Yoon (2004), describe a method to calculate the amount of lighting savings possible in a green commercial building based on current daylight. The authors considered several factors to save lighting energy, such as window size, shape, location, and workstation layout. They estimated the required lighting quality by measuring daylight luminance values which are determined by window location and external shading louvers. The building uses electric lighting when the daylight luminance value decreases. However, in the case of Langford A, most areas are drawing labs, which need good quality lighting lamps rather than indirect daylight.

To reduce lighting costs, Stansbury & Mittelsdorf (2001) proposed an efficient lighting system to save electric and environmental costs by converting the current lighting system to a more efficient system using LED kits and fluorescent lamps. This paper is not concerned about different types of lighting usage. Therefore, converting to energy efficient lighting fixtures was considered as well as applying different light fixtures depending on the purpose of the space in Langford A. Therefore, an efficient lighting system and the existing lighting system for the building were compared and energy savings were identified by calculating consumption of energy derived from Langford's energy data.

Mills (2002) proposed replacing kerosene lamps with a white LED electric lighting system to reduce greenhouse gases and save lighting energy. In addition, Mills considered fuel-based lighting savings to improve the effectiveness of the LED lighting system. Therefore, based on this paper, the fluorescent lighting system was applied to improve Langford building's energy efficiency.

Energy Efficient Windows and Film with LCC

Steve (2002) presented the energy savings from retrofitted window film on low-e windows. This study measured energy savings from window film by using eQUEST DOE-2, (Hirsch, 2011) simulating four climate zones, being southern central, south, north and northern central. He also obtained some efficiency values and payback periods from the window film used in this research. He noted that "*The payback periods of the window replacement was over forty years while the window film was less than thirtyyears*". In the southern climate zone, he insisted that applying window film can save energy costs by about ten times compared to replacing the entire windows. By applying life cycle cost (LCC) analysis, it was expected that the retrofitted window film will be a more efficient method than window replacement. He further noted that low-emissivity (low-e) film is one of the main energy saving strategies to reduce solar heat gain, especially in the southern climate zone as shown in Figure 11.

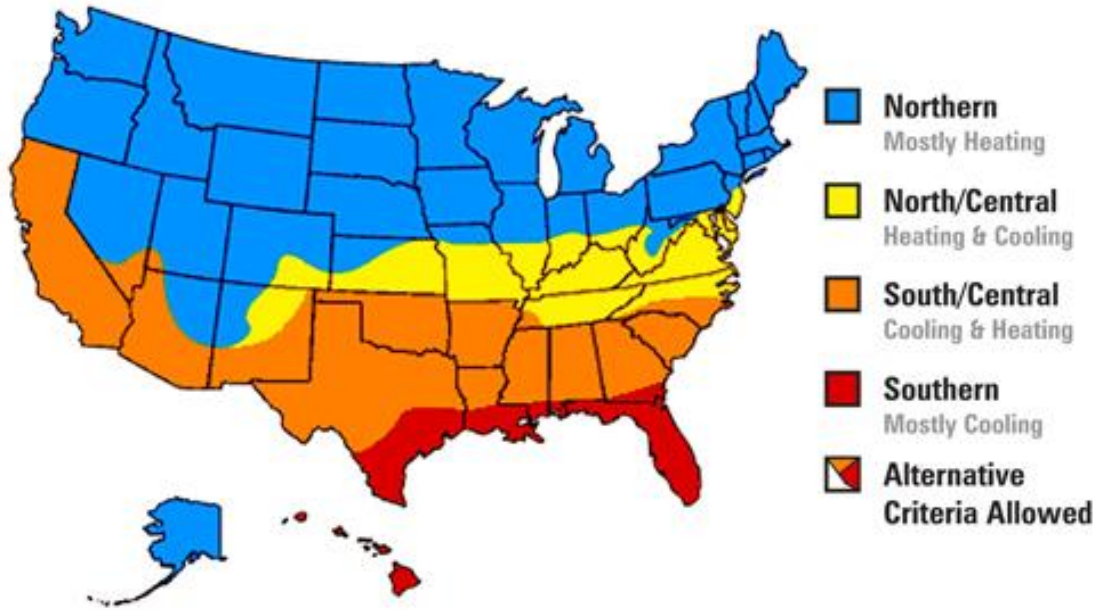

Figure 11. Requirements for Windows, Doors, and Skylights: Ver. 5.0 (April 7, 2009)

As noted by Fine Line "*In the case of Fresno State University, the window film reflects sixty nine percent of the entire solar energy and reduced cooling energy. The total energy costs from the university decreased by six percent due to the installation window film*" (Fine Line, 2010).

This research presents current lighting and cooling energy usage then shows the energy saving rate and payback periods by using an engineering economy analysis when the building is retrofitted with the energy saving lamps and the low-e window film. Low-e film is a thin, invisible metallic oxide film designed for window energy efficiency that works by blocking solar radiation. This material is being used in the world mainly to reduce the U-factor that measures the heat loss quantum by reflected radiative heat flow. This film acts to reduce heat transfer, UV, and ultraviolet rays (Efficient Window Collaborative., 2010).

Since it is critical to find ways to reduce load and increase efficiency, low-e films can be applied to the windows in Langford A to achieve energy saving.

Jung(2006) presented ways of reducing energy costs with multiple window coatings and showed an energy reduction rate in heating and cooling, which was calculated by LCC. This research used the EnergyPlus simulation program (U.S. Department of Energy, 2011) to measure heating and cooling energy usage based on weather data. The result achieved from the simulation shows an energy saving rate of about ten per cent per year can be achieved.

Lutz &Lutz L,(2006) analyzed life-cycle cost of an energy efficiency design. He looked to determine the energy efficiency standards for furnaces and boilers from using suitable comparisons of initial cost coupled with operating cost reduction. To install more efficient furnaces and boilers, a life cycle cost analysis was adopted to make an appropriate choice among the alternative products. Finally, Monte Carlo Simulation was used to account for variability and uncertainty of discount rates and length of lifetime (Korn, 2005; Kosina, Nedjalkov, & Selberherr, 2003;Marseguerra, Zio, Devooght, & Labeau, 1998). Because of this analysis, the author was able to choose the more efficient design option from the life cycle cost savings and payback periods.

Kim(2010) analyzed the different parts of a set of maintenance costs for an educational facility. The fluctuations range of the maintenance cost were analyzed for three educational buildings by applying the real maintenance cost data. To compare the maintenance cost analyzed by the data, LCC analysis was adopted and this study author used Monte Carlo Simulation. However, these studies did not consider government incentives or rebates for installing energy saving fixtures.

Summary

A full Monte Carlo simulation is warranted to determine the LCC.

CHAPTER III

METHODOLOGY

Background

In order to reduce energy consumption and minimize maintenance costs for lighting and windows in Langford A, this research has been divided into three parts:

1) cost data collection,
2) energy cost analysis,
3) LCC analysis.

Life Cycle Costs

First, life cycle costs for existing windows, film, and retrofitting double pane windows were calculated in this paper. Total costs for fluorescent tubes and LED tubes were compared according to the '*2009 RS Means Cost book*'(RSMeans, 2009).

Revit Model

In the energy consumption analysis, a Langford A model was generated by the Autodesk Revit architecture program and then the Revit file was exported to gbXML to analyze the building energy in web based Green Building Studio.

Economic Analysis

The total amount of building energy consumption and energy costs were calculated by using energy usage data for Langford A.

In order to implement sensitive analysis and net present value (NPV), the inflation and discount rates were applied for thirty years. In addition, Monte Carlo simulation (MCS) predicted the fluctuation range of future total cost.

After obtaining the energy cost for each scenario, for LCC analysis, payback periods and life cycle, the costs for lighting and windows were estimated for the study period. Then by comparing the payback periods and life cycle costs with the alternatives, a decision was made whether using energy efficient components is feasible or not. The overall procedure is shown in Figure 12.

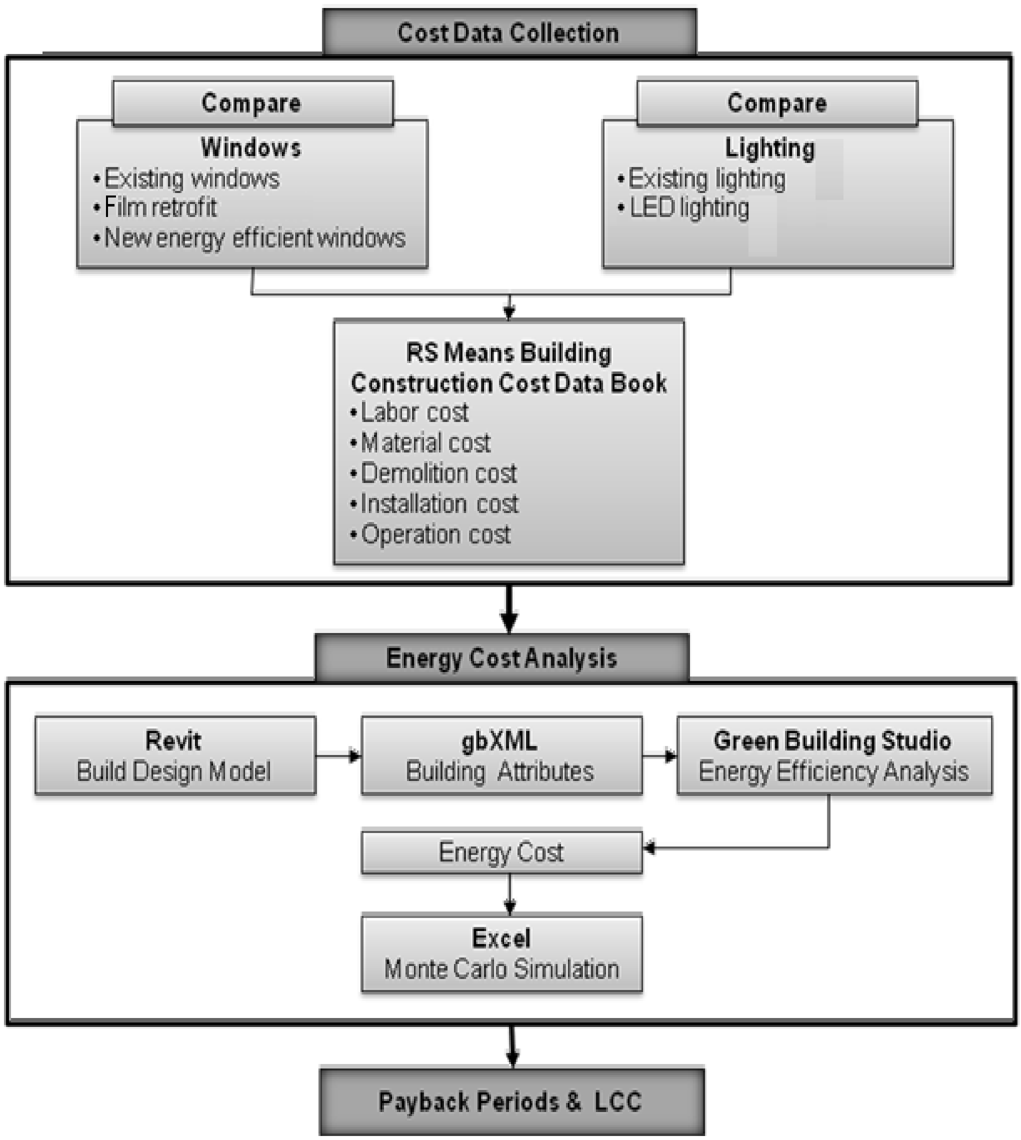

Figure 12.Overview of Process

CHAPTER IV

DATA COLLECTION

Background to the Case Study

Langford A has four floors and consists of computer labs, offices, classrooms, library, studios, and restrooms as shown in Figure 13. The reinforced concrete structure was constructed in 1977 with a floor area of 9,189 m^2. The building's lighting, which is fluorescent lighting and CFL replaced, but the single pane windows have not been changed since the building was constructed in 1977.

Figure 13. Langford Building A from the Front

Therefore, an efficient way to save energy cost should be strongly considered. Based on an energy analysis of lighting and cooling, an efficient lighting system and transparent heat-reflective window coatings, which can be applied for reasonable energy savings are investigated using an LCC.

Through this research, building energy saving was attained by applying same principle to the reinforced concrete building structures built in the 1970s. Table 3 presents a summary of the construction details for the case study building.

Table 3.

Langford Architectural Building A Details

Langford Details	
Building type	School Building (Langford A)
Year constructed	1977
Building area	9,189 m^2
Building structure	Reinforced concrete
Existing lighting type	Fluorescent + CFL
Existing window type	Single pane window + Blind

In this research, lighting and cooling energy usage has been analyzed for Langford A (hereafter referenced as Langford) by using a method that is specific to the building's functional purposes.

Table 4 shows the monthly energy usage and the total cost for the building which could be reduced by the proposed construction method. The energy usage data for a year was obtained from Carlos Teran, senior energy analyst in the Utility Energy Office at Texas A&M University (Teran, 2010).

Table 5 shows the chilled water costs used for cooling the building.

Table 4.

Monthly Electricity Usage at Langford A

Date	Electricity (kWh)	$ / kWh	Electricity Energy Cost ($)
Apr-09	162,649	0.113	18,379
May-09	153,618	0.113	17,359
Jun-09	146,475	0.113	16,552
Jul-09	155,245	0.113	17,543
Aug-09	147,242	0.113	16,638
Sep-09	152,989	0.113	17,288
Oct-09	162,093	0.113	18,317
Nov-09	162,255	0.113	18,335
Dec-09	160,088	0.113	18,090
Jan-10	143,116	0.113	16,172
Feb-10	143,028	0.113	16,162
Mar-10	143,283	0.113	16,191
Total Energy Usage	1,832,081		207,025
Unit cost			2.028

Table 5.

Chilled Water Costs

Date	Chilled water (mBtu)	$ / mBtu	Chilled Water Energy Cost ($)
Apr-09	576,885	0.0146	8,412
May-09	923,912	0.0146	13,472
Jun-09	1,182,110	0.0146	17,238
Jul-09	1,360,446	0.0146	19,838
Aug-09	1,277,437	0.0146	18,628
Sep-09	1,019,115	0.0146	14,861
Oct-09	760,251	0.0146	11,086
Nov-09	448,354	0.0146	6,538
Dec-09	177,834	0.0146	2,593
Jan-10	117,082	0.0146	1,707
Feb-10	56,029	0.0146	817
Mar-10	284,170	0.0146	4,144
Energy Usage	8,183,625		119,334
Unit cost			1.17

These tables describe Langford's monthly electricity and chilled water usage for a year, from April 2009 to March 2010. To calculate the total cost of energy usage, the electricity rate has been applied at $0.113 per kWh and $0.0146 per mBtu for the chilled water usage. This value was determined in accordance with the data presented in the literature review for TAMU.

The unit energy rate was provided by the Physical Plant Department for the period September 1, 2009 to August 31, 2010. The lighting and cooling energy cost was computed by applying the unit energy rate. Through these data, the current lighting and cooling energy usage and cost can be estimated. The total amount of energy saving can be derived when the existing light bulbs and old fashioned windows are replaced by LEDs and film.

Figure 14 shows the energy costs for the last thirty years. Based on DOE data, Figure 14 represents the change rate in electricity prices for the past thirty years. From 1980 to 2010, the change rate increased about fifty percent according to the historical electric cost. As shown in Figure 14, the trend line represents the average change rate for the past thirty years, which increased about three percent from 5.5 to 9.89; this change rate was used to obtain the expected future electricity price.

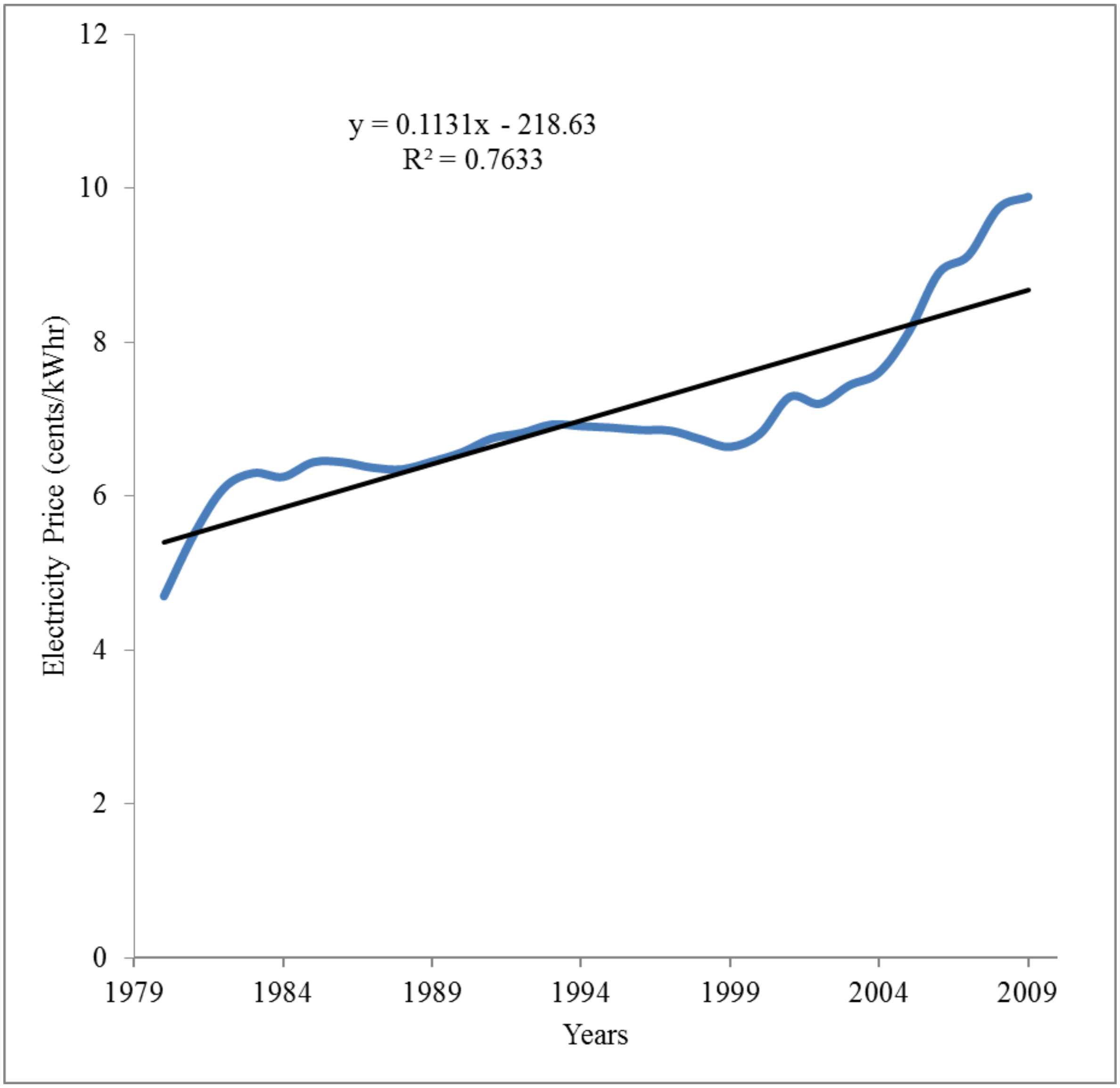

Figure 14. Trend of Electricity Cost for Past Thirty Years (US Department of Energy)

Building Design and Energy Cost

The Langford A design model was constructed through the Autodesk Revit Architecture program. Since this study is concerned with lighting and windows, the model focused on the lighting and window elements of the building. The usage of lighting in Langford is classified such that we will rate the importance of having efficient light bulbs in each place such as offices, layout rooms. Since not all of the places such as corridors and restrooms, require excellent lighting, this classification enables a more efficient lighting configuration. For the windows, it was decided to apply low-e film for each existing transparent single window in order to attain efficient heat isolation.

Revit Modeling

This Langford A model in Revit was generated for lighting and cooling energy simulation**.** Figure 15 to shows that LED lighting fixtures are settled in the building. Figure 15 is Langford's simple façade that was generated for energy simulation. Since the model was developed in a simple style for energy analysis, the roof was made flat.

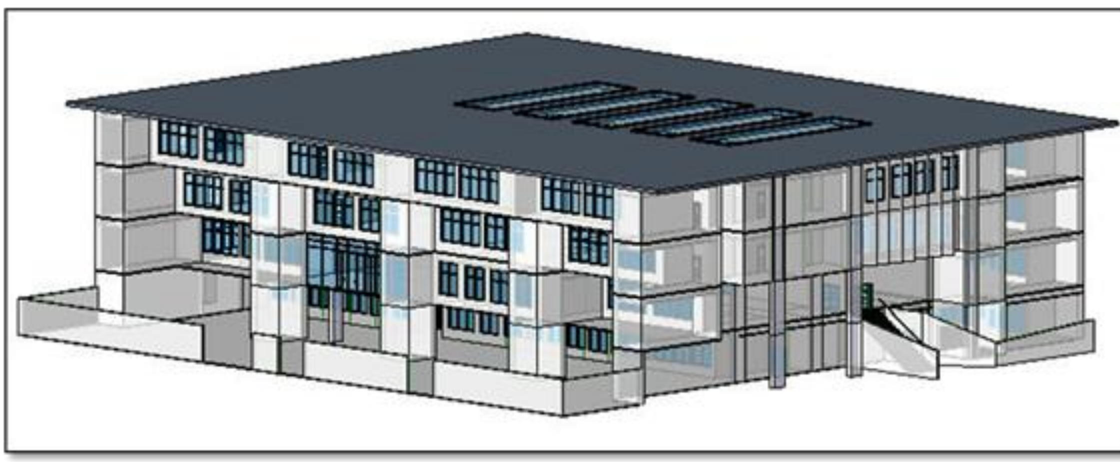

Figure 15. Langford A Revit Model Façade

Figure 16 shows the ceiling in Level 1, Figure 17 shows the ceiling 2 F plan, Figure 18 shows the ceiling 3 F plan and Figure 19 shows the ceiling 4 F plan.

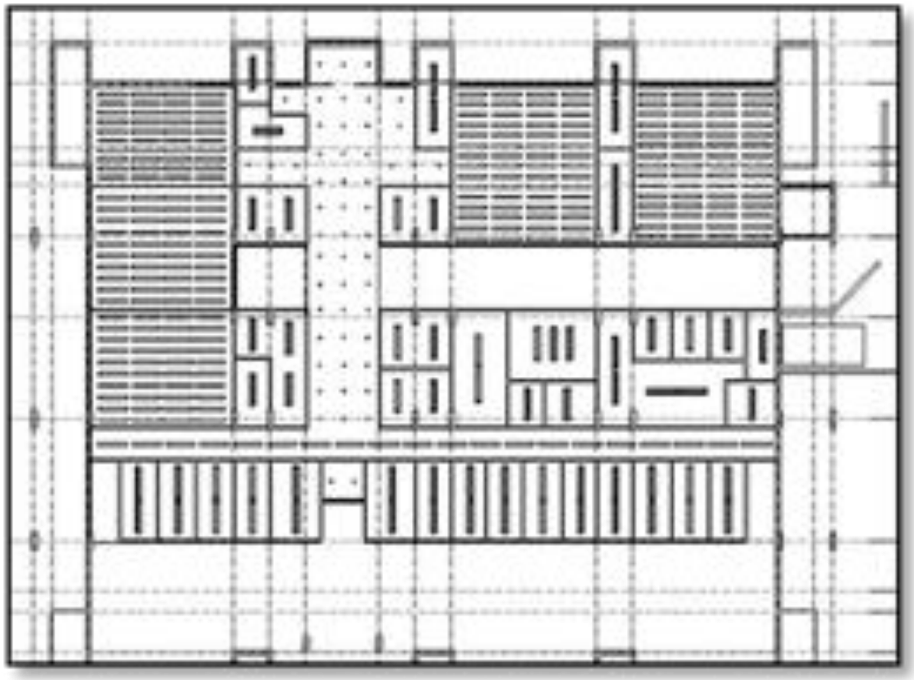

Figure 16. 1F Ceiling Plan

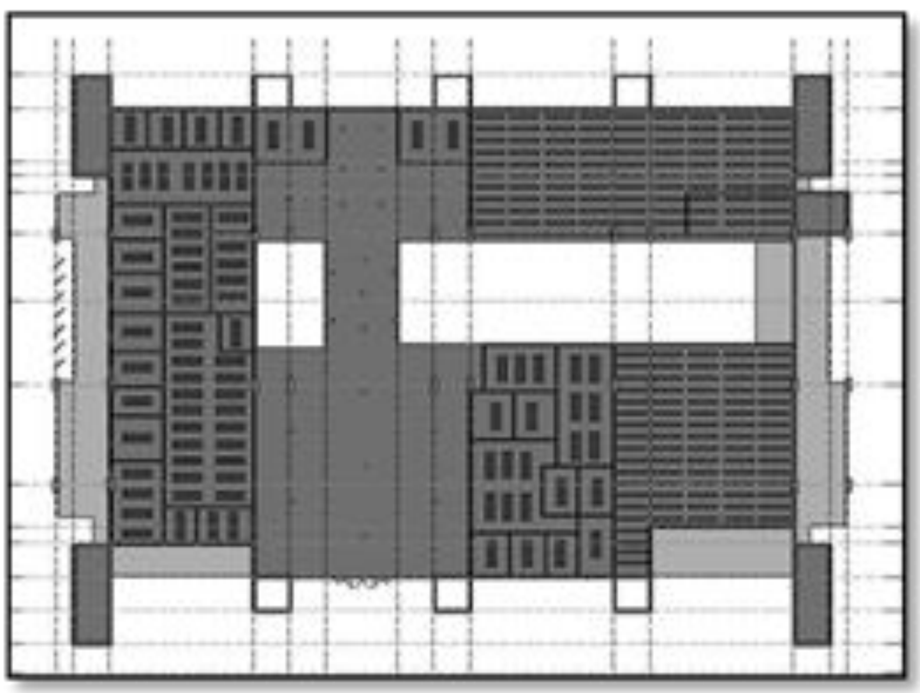

Figure 17. 2F Ceiling Plan

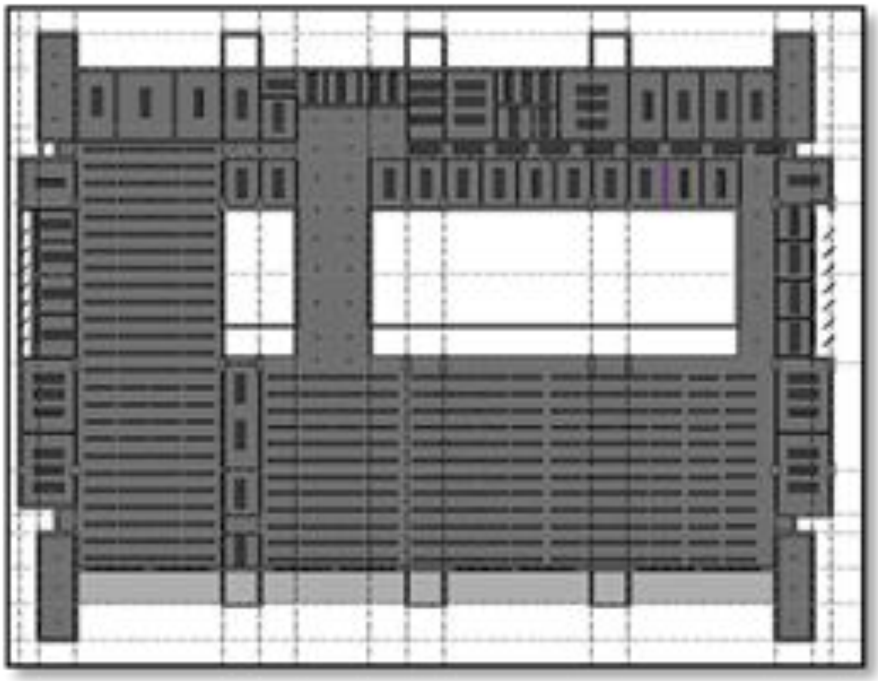

Figure 18. 3F Ceiling Plan

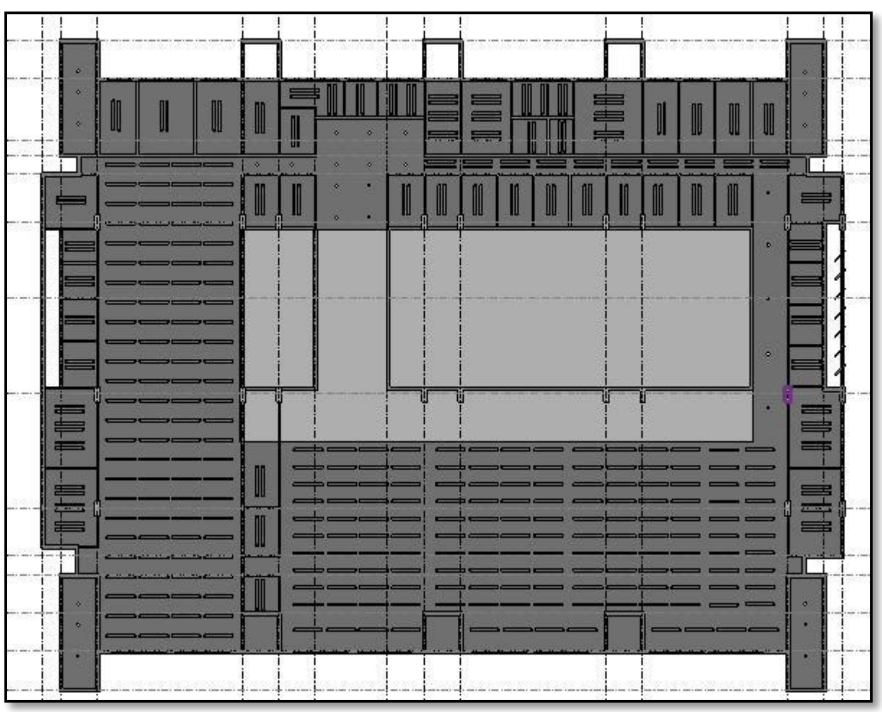

Figure 19. 4F Ceiling Plan

These ceiling plans with installed lighting systems were used in the energy analysis conducted using this Revit model.

Comparison of Lighting Tubes

Table 6 describes general information and compares lighting efficiency of LED, CFL, fluorescent, and incandescent bulbs.

Table 6.

Cost Comparison between LEDs, CFL and Fluorescent Bulbs (Houston, 2010)

Description	LED	CFL	Fluorescent	Incandescent
Light bulb lifespan (Hours)	50,000	10,000	7,000	1,200
Watts per bulb	14	20	34	60
Cost per bulb	$35.95	$3.95	$1.40	$1.25
kWh of electricity used over 50,000 hours	700 kW	950	1700	3000
Cost of electricity (@ 0.1130per kWh)	$79.1	$107.4	$192.1	$339
Bulbs needed for 50k hours of use	1	5	7.14	42
Total cost for 50,000 hours	$115.05	$127.10	$202.10	$652.50

Within the same exposure, LED has the longest lifespan with lowest wattage. In the case of electricity usage over fifty thousand hours, LED uses only seven hundred kW and the total cost comes to $115.05.

CFL is another good lighting source that is widely used in industry. Due to the long lifespan and reasonable material price, the total cost for 50,000 hours is similar to the LED.

Fluorescent and incandescent lights have a very cheap material price, but they are not energy efficient due to low power and short lifespan. Therefore, for the fluorescent, the total cost for fifty thousand hours is around $200 dollars, which is twice as much as the LED.

Incandescent is even worse than fluorescent with a total cost six times higher than the LED. Based on the comparison, it is simple enough to state that LED is the most efficient lighting source even though the material cost is high.

Lighting Tubes Lifetime

Since the lighting and cooling systems of the building are being operated almost every day, the energy consumption from this building is high. The lifespan of light bulbs is decided by how many times the lights are turned on and off; however the operating hours were derived by the following formula. Turning the lighting on and off can affect the lifespan of light tubes; however, the following formula was only used to determine out the total operating hours in the paper.

$$LEU\,(Kwh\,/\,day) = \frac{TBEU\,(Kwh) \times LEUR(\%)}{365(days)} \tag{4}$$

$$AEU\,(Kwh\,/\,day) = \frac{LEU\,(Kwh\,/\,day)}{TLB(EA)} \tag{5}$$

where, LEU is the lighting energy usage per day (kWh/day), TBEU is the total building energy usage (kWh), LEUR is the lighting energy usage rate (%), AEU is the tube energy usage per day (kWh/day) and TLB is the total light bulbs in the building (EA).

In order to accurately estimate lighting energy usage of the building, the amount of lighting energy consumption(LEU) was derived by multiplying thirty percent by the total energy usage (TBEU:1,832,081 kWh) and then dividing by three hundreds sixty five days in equation four.

The data for the Langford A was obtained from Charlie Shear, the Energy Coordinator of Utilities at TAMU(Shear, 2010). A lighting tube energy usage per day(AEU) was generated from LEU divided by total number of lighting tubes in the building (2). From this calculation, lighting tube usage was derived as twelve point ninety four hours per day. Using this result, the replacement cycle of the LED light bulbs was extended from fifty thousand hours (six years) to one hundred thousand hours (twelve years) per bulb.

Electric Energy Data

Langford's electric usage data extends from April 2009 to March 2010. For LCC analysis, the annual electric cost during research periods was assumed to be the same as the energy usage data, which was obtained from the Texas A&M University Utility Department (Shear, 2010).

CHAPTER V

DATA ANALYSIS

Introduction

This chapter on data analysis presents the key tables outlining the costs and comparison of the costs. The sections are:

1. Comparison of film and windows
2. Comparison of lighting
3. Comparing total cost

Comparison of Film and Windows

Comparing Initial Cost for Windows and Film

Table 7 outlines the initial cost for the low energy windows and application of the window film.

Table 7.

Initial Cost Data for Retrofitting Low E Windows and Applying Window Film

Description	Area	Unit	Material cost	Labor cost	Demolition cost	Additional cost (Six percent)	Total initial cost	Unit cost
Existing Window	1239	m^2	–	–	–	–	–	–
Apply Film	1239	m^2	38.90		_	_	48,185	38.90
Replace Window	122	EA	4,330	358	74.6	259.8	612,733	5,022

Two options can be taken to save on the total energy costs in Langford A. A first option is applying window film to the total area of 1,239 square meters. It would cost $38.90 dollars per square meter for the material and labor cost, so the total initial cost would be $48,185 dollars.

The other option is retrofitting with low-e windows. Since replacing single pane with double pane creates many difficulties, this option has a higher replacement cost. Besides the demolition cost, additional costs should be considered as well once the window is attached to the concrete (RSMeans, 2009). Therefore, these costs should be added to material and labor costs. The total initial cost was calculated as $590,773. By comparing the initial costs of these two options, retrofitting low-e windows requires an investment more than ten times the cost of using film.

Comparing Total Cost

By applying low-e film, an energy saving rate of seven percent was estimated by GBS and with retrofitting low-e window, twenty four percent of the energy cost can be saved as estimated by the software. According to information outlined in the literature review, when window film is applied, nine point nine percent can be attained in savings in a southwest climate zone (Steve, 2002).

The analysis based on this saving rate implies that window film can bring the energy usage down to 7,610,771mBtu while low-e windows would be 6,219,555mBtu. The cold water price rate for the period between April 2009 and March 2010 was $0.0146 per mBtu.

At this rate, the total energy cost of window film for thirty years was $3,333,518 and $111,117 per year and low-e windows was $2,724,165 with $90,806 per year. To calculate the total initial cost of the building, cost data for material, labor, and demolition have been collected from the "*2009 RS Means Construction Cost Data Book"*(RSMeans, 2009).

Table 8 summarizes the comparison of the different alternatives. By applying low-e film, an energy saving rate of seven percent was estimated by GBS and with retrofitting low-e window, twenty four percent of the energy cost can be saved as estimated by the software. According to information outlined in the literature review, when window film is applied, nine point nine percent can be attained in savings in a southwest climate zone (Steve, 2002).

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Table 8.

Comparison between Existing Window, Applying Film & Low E Window

Description	Existing window Single pane window + Blind	Applying film Single pane window + Blind + Film	Retrofitting window Low-e window
Data periods		2010 ~ 2040 (Thirty years)	
Window area (S.M.)	1267	1267	1267
Energy saving rate	-	7.00%	24%
Cooling energy usage (kWh)	8,183,625	7,610,771	6,219,555
Unit cost		0.0146	
Total energy cost	3,584,428	3,333,518	2,724,165
Initial cost	-	48,185	612,733
Replacement cost	-	48,185	-
Total cost	3,584,428	3,429,887	3,336,898

* Chilled water usage at the period of 04/2009 ~ 03/2010

Additional cost is incurred with the material cost as Langford is constructed from reinforced concrete that increases the complexity of the construction work. As shown in Table 8, the initial cost of low-e windows is more expensive than window film. However, by looking at a period of thirty years, the low-e windows consume less total energy when compared to the current window system and window film without any discount rate.

Comparison of Lighting

Comparing Initial Cost for Fluorescent and LED Lighting

Langford A is equipped with 3,402 florescent bulbs. Their material cost is inexpensive so that the initial cost was only $9,832 dollars. However, if LED tubes replace the lighting system, the initial cost jumps to $207,148.

Table 9 presents a summary of these costs estimates.

Table 9.

Initial Cost Data for Retrofitting Lighting Tubes

Description		Unit	Material cost	Labor cost	Total initial cost	Unit cost
Fluorescent Bulbs	3,402	EA	2	0.89	9,832	2.89
LED Bulbs	3,402	EA	60	0.89	207,148	60.89

Table 9 explains how much can be saved by retrofitting lighting with LED fluorescent. According to Relumination (2011) has an energy saving rate of around forty percent so electric energy use per year would be 1,099,249kWh, which is half of what the existing lighting system uses on an annual basis. At the current electricity rate, the energy cost for thirty years equals a cost of $3,726,453. By adding initial and replacement costs to that, the total cost becomes $4,347,896, which is much less than using fluorescent as shown in Table 9.

Comparing Total Cost

Table 10 summarizes all of the costs for the two alternatives.

Table 10.

Comparison between Existing Lighting and Retrofitted Lighting

Description	Existing Lighting Fluorescent	Retrofitting Lighting LED
Data periods	2010 ~ 2040 (Thirty years)	
Energy saving rate	-	40%
Electric energy usage Per year (kWh)	1,832,081	1,099,249
Unit cost *	0.113	0.113
Total Energy cost ($) (Thirty years)	6,210,755	3,726,453
Initial cost	9,832	207,148
Replacement cost	383,780	414,296
Total cost	6,604,366	4,347,896

* The unit cost at the period of 04/2009 ~ 03/2010

CHAPTER VI

RESULTS

Introduction

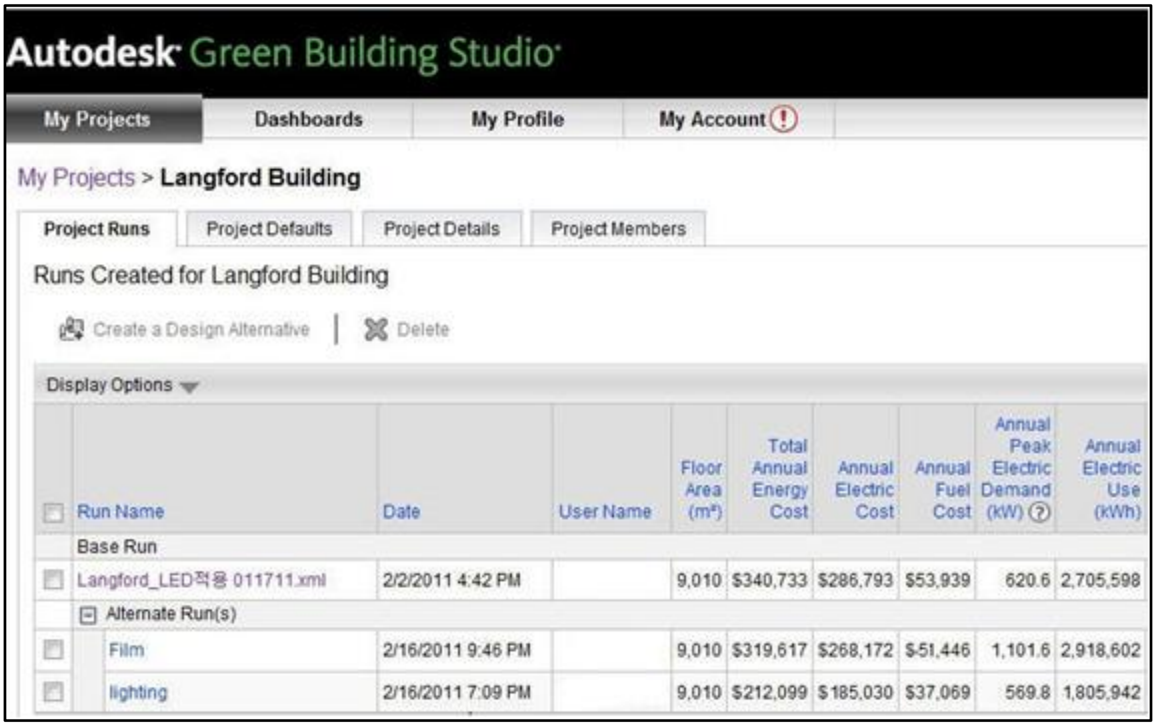
The proposed retrofitted lighting and film reduces the building energy consumption from the existing levels. The data analysis indicated that the LED tube saves electric energy with a payback period of about three years. The low-e window conserves cooling energy usage but the payback period is over thirty years due to the high initial cost. Moreover, to replace windows, construction difficulties have to be considered as well. However, the window film not only saves energy but also has a payback period of about five years.

Life Cycle Cost Analysis

This paper applied LCC analysis to estimate the total operation cost of the building using the alternatives. Future cost is discounted at the discount rate since the value of money consistently falls every year so all costs have been converted to present value by applying the discount rate. In this paper, the discount rate was set to zero, six and twelve percent. Inflation, the reduction in purchasing power every year, (ASTM, 1994) was assigned three point twenty one percent according to the average inflation in electricity prices for thirty years. This data was obtained from DOE (U.S. Department of Energy, 1995, 2011).

Green Building Studio

The gbXML file was generated from the Revit model. It was then imported to the GBS program to calculate the total building energy consumption. Figure 20 shows, based on this process, the total annual energy cost.



Run Name	Date	User Name	Floor Area (m^2)	Total Annual Energy Cost	Annual Electric Cost	Annual Fuel Cost	Annual Peak Electric Demand (kW)	Annual Electric Use (kWh)
Base Run								
Langford_LED적용 011711.xml	2/2/2011 4:42 PM		9,010	$340,733	$286,793	$53,939	620.6	2,705,598
Alternate Run(s)								
Film	2/16/2011 9:46 PM		9,010	$319,617	$268,172	$51,446	1,101.6	2,918,602
lighting	2/16/2011 7:09 PM		9,010	$212,099	$185,030	$37,069	569.8	1,805,942

Figure 20. Green Building Studio Results

As a result of this table, if window film is applied in Langford A, total annual energy cost will be $319,617 that is saved nearly seven percent more than the status quo. When LED lighting tubes are installed, total annual energy cost saved about forty percent. Using these saving rates, Life Cycle Cost for Langford A was calculated and used in the economic analysis.

Sensitivity Analysis

This paper represents the net present value (NPV) of each alternative for thirty years by applying the energy inflation rate and discount rate. Table 11illustrates the total annual cost without applying the discount and inflation rates and shows the cost of combined discount and inflation rate. The inflation rate, three point twenty one per cent, was derived from past electric cost data as outlined in the literature review and the discount rates were assumed as zero, six and twelve per cent since it was important to cover a range of discount rates. Table 11 shows the variation in NPV according to the different discount rates.

Table 11.

Calculating Present Value with Discount and Inflation Rates

Total Annual Cost			Present Value Inflation Rate	Present Value Discount Rate	Combined Cost		
Status Quo	Low-e Film	Double pane Window	Electric Cost	Materials	Existing Window	Low-e Film	Double pane Window
				0%	6,070,544	5,867,046	5,226,346
3,584,430	3,429,889	2,724,167	3.21%	6%	2,434,331	2,372,502	2,462,824
				12%	1,282,095	1,265,379	1,587,125

* Total cost for 30 years.

In order to identify the pattern of cost value change by the condition of various discount rates, the following three graphs have been derived from Table 11, Figure 21 to Figure 23.

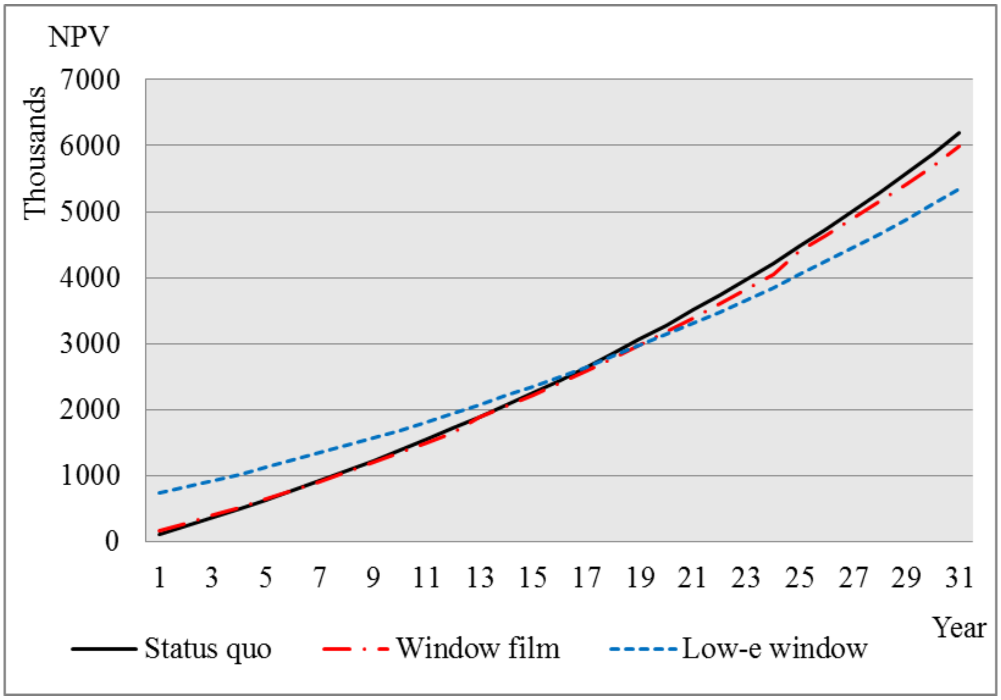


Figure 21. Discount Rate Zero Percent for Windows

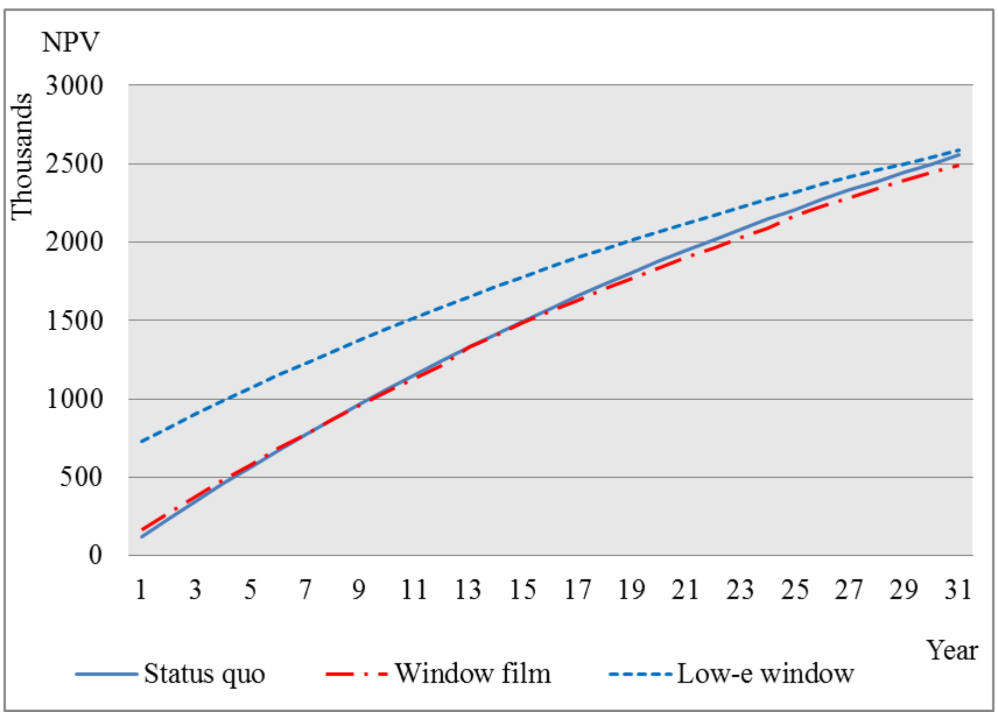


Figure 22. Discount Rate Six Percent for Windows

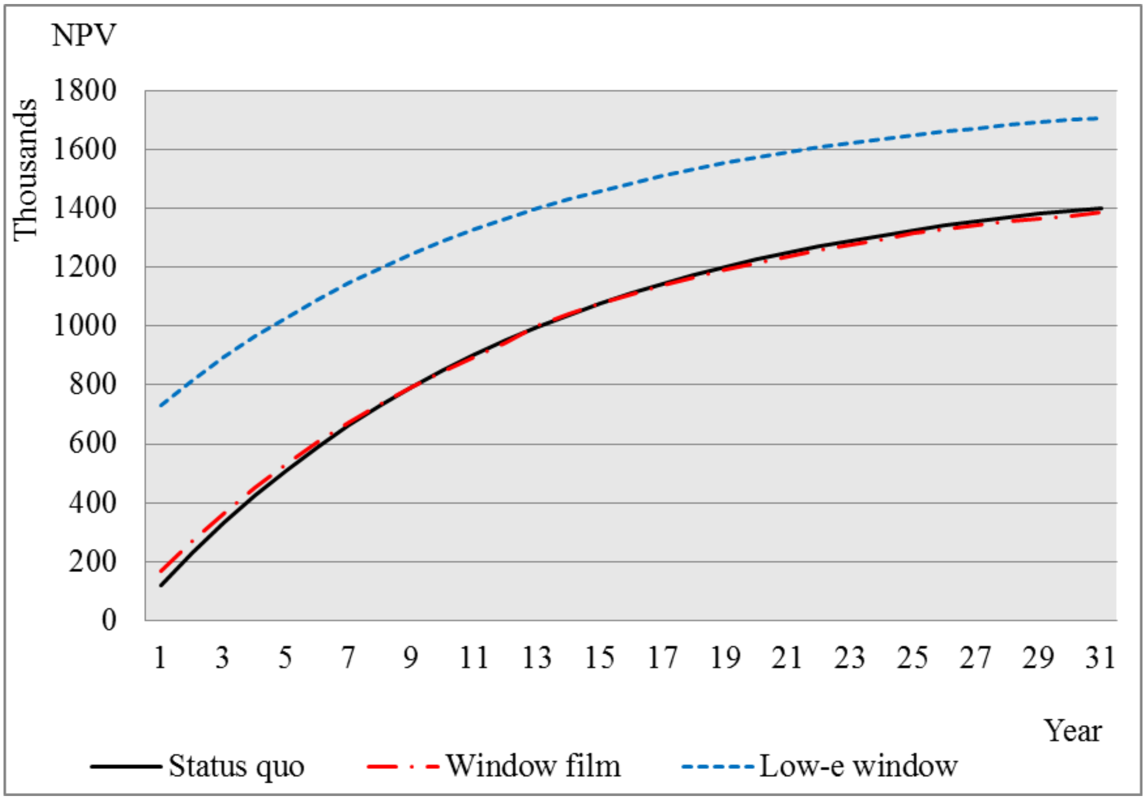


Figure 23. Discount Rate Twelve Percent for Windows

These figures show that once a zero discount rate was applied, the life cycle cost starts to decrease after seventieth year in case of retrofitting low-e windows. However, once the twelve per cent discount rate was applied, the option of replacing windows was the most cost effective.

PV for Fluorescent and LED

When the discount rate is zero percent, the alternative of retrofitting low-e windows is cheaper than the other two options.

Table 12 shows the present value for the lighting systems.

Table 12.

Calculating Present Value with Discount and Inflation Rates for Lighting

Present Value					
Total Cost		Inflation	Discount	Combined	
Status Quo (Fluorescent)	LED	Electric Cost	Materials	Status Quo (Fluorescent)	LED
			0%	11,187,322	6,635,164
6,604,368	3,892,316	3.21%	6%	4,484,291	2,621,682
			12%	2,360,361	1,350,848

* Total cost for 30 years.

Figure 24 shows the present value analysis for a discount rate of zero percent for lighting. The results show that LED is economically better than the alternatives at a low discount rate. Figure 25 and Figure 26 show the present value analysis for discount rates of six and twelve percent respectively.

The results for all discount rates show the LED has a distinct economic advantage.

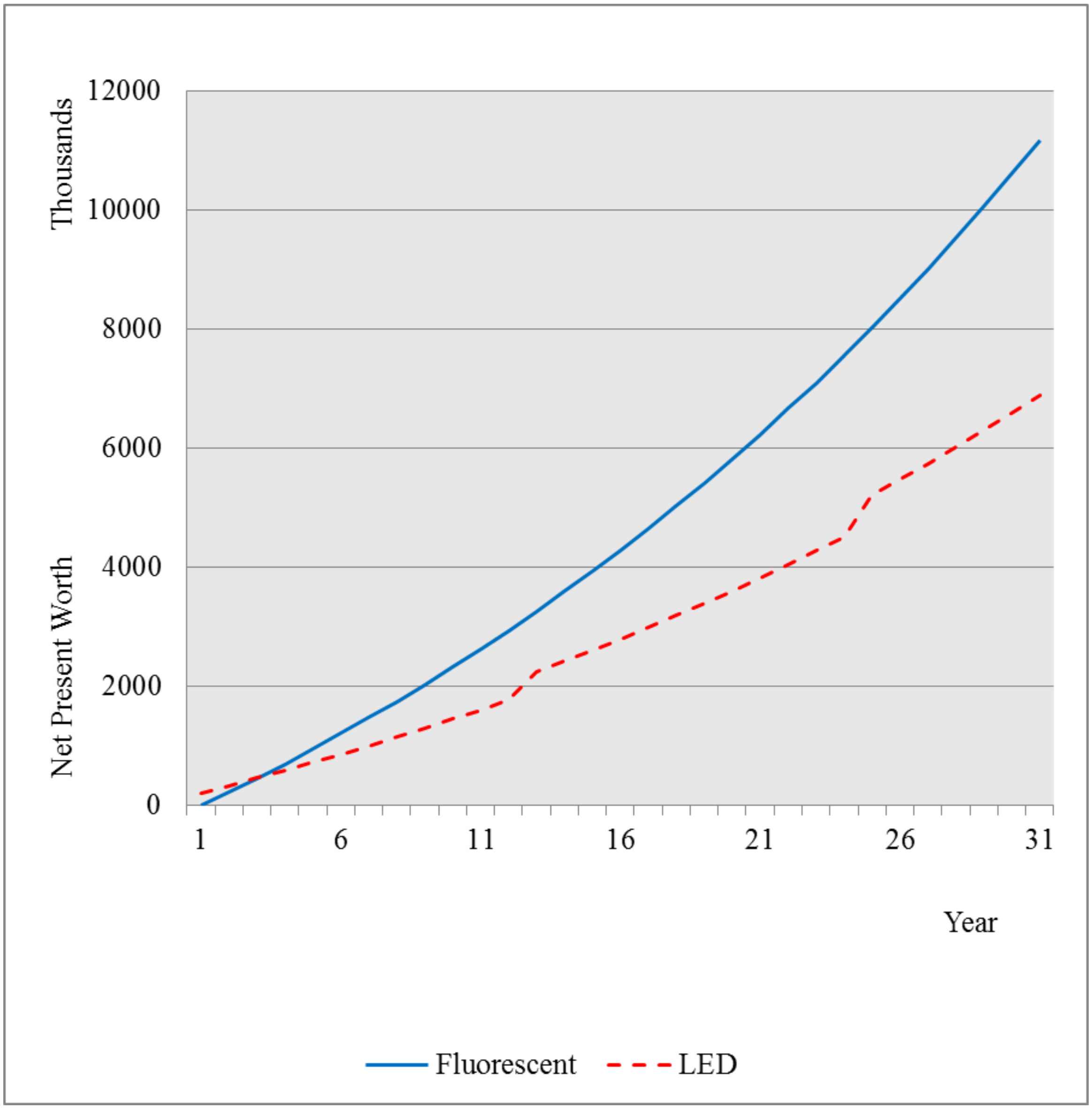


Figure 24. Present Value Analysis for a Discount Rate of Zero Percent for Lighting

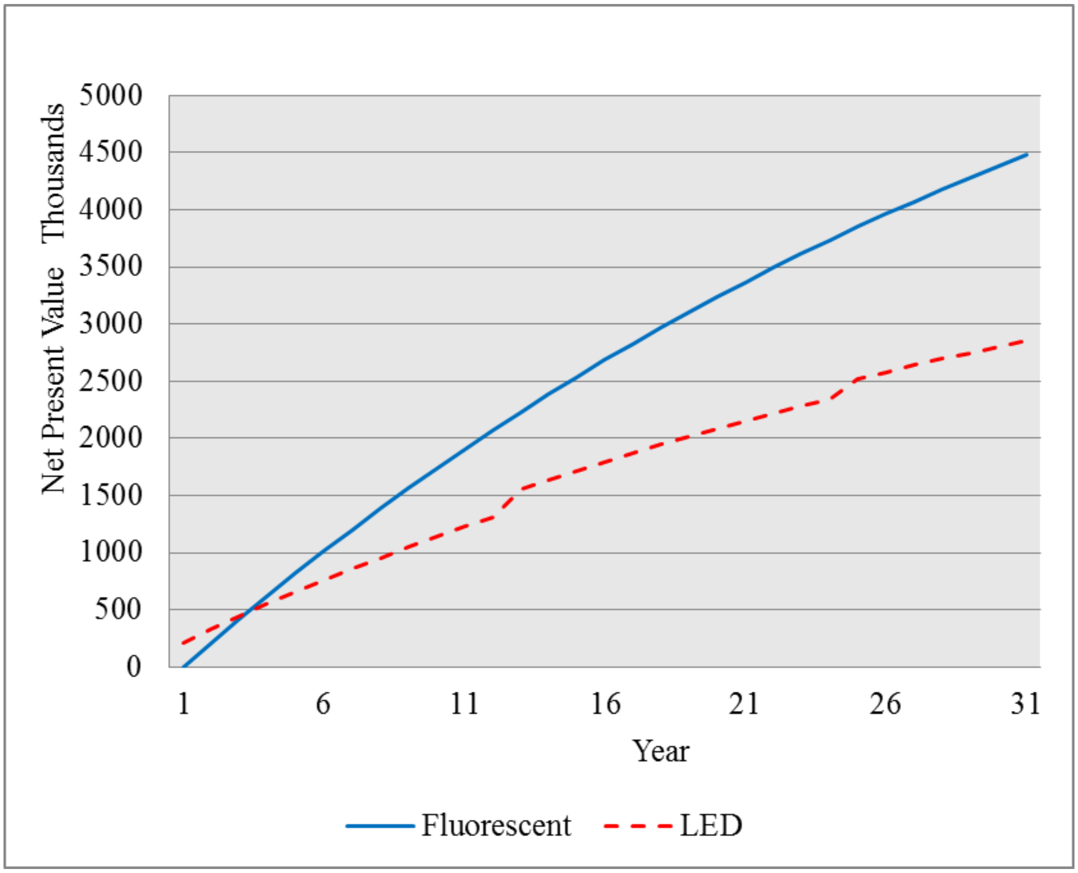


Figure 25. Present Value Analysis for a Discount Rate of Six Percent for Lighting

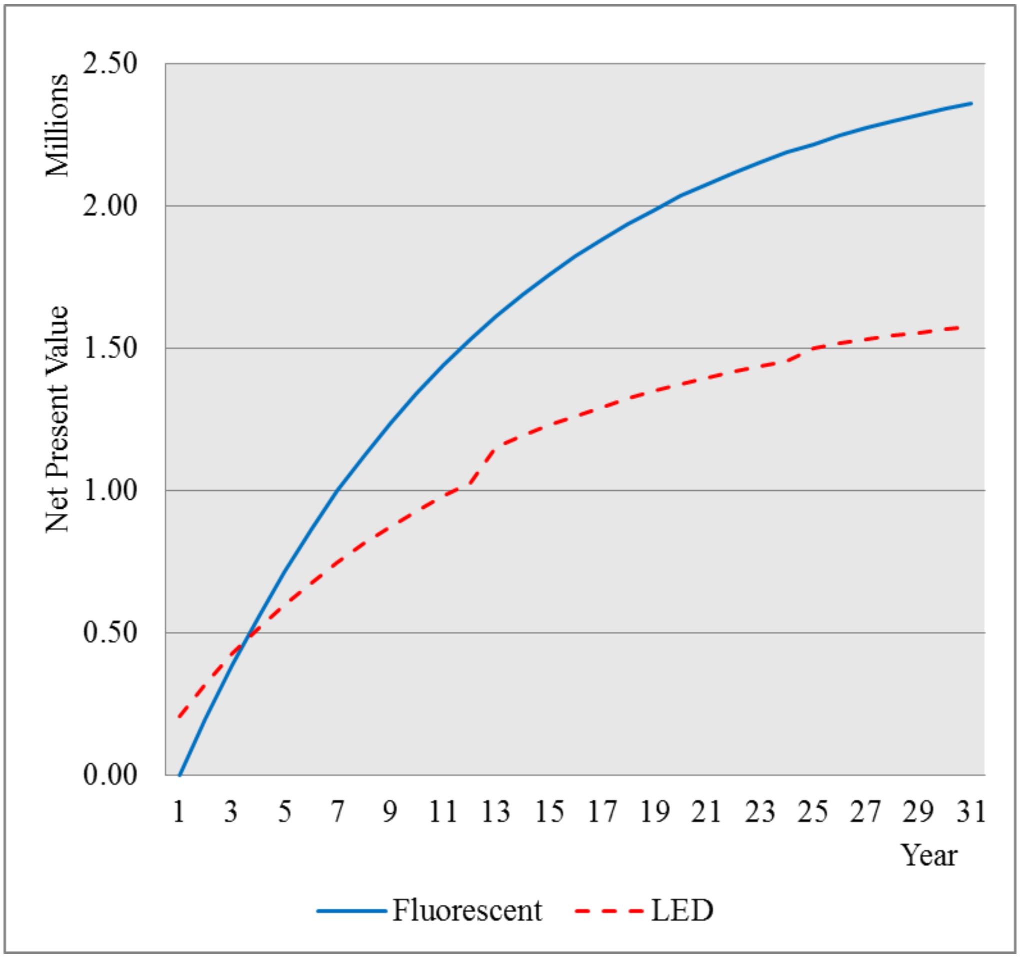


Figure 26. Present Value Analysis for a Discount Rate of Twelve Percent for Lighting

Monte Carlo Simulation

MCS Result for Windows and Film

A Monte Carlo simulation looks at variations in the key elements of an analysis to determine the sensitivity of the decision to potential changes in the economic results. The relevant equation is shown in equation

$$Te = \frac{Ta + 4Tm + Ti}{6} \tag{6}$$

where, *Te* is the mean value, *Ta* is the maximum value, *Tm* is the mode value, and *Ti* is the minimum value.

Figure 27 shows the mean cost values for the three alternatives, the status quo option and the alternatives for window film and low-e windows.

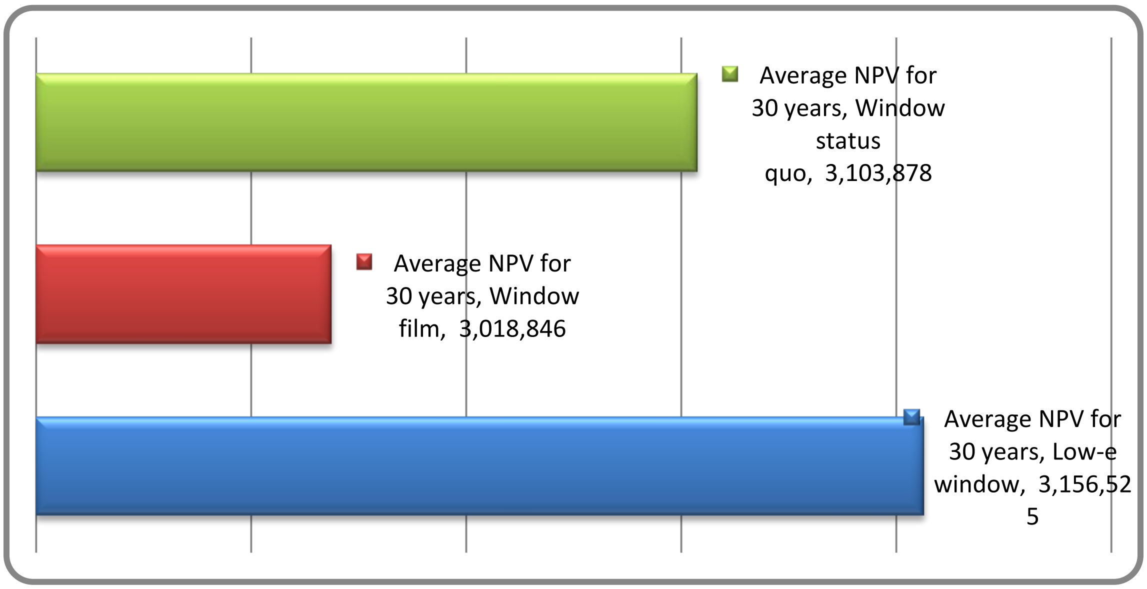


Figure 27. Comparison Cost Value Mean

This chart compares the total PV mean for each alternative. As shown in this chart, the low-e window is more expensive than the film alternative and the payback period is much longer than for film.

Construction difficulties should also be considered since these are important factors for decision makers. However, these are hard to measure; for example, employees cannot use the building while windows are being replaced so they need to find other places to work. This factor is not considered in the analysis as there are down times in the educational process that will permit the work to be a minimal disturbance to the operation of the building.

MCS Result for Fluorescent and LED Lighting

Figure 28 and Figure 29 show the Monte Carlo analysis for the status and LEDs tubes based on the previous cost estimates.

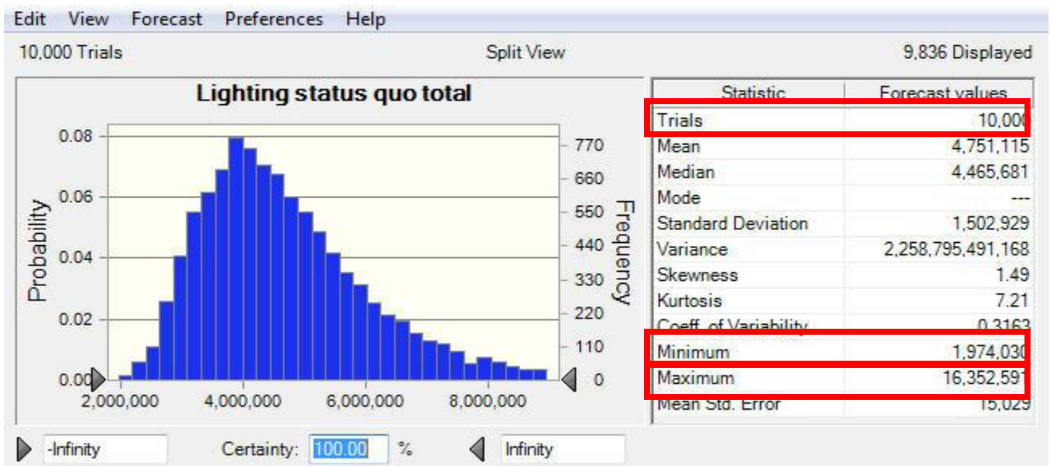


Figure 28. Result of Monte Carlo Simulation for Fluorescent Tubes

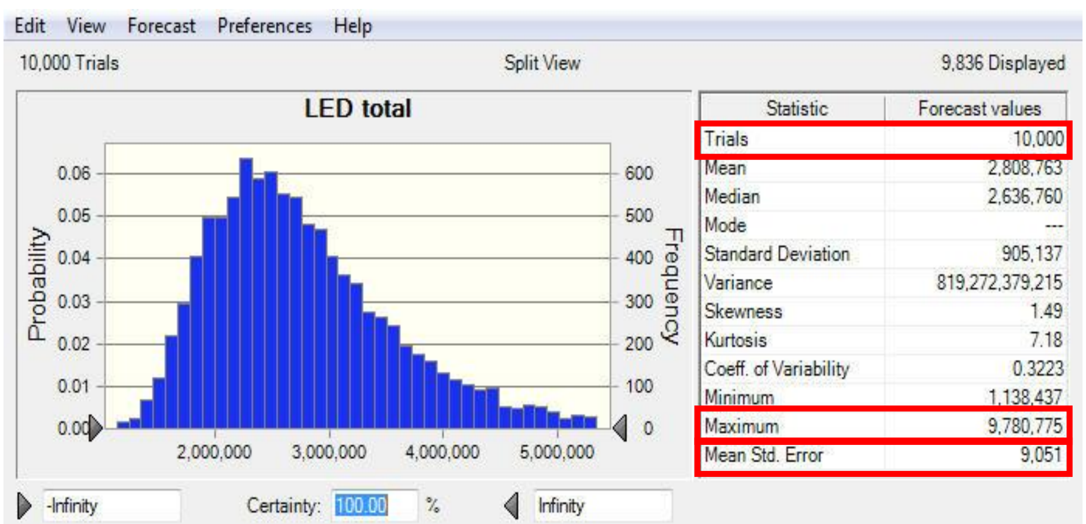


Figure 29. Result of Monte Carlo Simulation for LED Tubes

Figure 30 shows the total present value for a thirty year analysis period for two alternatives, fluorescent and LED lighting.

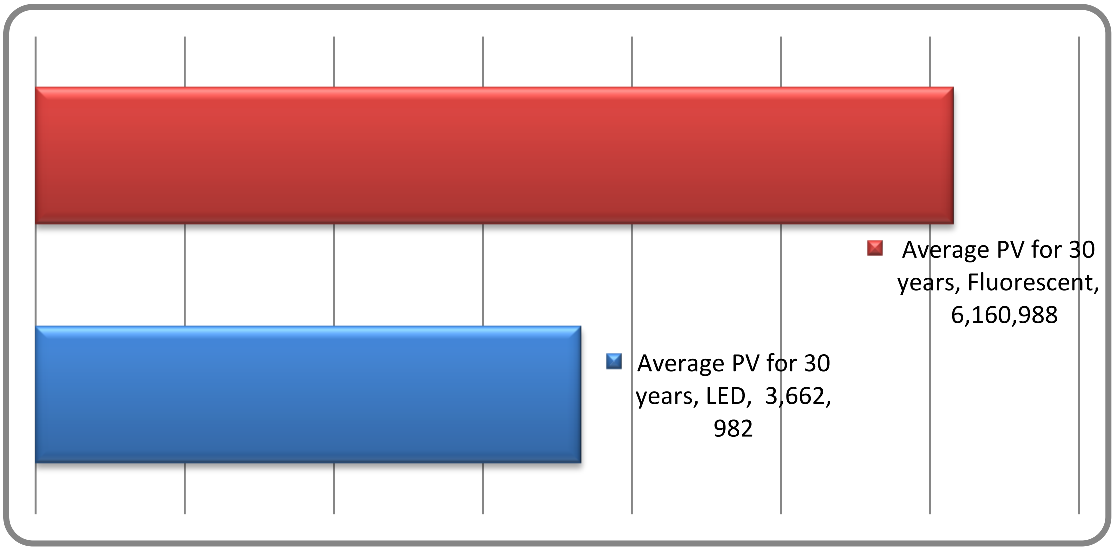


Figure 30. Comparison Cost Value Mean for Lighting

Figure 30 compares the total PV for LED tubes and fluorescent tubes as shown in this chart, the LED tubes are more economic than fluorescent tubes. The total PV of LED tube after thirty years is about $3,662,982, but the fluorescent tubes are about $6,160,988. Therefore, it is concluded that the cost of electric energy saved by retrofitting with LED alternatives is worth the cost of the initial investment in this alternative.

Cash Flow Diagram

Background

A cash flow diagram describes the financial process with times such as revenue and expense that depend on the time flow of the project. This diagram shows in part the financial validity of a project, or allows for the comparison of alternatives. The cash flow diagram in this research study uses data that include annual energy costs from the utility department at Texas A&M University and initial cost data from the (RSMeans, 2009).

The film's warranty is generally five years, but (Tyler & Scott, 2007) Tyler and Scott note that the lifespan of the window film is about ten to fifteen years. This study used and average for the replacement cycle as twelve years. Window life is over fifty years so it was not part of the economic period used in this study.

The method preferred by Rybkowski for the cash flow analysis uses a technique of comparing the differential between to two cash flows to select the preferred alternative. This technique is used in this analysis (Rybkowski, 2009).

Windows Cash Flow Analysis

The first alternative in the comparison is shown in Figure 31.

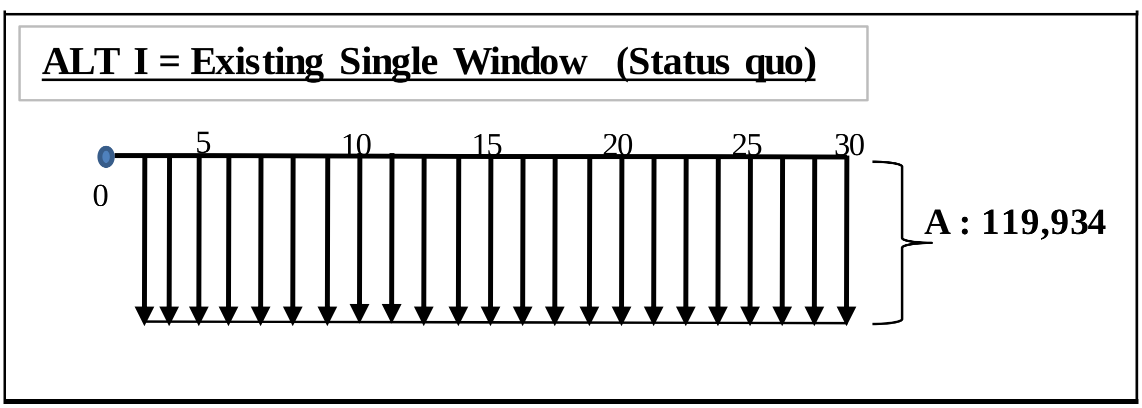


Figure 31. Alternative I - Status Quo Situation

The second alternative in the comparison is shown in Figure 32.

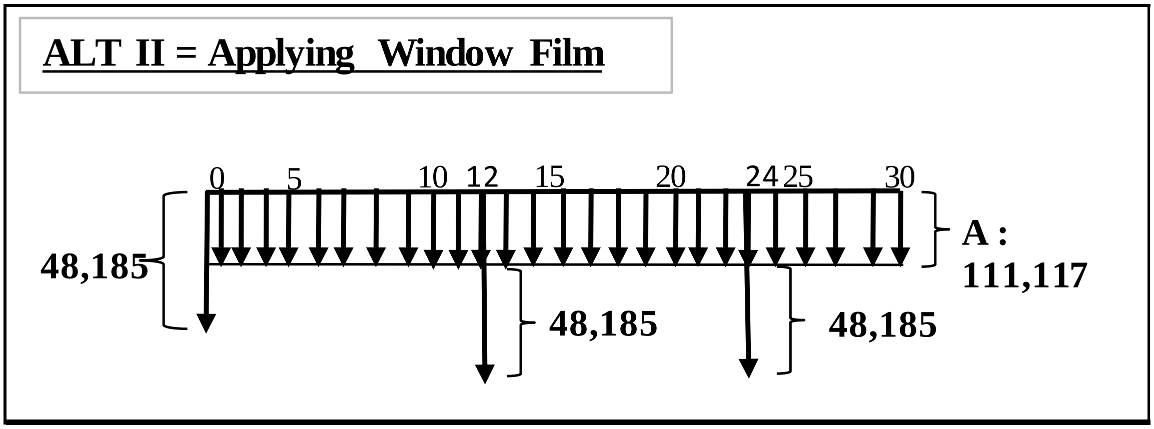


Figure 32. Alternative II - Applying Window Film

The differential cash flow is shown on *Figure 33*.

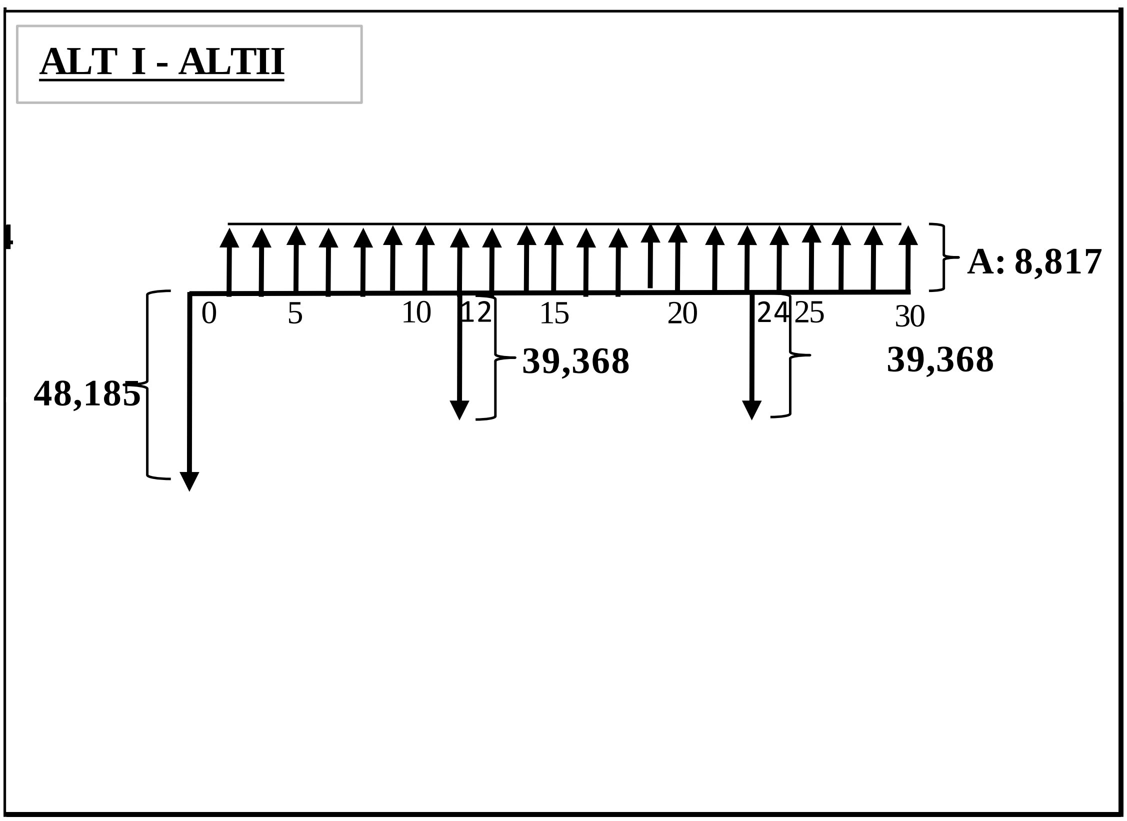


Figure 33. Differential Cash Flow Alternative I to II

Figure *34* shows the analysis of the cash flow differential as completed in an Excel spread sheet.

	Incremental Δ	
Fomula	Initial cost + Annual cost saving (P/A, i, 30) - Replacement cost (P/F, i, 12) - Replacement cost (P/F, i, 24)	
Alt II - I	-48,185 + (8,817 * (20.4)) - (39,368 * (0.719)) - (39,368 * (0.517))	**83,023**
Alt III - II	-564,548 + (20,311 * (20.4)) - (68,496 * (0.719)) - (68,496 * (0.517))	**-65,543**

* **Alt I** = Status Quo, **Alt II** = Window film, **Alt III** = Low-e windows

* (P/A, i, 30) = $\frac{(1+i)^N - 1}{i(1+i)^N}$, (P/F, i, 12) = $\frac{1}{(1+i)^N}$ Sullivan 2003)

* i = $\frac{i-\lambda}{1+\lambda}$, i = Discount rate, λ = Inflation rata (Sepulveda 1984)

Figure 34. Analysis of the Cash Flow for Alternative I to II (Sepulevda, Souder, & Gottfried, 1984; Sullivan, Wicks, & Luxhoj, 2003)

The incremental cash flow shown above is the incremental difference between window film and low-e window. The results are shown calculated in Figure 34. A positive value indicates that there is a profit in this project while a negative value shows when there is no profit. As shown in the figure, Alt II can expect a profit of $83,023 after 30 years. The Alternative II is preferred on economic grounds.

Figure 35 to Figure 37 a similar economic analysis for Alternative II to III.

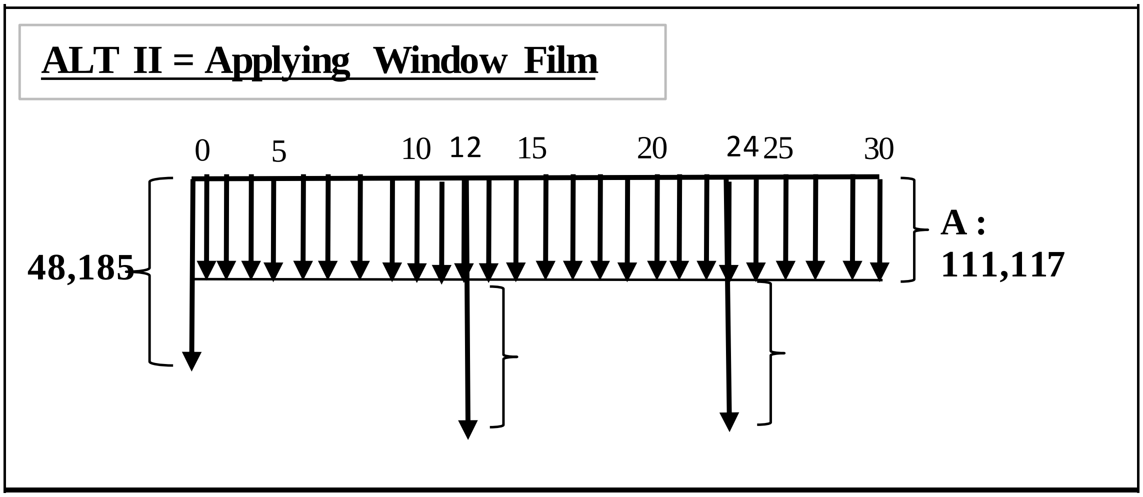


Figure 35. Overall Cash Flow Diagram for Low E Windows – Alternative II

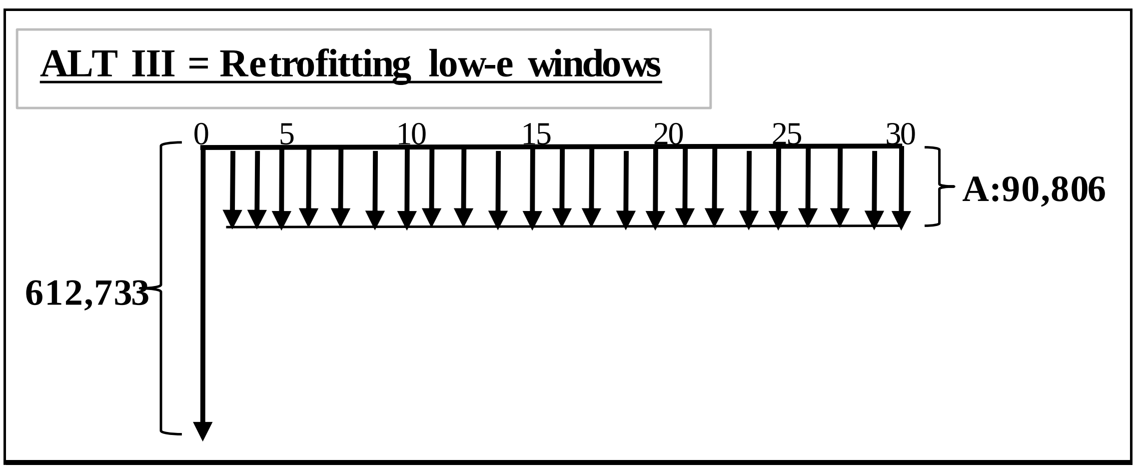


Figure 36. Overall Cash Flow Diagram for Low E Windows – Alternative III

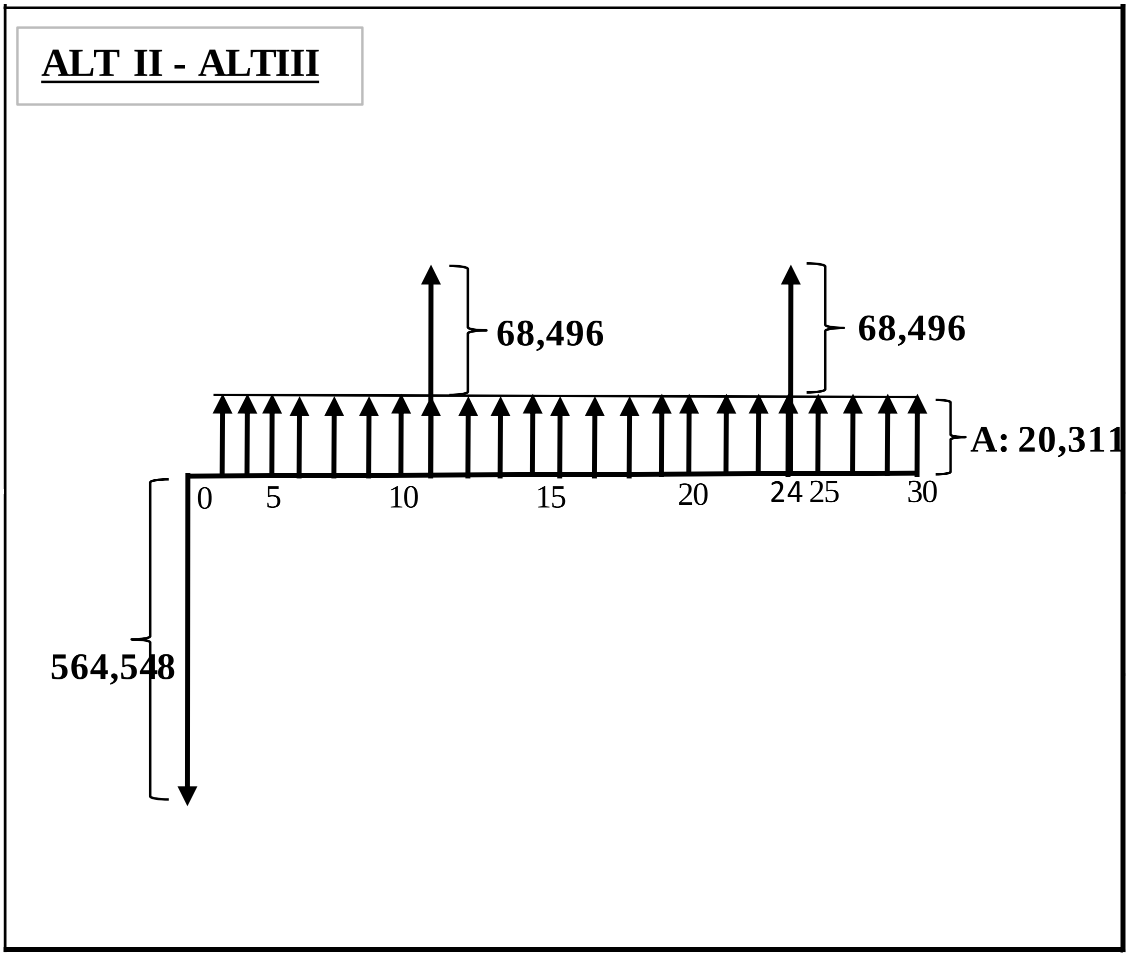


Figure 37. Overall Cash Flow Diagram for Window Film and Low E Windows

Figure 38 shows the analysis of the differential Alternative III to Alternative II, again from an Excel spreadsheet analysis.

	Incremental Δ	
Fomula	Initial cost + Annual cost saving (P/A, i, 30) - Replacement cost (P/F, i, 12) - Replacement cost (P/F, i, 24)	
Alt II - I	-48,185 + (8,817 * (20.4)) - (39,368 * (0.719)) - (39,368 * (0.517))	**83,023**
Alt III - II	-564,548 + (20,311 * (20.4)) - (68,496 * (0.719)) - (68,496 * (0.517))	**-65,543**

* **Alt I** = Status Quo, **Alt II** = Window film, **Alt III** = Low-e windows

* (P/A, i, 30) = $\frac{(1+i)^N - 1}{i(1+i)^N}$, (P/F, i, 12) = $\frac{1}{(1+i)^N}$ Sullivan 2003)

* i = $\frac{i-\lambda}{1+\lambda}$, i = Discount rate, λ = Inflation rata (Sepulveda 1984)

Figure 38. Analysis of Alternative II to III

The cash flow analysis can be summarized as follows for the possible window changes:

1. If Langford A keeps the single windows without any changes, the building does not require an initial installation cost so the energy cost will be $119,934 per year for the thirty year study period.
2. However, if the building adopts low-e film for the existing windows, then $48,185 is required for installation and the film has to be replaced every twelve years at the same installation cost. The energy cost will be decreased by seven percent so the annual energy cost will be $111,117.
3. If the building retrofits low-e windows, the initial investment cost will be $612,733, which is based on RS Means Cost Book (RSMeans, 2009), and the annual energy cost will be reduced by twenty-four percent and the energy cost will be $90,806 per year.

The results indicate an economic preference for Alternative II.

Lighting Cash Flow Analysis

The technique used for the windows has been repeated for the lighting alternatives. Figure 39 shows the status quo alternative, often called the do nothing option.

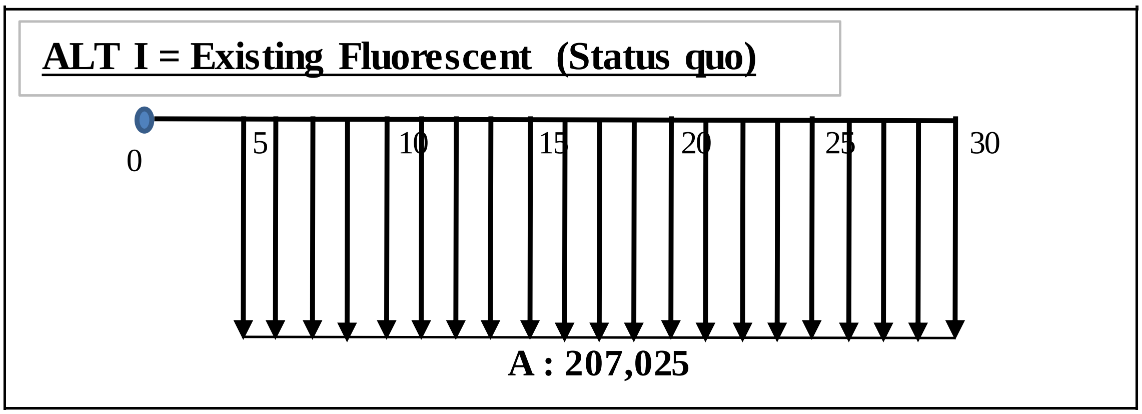


Figure 39. Cash Flow Alternative I - Status Quo

Figure 40 shows the second alternative cash flow for the LED Fittings.

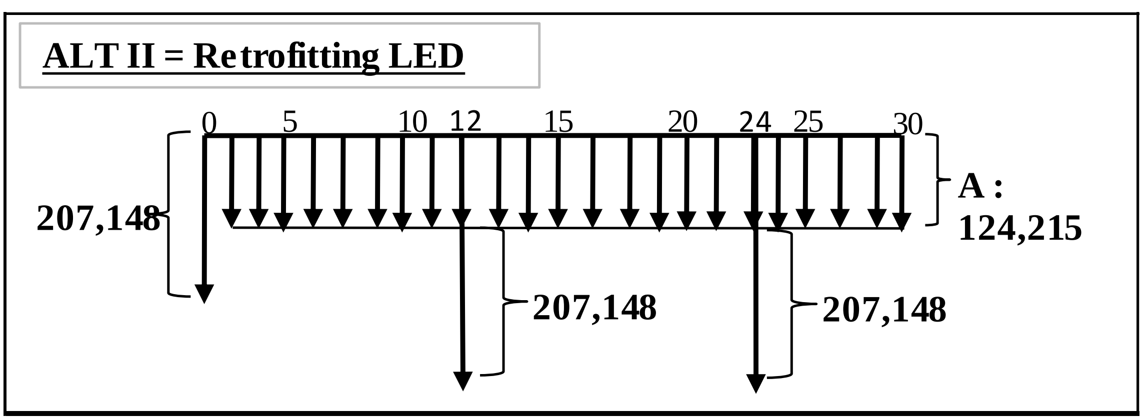


Figure 40. Cash Flow Alternative II - LED Lighting Retrofit to Langford Building A

Figure 41 shows the differential cash flow comparing Alternative I to Alternative II.

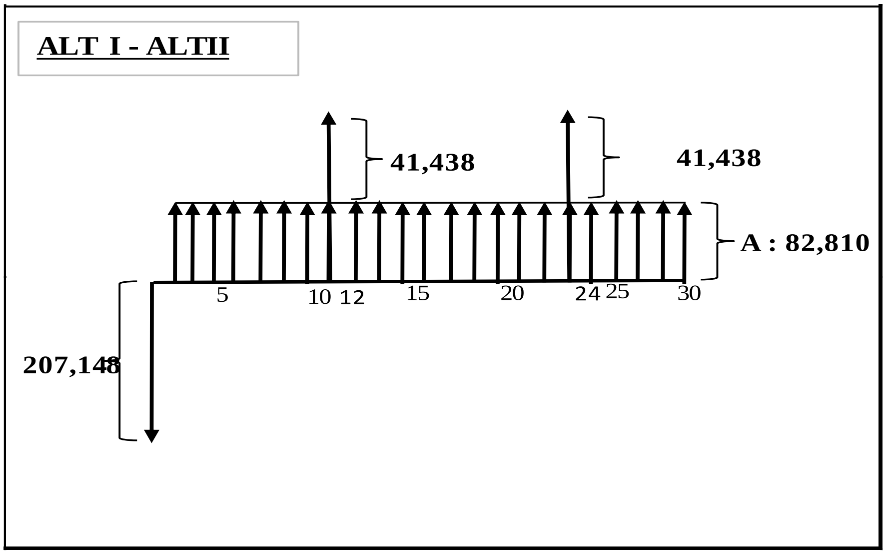


Figure 41. Differential Cash Flow Alternative I to II

Figure 42 shows the results of the cash flow analysis for the two alternatives, again completed in an Excel spreadsheet.

	Incremental Δ	
Fomula	Initial cost + Annual cost saving (P/A, i, 30) - Replacement cost (P/F, i, 12) - Replacement cost (P/F, i, 24)	
Alt II - I	-207,148 + (82,810 * (20.4)) + (41,438 * (0.719)) + (41,438 * (0.517))	**1,533,393**

* **Alt I** = Status Quo (Fluorescent tubes), **Alt II** = LED tubes

* (P/A, i, 30) = $\frac{(1+i)^N - 1}{i(1+i)^N}$,P/F, i, 12) = $\frac{1}{(1+i)^N}$ 'an 2003)

* i = $\frac{i - \lambda}{1 + \lambda}$ = Discount rate, λ = Inflation rata (Sepulveda 1984)

Figure 42. Analysis of the Cash Flow for Alternative II to I (Sepulevda et al., 1984; Sullivan et al., 2003)

The cash flow diagram for existing tubes and LED tubes can be understood by applying the process as shown above. The lifespan of existing lighting tubes (fluorescent lighting tubes) is about sixteen months when the light tubes are turned on for twelve hours per day and in case of LED, it is twelve years, which was derived from the formula in the data collection. Once the lighting systems are replaced by LED tubes, energy consumption will be reduced by forty percent from GBS. Therefore the annual energy cost will be decreased from $207,025 to $124,215.

The replacement cycle of the LED tubes is around twelve years, which was derived from the formula mentioned above, with a replacement cost $207,148 each time. The incremental cash flow diagram of LED tubes illustrates that the initial investment cost can be offset by the total amount of energy saved. Using the incremental cash flow diagram, the stockholders can understand the feasibility of alternatives.

The preferred alternative is Alternative II the LED lighting.

Payback Periods

Payback Periods for Windows and Film

Window film can save total building energy by seven per cent and requires a comparatively low initial cost, about $48,185. On the other hand, low-e windows have a high initial cost, but energy saving can be twenty-four percent. The net profit based on these aspects between applying window film and retrofitting windows has been compared as calculated in Table 13. This table is used to calculate the discounted payback period, in accordance with standard economic practice (Sepulevda et al., 1984; Sullivan et al., 2003).

Table 13.

Payback Periods for Film and Low-e Window

	NPV			Cumulative balance		
Year	Status quo	Film	Window	Status quo	Film	Window
0	$0	$48,185	$612,733	$0	-$48,185	-$590,773
1	$116,336	$104,819	$88,415	$116,336	-$36,668	-$562,852
2	$113,274	$102,060	$86,088	$113,274	-$25,454	-$535,667
3	$110,293	$99,374	$83,822	$110,293	-$14,535	-$509,196
4	$107,390	$96,758	$81,616	$107,390	-$3,903	-$483,423
5	$104,563	$94,211	$79,468	$104,563	$6,449	-$458,328
6	$101,811	$91,732	$77,376	$101,811	$16,528	-$433,893
7	$99,131	$89,317	$75,340	$99,131	$26,342	-$410,102
8	$96,522	$86,966	$73,357	$96,522	$35,898	-$386,936
9	$93,981	$84,677	$71,426	$93,981	$45,202	-$364,381
10	$91,508	$82,449	$69,546	$91,508	$54,261	-$342,419
11	$89,099	$80,278	$67,715	$89,099	$63,082	-$321,035
12	$86,754	$113,152	$65,933	$86,754	$36,684	-$300,214
13	$84,471	$76,108	$64,198	$84,471	$45,047	-$279,941
14	$82,247	$74,105	$62,508	$82,247	$53,189	-$260,202
15	$80,082	$72,154	$60,863	$80,082	$61,117	-$240,982
16	$77,975	$70,255	$59,261	$77,975	$68,837	-$222,268
17	$75,922	$68,406	$57,701	$75,922	$76,353	-$204,047
18	$73,924	$66,605	$56,182	$73,924	$83,672	-$186,305
19	$71,978	$64,852	$54,703	$71,978	$90,798	-$169,030
20	$70,084	$63,145	$53,264	$70,084	$97,736	-$152,210
21	$68,239	$61,483	$51,862	$68,239	$104,492	-$135,833
22	$66,443	$59,865	$50,497	$66,443	$111,069	-$119,886
23	$64,694	$58,289	$49,168	$64,694	$117,474	-$104,360
24	$62,991	$82,158	$47,873	$62,991	$98,307	-$89,242
25	$61,333	$55,261	$46,613	$61,333	$104,379	-$74,522
26	$59,719	$53,807	$45,386	$59,719	$110,291	-$60,189
27	$58,147	$52,391	$44,192	$58,147	$116,048	-$46,234
28	$56,617	$51,012	$43,029	$56,617	$121,653	-$32,646
29	$55,126	$49,669	$41,896	$55,126	$127,110	-$19,416
30	$53,676	$48,362	$40,793	$53,676	$132,424	-$6,534

Film Payback Periods (years 0–4)

Low-e Window Payback Periods (years 0–30)

$$\text{Payback Period} = \frac{A}{T} + L \tag{7}$$

where A is the absolute value of net cash flow in that year, T is the total cash flow in the following year, L is the last year with a negative net cash flow.

Hence the calculation for the Window film payback period are

$$= \frac{6{,}449}{6{,}449 + 3{,}903} = \frac{6{,}449}{10{,}352} = 0.622 + 4\,years = 4.62\,years$$

Low-e window payback period are

$$= \frac{5{,}824}{6{,}534 + 5{,}824} = \frac{5{,}824}{12{,}358} = 0.47 + 30\,years = 30.47\,years$$

The window alternatives for Langford Buildings A payback periods from the data above is shown in Figure 43.Table 14 shows the comparison of the alternatives.

Table 14.

Comparison of Window Film and Low-e Window Results

Description	Total Cost	NPV	Payback periods
Status quo	-$2,553,812	-	-
Window Film	-$2,491,983	$61,829	4.62 years
Low e Windows	-$2,582,305	-$28,493	31 years

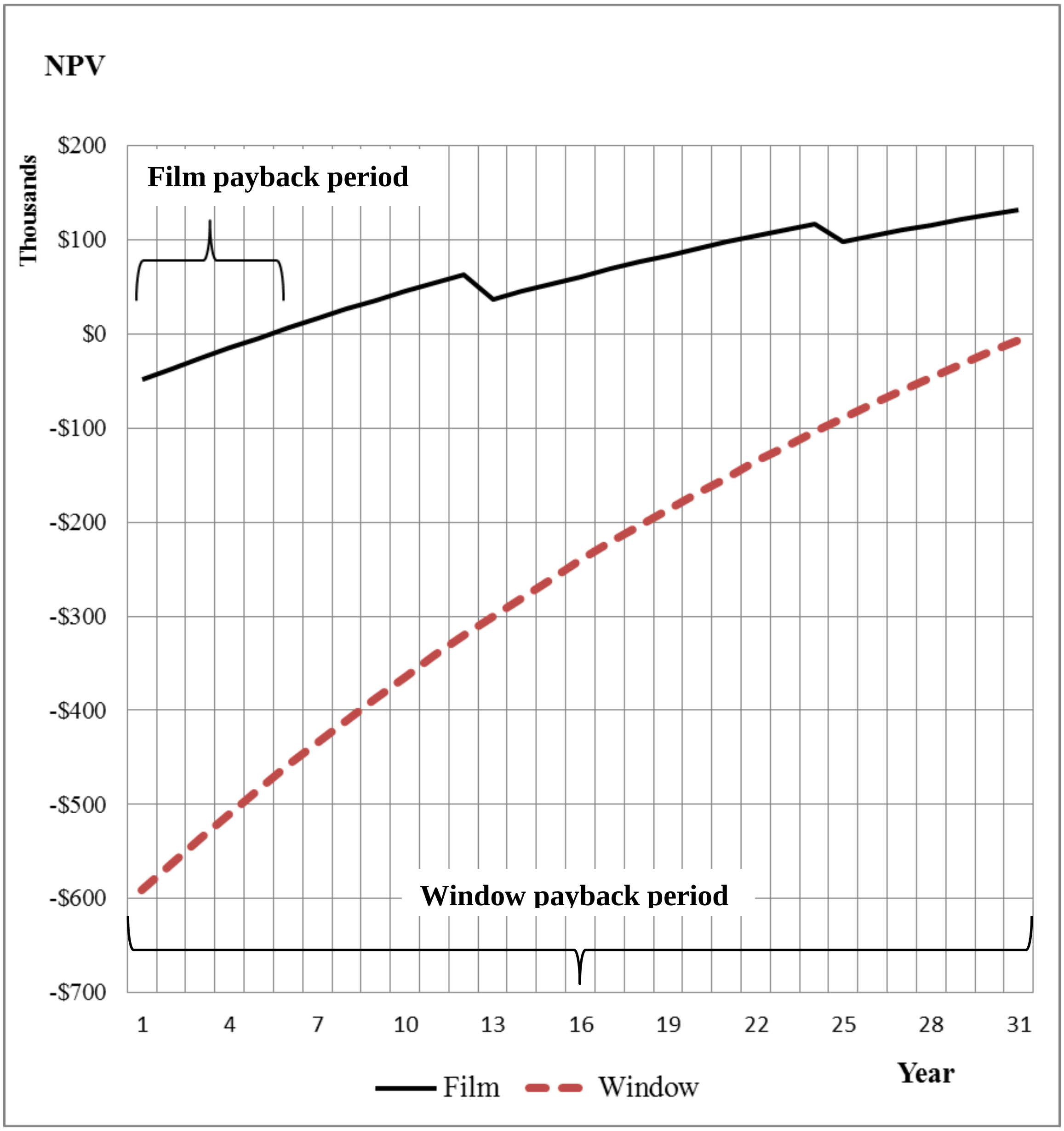


Figure 43. Payback Period for the Window Alternatives

In this sampling period, while there is a profit from low-e film after the fifth year, no profit has been derived from retrofitting windows due to the high initial cost. Therefore, it is concluded that applying low-e film is a better option for Langford A.

Payback Periods for Fluorescent and LED Lighting

Due to the high initial cost, LED tubes have not received much attention from the building industry, but they have a short payback period as shown on Table 15.

Table 15.

LED Tube Payback Periods

	NPV		Cumulative balance
Year	Fluorescent	LED	LED
0	0	207,148	**-190,138**
1	201,576	112,883	**-101,445**
2	208,817	109,911	**-2,539**
3	203,321	107,018	93,763
4	197,969	104,202	187,530
5	192,758	101,459	278,830
6	187,685	98,788	367,726
7	182,745	96,188	454,283
8	177,935	93,657	538,561
9	173,251	91,191	620,621
10	168,691	88,791	700,521
11	164,251	86,454	778,318
12	159,928	234,587	703,660
13	155,719	81,963	777,415
14	151,620	79,806	849,230
15	147,629	77,705	919,154
16	143,744	75,660	987,237
17	139,960	73,668	1,053,529
18	136,276	71,729	1,118,076
19	132,689	69,841	1,180,924
20	129,197	68,003	1,242,117
21	125,796	66,213	1,301,701
22	122,485	64,470	1,359,715
23	119,261	62,774	1,416,203
24	116,122	170,331	1,361,994
25	113,066	59,513	1,415,547
26	110,090	57,946	1,467,691
27	107,192	56,421	1,518,462
28	104,371	54,936	1,567,897
29	101,624	53,490	1,616,031
30	98,949	52,082	1,662,898

LED Payback Periods (years 0–2)

This table is used to calculate the discounted payback period, in accordance with standard economic practice (Sepulevda et al., 1984; Sullivan et al., 2003). The LED payback periods calculation is:

$$\text{LED payback periods } = \frac{93{,}763}{2{,}539 + 93{,}763} = \frac{93{,}763}{96{,}302} = 0.97 + 2\,years = 2.97\,years$$

The LED payback period is shown in Figure 44.

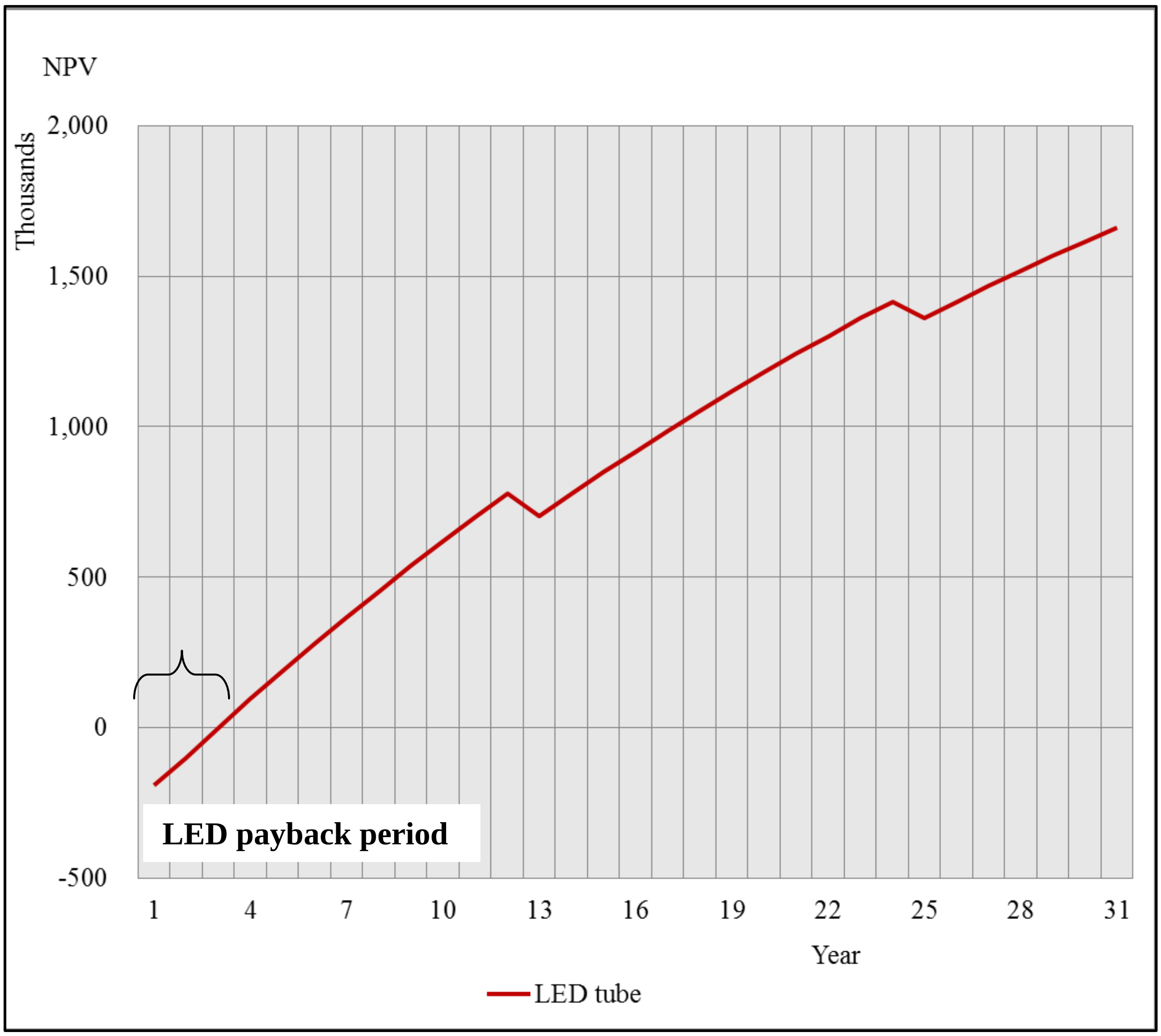


Figure 44. LED Payback Periods

Results of study are listed in Table 16.

Table 16.

Comparison of Fluorescent Tube and LED Tube Results

Description	Total Cost	NPV	Payback periods
Status quo (Fluorescent)	-$4,625,315	-	
LED tubes	-$2,997,549	-$1,627,767	2.97 years

Even though LED tubes cost twenty times more initially, with a greater annual energy saving. This is forty-four percent less than fluorescent and the payback period is only three years.

Figure 44 shows that the profit from LED tubes changes as time goes on. It has a positive net profit after the third year and continues to increase. By the end of the sampling period, the profit is more than $1.5 million dollars. Since LED tubes have to be replaced every twelve years, there are drop points in the cash flow at the twelfth and twenty-fourth years as shown on the graph.

Monte Carlo Simulation

In order to carry out a Monte Carlo simulation, uncertain random variables should be assumed and defined for the study, within acceptable limits given expected economic conditions over the analysis period. Then these variables must be transferred to be given as random variables that can be used to predict the sensitivity of the total NPV over the thirty study years. In this research, the inflation rate and discount rate have been assigned as random variable so these can be defined as normal distribution with a standard deviation that is one third of the average. As a result of ten thousand simulations with a crystal ball, the results are as presented in Figure 45.

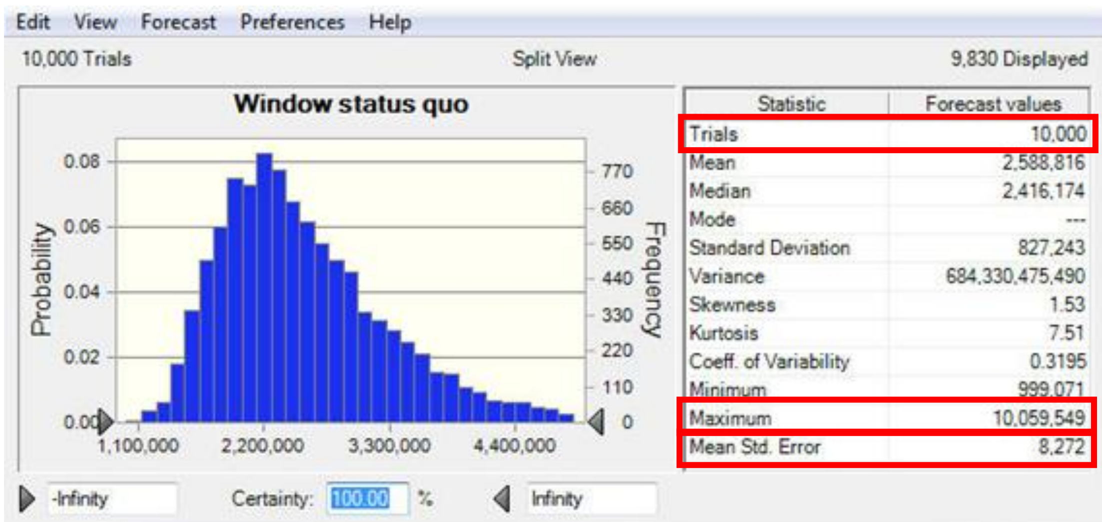


Figure 45. Result of Monte Carlo Simulation for Existing Window Alternative

Figure 46 shows the Monte Carlo results for the Window Film Alternative.

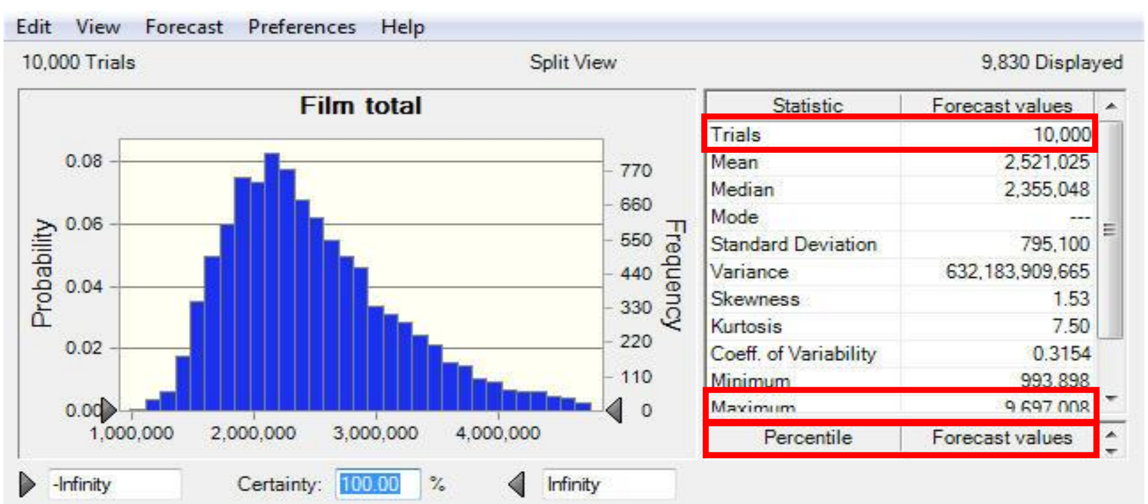


Figure 46. Result of Monte Carlo Simulation for Window Film

Figure 47 shows the results for the Monte Carlo Simulation for low-e Windows.

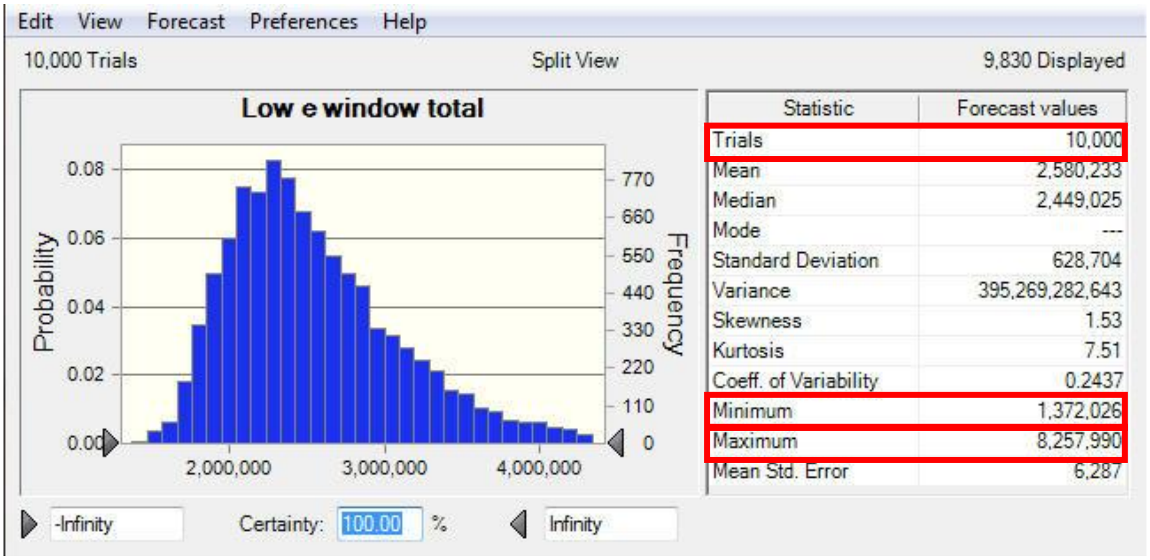


Figure 47. Result of Monte Carlo Simulation for Low-e Windows

The result of Monte Carlo Simulation are left skewed, the formula shown below was applied to convert left a skewed distribution to a normal distribution (Hinze, 2011).

The relevant equation is shown in equation

$$Te = \frac{Ta + 4Tm + Ti}{6} \tag{7}$$

Where *Te* is the mean value, *Ta* is the maximum value, *Tm* is the mode value, and *Ti* is the minimum value.

In conclusion, the window film alternative has a PV average of $2,367,101 over thirty years, while retrofitting windows was $1,942,495. This indicates that there is a higher possibility of spread in the lower range.

Summary

An energy conservation ratio, based on energy simulation, was obtained to compare the existing lamps in Langford A with light emitting diodes (LEDs). In addition, to reduce cooling energy consumption in the building, efficient heat reflective window film for the existing transparent single windows and retrofitting double pane windows have been considered.

This study shows that numerous old campus buildings that are using single windows and inefficient lightings can be modified to reduce the building energy cost through installing efficient lighting and low-e window film. The university can save unnecessary electric costs since they account for a large portion of the building's energy consumption. Furthermore, the building can save maintenance costs by using efficient lighting tubes with a long lifetime.

CHAPTER VII

DISCUSSION

In this research, once the window film and LED lighting was set up, the energy saving rate was derived through Green Building Studio. Net present values were then calculated by applying this saving rate onto the status quo alternative, which was around seven percent for the window film and forty percent for the LED. Those rates were close to the rate that was derived from the literature review, which was about ten percent and forty-four percent respectively. The results show that significant energy conservation can be accomplished in Langford Building A.

The net present value was lowest with the window film alternative and highest with the retrofitting window alternative taken over the thirty years study period for the economic analysis. The results show that savings can be achieved with simple building modifications. These alternatives are recommended.

CHAPTER VIII

CONCLUSIONS

This study shows that lighting energy consumption in Langford A can be reduced by two approaches. The first approach is converting inefficient fluorescent lighting tubes to energy efficient LED lighting tubes. The second approach is retrofitting with window film or low-e windows. To identify whether these alternatives were cost efficient, a life cycle cost analysis was applied and a Monte Carlo simulation was conducted. The payback period was derived by calculating the total amount of energy cost saving each year.

According to this study, once the windows are retrofitted, there is energy saving but it is not profitable due to the long payback periods of thirty-one years. However, once the window film was applied, the payback period was determined to be about five years through implementing a life cycle cost analysis. In the case of lighting, even though replacing with LED has a high initial cost, three years payback period was derived resulting in a significant energy saving. Retrofitting windows creates several problems, such as construction difficulties and long-term payback periods, this option is not acceptable to some decision makers in high and consistent use buildings. This problem does not apply to the Langford complex.

In having high-energy efficiency and a lifespan five times longer when compared to fluorescent, LED tubes can dramatically save energy and maintenance costs. LED lighting has a short three-year payback period, so this option has been proven to be feasible. An additional saving, around thirty to fifty thousand dollars could be derived by applying for some incentives for LED tubes and window film retrofitting.

In this research, a green building analysis was used since energy and cost information can be attained quickly by energy analysis.

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