Design and Implementation of Daylight Harvesting Illumination System in a Retail Environment

Jorge G. Redondo
Manufacturing Engineering
Edgar Torres, Ph.D.
Industrial Engineering
Polytechnic University of Puerto Rico

Abstract *— The study was conducted within a Retail Store Chain. The main objective of this project was to reduce energy consumption in a retail environment. An illumination design was performed. Light intensity level is measured in foot-candles (fc). The required level of foot candles according to the Illumination Engineering Society (EIS) Lighting Handbook for a retail environment should be between 50-120 fc. The established design guideline for the retail store which this analysis is based on is 50 fc. The focus was on introducing new technologies that would reduce the amount of electrical lighting necessary, while keeping the projects simple payback period under five years. Daylight harvesting was the technique used to reduce energy consumption. This term refers to a control system that reduces the use of electrical lighting in buildings interiors by the use of natural daylight. With the techniques used it can be shown that the energy consumption was reduced, from a monthly average of 492,485.73 KWh to 453,688.43 KWh. This reduction translates to yearly savings of $116,391.89. These techniques are easily transferrable to many other types of environments where lighting energy reduction is necessary.*

Key Terms – *Daylight Harvesting, Full Dimming, Step Dimming, Foot Candle.*

BACKGROUND & PROBLEM STATEMENT

Energy costs are constantly on the increase all over the world but particularly in Puerto Rico, where the cost of KWh is one of the highest of all the United States. These rising costs in energy are adversely affecting operational costs for Retail Store Chain X. Energy management and reduction techniques had to be implemented in order to maximize profits and reduce the carbon footprint for X, as that was one of its corporate objectives. Of course any capital project had to be economically feasible and have a simple payback not greater than five year with the lowest costs possible. Unit M, located in the north coast of Puerto Rico, was selected because of its similarity to the rest of the X's units, thus simplifying any future implementations across the Retail Chain. Energy consumption distribution for M is shown in Figure 1.

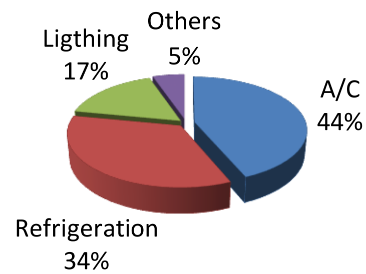

Figure 1
Electrical Consumption Distribution

The first logical step would be to reduce consumption in the areas where the most energy is being utilized, but in our particular situation that is not the possible. The Air Conditioning system has not concluded its useful life. Thus as with any other capital project that has not finished its life cycle it still has a value and will result in additional cost if it was to be replaced. The refrigeration systems useful life has also not expired and additionally it has already been retrofitted with R22 refrigerant and VFDs to control its condenser fans. Then the only area of energy consumption left to be reduced was lighting. Furthermore lighting consumption distribution was evaluated in order to understand which area had the biggest possible opportunity and implement the project accordingly. This information is shown in Figure 2.

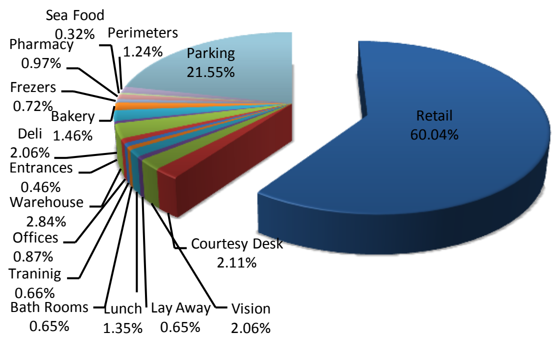

Figure 2
Lighting Consumption Distribution

This project consists of all the analysis, designs and implementation that were necessary in order install a daylight harvesting system in a retail environment. Then the data from these analyses will be compared to real energy consumption figures for store M.

PROJECT METHODOLOGY

The design and implementation of a daylight harvesting system was developed using project management, Six Sigma DMAIC methodologies and Lean concepts.

Project Management

A project is a temporary group action intended to yield a distinctive result [1]. A project is temporary because it has a defined timeframe, scope and resources. It is unique because it is not a routine activity but a specific plan designed to reach a predetermined goal. Project management, is the use of knowledge, skills and techniques to successfully implement projects proficiently.

Project management's traditional model, which is used by the Project Management Institute (PMI) has five process components that can be seen in Figure 3. Initiation, Planning, Execution, Monitoring and Controlling are continually being performed until the completion of the project which takes us to the final process known as closing.

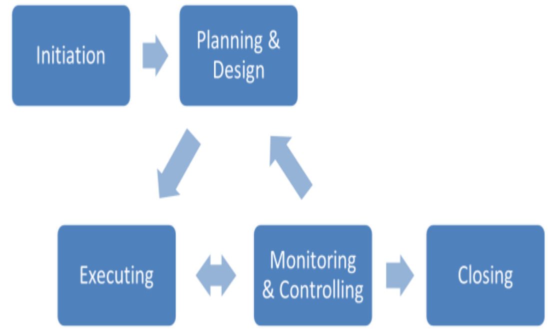

Figure 3
Process Components

Project Management knowledge is categorized in nine areas. Which are the following:

- Integration – Makes certain all the parts of the project are coordinated.
- Scope Management – Makes sure the need is defined, the expectations are set and met, all changes are managed, surprises are minimized and that projects acceptance is gained.
- Time Management – Makes sure the projects schedule is made and updated to any changes.
- Cost Management – Makes sure the project is completed within budget.
- Quality Management – Makes sure the project will meet the needs for which it was accepted.
- Human Resources Management – Makes sure staff is assigned and its performance assessed.
- Communications Management – Makes sure information is distributed accurately and in a timely matter to the correct individuals.
- Risk Management – Planning of how to handle risks.
- Procurement Management – Procedures executed in order to obtain external goods or services.

Six Sigma & Lean

Six Sigma is a business management strategy that focuses on process improvement and the reduction of variation. Six Sigma projects follow two methodologies DMAIC and DMADV [2]. DMADV (define, measure, analyze, design, verify) is the methodology used to develop new processes. DMAIC is the methodology that is used to improve existing business process and it is explained below.

1. Define the problem.
2. Measure the current process and collect data.
3. Analyze the data and verify cause effect relationships.
4. Improve the current process based on the analysis.
5. Control the future state in order to correct deviations from target.

The core idea of Lean is to maximize costumer value while minimizing waste. Muda is the word used in Lean to refer to waste, and refers to all non-value added activities. There are seven types of muda, which are: transportation, inventory, motion, waiting, overproduction, over processing and defects. Overproduction is the only type of waste that applies to this project, and will be discussed more in detail in the following section.

Research Project Results & Discussion

The analysis results and real data obtained for this project applying DMAIC are described below.

Define

A Project Charter was developed to summarize the scope of the project (Figure 4). The charter illustrates the scope, objectives, benefits, and the timeline to achieve expected results.

A communication Plan was developed in order to maintain all the necessary people involved informed. This plan includes the people involved and or impacted by the project: management, customers, team members and project owner.

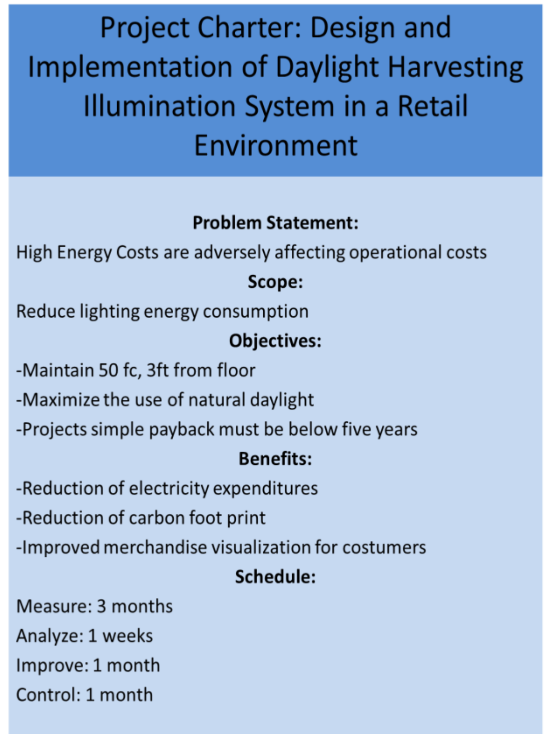

Figure 4
Project Charter

To further understand the process a process map was developed using the SIPOC (supplier, inputs, process, output, costumer). This process map can be seen in Figure 5.

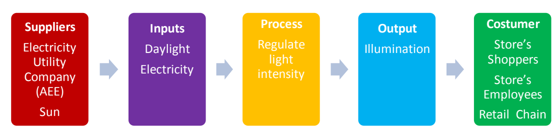

Figure 5
SIPOC Diagram

The lighting program that was used only had on/off modes because the lighting fixtures ballasts where non-dimming. Nevertheless step dimming was utilized in order to reduce energy consumption [3]. Step dimming is the term used to refer the partial shutdown of lights based on natural daylight available. The store's lighting fixtures where divided into groups, each comprising of 1/2 of the retail illumination. Depending on how much daylight came though the skylights it would turn them on and off. The control system only needed a minor upgrade and new programming in order to accommodate a full dimming system. With the installation of this system the overproduction of illumination could be minimized and thus eliminating muda. Below in Figure 6 we can see the process flowchart for step dimming [4].

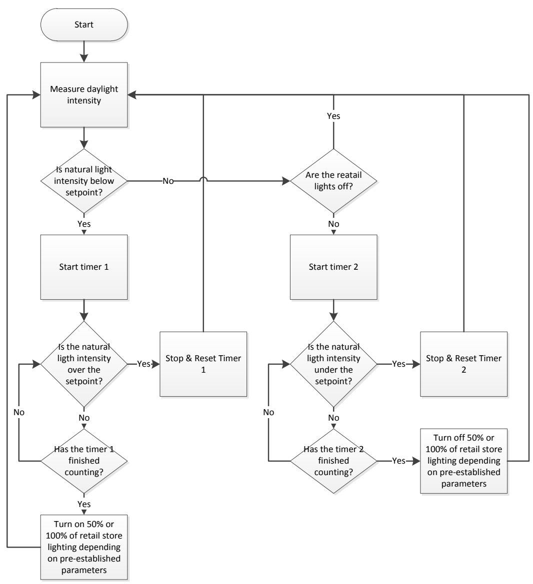

Figure 6
Step Dimming Process Flowchart

Measure

Power consumption was monitored for three months utilizing the power utilities monthly invoices. There was no specific metering available for the retail lights, thus calculations where performed to approximate lighting loads.

The power consumption for July through September can be seen in Table 1.

Table 1
Electrical Consumption With Step Dimming

Billing Cycle	KWh Consumed	Cost	KWh price
Jul-11	495897.19	$120,998.91	$0.244
Aug-11	485483.00	$129,623.96	$0.267
Sep-11	496077.00	$129,972.17	$0.262
Average	492485.73	$126,865.02	$0.258

Analyze

Before any funds were assigned to the project its economic viability had to be analyzed. The averages made reference in Table 1 where used to as the baseline values for this analysis. Below in Table 2 we can see the approximate lighting load for all retail illumination. This data was calculated utilizing hourly averages for daylight illumination for Puerto Rico. Also there are 5124 lamps in the retail area of the store each consuming a maximum of 32 W. We can see in Figure 7 the required foot candles from the luminaries in order to maintain the unit properly illuminated and showcase the merchandise properly [5].

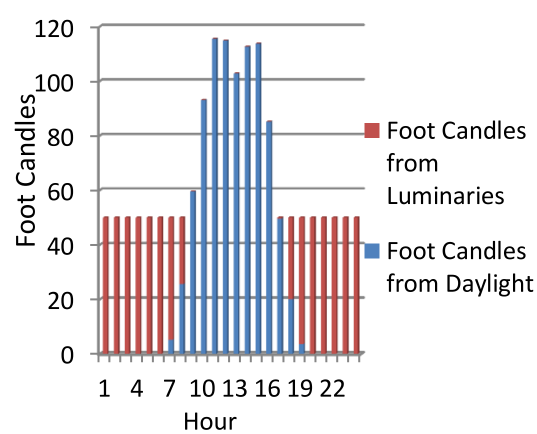

Figure 7
Luminaries Required Foot Candles

Table 2
Daylight FC per Hour

Hour (24 h format)	20 to 6	7	8	9 to 16	17	18	19
Average Daylight FC/hr	0	5.25	25.67	99.7	49.58	20.08	3.67
FC needed from Luminaries	50	44.75	24.33	0	0.42	29.92	46.33
% of power needed Full Dimming	60	50	30	0	10	40	60
Total Power Consumption Full Dimming (KWh)	98.3808	81.984	49.19	0	16.397	65.5872	98.3808
% of power needed Step Dimming	100	100	50	0	50	50	100
Total Power Consumption Step Dimming (KWh)	163.968	163.97	81.984	0	81.984	81.984	163.968

From the data in Table 2 we can calculate that the daily average power consumption from retail lighting is 2377.54 KWh, and the proposed full dimming projects consumption would be 1393.73 KWh. This is equal to a yearly difference of 359089.92 KWh. That translates to yearly savings of $89,772.48, using $0.25 as the cost of KWh. We can clearly see the difference in KWh consumption per hour in Figure 8.

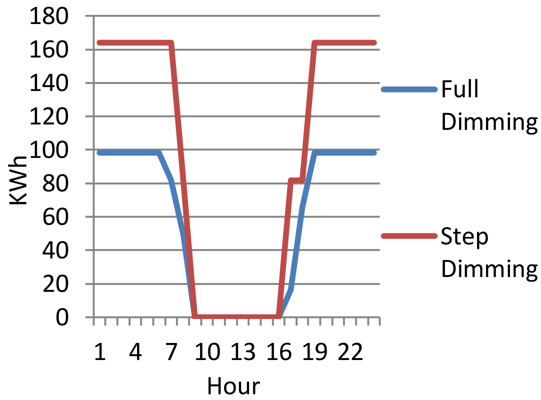

Figure 8
Full Dimming vs. Step Dimming Hourly Consumption Analysis

With these calculations proving that there would be savings associated with this project all costs had to be accounted for. Below in Table 3 the project's costs are shown.

Table 3
Costs of Project

Action Item	Cost
Skylights	$45,675.00
Skylights Installation	$7,398.00
Lamps	$10,071.86
Ballasts & Installation	$224,875.00
Lamps Installation	$7,394.79
Controller Upgrade and Programming	$4,500.00
Lamp Recycling	$4,355.40
Total Investment	$304,270.05

Based on these costs and projected savings the projects simple payback would be 3.39 years.

Improve

The projects improvement start date was October 16, 2011 and it was finalized 4 weeks later on November 12, 2011. Because of this, the months that will be used to verify real savings will be from December to February.

Control

The buildings automated controls were upgraded with an additional electronic board that is able to control the dimmable ballast depending on the natural light coming into the store [6]. The daylight is being monitored by the use an analog sensor, which was already being used for the step dimming [7].

Table 4
Electrical Consumption With Full Dimming

Billing Cycle	KWh Consumed	Cost	KWh price
Dec-11	466279.00	$117,502.31	$0.252
Jan-12	443515.00	$120,636.08	$0.272
Feb-12	451271.30	$113,269.10	$0.251
Average	453688.43	$117,135.83	$0.258

In Table 4 we can see the power consumption from December to February. Below in Figure 9 we can see the process flowchart for a full dimming system. If compared to Figure 6 it is apparent that both processes are very similar. The only difference is that with step dimming the control turns on 50% or 100% of the retail area lights and the full dimming system regulates or dims equally all luminaries in the retail area.

We can see in Figure 10, the difference in consumption for unit M before and after the full dimming system was implemented.

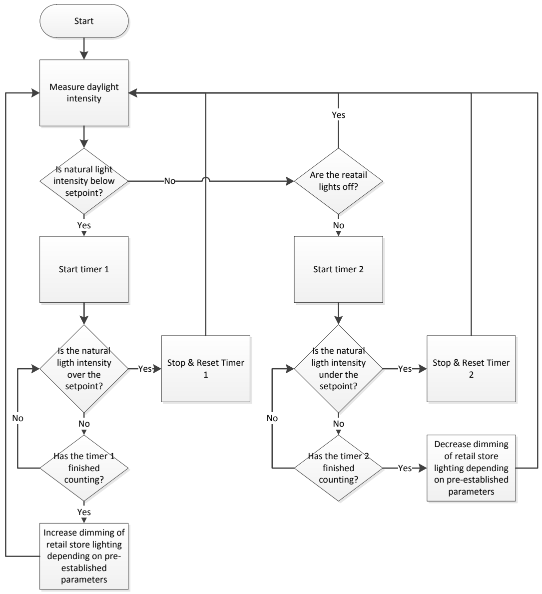

Figure 9
Full Dimming Process Flowchart

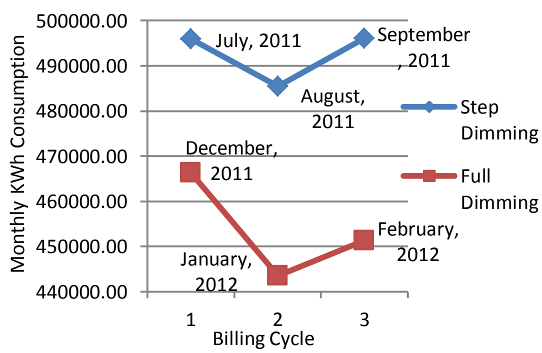

Figure 10
Full Dimming vs. Step Dimming Monthly Real Consumption

CONCLUSION AND RECOMMENDATIONS

The project was implemented using the DMAIC model. With the measurements taken after the daylight harvesting system was employed we can see that in fact significant savings where obtained. With the techniques used it can be shown that the energy consumption was reduced, from a monthly average of 492,485.73 KWh to 453,688.43 KWh**.** This reduction translates to yearly cost savings of $116,391.89, more than our original estimates. Minimizing the projects simple payback to 2.61 years, well below our goal of 5. As a benefit to lowering energy consumption and energy expenses, carbon emissions were also reduced by an average of 276,310 Kg/annually. A more precise payback number could be calculated if the real consumption for only the retail lighting was known. This information can be obtained with the installation of a dedicated meter for the lighting load. With the installation of this meter any load changes from the refrigeration or HVAC systems could be ruled out. Additionally all consumption data should be registered through the year for more precise calculations.

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