Special Issue - 2017
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
ESDST - 2017 Conference Proceedings

Cost-Benefit Analysis and Emission Reduction of Lighting Retrofits in an Academic Institution

Kuldeep Singh
Electrical Engineering Department,
Assistant Professor at Baba Banda Singh Bahadur
Engineering College, Fatehgarh Sahib, India

Simarpreet Singh
Electrical Engineering Department,
Assistant Professor at Baba Banda Singh Bahadur
Engineering College, Fatehgarh Sahib, India

***Abstract* - This study projects electricity savings, cost benefit analysis and emission reduction of lighting retrofits in an academic institution. The cost-benefit is determined as a function of energy savings due to retrofit of more efficient lighting system. The energy savings were calculated based on 25, 50, 75 and 100% of potential retrofits of inefficient lighting in the academic institution. The data used was collected by conducting a survey and by recording the actual load and operating hours of the existing inefficient lighting system at different places in the institution. The study found that, this strategy save a significant amount of energy and money. The study also shows that there is a good potential for reducing carbon emissions by retrofitting the inefficient lighting with efficient lighting.**

I. INTRODUCTION

There has been growing concern about energy consumption and its environmental implications for the last decade. A lot of energy efficient measures are being taken day by day to save energy. Lighting system in any building consumes a substantial part of total electricity consumption. Electric lighting accounts for about 25% of total building energy used by Ghisi and Tinker, 2005. A lighting retrofit means to replace inefficient lighting with the efficient one. Electricity savings over time is significant enough to not only pay for the new lighting, but also produce return on investment. This can be done by either reducing the input wattage or reducing the hours of operation of the lighting to reduce energy consumption. A lot of studies on retrofitting inefficient lighting by reducing input wattage are conducted as presented by Stefano, 2000; Lee, 2000; Guan et al.,1997. This study is also proposed to reduce consumption of electricity by retrofitting of conventional electromagnetic ballasts used with T8 fluorescent tube lights with more efficient electronic ballasts in an academic institution. The electronic ballast can replace electromagnetic ballast without any modification. Fluorescent tube light uses an arc of electricity to create light. This current must be applied in very precise ways to the gases within the tube--normal household electrical current is too erratic and powerful for the fluorescent tube. So the fixture requires a control device known as the ballast, which limits the current and meters it out in cycles that the tube light needs to keep lit.In all fluorescent lighting systems, the ballast provides the proper voltage to start the lamp and then regulates the electric current flowing through the lamp to stabilize output. There are two types of ballasts, the conventional electromagnetic ballasts and the newer electronic ballasts. Electronic ballasts increase lamp-ballast efficacy, leading to increased energy efficiency and lower operating costs. Electronic ballasts are more efficient than magnetic ballasts in converting input power to the proper lamp power, and their operating of fluorescent lamps at higher frequencies reduces end losses, resulting in an overall lamp-ballast system efficacy increase of 15% to 20% as presented by Eley et al., 1993.

One of largest advantages of electronic ballast is the enormous energy savings it provides. This is achieved in two ways. The first is its amazingly low internal core loss, quite unlike old fashioned magnetic ballasts. And second is increased light output due to the excitation of the lamp phosphors with high frequency.The life of FTL with magnetic ballasts is only 5000 burning hours whereas the life with electronic ballast increases up to 20000 burning hours given by Cris Gribbin,2006. This study attempts to calculate potential electricity savings, emission reduction and cost benefit analysis of lighting retrofit and to make a small effort in curbing the global warming.

II. COLLECTED DATA

Sant Longowal Institute of Engineering and Technology is located in Longowal, district Sangrur, Punjab, India. The data used for this study is collected from the institution buildings and comprises of number of fixtures, operating hours per year and wattage of Fluorescent Tube Lights. The building blocks selected for the study are 10 hostels and 5 Instructional blocks, Administration Block, Health Centre, Student Activity Centre and Estate Office. Location details and number of fixtures are provided in Table 1-3. Generally, in SLIET one semester holds for 16 weeks and classes are conducted for 5 days a week excluding Saturdays and Sundays. So number of days of working for instructional blocks is calculated as 160 and operating hours is taken as 6 hours/day. For office buildings the number of days of operation is calculated as 220. This can be calculated as there are 365 days in a year and offices are occupied for 5 days in week so number of days remaining excluding Saturdays and Sundays are 261 and further 20 days are deducted due to holidays and further 20/21 days are taken as reserve for leaves by the individual office occupants. For hostels the number of days of operation is taken as 250 as normally a student resides in the hostel for 8 months (approx.) per year and hours of operation taken is 10 hours per day. The data is collected by conducting survey at all these locations. The uncertainty, sensitivity analyses, life cycle cost and payback period of lighting system can be found by McMahon et al., 2000.

Table.1.Input data for fixtures in Teaching Blocks

Location	No. of fixtures
Electrical and Instrumentation	800
Computer Science	300
Mech. and Workshops	1500
Food and chemical	600
Applied sciences	500
Total	3700

Table.2.Input data for fixtures in Hostels

Items	Details
No. of Hostels	10
Fixtures in Hostel	200
Total	2000

Table.3.Input data for fixtures in Offices

Items	Details
Administration Block	300
Health Centre	20
Estate Office	30
Student Activity Centre	100
Total	450

ABBREVIATIONS USED

AS	annual savings (Rupees)
BS	bill savings (Rupees)
CC	capital costs (Rupees)
CERs	certified emission reductions (tCO_2)
d	discount rate
DO	days of operation in a year
E	electronic ballast lighting system
EC	energy consumption (kWHr)
EC^E	energy consumption with electronic ballast (kWHr)
EC^M	energy consumption with electromagnetic ballast (kWHr)
EF	emission factor
ES	energy savings (kWHr)
GRC	gross return on capital (%)
LL	lamp life (burning hours)
M	electromagnetic ballast lighting system
n	number of years
NF	number of fixtures
NPV	net present value
NRC	net return on capital
OH	operating hours
PC	power consumption (kWHr)
PE	price of electricity (Rs/kWHr)
PF_1	power factor with lighting system M
PF_2	power factor with lighting system E
R	number of replacements
TS	total savings (Rupees)

III. METHODOLOGY

A survey is necessary to determine the potential of retrofit lighting, the operating hours of fluorescent tube lights with electromagnetic ballasts and load taken by one fixture. The data obtained from the survey presented in Tables 4-6 was used to calculate projected electricity savings, emission reductions and cost-benefit analysis of lighting retrofits.

Table.4.Load calculations with electromagnetic ballast for Table 1

Items	Details
Electrical load per fixture	45 W
Operating Hours per day	6
No. of days per year	160
Total fixtures taken	3700
Total electrical load	166.5 kW
Total units consumed/year (kWHr)	159840

Table.5.Load calculations with electromagnetic ballast for Table 2

Items	Details
Electrical load per fixture	45 W
Operating Hours per day	10
No. of days per year	250
Total fixtures taken	2000
Total electrical load	90 kW
Total energy consumed/year (kWHr)	225000

Table.6.Load calculations with electromagnetic ballast for Table 3

Items	Details
Electrical load per fixture	45 W
Operating Hours per days	6
No. of days per year	220
Total number of fixtures	450
Total electrical load	20.25
Total units consumed/year (kWHr)	26730

3.1 *Number of Retrofits*

Number of retrofits is determined by conducting a survey and it was found that in SLIET there is a practice of using 1X36 W, T8 fluorescent tube light fixture with electromagnetic ballast. So total numbers of fixtures were counted and there is a potential of 6150 lighting retrofits.

3.2 *Energy Consumption*

Energy consumed by the existing system is calculated by the multiplication of total number of retrofits in each block, power consumption, number of days of operation per year and operating hours of the lighting per day. This can be represented by the following equation. All the calculations are done in according to Mahlia et al., 2004.

$$EC = NF \times PC \times OH \times DO \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.3 *Energy Savings*

Energy savings from retrofitting is the difference between energy consumption of inefficient and efficient lighting. This is given in table 7. This can be calculated using the following equation:

$$ES = EC^{M} - EC^{E} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Table.7.Predicted electricity consumption and savings

Location	EC^M(kWHr/year)	EC^E(kWHr/year)	Potential of electricity savings (kWHr/year)			
			25% retrofits	50% retrofits	75% retrofits	100% retrofits
Teaching Blocks	159840	127872	7992	15984	23976	31968
Offices	26730	21384	1336.5	2673	4009.5	5346
Hostel	225000	180000	11250	22500	33750	45000
Total	411570	329256	20578.5	41157	61735.5	82314

3.4 Emission reduction

The environmental impact from retrofitting is potential reduction of greenhouse gases which pollutes the environment or other element that caused negative impact on the environment. Carbon emissions can be reduced to some extent by retrofitting the inefficient lighting along with savings in energy. The potential CERs that can be generated from these measures are calculated by taking emission factor of 0.7240 kg of CO_2/kWHr given by the $CO_{2\ \text{Baseline}}$ Database for the Indian Power Sector, 2007. The emission reduction is a function of energy savings. The CERs are calculated by the following equation:

$$CERs = \frac{ES \times EF}{1000} \quad \text{……………………. (3)}$$

3.5 Gross return on capital

Gross return on capital is a function of total savings from the project and capital costs required for the implementation of the project. It expresses the "annual return" from the project as a percentage of capital cost. This can be calculated from the following equation:

$$GRC = (\frac{TS}{CC}) \times 100 \quad \text{…………………….. (4)}$$

3.6 Net return on capital

Net return on capital is also a function of total savings from the project and capital cost required for the implementation of the project. It is expressed with the help of following equation:

$$NRC = (\frac{TS - CC}{CC}) \times 100 \quad \text{……………….. (5)}$$

3.7 Bill savings

The bill savings of lighting retrofit is a function of energy savings and the average price of electricity. The potential bill savings by lighting retrofit is shown in Table 8 and is calculated by the following equation:

$$BS = ES \times PE \quad \text{………………… (6)}$$

Table.8.Bill savings and simple payback period for 100% retrofit

Items	Details
Total electricity savings per year (kWHr)	82314
Price of one electricity unit (Rs)	5
Total electricity bill savings (Rs)	411570
Cost of one Electronic Ballast (Rs)	200
Cost of one 36 W TFL 3250 lumens (Rs)	65
Replacement and labor charges per fixture (Rs)	45
Total replacement charges (Rs)	310
Total investment for replacing 6150 ballasts (Rs)	1906500
Simple payback period (years)	4.6

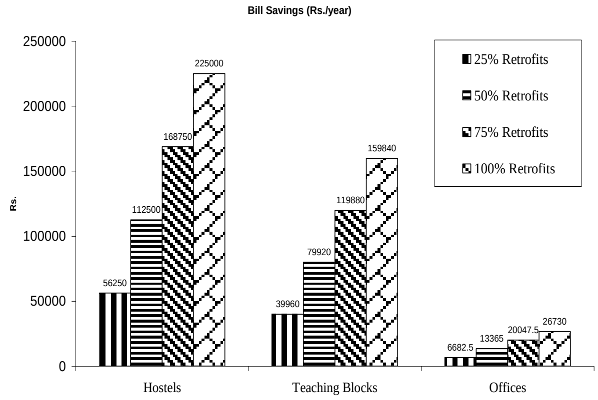

Fig.1. Annual Bill Savings due to lighting retrofit

3.8 Replacements

The replacement of the fixture is a function of rated life of the lamp and actual operating hours of the lamp. The burning hours of FTL with electromagnetic ballast is 5000 hours whereas with electronic ballast the life increases up to 20000 hours. So, number of replacements will decrease and running cost will also decrease with suggested replacements. The details of number of replacements and running costs are shown in Table 9. Number of replacements can be calculated with the help of following equation:

$$R = \frac{OH \times DO}{LL \times NF} \quad \text{…………………….. (7)}$$

Table.9.Comparison of running cost of system M and E

Items	Details	
	M	E
Annual electricity costs (Rs)	21222000	1527840
Lamp life (Burning hours)	5000	20000
Total replacements per year	1829.2	457.3
Replacement cost per FTL	32	65
Total replacement cost/year (Rs)	58534.4	29724.5
Total running cost per year (Rs)	2116384	1676005

Table.10. Predicted emission reduction (tCO_2)

Retrofits	Tons of Carbon Dioxide/year
25%	14.89
50%	29.79
75%	44.69
100%	59.59

3.8 Distribution losses

In an electrical system distribution losses are of great importance towards energy loss estimations. One factor which influences distribution losses is power factor of electrical system. A lot of emphasis is given to improve the power factor of the system to reduce distribution losses. The power factor of electromagnetic ballast is 0.5 only whereas power factor of electronic ballast is as high as 0.95. Reduction in the distribution loss % in kWh when tail end power factor is raised from PF_1 to a new power factor PF_2 will be as given by Mahlia et al., 2004., as give below

$$\left[1-\left(\frac{PF_1}{PF_2}\right)^2\right]\times 100 \qquad \text{……………………... (8)}$$

3.9 Net present value

Net present value depends on the discount rate. This is calculated for 8%, 9% and 10% discount rate for 10 years. This can be calculated from the following equation:

$$NPV = \frac{AS\times[(1+d)^n-1]}{[d\times(1+d)^n]} \qquad \text{………………. (9)}$$

4 RESULTS AND DISCUSSIONS

To calculate energy consumption and potential energy savings by retrofit, it is necessary to have daily average operating hour of lighting in the institution. Based on survey data collected in different locations in the institute the energy consumption and potential energy savings can be calculated. For this study, the calculation is done for 25, 50, 75 and 100% of retrofits. The calculation result is tabulated in Table 7.

It shows that electricity savings of 82314 KWh annually can be achieved by replacing electromagnetic ballasts with energy efficient electronic ballasts in the institution. Table 8 shows the potential bill savings of Rs 411570 per year and the pay-back period is only 4.6 years which is a short term pay-back period as it is less than 5 years. The power factor of the electromagnetic ballasts is only 0.5 whereas the power factor of electronic ballast is 0.95. With retrofitting of electromagnetic ballast by electronic ballasts the power factor of the system will increase which has additional advantage of reduction in distribution losses as if the overall power factor of the system is increased from 0.5 to 0.95 then distribution losses will reduce by 72% which will help the power generating company. Due to reduction of overall load the conductor heating will reduce and thus heat losses will also be lower. As a result, maintenance charges will reduce. With the installation of 36 W T8 energy efficient lamps with 3250 lumens there will be 33% increase in the luminance as compared to the existing lamp of 2450 lumens. Based on potential energy savings per year, the emission reduction can be calculated using Eq. (3). The result is tabulated in Table 10. The predicted annual emission reductions from teaching blocks and hostels is 59.59 tCO_2 with 100% retrofits. The emission reductions with 25, 50 and 75% retrofits are also shown in the Table 10. Net present values with 25%, 50%, 75% and 100% retrofits are also calculated with 8%, 9% and 10% discount rates separately for hostels, offices and teaching blocks which are presented by Figs. 2-5. Figures shows that for 25% retrofits the values are almost same with all the discount rates but with 100% retrofits there is a considerable difference in the values with different discount rates.

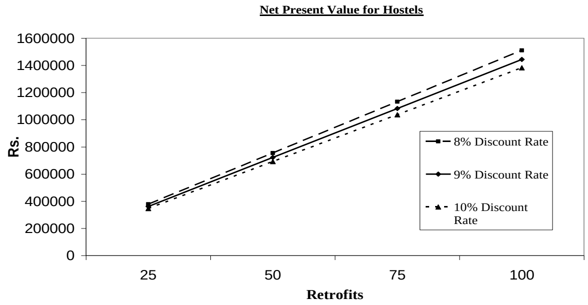

Fig. 2 Net present value for Hostels

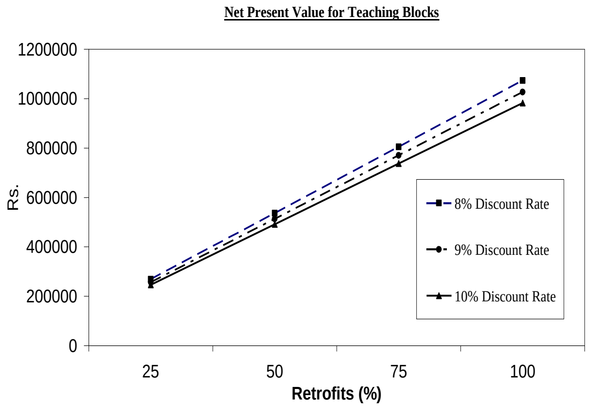

Fig. 3 Net present value for teaching blocks

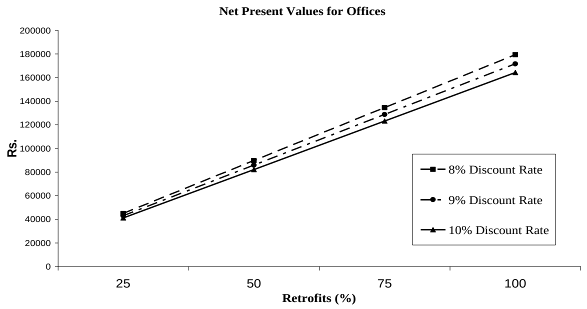

Fig. 4 Net preent value for offices

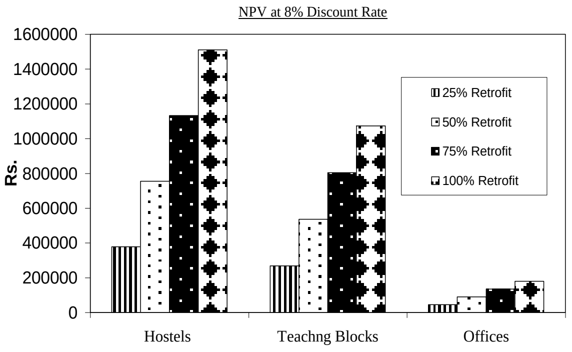

Fig. 5 NPV at 8% discount rate

Gross return on capital and net return on capital are calculated and presented by Fig. 6. It is found that the gross return on investment by retrofitting the lighting in hostels and offices is high which is 362.9 and 191.6 respectively, whereas by retrofitting the lights in teaching blocks the return is not so attractive and is 139.4. Similar is the trend for net return on capital value.

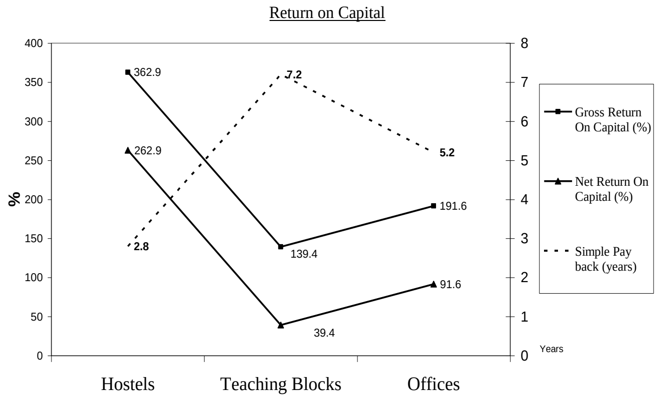

Fig. 6 Return on capital and simple payback period

IV. CONCLUSION

The calculation results show that lighting retrofits have significant impact on the institution electricity consumption. The recommendations based on findings can be considered for implementation in hostels and offices as considerable amount of energy can be saved and the cost benefit analysis shows that these two areas have high return rate. Furthermore, it will result in reduction in emission from power consumed by the institution. It can be concluded that the institution should encourage use of energy efficient lighting instead of inefficient lighting in the institution. A lot of energy can be saved and emission reductions can be achieved if such kinds of measures are adopted by other institutes also, which have hostel facilities.

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