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Retrofitting the electric lighting system in a commercial building; a case study of Civil Mall

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Abstract

The lighting system is one of the major components that consume a large amount of energy in the commercial building. Different types of colorful lights that consume more power are used to make the commercial building look attractive. Most of the commercial buildings are designed by ignoring the use of passive lighting system. This study focuses on the different aspects of energy efficient retrofit of the electric lighting system in the commercial building that includes a) lighting retrofit strategies b) electric lighting energy use and saving potential c) use of daylights. This study is carried out through both quantitative and qualitative analysis. In order to get the detailed data of the site energy auditing of the lightings that are being used in corridors, staircases and basements was carried out whose energy bill is paid by the owners. Civil Mall which is a commercial building located at Sundhara, Kathmandu, Nepal was chosen as the case study. The different lighting systems used in the Mall were studied and different ways of retrofitting the lighting system was explored. After using the retrofitting techniques the energy saved is calculated. The study concludes that using different retrofitting measure like dayighting systems, reducing lighting energy consumption and through the replacement of CFLs, fluorescent lamps and incandescent lamps with LEDs huge amount of energy can be optimized.

Keywords

Lightings, Retrofit, Compact Fluorescent Lamps (CFLs), Light Emitting Diodes (LEDs), Energy Efficiency, Daylights

1. Introduction

Lighting systems consume the most energy in commercial buildings. Approximately one-third of the electricity used in commercial buildings is consumed by lighting systems alone [1]. It is, therefore necessary to look after the lighting systems used so as to save the energy. A decreased use of energy means less to pay for energy bills, reduced load on the grid and less environmental impact. Lighting is the most common and naturally the most constant form of load. According to one study, investment in energy efficient lighting is one of the most cost effective ways for improving energy efficiency in buildings and reduce CO2 emissions [2].

Similarly, energy retrofits of lighting equipment are very cost-effective with typical payback periods of less than two years.[3] In addition, higher costs of electricity compared to most other energy sources (e.g. natural gas) in most countries further justifies ranking lighting retrofit measures high on the list of options as suggested by one of the study.[4] All these literature help to find out the importance of conservation of energy consumed by lighting so the retrofit of lighting system becomes inevitable. Retrofitting should be considered as one of the main approaches to achieving sustainability in the built environment at relatively low cost and high uptake rate[5]. These authors point out that most energy is consumed by existing buildings and the replacement rate of existing buildings by new build is only around 1.0-3.0% per annum and it is 2.2% per year in the commercial building sector. [5] These literatures show that rapid improvement in energy efficiency in existing buildings through retrofit is needed for the timely reduction in the global energy and promotion of energy sustainability research. This research is aimed at exploring the ways of lighting energy savings through retrofit that includes different strategies including the use of daylights.

2. Research Objective

The main objective is to find out the amount of energy that is optimized after the use of different retrofitting techniques for lighting system. Also, to analyze the data after the calculation of payback period.

3. Methodology

The study uses both qualitative and quantitative methods. The qualitative method is based on an interpretation of literature on approaches to retrofitting the electric lighting system. The information mainly found in peer-reviewed journal articles, conference articles and reports is studied which were identified by first performing a search in several databases (Science Direct, research gate, etc.) with the following keywords: lighting retrofit, energy-efficient lighting, daylights, bulbs, etc.

The quantitative method involves energy auditing in the initial phase which is followed by the study of different data of site (Civil Mall) that includes the power consumed by the lightings, their numbers and their usage. These collected data were used for the calculation of total energy usage by the lightings. After using different retrofitting strategies in the lighting systems, the newly obtained data were calculated and then compared with the original data (calculated before retrofit) to obtain the results.

4. Literature Review

Retrofitting of lighting systems is very necessary for the commercial buildings because of the fact that they consume a lot of energy. Because of lack of awareness and negligence about energy efficiency, almost all of the existing commercial buildings have not practiced the ways to conserve energy. Use of passive system i.e. daylighting decreases the use of active lighting systems. Some of the major commercial buildings in Kathmandu have used large advertising boards in the facades which clearly blocks the passive light. Use of passive lighting system is very important in the commercial buildings which help in lowering the energy bill by a huge amount. As seen in many commercial buildings especially malls the use of lights have been haphazard. Even at places where passive lightings can be used bulbs are being used for lightings. Using many bulbs to light a small space was also seen in many spaces of malls. There are many ways to retrofit lighting system of a commercial building. Some of the feasible ways to retrofit the lighting system of Civil Mall are listed below;

4.0.1 Replacing CFL lamps with LED lamps

LED lamps are superior to CFL lamps in every aspect [6] . For the retrofitting of the electric lighting system one of the methods used is the replacement of CFL lamps with LED lamps. LED lamps have more advantages in comparison to CFL lamps. For the lamps having the same power, LED lamps has more lumen value which can lighten up more space than the CFL lamps. Similarly the life span of LED lamps is much higher than the CFL lamps. The Table 1 clearly illustrates that for the same output (lumens) CFL lamp having the power of 23W is equivalent to 15W of LED lamp. This shows that energy can be saved by a huge amount in commercial buildings even though the initial price of LED is higher than the CFL light.

Table 1: Comparison of different lightings [6]

Comparison of normal bulbs compared to other lighting lamps.

Lamps (types)	Power (W)	Operating frequency	Efficiency (%)	Efficacy (Lm/W)	Formula (W × Lm/W)	Output (Lumens)
Bulb	100	50/60 Hz	1.9–2.6	17 (12–20)	100 × 17	1700
Tube	18	50/60 Hz	9–15	94 (70–100)	18 × 94	1692
CFL	23	30–100 kHz	8–11	74 (50–80)	23 × 74	1702
LED[a]	15	DC	20–22	113 (80–150)	15 × 113	1700
EEFL	21	2.5–3 MHz	9–14	81 (80–82)	26 × 65	1701
Ideal source	7	CW	35–37	242	7 × 242	1700
Theoretical limit	2.5	CW	100	683	2.5 × 683	1700

[a] LED efficacy 100 (available), SLED 130 (demonstrated) and 180 (realized).

Also in the Table 2 given by Viribright (2019), there is clear comparison of different types of light.

Table 2: Comparison of different lightings [7]

Lumens (Brightness)	LED Watts (Viribright)	CFL Watts	Incandescent Watts
400 – 500	6 – 7W	8 – 12W	40W
650 – 850	7 – 10W	13 – 18W	60W

4.0.2 Reducing lighting energy consumption

There are many ways to reduce lighting energy consumption. Electrical energy consumption can be calculated by using W= P * T, where P is calculated as a power in Watts and Time in hrs. Electrical energy consumption can be reduced by either reducing power or time or both. Power can be reduced by using LED lamps of small power having a high value of output(lumen). And operating time can be lowered by using automatic sensors also called as occupancy sensors. Occupancy sensors detect the presence of occupants in the room and can switch off the lights when the control area is unoccupied. Thus the operating hours can be reduced, causing a reduction in lighting energy consumption [8]. A survey conducted in France, IEA (2006) reported energy savings of up to 77% by installing more manual switches in open plan offices.Also the use of daylighting can reduce the use of electrical energy consumption. Based on the daylight level entering a room or area, the daylight-linked lighting control systems either switch or dim the light fixtures to maintain adequate light levels required for the task performed in the room. Reducing unnecessary usage of lights inside the building can also reduce lighting energy consumption. There are lots of spaces inside the commercial building where the lights have been used where there is no need.

4.0.3 Use of daylights

Building facades and roofing systems are mainly responsible for the daylights of the buildings. Maximum use of daylightings helps to reduce the active system for lightings. The most efficient daylighting systems for moderate climates seem to be automatically controlled blinds and louvres, because of their flexibility to respond to different daylighting conditions. The energy savings potential and economical aspects of daylighting systems was investigated under moderate climate conditions and concluded the pay back times for daylighting systems are typically extensive therefore also pleading for simple, cost effective, daylighting systems, such as blinds and louvers. These systems perform well under predominant sunny sky conditions as well. Potential energy savings by using different types of lighting control systems is given in the Table 3.

Table 3: Lighting Control systems[9]

	Potential energy savings	Retrofit studies	Source
Manual controls	23-77%	Yes	IEA (2006); Jennings *et al*. (2000)
Scheduling	12%	No	Itani *et al*. (2013)
Occupancy control	20-93%[a]	Yes	Motta Cabrera and Zareipour (2013); Garg and Bansal (2000); Moore *et al*. (2003); Richman *et al*. (1995); Guo *et al*. (2010)
Daylight-linked dimming	10-93%	Yes	Boyano *et al*. (2013); Doulos *et al*. (2008); Li *et al*. (2006); Lee and Selkowitz (2006); Onaygil and Guler (2003); Ihm *et al*. (2009); Kobav and Bizjak (2010); Chow *et al*. (2013); Li *et al*. (2006); To *et al*. (2002); Koyle and Papamichael (2010)
Combined daylight -linked and occupancy	26%	No	Granderson and Agonino (2006)

[a] Highly dependent on space occupancy and time delay

4.0.4 Current use of control strategies

For the control of use of lighting systems various lighting automation systems are available in the market. Manual and automatic lighting automation system are available which helps to control the use of lighting system. This system is more used in newly constructed buildings than the existing ones. According to the study for example, 61.8% of newly constructed commercial offices use some form of lighting automation, while this adoption rate is 57.5% for existing offices. Among the control schemes used for lighting automation, occupancy sensor technologies have been used for a long time and are used widely [8]. The occupancy sensor algorithm is shown in Figure 1.

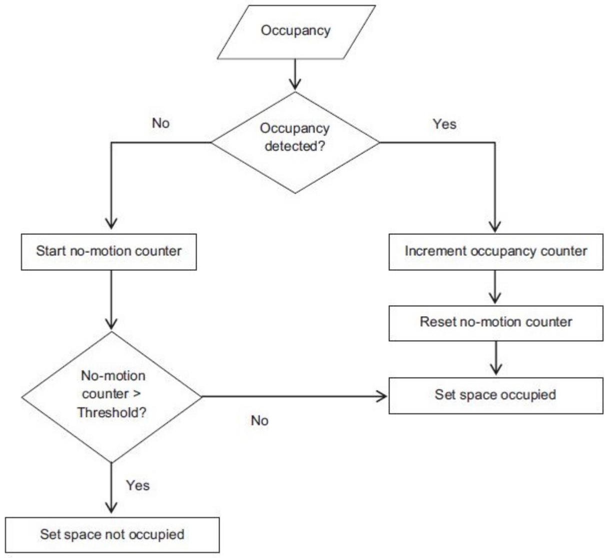

Figure 1: Occupancy sensor [8]

5. Case Study

Civil Mall which is located at Sundhara, Kathmandu, Nepal was taken as the case study for this research. It is rectangular in shape and has 9 floors and 2 basements. It covers 44213.47 sq.ft of the area. The housing is constructed in the reinforced concrete structure. The external wall in the façade is built with

Figure 2: Civil Mall

transparent glass and brick with cement mortar at some places. The internal partition walls are built with locally available brick with cement mortar. Walls are cement plastered on both sides. Big advertising boards are also placed at many places in the façade.

6. Data Set and Analysis

Total energy usage per month in the whole building = 80000 to 100000 units (Kw-hr)

Lights currently being used in the Civil Mall are:

1. PCL Compact Fluorescent Lamps of 18W
2. Tubular Fluorescent Lamps of 40W
3. LED lights of 5W
4. Power lights of 60W

6.1 Reducing lighting energy consumption

For reducing lighting energy consumption, analysis of the building was done. It was found that at some spaces of Civil Mall, unnecessary lightings have been used so by using retrofitting techniques for lighting systems those lightings can be removed or can be switched off. The current scenario is shown in the Figure 3.

Figure 3: Current scenario of lightings used in Civil Mall

By removing or switching off lights as shown in the Figure 4, lighting energy optimization can be done. There are many spaces in the in the Civil Mall where the use of unnecessary lights is high.

Figure 4: Lighting optimization

Total lighting energy saved by either removing or switching off unnecessary lights is calculated as:

12 nos. of PCL CFL lightings in each floor excluding the top two floors we have:
Total lighting energy saved per day = 12*18*7*10 = 15120 W
Total lighting energy saved per month = 15120*30 = 453.6 Kw-hr

6.1.1 Use of daylights

Even though there was sufficient daylighting, different lighting systems were used in the Civil Mall to light up space in many places. For example: Current scenario of lightings is shown in the Figure 5.

Figure 5: Current Scenario of lighting

Lightings that can be removed/switched off as those areas have sufficient daylights is shown in Figure 6.

Figure 6: Lighting optimization

Total lighting energy that can be saved by the use of natural daylights (upto the space that has sufficient light):
10 nos. of PCL CFLs of 18 W at around 9 spaces where the daylighting is sufficient including the opening at ground floor, first floor and second floor except the top four floors we have:
Total lighting energy saved per day = 10*18*9*10 = 16200 W
Total lighting energy saved per month = 16200*30 = 486 Kw-hr

6.1.2 Replacing CFL lamps with LED lamps

No. of CFL lights and fluorescent lamps used in corridors and staircases only in the Civil Mall = 75 Nos. of 18 W CFL and 6 Nos. of 60 W fluorescent lamps per storey.
No. of fluorescent lamps used in lower basement and upper basement = 160 of 60W power
Total operating times of these lamps = 10am - 8 pm for CFL lights i.e. 10hrs and 7am-11pm for fluorescent lamps i.e. 16hrs as they are used in the basements and the staircase. Two floors including lower ground floor and ground floor have already used LED lights but only in few numbers of around 80 altogether. And 3 floors in the top are using the space for office and Qfx movie theatre having 50 PCL CFLs of 18 W power altogether (excluding the movie theatre). Therefore calculation of total energy consumption per month by the lightings in existing scenario is as shown in the Table 4.

Around 7140 Units of electricity is consumed per month by just lighting system inside the building and that too only in corridors, staircase and basement.
Replacing PCL CFL lights and tubular fluorescent with LED lights as 10 W LED bulbs have similar output(lumens) to 18W CFL lamps [6]. The calculation is shown in the Table 5.
Hence the total optimization of power per month after replacing CFL, fluorescent and incandescent light with LED bulbs of similar output (lumen) = 7139.4 Kwhr -2778.6 Kwhr = 4360.8 Kwhr

Adding the power savings from the use of daylighting and reducing lighting energy consumption we have,
Total electrical energy saved per month = 4360.8 Kwhr+453.6 Kwhr+486 Kwhr=5300.4 Kwhr

Table 4: Calculation of total energy consumption in existing condition

Type of bulbs	Used in floors	No of bulbs	Power of bulbs (W)	Operating hrs (hrs)	Total Energy use (Whr)
PCL CFL bulbs	5	75	18	10	67500
PCL CFL bulbs	3	50 (In total)	18	10	9000
Tubular Fluorescent Lamps	8	9	40	16	46080
Tubular Fluorescent Lamps	2	80	40	16	102400
LED	2	40	5	10	4000
Power lights		15 (In total)	60	10	9000
Total Power					237980
Total power per month				237980*30=7139400	
Total Power in Kwhrs per month				7139.4Kwhr	

Table 5: Calculation of total energy consumption in improved condition

Type of bulbs	Used in floors	No of bulbs	Power of bulbs(W)	Operating hrs(hrs)	Total Energy use(Whr)
LED bulbs	5	75	10	10	37500
LED bulbs	3	50 (In total)	10	10	5000
LED bulbs	8	9	10	16	11520
LED bulbs	2	80	10	16	25600
LED bulbs	2	40	5	10	4000
Power lights		15(In total)	60	10	9000
Total Power					92620
Total power per month				92620*30=2778600	
Total Power in Kwhrs per month				2778.6 Kwhr	

For the calculation of payback period,
Per Unit Price of 10 W LEDs = Rs. 225
Total nos. of LED bulbs used = 5*75+50+72+160+80= 737
Total price of LED bulbs used = 737*225 = Rs. 165825
If the price per unit of the power is Rs 8 we have,
Total amount saved from the optimization of electrical energy = 4360.8*8 = Rs. 34886.4

From above calculations
Excluding the time value and salvage value we have,
Net Payback Period = Investment/benefits = 165825/34886.4 = 4.75 yrs

7. Findings

After calculation it was found that the total optimization of electrical energy per month after using different strategies for the retrofitting of the lighting systems is 5300 Kw-hr. After replacing CFL and fluorescent light with LEDs, total energy that can be optimized is found to be 4360.8 Kwhr. The replacement cost of LEDs without adding time value and salvage value is Rs. 165825. And it is paid within 4.75 yrs. Also by reducing lighting energy consumption and use of daylightings 939.6 Kwhr electrical energy can be saved. The comparison of retrofitting strategies used for lightings is given in Table 6. Similarly the decrement in electrical power consumption through the use of LED lights over CFL and fluorescent lamps is shown in graph in figure 7.

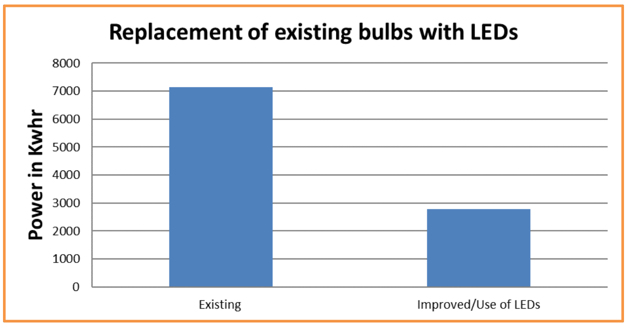

Figure 7: Lighting optimization

The pie chart shown in the figure 8 demonstrates the amount of energy that can be optimized through the use of different retrofitting strategies used for the lighting systems. Taking total of 100% lighting energy optimization, through the replacement of existing lights with LED lights 82% of lighting energy

Table 6: Comparison of retrofitting strategies used for lighting systems

Lighting energy optimization	Energy optimized per month (in Kwhrs)
Reducing lighting energy consumption	453.6
Use of daylighting	486
Replacement of existing lights with LED lights	4360.8

can be optimized and by reducing lighting energy consumption 9% of lighting energy can be optimized. Similarly, by the use of daylighting 9% of lighting energy can be optimized.

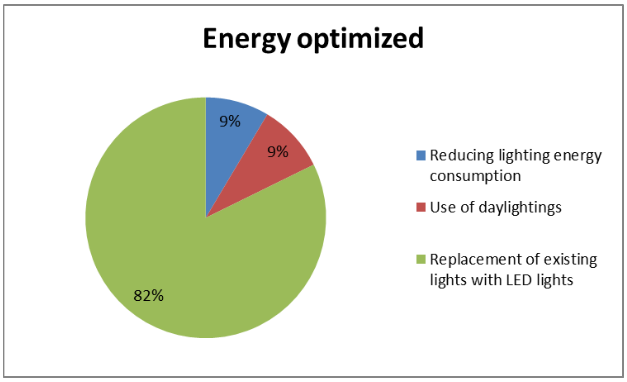

Figure 8: Lighting optimization

8. Conclusion

Energy retrofitting of the lighting system in the Civil Mall can be achieved through the replacement of CFLs and tubular fluorescent lamps with the LEDs, use of daylights and reducing lighting energy consumption. Huge amount of energy can be optimized through retrofitting the lighting systems. Use of different retrofit measures notably by just reducing lighting energy consumption and use of daylighting systems in the Civil Mall can save 939.6 Kwhr of lighting energy per month. The total optimization of electrical energy after replacing CFL, fluorescent and incandescent light with LEDs of similar output (lumen) was found to be 4360.8 Kwhr per month. Net Payback Period after replacing with LEDs without considering the salvage value and time value is found to be 4.75 years. Similarly, in commercial buildings maximum amount of lighting energy is consumed by the existing lights(Fluorescents and CFL).

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