Application of Energy Conservation Methods to Lighting System: Case Study

Mr. Tawfiq T. Al-saba
Saudi Aramco, Community maintenance department, Dhahran 31311, Saudi Arabia
E-mail: sabatt@aramco.com.sa

Abstract

The development of nations relies heavily on electrical energy. The proper use of the electrical energy avoids many problems from the utility side and costumer side. This paper presents an overview on energy saving applied to electrical lighting system load. It discusses the methods and the equipment that could be used for this regards. Also, it shows a case study and negotiates the obtained results through application of these methods. Finally, some recommendation points and conclusions will also be presented.

1. INTRODUCTION

The demand for electricity for lighting system is rapidly growing at a huge annual rate world wide, and it will be continuing to grow for the unforeseeable future, as economy and standard of living soar [1]. New commercial buildings, office buildings, and public facilities, will consume more and more electricity for lighting. As a result, lighting will consume a greater percentage of generated growing electricity demands over the coming years. Based on the studies, the demands for electricity capacity will necessitate the need to construct more electric power plants to meet this demand that require a massive new capital investment and results an environmental pollution issues that are produced from electricity production process [1-3]. Therefore, options to reduce growth in the demand for electricity must be a very high priority.

This paper presents an overview of equipment and methods used in improving lighting efficiency that results significantly in energy saving. Also, a case study that deals with using these methods for one of Aramco buildings will be discussed, and then it will be ended by some recommendations and a conclusion.

2. APPLICATION METHODS FOR LIGHTING CONSERVATION

This section deals with methods that aim to develop lighting systems and can help in saving energy. The ultimate goal is how to develop the efficiency of lighting system that is characterized by quality, economy, comfort, safety and reliability. The most effective method that can be applied in this regard, is replacing the existing lighting systems with the most cost-effective ones. Also, using electronic ballasts and their enhancement to the lighting system will be discussed. Applying control system with new communication technology and the effect of decorated interiors will be negotiated.

2.1 Replacements and relighting for high performance lights:

The modification of the existing lighting systems should be considered to provide energy conservation and financial savings. Several manufactures have produced new effective lamps that can be used to replace standard conventional incandescent electric base lamps under the consideration of initial and maintenance costs [4].

Before starting any relighting process, some information including the existing installation conditions have to be collected. However, the replacement can be made using one of the three ways. Replacing of higher wattage by a lower wattage, to obtain a saving in energy and cost of light, is the first way. Although this way will reduce energy consumption, it might lead to expense of reducing the luminance level. However, this is convenient in place where the existing illumination level is high. The second method is to keep the existing lumens through replacing the lamps with same wattage and with higher lumens which lead to minimizing the number of installed lamps. The third way is to install new lamps with same or different type as the existing lamp but with higher efficiency that attends to achieve energy savings [4].

The relighting process is perhaps the most attractive one, especially in situation of considering the conventional lighting system is already exist and needs only a replacement to higher efficient lamps. Such step does not require much of the added cost, as compared to the situation where a complete new system has to be installed, and the old one has to be discarded.

2.2 Applying Electronics Ballast

Ballast that can be found either in magnetic or electronic form is an important device for the operation of the entire fluorescent lighting system. It supplies the necessary voltage surge to develop an arc discharge to ionize the subjected gas material within the lamp. Also, it limits the current flow through the lamp and acts as a protective device to prevent the destruction of the lamp. However, it must be carefully selected to match the needs of the space to achieve optimal performance from a lighting system [5-6].

Electronic ballasts are significantly energy efficient device comparing to the magnetic ballasts. This is due to the results of several factors, including lower internal losses and higher operating frequencies. Also, it eliminates magnetic losses completely in which it leads to reduce ballast energy requirements. It operates at higher frequencies ranging from 20 to 60 kHz that results in the generation of 10 to 15 percent more light for the same energy use. Moreover, Operating at a higher frequency eliminates one of the most common complaints associated with fluorescent lamp which is the flicker. This is due to the higher operating frequency making it impossible for the eye to detect switching between on and off during arc application. It is available in two basic types: rapid-start and instant-start. Selection of the ballast type is usually made based on the application and leads to impacts overall energy use due to the differences in the operation. [5-6].

Ballast factor is one of the most important items when selecting lighting system components. It is dependent on both the ballast selected and the lamp installed. The higher ballast factor leads to higher light output of the lamps, while the lower ballast factor the lower the light output of the lamp which leads to lower energy use of the system. The electronic ballasts are available in a wide range of ballast factors from as low as 0.73 to as high as 1.2 while the magnetic ballast is available in a narrow range which is between 0.925 and 0.975. [5-6].

Dimming with conventional magnetic ballasts was an option but it was not cost effective in most applications. Most of magnetic ballast dimmer could not reduce light output much below 50 percent of full brightness and it tended to increase the problems associated with lamp flicker. However, electronic ballasts have eliminated the dimming problems in which the dimming process becomes inexpensive, practical, efficient and affordable way to control the output light to as low as 5 percent of full brightness. In addition to the dimming feature, it has the capability to adjust the light output as the amount of natural light varies through the application of automatic sensing [5-6].

The only problem with the electronic ballast is the power factor due to causing reductions in overall power factor by distorting the current wave shape. Correcting this distortion is difficult and expensive, but, this problem could not have an effect due to the existence of ballast that limits this type of distortion which helps to avoid problems of low power factor and the problems with other equipment [6-7].

2.3 Applying Control System & New Communication Technology

Automatic control system is another way that could conserve the energy required for lighting system by turning off or lowering lights brightness level when they are not needed, or not being utilized. It may consist of highly efficient continuous-dimming and light intensity sensors and controllers that control the automatic dimmer function. It could be microprocessor-based that provide fully automatic operation of lighting systems. Also, it may have a sensor that measures the brightness through continuous-dimmer function to eliminate excessive illumination that results from sunlight or due to the existence of extra lighting sources. Moreover, timers that switch the brightness of lights to certain level or to off for a certain period of time and space occupancy sensors that lower lights when the space is not in use are other forms of the control system. [8-9]

On the other hand, based on the fact that most of the modern buildings apply advanced automated lighting control systems, many manufactures are working on gateways that allow limited interoperability between their proprietary systems to open the protocol of those control networks. Those protocols signals could be carried either by normal low voltage wiring medium or by other communication media, including spread spectrum power line carrier (PLC), radio frequency (RF) and infrared (IR). Moreover, routers that extend the control system network over a transfer control protocol over the internet protocol network (TCP/IP) such as a corporate Intranet or the global Internet are being utilized especially for digital micro-processor base control system. This leads to have full efficiency of the lighting system or any electrical load by offering enhanced features in addition to cost reduction results from its application for power conservation to the load system. Also, it offers the flexibility by setting up the timing schedule to control or modify the schedule at any remote site and in any time of the day. [10]

2.4 Applying Light Reflecting Finishes in the Decorated Interiors

The colors of the walls and surfaces have a major effect in the design of the lighting system; this is due to the fact that the light surfaces reflect more light than dark ones. This means that lighter colors on the surfaces will increase the reflectance of lights compared to the dark colors because of the amount of light arriving on the work plane depending on the lights reflected from the space surfaces. This leads to say that the illumination level will increase at light colored surfaces.

As shown in the below equation, the mathematical representation shows the required number of lamps which are actually a function of the coefficient of the utilization. This coefficient describes the percentage of the light produced by the lamps that arrives on the work plane. Also, it depends on work plane reflectance values specified for space cavity ratio. However, as in the equation, lamps lumens depreciation factor depends on the selected lamps and ballast, likewise, lumen dirt depreciation depends on environment, cleaning schedule and the type of the illumination. Both factors values depend on the manufacturers setting values under the condition specified in catalog which leads to assume both factors as constant values. In addition, the illumination per lamps is constant values depending on selected lamp and ballast. Clearly stated, the coefficient of utilization is an important aspect in the energy efficient installation that can affect power conservation. [11]

$$N = \frac{Dc \times A}{CU \times LLD \times LDD} \qquad (1)$$

Where Dc is recommended illumination level, ***N*** is number of lighting fixture, ***A*** is the area to illuminated, ***CU*** is the coefficient of utilization, ***LLD*** is the lamps lumens depreciation, ***LDD is*** lumen dirt depreciation

3. CASE STUDY

In this section we are going to discus the cost effect through utilizing all methods explained in the last section for one of Saudi Aramco office buildings.

3.1 Situation before the Upgrade

This office building is a high rise, with eleven stories. It contains a very huge load of lighting system. Table 1 shows that this building has eleven types of lighting fixtures with more than 18,000 fluorescent lamps using magnetic ballast. As shown in table 2, the power required for the lamps is 787.5KW while the magnetic ballast requires 38.3KW. This is because the magnetic ballast requires two to three watts to heat the starter coil. The total power of lighting system for this building is 825.84 KW. The annual energy bill for the 8-hours shift is $ 55,814 yearly. Moreover, as shown in table 3, the building requires $111,628 yearly when is used for two shifts operation, while it costs $167.424 yearly for three shifts operations. These costs were calculated under the assumption of five working days per week and the rate of the kWh is considered as $ 0.032, as per the price of Saudi Electric Company for the industrial and commercial loads.

Table 1,
Existing fluorescent lighting fixtures component replace existing fixtures

TYPE OF LTG. FIXTURES (NOM. SIZE)	RECESSED GRID (24" X 24")	RECESSED GRID (24" X 48")	RECESSED GRID (24" X 48")	RECESSED GRID (24" X 48")	PENDANT IND.FIXT. OPEN REFLECTOR (12" X 48")	WRAP AROUND PENDANT (8" X 48")	PENDANT IND.FIXT. FIXT. (LOUVER DOOR) (24" X 48")	PENDANT MOUNTED LTG. FIXT. (48" X 48")	COVE SINGLE FLUOR. GEN. PURP. STRIP FIXT. (3" X 48")	HANDRAIL SINGLE FLUOR. FIXT. OPEN STRIP (3" X 24")	SINGLE FLUOR. PENDANT MTD. (6" X 48")
BALLAST TYPE (QTY)	T-12 MAGNETIC (1)	T-12 MAGNETIC (1)	T-12 MAGNETIC (2)	T-12 MAGNETIC (2)	T-12 MAGNETIC (1)	T-12 MAGNETIC (1)	T-12 MAGNETIC (2)	T-12 MAGNETIC (4)	T-12 MAGNETIC (1)	T-12 MAGNETIC (1)	T-12 MAGNETIC (1)
LAMP TYPE (QTY)	F40 T12 U (2)	F40 T12 (2)	F40 T12 (3)	F40 T12 (4)	F40 T12 (2)	F40 T12 (2)	F40 T12 (4)	F40 T12 (8)	F40 T12 (1)	F20 T12 (1)	F40 T12 (1)
WATTAGE/VOLTAGE	40W/277V	40W/277V	40W/277V	40W/277V	40W/277V	40W/277V	40W/277V	40W/277V	40W/277V	20W/277V	40W/277V
LOCATION	NUMBER OF FLUORESCENT LIGHTING FIXTURES AFFECTED										
1st Floor	71		464		1	6			36	28	12
2nd Floor	16	1	479	4	6	6			36		12
3rd Floor		20	600	4	9	6	3	8	17		
4th Floor		20	619	4	6	6	6	8	17		
5th Floor		20	597	4	6	6	6	8	17		
6th Floor		19	597	4	6	6	6	8	17		
7th Floor		20	606	4	6	6	6	8	17		
8th Floor		20	594	4	6	6	6	8	17		
9th Floor		20	594	4	6	6	6	8	17		
10th Floor		20	621	4	6	6	6	8	17		
BASEMENT			148		20	13	27		15		
Total	**87**	**160**	**5919**	**36**	**78**	**73**	**72**	**64**	**227**	**28**	**24**

Table 2,
Details of the power analysis for the existing situation

FLOOR	Total number of ballast	Power losses in the Magnetic Ballast (Watt)	Total number of the lamp	Total wattage required for the lamps (KW)	Total required power for the ballast & the lamp
1st Floor	1082	3246	1624	64.96	68.20
2nd Floor	1043	3129	1551	62.04	65.14
3rd Floor	1298	3894	1963	78.52	82.32
4th Floor	1339	4017	2034	81.36	85.37
5th Floor	1194	3582	1968	78.82	82.40
6th Floor	1192	3576	1963	78.52	82.10
7th Floor	1313	3939	1995	79.80	83.74
8th Floor	1289	3867	1959	78.36	82.23
9th Floor	1289	3867	1959	78.36	82.23
10th Floor	1343	4029	2040	81.60	85.63
BASEMENT	398	1134	633	25.32	26.45
Total	12760	38280	19689	787.56	825.84

Table 3,
Details of the energy's cost analysis for the existing situation

Total energy cost required for one year in case of one shift operation ($)	Total energy cost required for one year in case of two shift operation ($)	Total energy cost required for one year in case of three shift operation ($)
55,814	111,628	167,424

table-4,
proposed fluorescent lighting fixtures component replace existing fixtures

TYPE OF LTG. FIXTURES (NOM. SIZE)	RECESSED GRID (24" X 24")	RECESSED GRID (24" X 48")	RECESSED GRID (24" X 48")	RECESSED GRID (24" X 48")	PENDANT IND.FIXT. OPEN REFLECT OR (12" X48")	WRAP AROUND PENDANT (8" X 48")	PENDANT IND.FIXT. FIXT. (LOUVER DOOR) (24" X 48")	PENDANT MOUNTED LTG. FIXT. (48" X 48")	COVE SINGLE FLUOR. GEN. PURP. STRIP FIXT. (3" X 48")	HANDRAIL SINGLE FLUOR. OPEN STRIP LIGHT (3" X 24")	SINGLE FLUOR. PENDANT MTD (6" X 48")
NEW BALLAST TYPE (QUANTITY)	SEE NOTE 2 (1)	SEE NOTE 2 (1)	SEE NOTE 1 (1)	SEE NOTE 1 (1)	SEE NOTE 1 (1)	SEE NOTE 2 (1)	SEE NOTE 1 (1)	SEE NOTE 3 (2)	SEE NOTE 2 (1)	SEE NOTE 2 (1)	SEE NOTE 2 (1)
NEW LAMP TYPE (QUANTITY)	F32T8/SPX 30/U/6 (2)	F32T8/XL/ SPX30 (2)	F32T8/XL/ SPX30 (3)	F32T8/XL/ SPX30 (4)	F32T8/XL/ SPX30 (2)	F32T8/XL/ SPX30 (2)	F32T8/XL/ SPX30 (4)	F32T8/XL/ SPX30 (8)	F32T8/XL/SPX 30 (1)	F17T8/SPX30 (1)	F32T8/XL/ SPX30 (1)
WATTAGE/VOLT AGE	32W/120-277V	32W/120-277V	32W/120-277V	32W/120-277V	32W/120-277V	32W/120-277V	32W/120-277V	32W/120-277V	32W/277V	17W/120-277V	32W/120-277V
LOCATION	NUMBER OF FLUORESCENT LIGHTING FIXTURES AFFECTED										
1st Floor	71		464		1	6			36	28	12
2nd Floor	16	1	479	4	6	6			36		12
3rd Floor		20	600	4	9	6	3	8	17		
4th Floor		20	619	4	6	6	6	8	17		
5th Floor		20	597	4	6	6	6	8	17		
6th Floor		19	597	4	6	6	6	8	17		
7th Floor		20	606	4	6	6	6	8	17		
8th Floor		20	594	4	6	6	6	8	17		
9th Floor		20	594	4	6	6	6	8	17		
10th Floor		20	621	4	6	6	6	8	17		
BASEMENT			148		20	13	27		15		
Total	87	160	5919	36	78	73	72	64	227	28	24

1. For 4 or 3 linear lamps, use single ballast, model # es-4/3-t8-32/25/17-unv-b (4804).
2. For 2 or 1 linear lamps and 2-u shaped lamps, use single ballast, model # es-2/1-t8-32/25/17-unv-b (4800).
3. For 8 linear lamps, use two ballasts, model # es-4/3-t8-32/25/17-unv-b (4804).

3.2 Proposed Design Applications

The study for the new proposal is performed under the same conditions of the existing assumption for the usage of the building and for the rate of kWh. The concern is to minimize this annual operating cost considering all design lighting system constraints. In order to achieve that, two proposals can be implemented. The first one is to do a complete demolition of all the fixtures with associated accessories and cables, and perform new installations for different types of fixtures with a new distribution including all required wiring and fittings. This way will cost more than $750,000, which means that payback period along with the maintenance cost is going to be very long time and no cost benefits in the energy conservation.

The second choice is to clean the existing fixtures, to keep the existing infrastructure as is and to change all the lamp tubes to a lower wattage rate with same or more luminaries. In addition, all the magnetic ballasts would be changed to electronic type with a dimming feature. Also, a control system with occupancy and lights sensors along with timer feature would be installed. Hence the new ballast has the dimming features; utilization of the solar illumination is possible and applicable to reduce the unnecessary energy. Moreover, to improve the utilization coefficient of the lamps, all the walls, ceiling and carpet, should be very bright colors to increase the level of the light reflectance. Table 4 shows the details of the proposed scheme.

3.3 Results Discussion

Fluorescent lamps of 32W rating are used instead of the 40W units. The required power for the light operation will be reduced by 20%. The associated power required for starter coil will be ignored in case of applying the electronic ballast. Although, the ballast will contribute in the conservation with less than 5% of the total lighting power, but it has some other features and functions which make it more flexible to enhance the performance of the lighting system [5]. As shown in table 5, power required will be minimized from 825.8 KW to 630KW.

The timer effect is less, when compared to the other factors. The installation price of the timer is included in the control system, which means no requirement for additional cost. The effect of the scheduling the power will be during lunch or break hours, and it might be used to turn the light off in some portion that would not be in utilization at certain period of time. On the other hand, operation principle of occupancy sensor depends on the movement of the occupant. The overall effect of both factors would lead to minimize about 10 % of the used power. By applying equation 2, this percentage was calculated based on all the area affected, and 60 % of the lights would be switched off for three hours daily during the break time. That results 7.5% while the other percentage (2.5%) came from the occupancy sensors, due to the expected usage of the working area, and due to the employee movements.

Moreover, the affected area by the solar illumination is only 40% of the total building area, due to location of the affected offices around edges. The minimum effect of the sun lights for illumination during the mid day (peak time) is 65% for five hours while, during other seven hours of the day time, the sun light could minimize about 40% of the required power. This imply, through applying equation 2, to say that for the period of 24hours daily the overall effect of the solar light is almost 10.0%.

$$PE = \frac{A_k}{A_t} \times \frac{\sum H_{op} \times P_l}{H_t} \qquad (2)$$

Where ***PE*** is overall percentage affected, A_k is affected area, A_t is total area, H_{op} is number of operational hours, P_l is percentage of effected illumination, H_t is total working hours

In addition, as explained in section 2.5 that the number of lamps is function of utilization coefficient which is depending on the reflectance factor for the existing surfaces. So, if the value of this coefficient is high as per equation 1 this leads to lower the number of the required lamps for a desired certain level of the illumination. However, based on the values of the used cavity and the reflectance values which is 30%, the value of CU in the building is 0.712 (as per the table in [13-14]) but by painting the wall to a lighter color, the reflectance values would go to 60% in which the utilization coefficient will increase to 0.768. This leads to conserve about 7% of power required to keep the level of the illumination [13-14].

Replacing the lighting system to higher performance, which leads to consume less power, is always recommended. The results obtained in tables 4, 5 and 6 show that the upgrading process is not always applicable and cost effective if the payback period constraint is considered. For example, this case study shows that if this building is used for two shifts or three shifts, then the upgrade will be beneficial in term of cost and power aspects. This is because the payback period is in acceptable ranges which are 5.7 and 3.8 years respectively. However, this upgrade will not be cost effective in case of utilizing this building for one shift. This is because the payback period is very long that is more than eleven years.

Table 5
Proposed Details of the energy and cost analysis for the proposed situation

FLOOR	Total number of the lamp	Total required power for the ballast & the lamp before the replacement (KW)	Saved power wattage from the new lamps (*1) (KW)	Saved power wattage from the applying the electronics ballast (KW)	Saved power through the application of control system (*2) (KW)	Saved power through the application of the dimming and the daylight principle (*3) (KW)	Saved power through the application of reflecting finishes(*4) (KW)	Total saved power for the lighting system (KW)
1st Floor	1624	68.20	13.00	3.20	5.196	7.794	3.637	32.80
2nd Floor	1551	65.14	12.40	3.10	4.963	7.444	3.472	31.33
3rd Floor	1963	82.32	15.70	3.90	6.282	9.423	4.396	39.60
4th Floor	2034	85.37	16.27	4.00	6.509	9.763	4.556	41.06
5th Floor	1968	82.40	15.76	3.60	6.306	9.459	4.414	39.63
6th Floor	1963	82.10	15.70	3.60	6.282	9.423	4.397	39.49
7th Floor	1995	83.74	15.96	3.93	6.384	9.576	4.468	40.28
8th Floor	1959	82.23	15.67	3.86	6.269	9.403	4.388	39.55
9th Floor	1959	82.23	15.67	3.86	6.269	9.403	4.388	39.55
10th Floor	2040	85.63	16.32	4.03	6.528	9.792	4.569	41.20
BASEMENT	633	26.45	5.06	1.10	2.025	3.037	1.417	12.72
Total	19689	825.84	157.40	38.18	63.005	94.507	44.135	397.21

1. New lamps have the same illumination with lower power wattage.
2. The application of control system including timer operation and occupancy operation which expected to save of 10% of the light power
3. The application of dimming the lights with using the solar illumination expected to save about 12.5% of the light power.
4. The application of bright reflecting surfaces will not affect in this utility more than 7% of saved power.

Table 6,
Break down cost for the upgrade

Items	Cost ($)
Lamps	40,016
Ballast with Dimming Feature	232,350
Control System and accessories	25,000
Repaint some portion	2,100
Contingency	9000
Total	**308,466**

Table 7
Cost analysis with the payback period

In case of operational shift	Total saved cost per year ($)	Repay back period (years)
One	**26,864.65**	**11.50**
Two	**53,729.30**	**5.74**
Three	**80,593.90**	**3.82**

4 CONCLUSION

An overview on energy saving for lighting system through different methods was presented. Also, a case study for one of Aramco building was discussed which proved that it is possible to reduce the energy required for the lighting system through applying those methods. It appears from the results that modifying or upgrading the lighting system, when considering the constraints of the payback period, might not be cost effective for the power conservation, while it is recommended for some other situations. However, for any new construction, the selection of the lighting system components has to fit all requirements in term of design and power conservation issues.

There are some other recommendations that might help on power reservation for the lighting system. First, improvements of policies, standards and codes for efficient lighting systems have to be achieved. This leads to an efficient way to establish a healthy market for products that are characterized by good lighting quality. Secondly, quality certification procedure has to be developed to upgrade the quality of lighting products. This implies to perform quality assurance measures for efficient lighting products, and to monitor institutes and manufacturers to undertake certification activities. The third recommendation is to establish international exchange meetings for advanced technology, and experience that help in this regards. This can be achieved by providing technical supports to manufactures that rely on high-technology capacity. [12]

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