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A CASE STUDY

Energy auditing of chemical industry and scope for renewable energy

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ABSTRACT

Chemical industry is one of the oldest industries in India. Indian chemical sector has grown a long way since its early days of independence. The chemical industry forms the backbone of the industrial and agricultural development in India and also provides building blocks for downstream industries. This industry is a significant contributor to India's national economic growth. To know the extent of energy being wasted it is essential to know the amount of energy being consumed. Energy audit is an inspection, survey and analysis of energy flows for energy conservation to reduce the amount of energy input into the system without negatively affecting the output. The energy audit is the key for decision-making in the area of energy management. This paper presents, electrical energy auditing carried out in production plant of (PIL) chemical industry, in which lighting system was tested according to BEE standards. The annual energy wastage through lighting system was 528.24 kWh and found 600 kWh annual energy saving opportunities by replacing high power rating lamps. It was suggested that 2 kW capacity solar photovoltaic (SPV) system is capable for running indoor lighting system. Payback period of the SPV system comes 44 months compare to conventional electricity.

KEY WORDS : Energy audit, Chemical Industry, Renewable energy, Lighting system

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INTRODUCTION

India is projected to sustain the world's second-highest rate of gross domestic product (GDP) growth, averaging 5.6 per cent per year from 2006 to 2030 (Annual report, 2007 and GOI, 2006 and 2010). This translates into a 2.3 per cent average annual increase in delivered energy to the industrial sector Maricar and Othman, 2013. India's economic growth over the next 25 years is expected to derive more from light manufacturing and services than from heavy industry, so that the industrial share of total energy consumption falls from 72 per cent in 2006 to 64 percent in 2030. The changes are accompanied by shifts in India's industrial fuel mix, with electricity use growing more rapidly than coal use in the industrial sector. The Indian chemical industry was the 5th largest in the world, and 2nd largest in Asia, after China. The volume of major chemicals produced in India amounted to 8.3 million metric tons (MMT) in 2011-12. The energy conservation and utilization of renewable sources are essential factor to full fill energy demand. Renewable energy and nuclear power are the world's fastest-growing energy sources, each increasing by 2.5 per cent per year. Among the various sectors contributing to greenhouse gas (GHG) emissions, the contribution of the industrial sector was significant. Thus, mitigating GHG emissions from the industrial sector offers the best means of reducing overall GHG emissions. Therefore, energy conservation means less reliance on energy imports and, thus, less GHG emissions (Chaudhary *et al*., 2012). It can be achieved either by reducing total energy use or by increasing the production rate per unit of energy used. On the other hand, improving energy efficiency is the key to reducing GHG emissions (Export-Import Bank of India, 2013).

Energy audit is an inspection, survey and analysis of energy flows for energy conservation to reduce the amount of energy input into the system without negatively affecting the output. The energy audit is the key for decision-making in the area of energy management. It helps any organization to analyze its energy use and discover areas where energy use can be reduced and waste can occur, plan and practice feasible energy conservation methods that will enhance their energy efficiency (Abdelaziz *et al.*, 2011). The primary objective of energy auditing in chemical industry is to determine ways to reduce energy consumption per unit of product output or to lower its operating costs. The present scenario of energy demand in chemical industries is the indication of energy conservation and optimum utilization of renewable sources of energy (BEE).

This work was carried out in production plant of Phosphate India Pvt. Ltd., Udaipur. Study had been determined wastage of electricity and evaluated diversity ratio in lighting system of plant also given energy saving opportunities and suggestions for the application of renewable energy (Chakarborty *et al.*,2008; Demirbas, 2005; Maheshwaran and Jembu, 2012 and Umesha and Miste, 2013). It will create awareness among the industrial energy users to reduce the motor energy uses along with environmental pollution reduction. Energy auditing of chemical industry and scope for renewable energy- A case study has performed with following objectives :

Objectives :

– To study of lighting system in production plant of chemical industry.

– To identify energy saving opportunities and suggest possible application of renewable energy.

EXPERIMENTAL PROCEDURE

The methods given in BEE lighting code 2006 for evaluating energy efficiency of lighting systems with respect to the illuminance available at task areas and non-task areas and recommend illuminance levels suitable for various activities with guidelines for identifying energy saving options in lighting. Efficiency evaluation of lighting system defined and described in this code includes the measurement of following parameters:

– Illuminance levels

– Power consumption in light fittings

– Building parameters like area, room index etc.

Definitions and description with procedure :

Lux :

Lux is the metric unit of measure for illuminance of a surface. Average maintained illuminance is the average of lux levels measured at various points in a defined area. One lux is equal to one lumen per square meter. Lux is measured by lux meter.

Lux meters corrected for V-lambda should be used for measurement of illuminance. The accuracy of 5 % and suitable range up to 10000 lux should be used. The following (Table A) correction factor is used on the measured value of lux.

Table A : Correction factors for lux meterorrection factor

Light source	Correction factor
Mercury lamp	× 1.14
Fluorescent lamp	× 1.08
Sodium lamp	× 1.22
Daylight	× 1.00

Determination of illuminance measurement points :

Room index:

This is a ratio, which relates the plan dimensions of the whole room to the height between the working plane and the plane of the fittings :

$$\textbf{Room index (RI)} = \frac{(\mathbf{L \times W})}{\mathbf{Hm(L \times W)}} \qquad (1)$$

where,

L = Length

W = Width

Hm = Height of the luminaires above the plane of measurement

Based on the room index, the minimum number of illuminance measurement points is decided as per the following Table B.

Table B : Number of points for measuring illuminance

Room Index	Minimum number of measurement point	
	For ± 5 (%) accuracy	For ± 10 (%) accuracy
RI < 1	8	4
1 < RI < 2	18	9
2 < RI < 3	32	16
RI > 3	50	25

Installed load efficacy :

This is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior expressed in lux/W/m². It is required to calculate installed power density and target load efficacy.

Installed Load Efficacy, ILE :

$$\mathbf{ILE = \frac{Average\ luminous\ flux\ on\ the\ surface}{Circuit\ watts}, Im/Wm^2}$$

where,

Average luminous flux on the surface = Eav × (L × W)

Eav = Average illuminance

Multiply average illuminance(Eav) with the area to get total luminous flux (lumens) incident on the measurement plane. Calculation of the average value of measured illuminance at all points. If E1, E2,…, En are illuminance measurements at points1,2,….,n and correction factor was taken from Table A.

$$\mathbf{Eav = \frac{E_1 + E_2 + ...+ E_n}{n} \times correction\,factor}$$

Installed power density :

The installed power density per 100 lux is the power needed per square metre of floor area to achieve 100 lux of average maintained illuminance on a horizontal working plane with general lighting of an interior. It is expressed in watts per square metre per 100 lux (W/m²/100 lux) :

$$\mathbf{Installed\ power\ density\ (W/m^2\,100\ lux) = \frac{100}{Installed\ power\ efficacy\ [(lux/W)/m^2]}}$$

Color rendering index (CRI) :

CRI is a measure of the effect of light on the perceived color of objects. A low CRI indicates that some colors may appear unnatural when illuminated by the lamp. It helps to decide target load efficacy.

Estimation of target load efficacy :

Target load efficacy (TLE):

The value of installed load efficacy considered being achievable under best efficiency, expressed in lux/W/m². The values of target load efficacy, TLE is given in Table C for different types of applications. Room index values from the estimated room index and corresponding TLE value taken for the type of installation.

The principal difference between the targets for commercial and industrial Ra: 40-85 (Cols.2 and 3) of Table C. is the provision for a slightly lower maintenance factor for the latter. The targets for very clean industrial applications, with Ra: of 40 -85 are as column 2.

Installed load efficacy ratio (ILER) :

Installed load efficacy ratio :

This is the ratio of Target Load efficacy and Installed load efficacy :

Table C : Recommended TLE values target lux/W/m² (W/m²/100lux)			
Room Index	Commercial lighting (Offices, Retail Stores etc.) & very clean industrial application. Standard or good colour rendering Ra: 40-85	Industrial lighting (Manufacturing areas, Workshop, warehousing etc.). standard or good colour rendering Ra:40-85	Industrial lighting installations where standard or good colour rendering is not essential but some colour discrimination is required. Ra: 20-40
5	53 (1.89)	49 (2.04)	67 (1.49)
4	52 (1.92)	48 (2.08)	66 (1.52)
3	50 (2.00)	46 (2.17)	65 (1.54)
2.5	48 (2.08)	44 (2.27)	64 (1.56)
2	46 (2.17)	42 (2.38)	61 (1.64)
1.5	43 (2.33)	39 (2.56)	58 (1.72)
1.25	40 (2.50)	36 (2.78)	55 (1.82)
1	36 (2.78)	33 (3.03)	52 (1.92)

Ra: Colour rendering index, source: Bureau of energy efficiency(2006).

$$\mathbf{ILER} = \frac{\dfrac{\mathbf{Actual}\,\dfrac{\mathbf{lux}}{\mathbf{W}}}{\mathbf{m^2}}}{\dfrac{\mathbf{Target}\,\dfrac{\mathbf{lux}}{\mathbf{W}}}{\mathbf{m^2}}} \qquad (2)$$

Following procedure was used to determine ILER (Table D.)

Table D : Calculation of the Installed Load Efficacy (ILE) and Installed Load Efficacy Ratio (ILER) of a general lighting system		
Step 1	Measure the floor area of the interior:	Area = ---------- m²
Step 2	Calculate the Room Index (Eq.3.1)	RI = ----------------
Step 3*	Determine the total circuit watts of the installation	Total circuit watts = --
Step 4	Calculate Watts per square metre, Value of step 3 ÷ value of step 1	W/m² = ---------
Step 5	Ascertain the average maintained illuminance by using lux meter, Eav. Maintained	Eav.maint. = --------
Step 6	Divide 5 by 4 to calculate lux per watt per square Metre	Lux/W/m² = ---------
Step 7	Obtain target Lux/W/m² lux for type of the type of interior/application and RI : (Table 2 and Eq.i)	Target Lux/W/m² =
Step 8	Calculate Installed Load Efficacy Ratio (6 ÷ 7).	ILER =

Source: Bureau of energy efficiency,
* This reading is obtained by totaling up the lamp wattages including the ballasts available in room.

Calculation of above table was performed in MS Excel for saving paper work.

The calculated ILER was compared with the information given in Table E. for assessment and also ILER is required for calculating average annual wastage of energy according to Eq iii.

Table E : Indicators of performance	
ILER	Assessment
0.75 or over	Satisfactory to good
0.51 – 0.74	Review suggested
0.51 or less	Urgent action required

Source: Bureau of energy efficiency

$$\mathbf{Annual\ energy\ wastage\ (in\ kWh) = 1.0 - ILER \times Total\ load\ (kW) \times annual\ operating\ hours\ (h)}$$

Having derived the ILER for an existing lighting installation, then the difference between the actual ILER and the best possible (1.0) could be used to estimate the energy wastage. For a existing installation.

Estimating task lighting effectiveness (diversity ratio) :

Estimation of task lighting effectiveness involves measurement of illuminance on task and nontask areas. The diversity ratio is the ratio of average illuminance on task area and average illuminance on non-task area and is expected to be 3:1 for effective task lighting for usual commercial areas. For fine reading applications requiring lumens more than 700 lux, this ratio can be 10:1. Chronological order of measurements and calculation of diversity ratio is as follows:

$$\text{The number of illuminance measurments points on task areas} = \frac{\text{Atask}}{\text{Atask} + \text{Anon task}} \times \text{Total number of illuiminance measurement points (as per Table B)}$$

– The calculation of effectiveness of task lighting is given for illuminance upto 300 lux, which is a good lighting level for usual commercial tasks, manufacturing areas etc. From the illuminance measurements as described in above section 2, estimate the average illuminance on task areas and average illuminance on no-task areas separately.

– If task area = A_{task} and non-task area = $A_{non\text{-}task}$

The number of illuminance measurements points on task areas:

It is recommended to take measurements at more number of points additionally to improve accuracy.

– Measure illuminance at task and non task areas

– Calculate the diversity ratio $E_{av\text{-}task}$: $E_{av\text{-}non\ task}$

$E_{av\text{-}task}$ = Average illuminance on task area

$E_{av\text{-}non\ task}$ = Average illuminance on non-task area

If diversity ratio = $E_{av\text{-}task}$: $E_{av\text{-}non\ task}$ = 3:1, the task lighting effectiveness can be considered to be satisfactory for general lighting purposes.

If high illuminance of the order of 700-1000-2000 lux is required for tasks, the diversity ratio can be 10:1. If the diversity ratio is less than 3:1, that is, if the non task area lighting is more than 33 per cent of task lighting, there is a need to review lighting scheme. However, it is noted that at least 20 lux should be available at non task areas. The measures to improve diversity ratio are as follow :

– Reducing mounting heights or providing task lights for task areas
– Switching off/relocating lamps in non- task areas

Instruments and methods of measurements :

To perform these tests, the required instruments are shown in Table F.

Table F : Typical instruments used for assessment of lighting system

Instrument	Type	Measurements
Measuring tape	Portable	Dimension of room
Lux meter	Portable	Light intensity

Environment impact assessment :

The emission rates of the direct and indirect GHGs obtained from the Indian thermal power plants in the year 2003–2004 are as shown in Table G.

Table G : Estimated emission of green house gas from Indian thermal power plants

GHG	Emission per unit (kWh) of electricity			
	CO_2	CO	SO_2	NO
Average value of GHG emission	1.13 kg	12.27 g	10.6 g	2.4 g

Source: Chakraborty (2008)

EXPERIMENTAL FINDINGS AND ANALYSIS

The trials and measurement had been taken according to section I and II. As per the Table F instruments were used and audited lighting system for finding the energy conservation opportunity and availability of luminance at task and non-task area. The detail analysis was done according to Table D and results which has been shown in Table 1.

The lighting system was tested by BEE code, luminance recorded at different point according to room index. The average luminance was used to calculate ILER simultaneously got diversity ratio by luminance at task and nontask location. The diversity ratio found less than 3 where as it should be 3:1 as per standards. Hence diversity ratio indicates the improper

Table 1 : Calculation of ILER of lighting system

Width in m	Length in m	Height in m	Step 8 ILER	Annual wastage in kWh	Diversity ratio
23	12	6	1.61	-454.36	1.73
23	23	5	1.36	-581.72	1.43
23	15	5	1.86	-641.31	2.67
20	12	6	1.89	-663.82	2.00
15	12	3	1.20	-300.00	3.33
		Average annual wastage		-528.24	

orientation or installation of lighting and ILER had shown wastage of luminance due to higher wattage halogen and mercury were used. Finally calculated average annual wastage of electrical energy was 528.24 kWh.

Energy saving in lighting system and application of renewable energy :

The average annual wastage of electricity found in lighting system was 528.24 kWh worth of Rs 5018 in production plant with lab of 1750 m^2 area. The observation evaluates wastage occur due to improper orientation of light and high power consuming halogen was used. To improve diversity ratio without wasting electricity, it is essential to reduce mounting height and increase number of halogen having low power ratings such as replace a 550 watt halogen light by two halogen having 250 watt power rating. Finally, out of 4 high power rating light saves 200 watt.

Having,

Daily operating hours =10

Annual working days = 300

Therefore, total energy saving per year = 200 ×10×300/1000 =600 kWh

Total worth saving per year = 600 ×8.5 = ‘5100

As per the Appendix-I total electricity consumption by lighting system was 1.8 kW included average annual wastage which can be reduced. Hence it is recommended that the complete lighting system can be run on 2 kW off-grid photovoltaic systems.

PV system impact assessment :

Annual grid connected load in kWh =1.8 × 10× 300 = 5400

Annual worth of connected load in ‘ = 5400 × 8.5

= 45900 (*i.e.* annual saving)

Now, find the installation cost of (2 kW) PV system = 2000 × 120 = ‘240000

[Note-Cost/watt of PV-system is equal to Rs 120 (Source- www.bijilibachao.com)].

MNRE provides 30 per cent subsidy on capital expenditure for rooftop PV system. (*i.e.* 30 % of ‘240000 = ‘72000).

Therefore,

Total installation cost of PV system with subsidy in ‘ = 168000 /-

So that,

$$\textbf{payback period} = \frac{\textbf{Total cost of istallation}}{\textbf{Annual saving}} = \frac{\textbf{168000}}{\textbf{459}} = \textbf{3.6 years} = \textbf{43 months 6 days (approx 44 months)}$$

Installed PV-system will work for 20 years.

Environmental impact assessment :

In Indian thermal power plant average green-house gas emission per kWh electricity production is given in Table G. Total GHG emission reduced per year from annual load 5400 kWh will be CO_2 = 6.1 Ton, CO = 66.26 kg, SO_2 = 57.24 kg, NO = 12.96 kg.

Conclusion :

The energy consumption was studied and analyzed annual energy use. Annual wastage of energy from lighting system was 528.24 kWh. Diversity ratio indicated improper orientation of lighting lamps *i.e.* Diversity ratio was found below 3. Energy can save by replacing 550 watt power rating halogen light by 250 watt with reducing mounting height could save 600 kWh annualy. Suggested to install 2 kW off-grid photovoltaic systems for running indoor lighting system of plant worth of ‘ 168000 could save ‘ 45900 annually compared with conventional electricity. *i.e.* approximate payback period 44 month.

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