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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Oluseyi, Peter Olabisi/Somefun, Tobiloba Emmanuel et. al. (2020). Evaluation of energy-efficiency in lighting systems for public buildings. In: International Journal of Energy Economics and Policy 10 (6), S. 435 - 439.
https://www.econjournals.com/index.php/ijeep/article/download/9905/5477.
doi:10.32479/ijeep.9905.

This Version is available at:
http://hdl.handle.net/11159/8050

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2020, 10(6), 435-439.

Evaluation of Energy-efficiency in Lighting Systems for Public Buildings

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Received: 08 May 2020 **Accepted:** 01 September 2020 **DOI:** https://doi.org/10.32479/ijeep.9905

ABSTRACT

Adoption of energy efficiency and conservation techniques in public buildings in Nigeria is significantly low due to the ignorance of its potential benefits. Consequently, this study presents the prospects of energy saving using different methods in a public building at a Nigerian University. A proposed remodelled students' residential hostel at the University of Lagos, Nigeria was chosen as a pilot study. This research utilized three energy efficient lighting technology alternatives namely; intelligent controlled Incandescent lamp (ICIL), compact fluorescent lamp (CFL), and intelligent controlled CFL (ICCFL) and compared with a base case of conventional incandescent lighting configuration. Energy consumption, at the proposed hostel is analysed and modelled. The effectiveness of each lighting technology alternative and base case in terms of cost is estimated using economic indices such as the net present value (NPV), savings to investment ratio (SIR) and the discounted payback period (DPP). Results show that the CFL lighting technology give 39% cost benefit as compared to ICCFL which gives 11% overall cost benefit. From the study, it is established that adoption of energy efficient lighting techniques save a significant amount of energy, operational cost, electricity bills and consequently reduce emission.

Keywords: Energy Saving, Net Present Value, Savings to Investment Ratio, Discounted Payback Period
JEL Classifications: C63, Q48

1. INTRODUCTION

Looking at the concept of energy conservation with a global view, it is an important topic for public to be aware of. This is because it reduces individual energy consumption and overall energy demand, which in turn can set at equilibrium the available energy supply and the increase in energy demand as well as population growth. Employing energy efficient strategy and conservation in buildings has a lot of potential benefits such as low tariff rate, reduction in CO2 emissions etc.

Energy conservation can be realised by employing innovation and technological interventions such as responsive controls. Control has seen tremendous growth in recent years, in both the number of users and the types of new services through intelligent devices (Passino, 2001). Intelligent control achieves automation via the emulation of human intelligence. It is a multifaceted technological system, which embraces several disciplines. It either seeks to replace analytical (manual) ways of doing things or it borrows ideas from human methodological approach to solve problems (Diesendorf and Diesendorf, 2007). It is also applicable to the solution of control problems such as intelligent control of electric power consumption.

Intelligent control of electric power consumption has proven to be a cost-effective strategy for buildings (Dobrev, 2016). Likewise, in this research work, it is employed to improve energy performance of public buildings without necessarily decreasing comfort.

Furthermore, energy improvement efficiency can be referred to as having more output with the same amount of energy use (Oluseyi et al., 2016). According to (Akinbulire et al., 2014; Oluseyi et al., 2016), general adoption of energy efficient technologies among industrial and commercial sectors will effectively reduce the amount of energy used by populace. While other studies (Bevington and Rosenfeld, 1990; Holdren, 1987; 1990; Hollander and Schneider, 1996; Hubbert, 1949; Kamal, 1997; Levine et al., 1995; Lin and Chang, 1996; Reddy and Parikh, 1997; Starr, 1995) consider the benefit of energy efficiency measure to the environment, by looking at significant reduction in greenhouse gas that can be achieved at both national and global scales.

Moreover, 30-40% of energy used is on lighting systems in commercial buildings (Swisher et al., 1994; Ullah, 1996; Yarnell, 1995). This is invariably equal to 33.33% of the total electricity bill of a building (Busch et al., 1993). Nevertheless, inefficient use of lighting systems does not diminish. However, there is a great possibility of enhancing energy efficiency of lighting systems worldwide (Mills and Piette, 1994). Several studies in the past show that energy efficient lighting technology is a promising platform to greatly minimise energy usage in industrial and commercial buildings (Busch et al., 1993; Mills and Piette, 1994; Min et al., 1997; Nilsson and Aronsson, 1993; Piette et al., 1995). A survey shows that 23% of energy savings is achievable through energy efficient lighting systems for 364 industrial companies in Australia (Di Stefano, 2000).

This research work considered a proposed Elkanemi Hall of University of Lagos as its case study (in which there are 76 rooms on the average with four students in each of the rooms), to implement intelligent control together with energy saving measure for efficient energy management in the proposed hostel. Combining the strength of energy saving measures with intelligent control brings to bear the potential of large-scale application of the proposed method.

2. MODEL DESCRIPTION

In this research, the possibility to save electricity by intelligently controlling lighting points' energy consumption, at the hostel, is estimated by modelling three different alternatives of energy efficient lighting technology. And from this model, cost effectiveness of each technology is estimated.

2.1. Lighting Survey

The lighting points for the proposed hostel is divided into five categories namely; room, stairs and corridor, reading room, kitchen, and surroundings. A survey of every lighting point within the proposed hostel is observed from the electrical drawing to establish the number of fittings and types required for each category. Table 1 shows the division of the proposed hostel lighting point category.

2.2. Evaluation of Electricity Consumption and Cost

The mathematical model for the evaluation of the amount of electricity consumed per year for each category is expressed in equation 1. Overall electricity cost is also evaluated from equation 1 for each alternative. The three alternatives are chosen because of uncomplicated installation approach as well as great possibility to save considerable amounts of energy.

Table 1: Division of the proposed hostel lighting points for energy savings

S/n	Category	Fitting
1	Room	Compact fluorescent
2	Stairs and Corridor	Compact fluorescent
3	Reading room	Compact fluorescent
4	Kitchen	Long fluorescent
5	Surroundings	Bulk head

$$AEC(kWh) = \frac{1}{1000}\left(\sum_{i=1}^{NR}(W*H)_{Ri}, + \sum_{i=1}^{NSC}(W*H)_{SCi} + \sum_{i=1}^{NRR}(W*H)_{RRi} + \sum_{i=1}^{NK}(W*H)_{ki} + \sum_{i=1}^{NS}(W*H)_{si}\right) \quad (1)$$

2.3. Economic Analysis

An economic analysis of the three-proposed energy efficient lighting technologies is carried out to determine the one with the highest cost effectiveness. In this analysis, the primary monetary expenditure is evaluated for each of the considered technologies in each category and for different approach. Likewise, cost of electricity as well as material and labour costs are all considered. The three economic analysis employed to verify the cost effectiveness of the lighting technology considered are; Net Present Value (NPV), Savings to Investment Ratio (SIR), and Discount Payment Period (DPP).

2.3.1. Net present value (NPV)

The NPV technique computes the present value of an investment certain years (n) into the future. NPV is known as a comprehensive method for jointly evaluating several investment opportunities with diverse primary investment amounts and different patterns of cash flow (Bowlin, 1990). The formula for calculating NPV is given in equation 2.

$$NPV = \sum_{i=1}^{n} \frac{S_t}{(1+d)^t} - I_o \quad (2)$$

It is assumed that the various savings in equation 2 are collected at the end of years. 8% is chosen as the discount rate "d." This is because it is within the range of returns from industrial and commercial organizations when it comes to investing in lighting systems for efficient energy usage (Wood, 2004). The discount rate "d" and NPV are inversely related meaning that increase in "d" causes decrease in NPV, assuming that other parameters are constant. Finally, it is worth mentioning that an investment would be possible, if NPV >0, But, when different investments are compared, investment with higher NPV will be considered.

2.3.2. Savings to investment ratio (SIR)

SIR is the time taken for a primary investment to be recovered. More so, the SIR is the ratio of an investment computed for future savings of the evaluation years to the future investment for the same period: this statement is expressed in equation 3.

$$SIR = \frac{\sum_{i=1}^{n} \frac{S_t}{(1+p)^t}}{\sum_{i=1}^{n} \frac{I_t}{(1+p)^t}} \quad (3)$$

2.3.3. Discount payback period (DPP)

This method ascertains the period of times that are required until an investor recuperate the primary outflow of an investment. This is achieved through expected savings. According to DPP, the present value of the expected net cash flows is computed based on the discount rate, and then set equal to the primary investment I_0. The expression in equation 4 depicts depreciated payback period.

$$DPP = \frac{-In(1-\frac{pI_o}{S_t})}{In(1+p)} \quad (4)$$

where it is assumed that the S_t remains constant for every year.

If the present value of inflows equals to the present value of outflows,

i.e. NPV = 0, then SIR = 1,

If the present value of inflows is greater than the present value of outflows,

i.e. NPV > 0 then SIR > 1

If the present value of inflows is greater than the present value of outflows,

i.e. NPV < 0, then SIR < 1.

When the observed investments are economically independent, then anyone investment with SIR >1 is attractive. Moreover, when several investments are considered, then the most attractive of them all is the one with the higher SIR.

3. RESULTS ANALYSIS

In order to ascertain cost effectiveness of implementing intelligent control as a constraint against energy mismanagement, lighting points of the proposed hostel are considered. These lighting points were divided into five categories for easy assessment of where energy savings is more pronounced. The cost benefit over a period of 10 years is determined.

Number of fittings and initial cost of implementation are presented in Tables 2 and 3 respectively. The information presented in these Tables 2 and 3 were obtained from the electrical drawing of the proposed hostel.

Of all the category fixtures considered, room takes the highest percentage which is obvious as shown in Figure 1. Hence, the room has the largest energy consumption and cost compare with other fixtures which can be confirmed from Table 4. In Table 4, proposed values of energy consumption and cost as against the category fixture for conventional incandescent bulb, energy saving bulb, conventional bulb with control and energy saving bulb with control can be obtained. It is obvious from the result that energy consumption and cost are minimal after implementation of intelligent control for both conventional and energy saving fittings. This statement is also true for the overall energy consumption and cost of the whole proposed building as presented in Figure 2.

Though, implementation of intelligent control reduces energy consumption and cost, it is not cost effective because it has the highest capital cost of implementation in the entire energy efficient categories. However, considering the savings in cost by the adopted methods, energy saving fixture gives the most cost-effective result among others, it is also obvious that employing intelligent control with energy saving fixture minimises energy consumption and cost compare with doing same for conventional. Moreover, both conventional and energy saving fixtures are preferable to intelligent control approach, this will be further justified in the next paragraph. But, a keen observation of savings in cost point out that instead of investing in intelligent control on the whole proposed hostel, it will rather be economical to implement it only on rooms, stairs and corridors and surroundings.

Table 2: Lighting points division survey.

S/n	Category	Number available	Number of lighting point	Total wattage
1	Room	76	608	15808W
2	Corridor and stairs	4	95	2470W
3	Kitchen	17	17	680W
4	Reading room	4	48	1248W
5	Surroundings	1	32	3200W

Figure 1: Lighting points survey

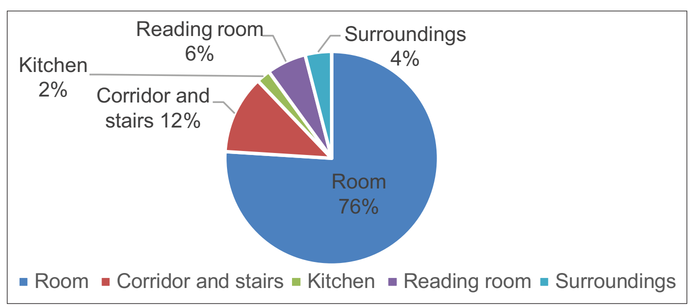


Figure 2: Proposed overall energy consumption and cost

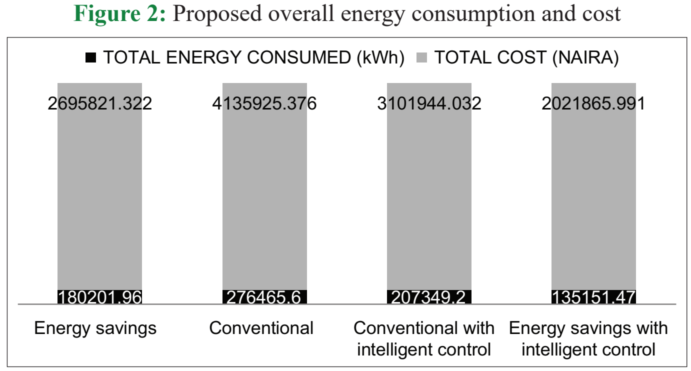


Table 3: Initial cost of installation

S/n	Category	Conventional	Energy savings	Intelligent control with conventional	Intelligent control with energy savings
1	Room	30400	273600	220400	463600
2	Stairs and Corridor	4750	42750	14750	52750
3	Kitchen	1190	10200	43690	52700
4	Reading Room	2400	21600	122400	141600
5	Surroundings	4800	32000	6000	33200
6	Overall	43540	380150	407240	743850

*If the hostel is always opened to the user (i.e. 24 h a day and 365 days a year). And that cost of electricity remains constant

Table 4: Energy consumed and cost by the considered energy saving measure

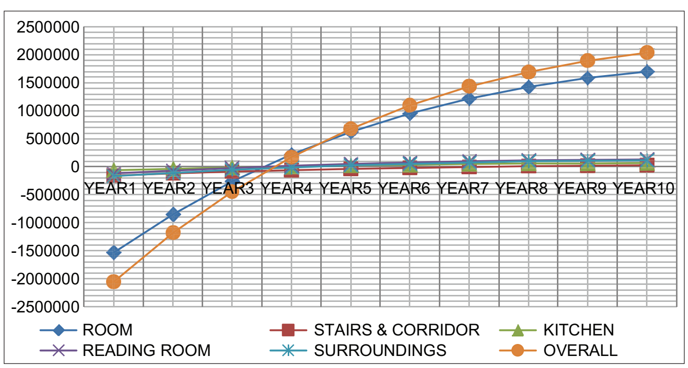
S/N	Category	Conventional		Energy savings		Intelligent control of conventional (assuming that light is ON for 75% in case of Room, Kitchen, and Reading room)		Intelligent control of energy savings (assuming that light is ON for 75% in case of Room, Kitchen and Reading room)	
		Energy Consumed (kWh)	COST (n)	Energy Consumed (kWh)	COST (n)	Energy Consumed (kWh)	COST (n)	Energy Consumed (kWh)	COST (n)
1	Room	213043.2	3187126.27	138478.08	2071632.08	159782.4	2390344.7	103858.56	1553724.06
2	Stairs and corridor	16644	248994.24	10818.6	161846.256	12483	186745.68	8113.95	121384.692
3	Kitchen	8935.2	133670.592	5956.8	89113.728	6701.4	100252.944	4467.6	66835.296
4	Reading room	16819.2	251615.232	10932.48	163549.901	12614.4	188711.424	8199.36	122662.426
5	Surroundings	21024	314519.04	14016	209679.36	15768	235889.28	10512	157259.52
6	Overall	276465.6	4135925.38	180201.96	2695821.32	207349.2	3101944.03	135151.47	2021865.99

Table 5: NPV for the considered energy saving measure

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
E.S	–2054218	–1183835	–448004	168433	679126	1096359	1431176	1693497	1892225	2035341
I.E.S	–2478443	–2233728	–2026844	–1853528	–1709943	–1592635	–1498499	–1424746	–1368872	–1328634
I.C	–2888553	–2359868	–1912911	–1538477	–1228273	–974838	–771465	–612127	–491416	–404484

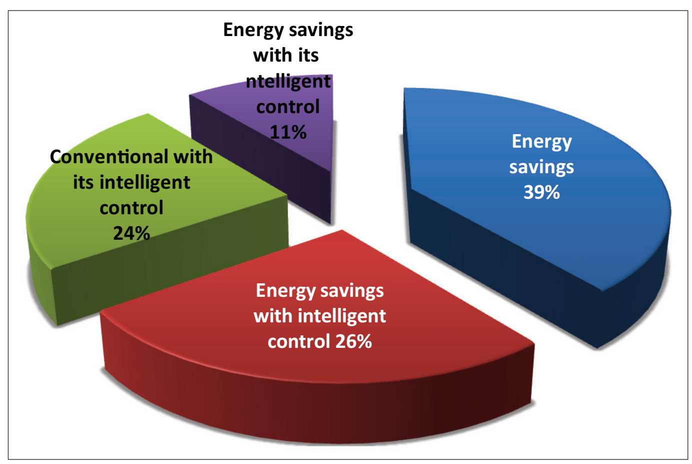
Where; E.S represents Energy savings, I.E.S represents Intelligent control of energy savings and I.C represents Intelligent control of conventional

Figure 3: Fluctuation of NPV for energy savings over a period of 10 years



From the theory of net present value (NPV), savings to investment ratio (SIR) and discount payback period (DPP), it is therefore ascertained that if energy saving fixture is deployed on the whole proposed building, the investment will payback in 4 years' time as shown in Figure 3. Meanwhile, critical look of other saving measures from Table 5 reveals that it is not economical to implement intelligent control on the proposed building, because it will take more than 10 years before it will yield return (i.e. payback). The best option will be to deploy intelligent control on surroundings alone for energy saving fixtures.

Figure 4: Overall savings in cost



Finally, from Table 5, it can be inferred that the most attractive of all the investment is energy saving fixture. In all, Figure 4 displays the overall percentage savings in cost for each of the measures considered.

4. CONCLUSION

The major objective of this study is to proffer solution to inefficient usage of energy supply at public buildings in which the proposed

Elkanemi hostel of the University of Lagos is an example. The results point out that there is a great possibility to lessen the amount of electricity consumed by energy saving fixtures through intelligent control at the proposed hostel. In addition, achieving this possibility would result in a considerable reduction in energy consumption compare to traditional incandescent bulbs and energy efficient bulbs without intelligent control. Furthermore, the relative cost effectiveness of employing different energy efficient lighting systems is ascertained. By implementing intelligent control, it is obvious that energy consumption is minimised but at high cost. From the analyses and results obtained for the proposed hostel, it is therefore recommended that, only the surroundings fittings should be intelligently control while energy efficient fittings are installed for other categories

5. ACKNOWLEDGMENT

The authors wish to acknowledge the management of Covenant University for her financial sponsorship and support toward the success of this research work.

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