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Impact Of Energy Efficient LED Lighting On Overall Energy Use Intensity In Commercial Buildings: A Case Study Of Co-op House

Nancy Mwari Murithi
Mechanical and Manufacturing Engineering Department
University of Nairobi
Nairobi, Kenya
mwarinancy@gmail.com

Peter Musau Moses
Electrical & Information Engineering Department
University of Nairobi
Nairobi, Kenya
pemosmusa@uonbi.ac.ke

Abraham Nyete
Electrical &Information Engineering Department
University of Nairobi
Nairobi Kenya
anyete@uonbi.ac.ke

Abstract: Energy efficiency is key for organizations that are keen on managing their energy costs. Lighting is one of the low hanging fruits, that buildings can implement to achieve savings. This study sought to quantify the savings potential through efficient lighting in Co-operative House, a commercial building in Nairobi. A literature review was done to understand the research gaps that exist. Data was collected by administration of a structured questionnaire that required the energy manager to fill in the electricity billing parameters. An inventory of the existing lighting was taken, detailing the type of fixtures type of lamps, energy consumption per fixture as well as hours of use. The data was tabulated and analyzed through Excel sheet. The analysis showed that replacement of all fluorescent lights with LED equivalent would contribute to 18.3 % improvement of the Energy Use Intensity.

Keywords: Energy Efficiency, Energy consumption, Lighting, Savings

I. INTRODUCTION

The concept of green buildings is slowly gaining popularity around the globe. A green building is one that reduces negative environmental impacts in its design, construction, and operation. A key feature of green buildings is efficient use of energy, water as well as other resources.

The Kenya National Energy Efficiency and Conservation Strategy (KNEECS) 2020 identifies five strategic sectors of focus, key among them, buildings. KNEECS targets to improve the lighting load in public buildings by 50% by the year 2025. This is to be achieved through retrofitting of lighting with more efficient alternatives and use of passive energy such as natural light [1]

Globally, in 2018, the buildings and construction sector accounted for 36% of total energy use and 39% of energy and process related CO_2 emissions [1]

Lighting forms a key component of energy consuming loads in a building. Therefore, the implementation of efficient lighting can translate into substantial savings in energy costs. Lighting Energy Conservation Measures (LECMs) aim to reduce lighting demand and/or energy use by:

i) Retrofitting existing old technology lamps with more efficient lamps.
ii) De-lamping (removal of unnecessary light fixtures and/or lamps).
iii) Lighting controls such as sensors, dimmers, and timers.

Cooperative Bank is a money lending institution in Kenya, established in 1965 when it began operations as a cooperative society. It was licensed in 1968 and so far, has grown into 156 branches countrywide. Co-operative House (Co-op House) is one among four premises that offer support services for Cooperative Bank. The building has twenty-two floors.

Efficient lighting is one of the most popularly recommended energy costs saving measures for buildings. This is key in managing costs, but facilities sometimes do not implement the measures due to ignorance and skepticism of the savings potential. Banks are often viewed as money-lending institutions rather than as commercial buildings with the potential to save on energy. Therefore, their huge energy-saving potential can be easily downplayed leading to high energy inefficiency levels in the buildings.

Co-op House has fluorescent lamps that are more energy consuming compared to LEDs. Energy Use Intensity is not commonly calculated hence benchmarking buildings against similar buildings is not possible. This can lead to an assumption that the current energy consumption is optimal.

In 2020, The overall Energy Use Index averaged at 296 kilowatt-hours per square meter per year against the recommended benchmark of 226. Lighting had an Energy Use Intensity of 124 kilowatt-hours per square meter per year, against the recommended value of 54.

II. LITERATURE REVIEW ON LED LIGHTING

Vahl et al [2] analyzed the long-term sustainability of retrofit of inefficient light bulbs with more efficient ones such as CFLs and LEDs. They realized that CFLs have the highest costs annually and the highest toxic waste. On the other hand, FL tubes turned out to be more economical, However, as the prices of LEDs reduced, they noted that, eventually, LEDs would be the most economical and sustainable option.

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Chen and Chung [4] undertook a study in China, in which they retrofitted LEDs with T8 fluorescent tubes. They realized that by replacing the existing 36 W T8 fluorescent lamps with 20 W LED lamps, a total of, around $288 saving would be saved within 5 years. The study also did not analyze in-depth the impact of LED lighting on energy use intensity. The energy-saving per bulb was assumed to be:

$$ES\ per\ bulb = 36W - 20W \quad (1)$$

Ganandran [3] in their analysis of the saving potential of buildings in Universiti Tenaga Nasional in Malaysia. A lighting inventory was done which revealed there were a total of 62,684. The lamps were broken down as:

i) 8751 fluorescents 4 ft tube each 36 Watts.
ii) 12674 fluorescent, 2 ft tube, each 18 Watts.
iii) 12719 PL-C 2 pin bulbs each 13 Watts.
iv) 109 Philips CFL bulb each 14 Watts.

The study estimated that a full retrofit of the lamps would save about1,463,450.56 kWh of energy which translated to RM (Malaysia) 517,622 annually, which is about USD 118,181. The total daily energy consumption (EC) was computed simply as the multiplication of the number of lamps (N) by the lamp power consumption (W), by total operation hours (OH) i.e.

$$EC = (N \times W \times OH)1000 \quad (2)$$

The Energy Saving (ES) was then calculated by subtracting the energy consumption of the current system (EC Current) from the retrofit lighting (EC Retrofitting) system:

$$ES = EC\ Current - EC\ Retrofitting \quad (3)$$

The study also does not consider the effect of LED lighting on the power factor which could reduce the cost-saving potential if the facility is surcharged for poor power factor. The energy use intensity is also not mentioned in the study.

Ryckaert et al [4] researched the pros and cons of retrofitting LED tubes with T8 FL lamps. Upon analyzing 12 LED tubes, the results demonstrated that a one-to-one lamp replacement can result in inadequate illumination of a surface. This underscored the need for careful analysis in LED retrofit projects to ensure occupant comfort is not compromised.

Whereas the use of LED lighting has gained traction, Xu X et al [5] note that the wide use of LED lamps causes various problems that arise in power grids resulting from the non-sinusoidal waveform of the current consumed by such lamps. Despite the small power and current consumed by a single lamp, problems arise from many such lamps in the same grid and their synchronous operation forced by voltage waveform in the power grid. These issues are discussed in [6] [7] [8]

Oliveira [9] also studied LED and Compact Fluorescent Lamps in terms of the resulting impact on the electricity transmission grid (measurements of power factor and current harmonic distortions) which confirmed that LEDs have unfavorable energy properties such as harmonic distortion factor of current waveform often greater than 100% and low power factor between 0.4 and 0.95 depending on the power supply type.

Robotyka et al [10] further notes that on the consumer market there are a lot of energy-saving LED bulbs available from various manufacturers. Manufacturers persuade consumers by presenting data on the packaging as catchy phrases that are not informative on the properties of the lamps. (e.g., "4 W = 60 W"), the only data given is often the current, power and the rated voltage. The study further measured the energy parameters of several, arbitrarily selected LED lamps and two compact fluorescent lamps (CFL) available in popular commercial networks and compared the obtained measurement data with the parameters declared by the manufacturers. The power factor of the lamps was found to be low and ranging from 0.5 to 0.65. This suggests that LED lighting could reduce the overall power factor of a building.

III. Methodology

Data was collected through primary data collection methods whereby a structured data sheet was given to the energy manager of Co-op House. The questions targeted data on kWh energy consumption, demand in kW, and power factor for Year 2019 and 2020. An inventory of the current lighting was done.

The data on high rate, low rate, bill in Kenya Shillings, demand in kW, kVA and power factor was tabulated into Excel Sheets. A post retrofit scenario was projected by calculation of energy consumption, kW demand and lux levels.

The savings from LED lighting retrofit were calculated by subtracting the New Wattage from the Existing Wattage, then multiplied by the number of hours of use of the lamps [3]

The Energy Use Intensity of the building was calculated as:

$$Energy\ Use\ Intensity = \frac{Energy\ Consumption}{Area\ in\ M2} \quad (4)$$

IV. Results and Analysis

A. Energy Consumption

Co-op House consumes on average 128,000 kWh units in a month as shown in Table I. The facility is billed on Commercial Industrial tariff. The 2020 data showed that most of the energy (69%) is consumed during the day, while the remaining 31% is spent at night. The electricity bill is USD 21,818. The blended unit cost per kWh is USD 0.17. The kW averages at 464 while the kVA demand averages at 504 translating to a power factor of 0.92.

TABLE I. ENERGY CONSUMPTION

Date	High Rate	Low rate	Total kWh	USD	kVA	kW	Power Factor
Jan	102,252	42,076	144,328	24,578	540	493	0.91
Feb	92,522	37,846	130,368	22,600	565	513	0.91
Mar	112,970	41,336	154,306	25,402	533	486	0.91
Apr	77,652	41,778	119,430	20,577	502	461	0.92
May	83,624	39,738	123,362	21,031	523	479	0.92
Jun	76,222	36,526	112,748	19,567	504	463	0.92
Jul	88,702	42,436	131,138	22,357	487	447	0.92
Aug	80,898	37,626	118,524	20,548	480	440	0.92
Sep	85,638	42,806	128,444	22,235	482	442	0.92
Oct	83,038	36,286	119,324	21,608	480	439	0.91
Nov	87,324	39,568	126,892	21,944	448	444	0.99
Average	88,258	39,820	128,079	22,041	504	464	0.92

B. *Impact on Energy Use Index*

Lighting Retrofit has been carried out for only floor seven and eight. These were installed to replace inefficient lamps that had burnt out.

The current lights at the facility are 4 feet T8 fluorescent tubes which consume 36 Watts each and these can be replaced with LED tube lights of 18 Watts each. There are also 2 feet T8 fluorescent tube lights of 18 Watts; these can be replaced with LED tube lights of 9 Watts. There would be no need to change the current fixtures during the retrofit.

A comparison of the current lighting and a post retrofit scenario was done using the lumen method for sampled rooms in Co-op House This revealed that a 1:1 fluorescent: LED replacement would have no effect on the lux level of the facility. This is because the lumen LED lamps do not have a ballast.

Replacing the current fluorescent lights with LED equivalent would save energy costs the facility. One to One Ratio replacement of both working and faulty lamps with LED lighting would translate to 38% of the facility's energy consumption by lighting. However, retrofitting only, the working lamps would translate into 45% savings on the lighting energy consumption. This would require baseline adjustments to be made when computing for the actual savings

Retrofitting all the existing fluorescent lamps with their LED equivalent would translate to 18.3 % of the overall monthly energy use intensity as shown on Table II.

TABLE II. ENERGY USE INDEX IMPROVEMENT

Daily Saving in kilowatt-hours	780.70
Monthly Saving in kilowatt-hours	23,421
Reduced Monthly EUI	4.52
Overall Monthly EUI before retrofit	24.72
Overall Monthly EUI post retrofit	20.20
% Improvement	18.3%

Lighting benchmarks estimate the Energy Use Index for lighting at 54 kilowatt-hours per square meter per year [11]. Currently the lighting Energy Use Index for Co-op House is at 124 kilowatt-hours per square meter per year. With lighting retrofit, the Energy Use Index would translate to 64 kilowatt-hours per square meter per year, which would be closer to the recommended value of 54 kilowatt-hours per square meter per year.

C. *Energy and Cost Saving*

The facility would save 781 kilowatt-hours daily, 23,421 kilowatt-hours monthly and 281,052 kilowatt-hours annually. At the current cost per kilowatt-hour, the monetary savings would be USD 48,432 Annually.

TABLE III. ENERGY COST SAVINGS

	Existing	Post Retrofit	Projected Saving	Unit
Current Daily Consumption	1,748	967	781	kWh
Monthly Consumption (30 days)	52,426	29,005	23,421	kWh
Annual Consumption in kWh	629,112	348,060	281,052	kWh
Cost per kWh in USD		0.17		USD
Saving in USD			**48,432**	USD

The EUI results were benchmarked against other standards and found to be close to other typical EUI of offices as shown in Table IV. The energy potential energy savings results were also benchmarked against other commercial buildings carried out in Egypt as shown on Table V.

TABLE IV. COMPARISON AGAINST BENCHMARKS OF ENERGY USE INTENSITY

Author	Project	Location	Lighting Benchmark	Overall Energy Use Index	Units
CISBSE [11]	Benchmarking Standards	UK	54	226	kWh/m^2/Year
Sans 204 [12]	Benchmarking Standards	South Africa	42.5	185-210	kWh/m^2/Year
Nancy Mwari	A Case Study of Co-op House	Kenya	67	242	kWh/m^2/Year

TABLE V. COMPARISON WITH OTHER LIGHTING RETROFIT SAVINGS

Authors	Project	Location	Building type	No. of LED Lamps	Annual Saving (kWh)	Lighting energy saving (%)	Payback period (year)
Ayman et al [13]	Improving Energy Efficiency of Lighting & Building Appliances Project	Egypt	Public Building	3,600	231,922	77%	3.4
			Public Building	2,295	128,824	66%	3
			Bank	1,601	312,136	77%	1.1
Nancy Mwari	A Case Study of Co-op House	Kenya	Bank	2,743	281,052	50%	1.9

D. Cost of Retrofit

Retrofitting all the lamps at once would cost the facility a total of USD 82,195 as shown on Table VI.

TABLE VI. RETROFIT COST

	Item	Amount in USD
1	4 ft Retrofit	15,771
2	2 ft Retrofit	49,985
3	Installation Cost	16,439
	Total	82,195

E. Payback Economics

Fig. 1 shows that the project would pay back in 1.7 years and there would be positive cash flow by Year 3.

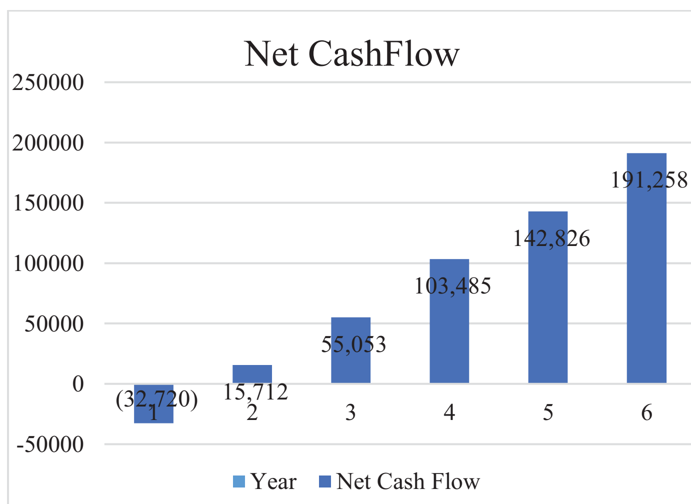

Fig 1. Net Cash Flow

V. CONCLUSION

Lighting accounts for 30 % of the total energy consumption and retrofitting the lights with more efficient options can contribute to improvement of the overall energy use intensity of the building by up to 18%.

Group Re-lamping of the lamps. This is a maintenance practice whereby several lamps are replaced at the same time once the lamps reach 60-80% of their rated lamp life [14]. Currently LED lights are installed randomly and therefore the facility may not realize the energy saving accrued from use of LED in the respective areas. Group re-lamping reduces the cost of maintenance and ensures uniformity hence the lighting quality is maintained [15].

Beyond the monetary savings that facilities look at when implementing energy cost saving projects**,** the project provided a benchmark that commercial buildings and office space can use when carrying out lighting retrofit projects. With such a benchmark, the facilities will be prompted to interrogate their energy consumption further and to optimize their operations further which will in turn result to more energy cost saving and overall competitiveness of buildings

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