Energy Savings and Maintenance Optimization of Energy Efficient Lighting Systems

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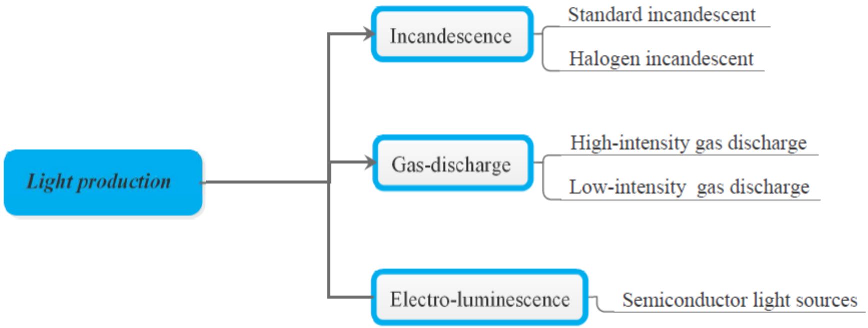
Outline

Background

Why is Energy Efficient Lighting Important?

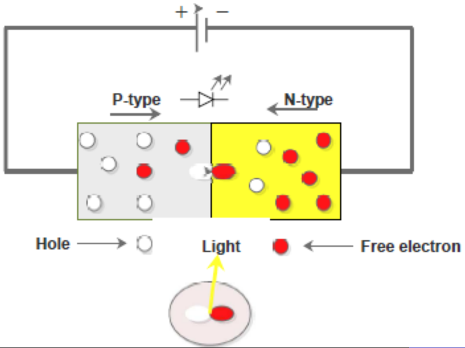
- Energy Savings
- Environmentally friendly
- Improved Lighting Quality
- Improved Productivity

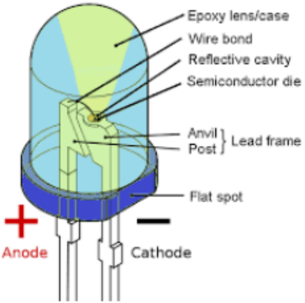
Electric lights classification



Light-Emitting Diode (LED)

What is an LED?



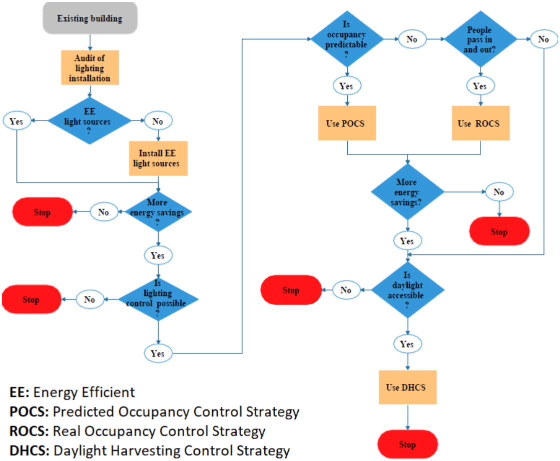


Types of Lighting

Types of Lighting

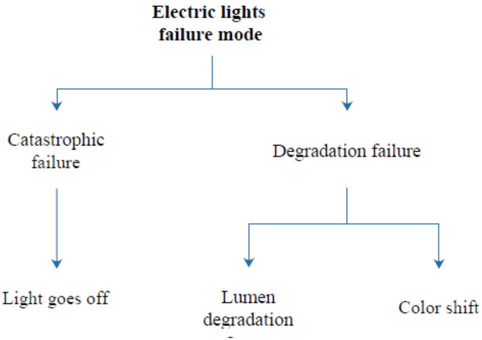
1. **Task lighting:** lighting that illuminates a particular area in a given space and facilitates the execution of a task.
2. **Accent lighting:** also referred to as highlighting, focuses light on a certain zone or object. It is usually used to showcase works of art or other attention-demanding activities such as concert-stage lighting.
3. **General lighting:** illuminates a general area to provide uniform illuminance over the space. This system employs luminaires, shade and reflectors to provide equal illumination in all directions.

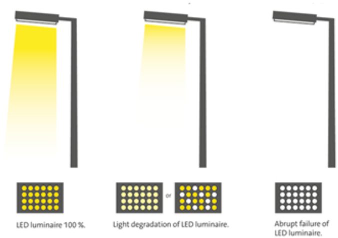
Lighting System Retrofitting



EE: Energy Efficient
POCS: Predicted Occupancy Control Strategy
ROCS: Real Occupancy Control Strategy
DHCS: Daylight Harvesting Control Strategy

Electric Lights failure Modes





Research Conducted

Research Focus areas

1. Lumen degradation of LEDs
2. Lighting System Maintenance
3. Optimization

Lumen degradation of LEDs

Lumen degradation of LEDs

The lumen degradation of LED lights is modeled based on the variation in operating junction temperature due to the users' lighting level requirements.

$$\phi_i(j) = \phi_0 \; e^{-\beta_i(j) t_j}, \tag{1}$$

where ϕ_0 is the initial luminous flux (in lm), t_j is the operating hours (in h), and $\beta_i(j)$ is the degradation rate of lights in the workstation i at time j.

Lumen degradation of LEDs

Lumen degradation of LEDs

The degradation rate of lights varies with the variation in operating junction temperature. The relationship between the degradation rate and operating junction temperature is expressed as

$$\beta_i(j) = a\ e^{\left(\frac{-E_{act}}{k_b T_{m,i}(j)}\right)}, \tag{2}$$

where a is the Arrhenius pre-exponential factor, k_b is the Boltzmann constant (8.617385×10^{-5} eV/K), E_{act} is the activation energy (in eV), and $T_{m,i}$ is the operating temperature (in K).

Lumen degradation of LEDs

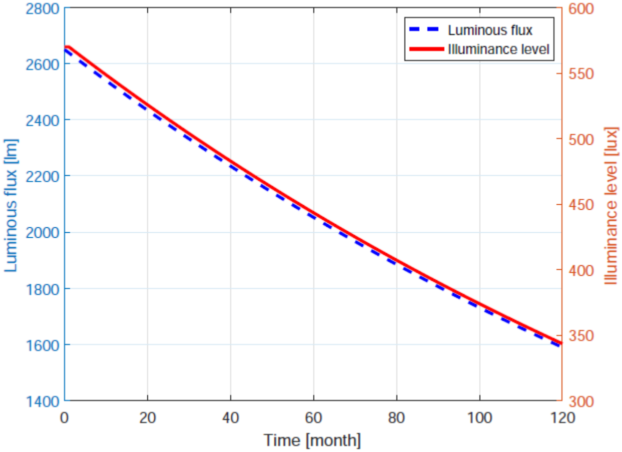
Lumen degradation of LEDs

The measured light level in workstation i at time j is expressed as

$$E_i(j) = \frac{n \times \phi_i(j) \times U_f \times M_f}{A}, \tag{3}$$

where $E_i(j)$ is the light level in workstation i (in lux) at time j, n is the number of LED lights in each workstation, $\phi_i(j)$ is the luminous flux (in lm) of each LED light in workstation i at time j, U_f is the utilization factor, M_f is the maintenance factor, and A is the area (in m^2) of workstation.

Lumen degradation of LEDs



Lighting System Maintenance

Lighting System Maintenance

- Maintenance refers to a combination of all actions (e.g., cleaning, repairs, and replacement, etc.) intended to improve system efficiency and guarantee safety during operation.
- Depending on when maintenance is performed (before or after failure), maintenance activities are grouped into two categories: corrective maintenance (CM) and preventive maintenance (PM).
- CM is performed after an item has failed while PM is performed regularly to maintain the item or system in satisfactory operating condition.

Lighting System Maintenance

Lighting System Maintenance

For a lighting system, the periodic PM is the most practical and applied most frequently. It is performed by replacing failed lamps at a certain maintenance level.

Lighting System Maintenance

Lighting System Maintenance

By applying the PM maintenance the lumen degradation model (1) becomes

$$\Theta_i(j+1) = \sum_{l=1}^{L} \phi_i^l(j)\ e^{-\beta_i\left(T_{m,i}(j)\right)t_{s,i}} + m_i(j)\phi_0\ e^{-\beta_i\left(T_{m,i}(j)\right)t_{s,i}}, \tag{4}$$

where $L = n - m_i(j)$, and $\phi_i^l(j)$ is the luminous flux of non-replaced lamps l at time (j).

Optimization

Optimization

Two main questions are asked to select an effective maintenance plan:

1. The first question is what type of maintenance policy should be considered, and
2. The second question is when to perform the chosen maintenance to achieve the best results.

Optimization

Optimization

Optimization is defined as a method used to solve the conflicts of a decision situation so that the decision variables take the best possible values.

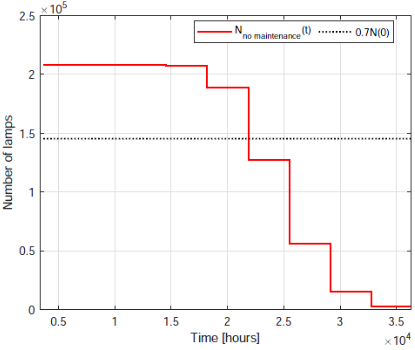
$$\text{minimize } f(x) \quad \text{or} \quad \text{maximize } -f(x) \quad \longleftarrow \quad \text{Objective function}$$

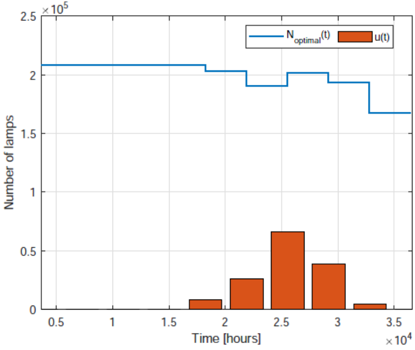
$$\text{subject to} \begin{cases} h(x) = 0 & \longleftarrow \quad \text{Equality Constraints} \\ g(x) \leq 0 & \longleftarrow \quad \text{Inequality Constraints} \\ x_{min} \leq x \leq x_{max} & \longleftarrow \quad \text{Variable Bounds} \end{cases}$$

Case Study

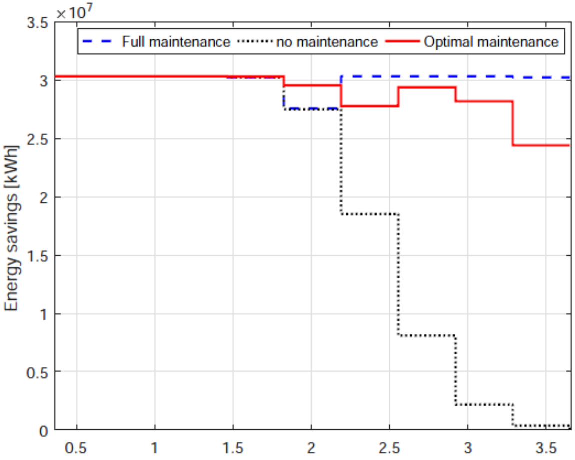
The formulated model is used to plan effective strategic maintenance for a large-scale lighting retrofit project. In South Africa, Eskom in its program of residential mass roll-out (RMR) encourages the project developers to implement EE lighting retrofit projects. In one of the sub-RMR projects, 207, 693 LED light bulbs are replacing halogen light bulbs in households in different provinces of South Africa. LEDs installed have the equivalent lumen output to the replaced halogen. LUXEON-based LED light bulbs with a rated power of 10 W and lumen output of 800 lm are considered to replace halogen light bulbs of the rated power of 50 W and lumen output of 800 lm.

Result Analysis





Result Analysis



Result Analysis

Factor	Full Maintenance	Optimal Maintenance
Energy Savings (in MWh)	297.6 10^3	282.2 10^3
Number of Replaced Lamps	207 693	143 456
Maintenance Cost (in R)	11 838 501	8 176 992
Performance Indicator (R/MWh)	**98.9**	**78.3**

Conclusion

Conclusion

- A case study carried out shows that, in 10 years, the optimal lighting maintenance plan would save up to 59% of lighting energy consumption with acceptable maintenance costs.
- It is found that the proposed maintenance plan is more cost-effective than full maintenance.
- Lumen degradation failure should be considered when investigating the performance of lighting retrofit projects, as this may not only affect the energy savings, but also reduce the level of illumination, which can cause visual discomfort.
- The implemented lighting retrofit project could reduce 275.02×10^3 tons of CO_2 emissions in 10 years.

References

Publication

1. A. Ikuzwe, X Xia, X. Ye. Maintenance optimization model incorporating lumen degradation failure for energy efficiency lighting retrofit projects. Applied Energy 267 (2020) 115003.
2. A. Ikuzwe, X. Ye, and X. Xia. Energy-maintenance optimization for retrofitted lighting system incorporating luminous flux degradation to enhance visual comfort. Applied Energy 261 (2020) 114379.
3. A. Ikuzwe, X. Xia, X. Ye. Optimal maintenance plan with lumen degradation failure for energy effeciency lighting retrofit projects. 11th International Conference on Applied Energy (ICAE), Aug. 12-15, 2019, Västerås, Sweden.