

Reduction of Energy Consumption in Building Requires a Comprehensive Electrical Design of an Integrated Interior Lighting Systems Using Light Emitting Diode (LED)

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ABSTRACT: Energy consumption in residential and commercial buildings remains a subject which needs to be given the necessary and urgent attention it deserves as far as energy reduction and efficiency is concerned.

This paper, presents a designer point of view of future electrical wiring of interior lighting systems using light emitting diode (LED), suited for residential and commercial buildings. The work focuses on advanced building technologies through the integration of LED for achieving an optimal control of interior lighting hence, reducing considerably the energy consumption of the entire building. The proposed electrical wiring in this work is one that addresses the real world issues energy consultants, designer, and wiring electricians face. Our suggested solution is straight forward and simple to integrate. Implementing it will drastically reduce energy consumption to a decimal point and facilitate a new avenue for the learning process.

Keywords: Electrical design, Integration, Energy reduction, and learning.

NOMENCLATURE

θ : Total required lumens [lm]
 E : Desired Illumination [lm/m^2]
 A : Area of working plane to be illuminated [m^2]
 P : Depreciation factor
 η : Utilization factor
 V_f : Forwarded LED voltage at operating current [v]
 I_f : Operating current (LED)
 R : Resistance of the conductor [ohms]
 L : length of the conductor [m]
 V_{ind} : Driver's input voltage [v]

V_{outd} : Dirver's output voltage [v]
 V_{SNS} : represents the voltage dropped across current sensing element
 ρ = Resistivity of the material used

1. INTRODUCTION

Energy consumption in interior lighting system of buildings remains a subject which has not yet been given an appropriate attention. Although, the architectural quality of most buildings being integrated with LEDs continue to make wave of improvement daily. The paper under

consideration, illustrates an electrical engineering point of view of wiring techniques of interior lighting, using LEDs, suited for residential and commercial buildings, geared towards reducing the energy consumption. The necessity and urgency to achieve energy efficiency at an acceptable consumption is now a top priority among experts. But, finding the right way to accomplish such goal,, calls for ingenuity and effort needed to display into the development of LEDs technologies. Extensive research and development investment in these technologies have already getting a considerable momentum and several recent installations mostly for out door and traffic lighting is demonstrating the viability and efficiency of LEDs in such area where it was impossible to connect conventional power supply. The real obstacles for LED's applications in interior lighting is not whether it is possible, but how it will be integrated. There is no question that LED represents an enviable opportunity in energy reduction portfolio if and only if, its integration follows the acceptable norms as detailed in engineering practices.

It is apparently evident that optimized technologies and considerable reduction in prices alone may not be sufficient for massive outreach LED technologies could expect. As the trend in LED continue growing, all other aspects associated with its applications, have to follow suit, to make it more compact to all concerned. Outdoor lightings already offer users and designers considerable freedom which greatly broaden integration possibilities. Contrarily to the above, the interior lighting using LED, continue to lag behind, and the possibility to fully integrate it into electric wiring network of buildings will add more flexibility if the stumbling issue related to knowledge transfer of such practices and product are fully resolved now when energy consumption has been considered as a problem to be solved at all cost by the scientists.

Integration of LED in interior lighting systems for residential/commercial buildings is a major concern for the development of LED as one of the most fundamental component for the reduction of energy consumption. The major problem has been identified in thermal management, the optics and an acceptable electrical wiring methodology. Most of these enumerated obstacles have been given adequate attention, but, much need to be done for the design of electrical wiring and analysis. However, if LEDs have to be considered as true replacement of the existing light source, concentrated works in electrical wiring analysis/design will be necessary to actualize this trend, mostly in interior lighting. Extensive research and training will guaranty a smooth transition to these new technologies. It is apparently clear that the necessity to develop a new pattern of electrical wiring analysis/design will be fundamental fact for the easy integration of LEDs in architectural buildings. What might be a large building structure will look like, if its interior lightings are new technologies (LEDs) based? The answer is obvious, flexibility, efficacy, and of course total reduction of energy to be consumed. The real challenge for energy reduction is not whether is possible, but how best the electrical wiring of such design will be implemented. There is no question that LEDs enshrine a basket full of opportunities as far as energy consumption in building is concerned. There is need for special strategy, collaboration among the actors (manufacturers, installers, and designers) and understanding of this opportunity to guaranty LEDs exploitation and integration to its full potential.

In line of the goals of this work, we have underlined certain targets by which their realization will actualize the followings:

- Demonstration of the viability which may emerge from LEDs as true energy-efficiency lighting. Demonstration of a true partnership between the manufacturers

(industries), electrical wiring designers, and the installers.

- Development of topology of installation structure and a mathematical analysis as basis to predict the intended energy consumption, while assuring continuous flexibility for expansion.

- Provision of high luminous efficiency lighting and necessary arrangement for similar lighting source as replacement if need arises.

2. ELECTRICAL WIRING DESIGN REQUIREMENTS FOR ARCHITECTURAL LIGHTING SYSTEM

Design requirements for electrical wiring, is an important step to initiate the load analysis and asset identification. Through this step, the selection of right components and their specifications is made possible to provide room for subsequent replacement and load expansion. The next step will consist of collection of data that is, load specifications, then adaptability and integration, in line of the following: -

2.1. Collection of data: - By data, we mean the specifications of the rooms, their measurements and the intended function of each space, room or office.

2.2. Adaptability: - This is a key function of the design. The required luminance need to be adapted with the available LEDs in the market, taking into consideration that the energy consumption needs to be reduced and sustained.

2.3 Integration: - The acquired information as described in section (2.1) needs to be implemented and analyzed mathematically to achieve the intended objective. [1]

2.4 Key Components for the system sizing: - By key components, we mean the necessary steps, items or group of items required to achieve illumination. See Figure 1.

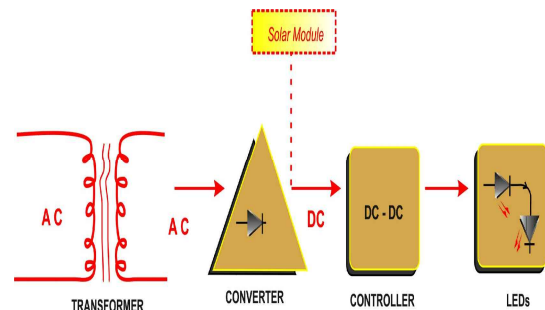


Figure 1: Interior Lighting Topology

2.4.1 AC/DC converter, Bridge Rectification

2.4.2 Voltage regulator (switching), power management

2.4.3 DC-DC converter (switching)

3. DC TRANSMISSION AND DISTRIBUTION

Direct current source constitutes one of the most important features of LEDs applications. This source comes from either through AC-DC convention or Renewable sources, such as solar energy, small wind turbine and many other sources as applicable in renewable energies.

By transmission and distribution of power is meant the conveyance of such power from its source to places where it is demanded. There exist several methods in transmitting DC power. [2] Our point of interest is to make sure that the adopted medium of conveyance of power is fulfilled. The accepted requirement in maintaining the voltage at the point of need within a small margin of depreciation of the estimated voltage is in accordance of the load, equally, the loss of power in the system should be a very small percentage of the transmitted one. In the long list of these requirements, it is to

be noted that the current passing through the conductor should be limited to such a value as not to overheat the conductor. As a safety measure, the insulation resistance of the whole system should be high to avert the undue leakage which may be harmful.

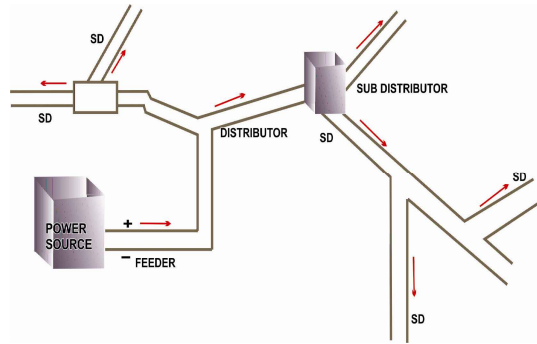


Figure 2: Distribution topology of a 2-wire system configuration

From the source, the power is carried by the feeders which radiate to various part of the building. These feeders deliver power to a certain location via distributors, which run along the various rooms and places. The feeder is designed on the basis of its current – carrying capacity, whereby the design of the distributor is based on the voltage drop occurring in it.

We have adopted a two wires transmission; fed in one end with the unequal voltages along the transmission line.

4 SIMULATION

4.1 Analysis of power distribution

The concentrated loads along the distributor fed at one end, are going to be scrutinized in the following pattern, as shown in figure 4 (a) and (b).

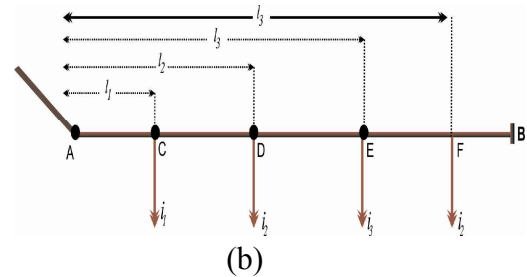
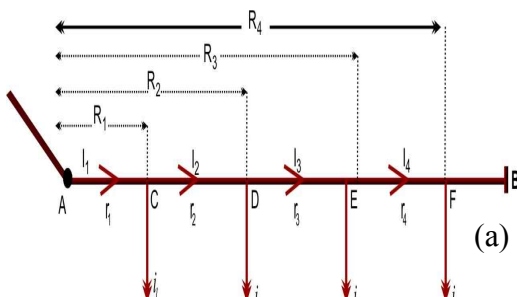


Figure 3: Radial distributor feed at one end

The distribution consists of 2 wires feed at A of length A.B. The various lightning points (load) and their distances in respect to the source A will be determined equally. Invoking the Kirchhoff's voltage law in a different form in terms of voltage drops and rises [3]

We have is

$$\sum IR = 0$$

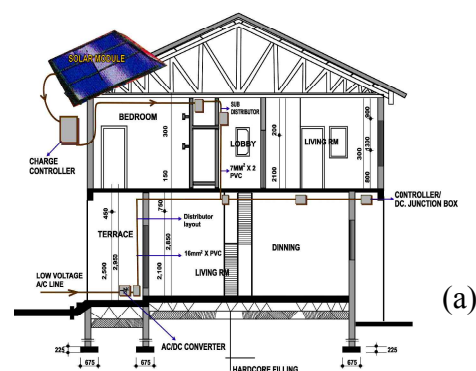
$$2(\sum IR + e.m.f) = 0 \dots \dots \dots (1)$$

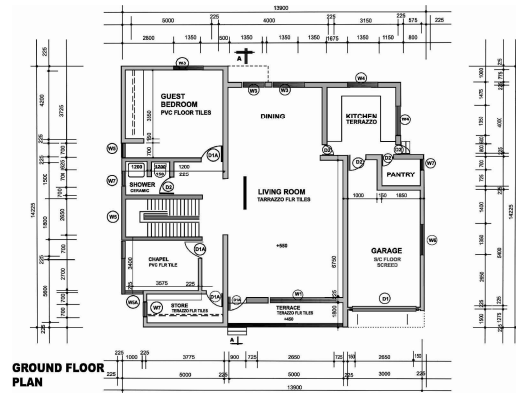
From figure 4, the distance from point A to load at C is ℓ_1

$$R_c = (\rho \times l_1)/A \dots \dots \dots (2)$$

It is to be noted that at worst case scenario, it will be assumed that $\sum e.m.f. = 10 \text{ volts}$, that is the voltage drop in the transmission line. [4]

The architectural design has provided necessary specifications needed for the determination of the distance from the feeder to the load (LED), hence, facilitating the calculation of the sectional area (A) and other necessary parameters.





(b)

Figure 5: Architectural layout of the building.

4.2 Analysis of needed Lumens Needed

Having satisfied the room specifications and measurements from the architect, the next step is to use the following expression to determine the needed lumens.

$$\Phi = \frac{E \times A}{\eta \times f} \dots \dots \dots 1$$

5. LEDS SELECTION AND QUANTIFICATION

The selection of LEDs to be integrated for the interior lighting is influenced by several factors, among them are the operating current to be used for the LEDs and an appreciable number of LEDs needed to achieve a pre-determined illuminations.

The manufacturer's specification manual will play a greater role in this respect.

In the course of this work, and for ease of calculation, we have decided to make use of two different type of luminaries see appendix 2. Hence, the number of LEDs required in each room/location was calculated as follows:

$$\text{Number of LEDs} = \frac{\text{Estimated Lumens}}{\text{LED's Lumen}} \dots \dots (4)$$

Ground Floor, Distribution Lumens

Description	Specifications (m ²) A	Lumens	LEDs
Bedroom	5 x 4.2	1000	11
Dining Room	5 x 5.6	1,300	8 + 2*
Kitchen	5.6 x 5.4	1,440	10+2*
Pantry	3.1 x 4	1,771	16
Passage	1.8 x 1.4	360	4
Garage	1.4 x 1	66	1
Store	2.85 x 5.4	2,200	22
Chapel	4 x 1.4	400	4
Corridor	3.4 x 3.5	1,130	15
Corridor	1. x 2.7	64	2
Corridor	1.2 x 1.5	42	1
Shower	1.3 x 3.8	705	7
Total Estimated Lumen		10,478	90+4*

First floor

Table 1: Lumens distribution Ground Floor

Descriptions	Specifications (m ²) A	Lumens	LEDs
Living room	6 x 4.2	1,200	12
Bedroom	5.25x 4.8	1,200	12
Lobby	3.5 x 1.2	400	4
Dress Room	2.15x 1.8	553	6
Toilet (1)	1.8 x 3.2	825	8
Toilet (2)	2.05x2.4	703	7
Bedroom (1)	5.05x5.6	1,347	14
Bedroom (2)	4.2 x 3.7	740	8
Balcony (1)	2.5 x 3.2	190	2
Balcony (2)	3.7 x 1.2	105	2
Balcony (3)	4.2 x 1	100	2
Shower	1.6 x 2.8	640	8
Lobby	1.2 x 1.6	183	2
Total Estimated Lumens		8,184	89

Table 2: Lumens Distribution 1st Floor

Having determined the required lumens and number of LEDs in each room/space, the next stage will be to calculate the power demand in such room and space.

P_{LED} , is but, the power consumption of one LED, which is found in manufacturer's catalogue or can be calculated as $P_{LED} = \text{operating current} \times (\text{typical } V_f @ \text{operating current})$. [5]

$$P_{LED} = I_f \times V_f \dots \dots \dots (5)$$

For a room using n number of LEDs, total power consumption will be $P_{total} = (nLEDs) \times P_{LED}$. (6)

Then;

Ground Floor

Locations	$P_{LED} = I_f \times V_f$ w	LEDs	P_{LEDs} (w)
Guest room	2.45	10	24.50
Dining	2.45	12	29.35
Living Room	2.45	14	33.50
Kitchen	2.45	16	39.20
Pantry	2.45	4	9.80
Area	2.45	1	2.45
Garage	2.45	20	48.00
Balcony	2.45	2	4.90
Chapel	2.45	10	24.5
Corridor	2.45	1	2.45
Corridor (1)	2.45	1	2.45
Shower	2.45	8	19.60
Luminaries	(11.4)	4	45.6
			289.3

Table 3: Estimated Power from LEDs, Ground Floor

First Floor

Locations	Unit, P_{LED}	LEDs	$P_{LEDs}(w)$
Room	2.45	12	29.4
Bedroom	2.45	16	39.2
Lobby	2.45	4	9.8
Dress Room	2.45	6	14.7
Toilet (1)	2.45	8	19.6
Toilet (2)	2.45	7	17.15
Bedroom	2.45	12	29.4
Bedroom	2.45	6	14.7
Balcony	2.45	3	7.35
Balcony	2.45	2	4.9
Balcony	2.45	2	4.9
Shower	2.45	6	14.9
Passage	2.45	2	4.9
			210.7

Table 4: Total Estimated of LEDs, 1st Floor

6. INPUT VOLTAGE

It becomes obvious to investigate the input voltage transformation within each localized space/room.

Taking the forward voltage of an LED to be V_f , and in a place whrer there are have numbers of similar LEDs, the total output voltage required will be;

$$V = n \times V_f + V_{SNS} \dots \dots (7)$$

In addition to the above, we need to consider Drivers relationship to LED forward voltage. There must be some level of voltage drop due to wire resistance and by the nature of driver topology; the input voltage of the driver will remain greater than its output voltage. Consequently, $V_{in} = V_{out} + \text{Wire voltage drop} + \text{a certain margin}$. [5]

In guise of calculation we will add 5V as such margin.

$$V_{inD} = V_{outD} + V_{wire} + 5V \dots (8)$$

As described in expression (8), $V_o = nV_f + V_{SNS}$

$$V_{inD} = V_o + V_{wire} + 5$$

Drivers, controllers and regulators are all electronics entities, and they are equally consumers of energy.

Driver's power input can be calculated using the following expression.

$$P_{in} = \frac{(Driver V_{in}) \times (I_{in})}{1000} \dots (9)$$

$$I_n \text{ (m a)} = \frac{\sum V_{LedT} \times Driver I_{out}}{(0.85) \times (Driver V_{in})} \dots (10)$$

$$P_{out} (w) = (P_{in}) \times (\text{Number} \times \text{Drivers})$$

$$= \left\{ \frac{(Driver V_{in}) \times (I_{in})}{1000} \right\} \times \text{Number of Drivers} \dots (11)$$

It is to be noted that the manufacturers will provide necessary information on LED voltage, Driver I_{out} , and Driver V_{in} . Hence, Driver $P_{out} (w)$ will be determined using expression (11) above.

7. SELECTED DRIVERS

In the course of this simulation, let adopt divers of the following characteristics:

- $V_{in} = 6$ to 40 VDC (Driver's Specification).
 - $I_{out} = 700\text{ma}$, LED forward voltage at 700MA = 3.5V.
 - $V_{out} = 24\text{V}$
- Then,

Ground Floor

	LEDs	V_{LED}	I_{in}	P_{inD} (w)	P_{outD} (w)
room					
C ₁	5	17.5	360	14.4	72
C ₂	5	17.5	360	14.4	72
C ₃	2	7	144	5.76	11.52
Din.					
C ₁	4	14	288	11.52	46.08
C ₂	4	14	288	11.52	46.08
C ₃	2	20	411	16.44	32.88
room					
C ₁	5	17.5	360	14.4	72
C ₂	5	17.5	360	14.4	72
C ₃	2	7	144	5.76	11.52
Kite					
C ₁	6	21	423	17.28	103.68
C ₂	7	24.5	504	20.16	141.12
C ₃	3	10.5	216	8.64	25.92
C ₁	4	14	288	11.52	46.08
Entr.	4	14	288	11.52	46.08
Park					
C ₁	4	14	288	11.52	46.08
C ₂	7	24.5	504	20.16	141.12
C ₃	10	32	720	28.8	
Ter.	5	17.5	360	14.4	72
Corr	5	17.5	360	14.4	72
Shor	5	17.5	360	14.4	72
chap					
C ₁	7	24.5	504	20.16	141.12
C ₂	8	28	576	23.04	184.2
Store	4	14	288	11.52	46.08
Step	4	14	288	11.52	46.08

Cumulated drivers Power Out 1.619.64 w

Table 5: Drivers Power Out (w), Ground floor.

First floor

	LEDs	V_{LED}	I_{in}	P_{inD} (w)	P_{out} (w)
room					
C ₁	6	21	432	17.28	103.68
C ₂	4	14	288	11.52	46.08
C ₃	3	10.5	216	8.64	25.92
Balc					
C ₄	3	10.5	216	8.64	25.92
Shor					
C ₁	4	14	288	11.52	46.08
C ₂	5	17.5	360	14.4	72.00
Step	6	21	432	17.28	103.68
Lob.	5	17.5	360	14.84	72.00
room					
C ₁	4	14	288	11.52	46.08
C ₂	4	14	288	11.52	46.08
C ₃	4	14	288	11.52	46.08
Toile	7	24.5	504	20.16	141.12
room					
C ₁	7	24.5	504	20.16	141.12
C ₂	4	14	288	11.52	46.08
Bal.	2	7	144	5.76	11.52
room					
C ₁	6	21	360	17.28	103.63
C ₂	3	10.5	216	8.64	25.92
C ₃	3	10.5	216	8.64	25.92
C ₄	3	10.5	216	8.64	25.92
room	7	24.5	504	20.16	141.12
Toile	7	24.5	504	20.16	141.12
Balc	3	24.5	216	8.64	25.92

Table 6: Drivers Power out (w) First Floor (Cumulated power out) = 1, 462.99 w

8. DISTRIBUTOR'S PARAMETERS AND SPECIFICATION

From table 5, $P_{out} = 1,619.64\text{w}$

$$R = p \frac{p}{A},$$

$$I_{t1} = 40.49, \text{ amps } P = Vi_t$$

If: $l = 100\text{m}$

$$A = 17\text{mm}^2 \text{ for 2 wires}$$

$$= 8.5\text{mm}^2 \text{ each}$$

$$R = 0.99 \text{ ohms.}$$

From table 6, $P_{out} = 1,642.99w$

$$I_{t2} = 36.6 \text{ amps}$$

$$A = 16mm^2 \text{ for 2 wires} \\ = 8mm^2 \text{ each}$$

The total power to be consumed in this building is

$$P_{total} = 3,082.63w$$

$$I_t = 77 \text{ amps}$$

$$A = 33mm^2 \text{ for 2 wires} \\ = 16.5 mm^2$$

In verifying the Kirchhoff's law, we have

$$I_t = I_{t1} + I_{t2}$$

$$P = I V$$

$$I = \frac{P}{V} = 36.57 \text{ amps}$$

$$1,452.47 (w)$$

$$A = 16mm^2$$

$$R = 1.12 \text{ ohms}$$

9.2 total carrying capacity of the distributor

$$P_{out \text{ total}} = 3,082.63w$$

$$I_{t12} = \frac{P_{out \text{ total}}}{V} = 77 \text{ Amps}$$

$$A = 3.318 \cdot 10^{-2} m^2 \\ 33mm^2 \quad R = 0.52 \text{ ohms.}$$

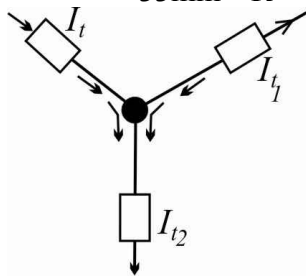


Figure 6: Kirchhoff's nodal circuit

9. RESULTS

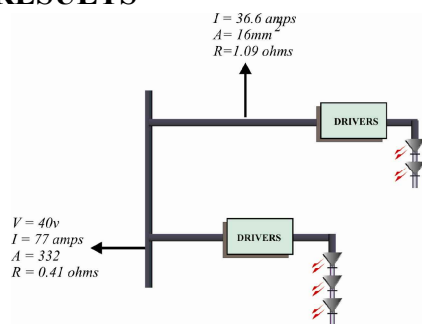


Figure 7: The actual systems distributor and transmissions layout

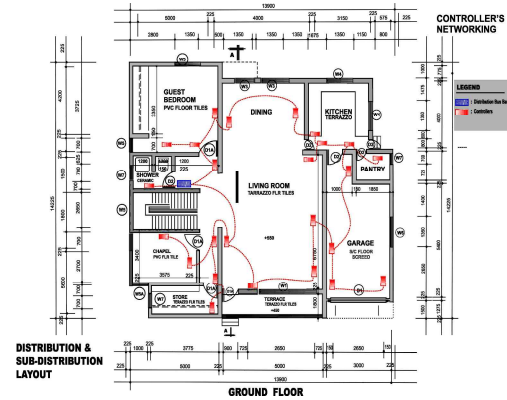


Figure 8: Drivers' implementation layout

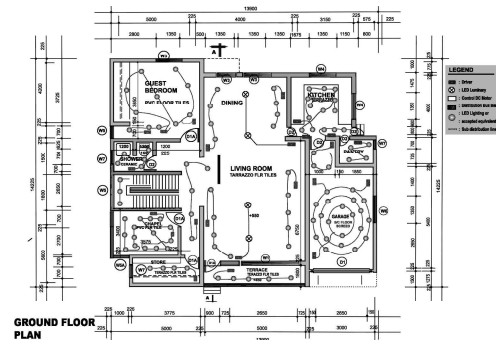


Figure 9: Ground floor, LEDs installation layout

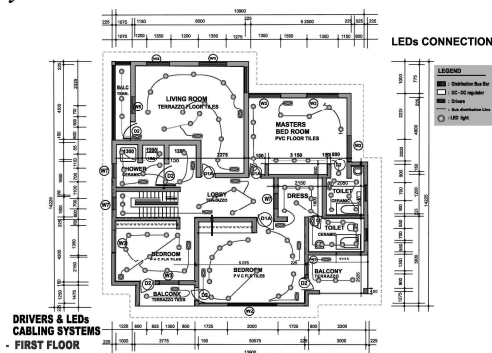


Figure 10: First Floor, LEDs installation layout

Figure as display above show the distribution topology from the DC power supply, the 40v, 77amps feeder with resistance $R=0.52ohms$. Figures (9) and (10) show the drivers layout for ground floor and first floor respectively. The relative light output for the 2 floors have been equally displayed in figures (9) and (10).

It was observed that it takes 9 LEDs to replace one conventional light source (bulb). But the multiplicity of LEDs does not contradict the objective of the project, as a

100w standard bulb consumes more energy than 10 single LEDs. The onerous belongs to the architects and builders to reconfigure LED as decorative lighting such as wall sconces, pendant lights, and wall washes. When such arrangements are implemented, lighting, source will be enviable but its effects of light will be made manifest. A well trained lighting expert can improve these effects even further.

10. CONCLUSION

The amount of DC Voltage controlled and sent to the bus bar and the current demand are the two controlling factors in the architecture lighting systems. The selection of LEDs ranged for each specific application in the design is dependent on the location and methodological configuration of the chosen LEDs, including the drivers. Other contributing factors are the luminance which the LEDs can emit, the various optics instrument needed to amplifier or magnify the luminance are also important. Factors such as, elevation of the floor, size of the room, court yard, dining room, and conference room must be weighted during or before the design.

The collection of this information's is useful exercise for calculating the energy sought to be reduced and the required luminance for each location.

Above all, the manufacturers of light emitting diode ought by now define the ease of use of these components, taking into consideration their efficiency, failure rate, protection also, adaptability, and in the other end, the electrical wiring engineers need to define a combination of methodology, analysis, and implementation of these products (LEDs) in various environments.[6]

A suitable wiring design and analysis is the use of interconnectivity and exchangeable of different products to one and only one design, in which various

products can provide services. However, protocols, regulations, and codes need to be implemented to match with the trend as being exhibited in the industries by manufacturers.

As light emitting diode continues to witness an unprecedented market surge, residential and commercial buildings will definitely provide an enviable ground for business to flourish. This trend will influence and impact positively to:

- (a) Reduction in Energy consumption
- (b) System efficient
- (c) Better utilization of installed capacity
- (d) Justifiable investment with added benefits
- (e) Simple and costless installation.

To fully enhance these goals, there is urgency to invest in human capacity. Highly skilled lighting / electrical wiring designers will assure a balance matching between the manufacturers and the end users. That will serve the purpose in the wish the LEDs are made for, and to operate as true replacement of the existing light source.

11. APPENDICES

11.1 Illumination required for different purpose (lm/m^2)

- Machine Workshop - above 500lm^2
- Extra fine machine, e.g sawing machine room - $200\text{-}500\text{ lm}/\text{m}^2$
- Proof reading, drawing room, bench work - $100\text{ }200\text{ lm}/\text{m}^2$
- Exhibition hall, usual reading - $60\text{--}100\text{ lm}/\text{m}^2$
- Bed-rooms, waiting rooms $20\text{--}60\text{ lm}/\text{m}^2$
- Hospital Wards, railway platforms and Corridors - $5\text{--}10\text{ lm}/\text{m}^2$

11.2. Ultra – Thin LED luminaries at $200\text{ma } 87\text{ lm}/\text{w}$

12. REFERENCE

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