IMPROVEMENT OF BUILDING ENERGY PERFORMANCE AND HUMAN OCCUPANT COMFORT THROUGH ENERGY EFFICIENCY MEASURES

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ABSTRACT

The reduction of energy consumption in buildings through the adoption and implementation of energy efficiency and conservation measures has been identified to reduce energy cost, mitigate climate change, increase energy accessibility, improve occupancy comfort and achieve sustainable development. This paper reports the savings made when compact fluorescent lamps are deployed within the functions room of University of Lagos Guest Houses and Conference Centre. The total cooling load of the functions room before the installation was 27.63 kW, requiring four units of 7 kW free blow stand-alone air-conditioners to cool. On a 4 to 5 ratio; for each 100W incandescent lamp, 5 CFLs of 8 W were replaced. 100 W incandescent lamps were each replaced with 8 W compact fluorescent lamps. After the replacement, the cooling load reduced to 18.77 kW and the number of air conditioners required reduced to two (2) units of 7 kW free blow stand-alone air conditioners, which translates to a saving of 18%. A proposal to totally replace all the incandescent lamps with the required quantity of energy efficient lamps is also made. When the proposal is implemented, 32% saving can be realised from the total initial load; and this load will require three 7 kW free blow stand-alone air conditioners of any brand. The study recommends that energy-efficient technologies are necessary for new, existing buildings and refurbishment projects, since this will help reduce energy consumption, improve building energy performance and human occupant comfort.

Keywords: Building Energy Performance; Lighting; Cooling Load; Occupancy Comfort; Compact Fluorescent Lamps; Energy Efficiency

1.0 INTRODUCTION

A building provides spaces and generally has an environment that is conditioned from that of its surroundings to suit particular purposes. Buildings therefore includes a physical enclosure with some means for creating a comfortable internal environment for human habitation and are used to provide microclimate for human existence and space for all human activities [1, 2].

There is a strong relationship between a building's interior and corresponding energy performance, reason being that most of the energy consumed in the interior environment is expanded to ensure occupants' comfort especially in environment and lighting. The major factor in building design is human comfort. Temperature and humidity have large impact on the body's heat transfer and are largely responsible for human comfort [3]. Other factors include building surface colour and texture, face temperature, transmissivity, characteristics of the sun or night sky, human body (surface area exposed and colour or texture of clothing) and energy consuming equipment or devices within the building space. The physiology of human beings as warm-blooded mammals requires the internal body temperature to be maintained within very close limits (between 36^{o}C and 38^{o}C, the normal temperature being 37^{o}C). Falling below 30^{o}C and rising above 41^{o}C, death is imminent. Considering that humans live in environments where the external temperature varies between -40°C to over 50°C, this is quite a demanding requirement and is

achieved with a number of mechanisms.Heat is released into the body by all metabolic processes including nutrition, respiration and movement to mention a few. In order to maintain a balanced temperature, the body must therefore find ways to lose heat at the same rate at which heat is being produced by these processes [4].
The four basic mechanisms by which the body exchanges heat with its environment are evaporation, convection, conduction and radiation. Evaporation and convection are mechanisms of heat loss from the body. Radiation and conduction can result in either heat gain or heat loss depending on the temperature of body relative to its surroundings [5].

One major energy-consuming appliance that contributes to space heating is lighting. Maintaining sufficient lighting levels in a sustainable manner is necessary for the productive operation of a building and improvement of occupant performance. Lighting need is important to energy analysis for two main reasons.Lights consume energy and in general lights produce heat [6]. Over the years, more priority is being given to building aesthetics while energy demand continues to receive little or no attention during building design and construction.This trend continues to hold notwithstanding increase in population which results in high energy consumption. To minimize energy consumption in buildings, architects and builders ought to pay attention to the lighting requirements of buildingswith building designs made to allow for as much natural lighting as possible, so that building occupants can depend less on artificial lighting. Presently, artificial lighting contributes significantly to high energy consumption in most buildings. In most developed countries for instance, where energy data is taken seriously such as United States, a report by the Energy Information Administration shows that buildings account for 37% of the energy use in the country. Of this amount, 53% is consumed by residential buildings.In most advanced countries, building account for about 40% of total energy use [7]. Lighting accounts for 8.8% of the total capacity consumed in residential [8] and 23% in commercial buildings [9].

With increase in global population, energy use in buildings has become a growing concern. This is because increase in population results in increasing demand for more houses and office accommodation. This in turn increases building service demand such as air conditioning, lighting, computers and other electrical and electronic appliances. All of these contribute to the building energy demand. Energy consumption in buildings accounts for a significant percentage of total world energy consumption, with values that range from 40% in Europe and USA [10, 11] to 30% in some Mediterranean countries [12,13, 14]. Buildings are responsible for at least 40% of energy use in most countries. The absolute figure is rising fast as construction booms, especially in developing countries (U.S Congress, Office of Technology Assessment, building Energy Efficiency, OTA-E-518). However, increase in energy usage, though desirable, has its implications on humans, the environment, economy and even the energy supply system [15].

Against this backdrop, it is imperative that measures are taken to reduce energy demand in buildings and also ensure that human comfort is given very high priority. In designing buildings, energy conservation can be prioritized by introducing proper energy management and control measures especially at the architectural design stage of building creation [16].Also energy efficient technologies can be incorporated and

alternative energy sources integrated into building architecture so as to provide buildings with a diversified energy mix and generate energy enough to meet occupants' needs with any excess fed back into an intelligent grid infrastructure [17].
Efficiency in building involves reduced energy consumption for acceptable levels of comfort, air quality and other occupancy requirement. Energy efficiency in buildings provides a wide range of societal benefits including significant consumer cost savings, reduced energy demand and improved electric system reliability.

This study provides an energy management solution to energy waste and building-occupant discomfort observed within the functions room of University of Lagos Guest Houses and Conference Centre. The lighting need within this room was initially met using 108 units of 100 W incandescent bulbs resulting in energy waste since this lighting type is found to be highly inefficient in energy conversion. However, there are more efficient lighting types (Compact Fluorescent Lamps and LEDs) that could be deployed to illuminate the interior spaceeven better yet save energy. This problem is not only peculiar to the functions room being discussed as similar observation is found to exist in many building types such as eventcenters and shopping malls across the country.
The purpose of this work is to determine the energy need, calculate the cooling load inside the functions room over specified period of time and size the HVAC equipment needed when all the light bulbs are incandescent type andenergy-saving alternative. The next stepis to compare the use of inefficient light bulbs (incandescent bulbs) and energy saving lamps (compact fluorescent lamps) on both the cooling requirements and human-occupancy comfort. These quantifications will aid architects, builders and engineers in making appropriate building design decision by adopting energy efficiency measures that seek to provide comfortable indoor conditions for building occupants.

2.0 METHODOLOGY

The entrance of air into the space under consideration is primarily through the door and air conditioning system installed, as all other openings such as windows have been sealed. This room initially designed for 40-capacity has over the years become overstretched as it now accommodates more occupants than its initial design capacity.

Prior to a lighting retrofit exercise conducted by the National Centre for Energy Efficiency and Conservation (NCEEC), the University functions room under consideration had a total of 108 units of 100W incandescent bulbs of different colours (yellow – in majority, blue and red making up the remaining) installed. As part of the implementation of energy efficiency measures and contribution to the reduction in energy consumption, attendant pollution and heat, the Centre replaced 60 units of these inefficient bulbs each with 8W rated energy saving lamps.

Based on the retrofit, the paper examines the reduction in cooling load within this space and its influence on human-occupant comfort, energy demand, cost and the environment. This helps demonstrate a practical consequence of installing and using typical lighting application within a space.

2.1 COOLING LOAD ESTIMATION

The various methods for estimating cooling load include thetransfer function methods, cooling load temperature differential/cooling load factors and total equivalent temperature differential/time-averaging methods [18].

In this paper, the cooling load temperature differential/cooling load factors (CLTD/CLF) method as described in the ASHRAE [19]was considered. This method though not optimum will yield the most conservative results based on the peak values to be used in sizing equipment.

The cooling load compares the sensible and latent heat required to maintain human comfort in a space with incandescent bulbs and energy efficient lamps. Information on location, site and weather data, internal design information and operating schedules were obtained.

The total building cooling load consists of heat transferred through the building envelope (walls, roof, floor, windows, doors etc.) and heat generated by occupants, equipment and lights. Ashrae [19], Urban [20] and Bansal [21] published the heat output of human bodies for various activities as shown in Table 1. The table consists of sensible heat gain with effect on the dry bulb temperature and latent heat gain with effect on the moisture content. The manner in which heat enters into this space includes:

1. Solar radiation through transparent surfacessuch as windows
2. Heat conduction through exterior walls androofs
3. Heat conduction through interior partitions,ceilings and floors
4. Heat generated within the space by occupants, lights, appliances, equipment and processes
5. Loads as a result of ventilation andinfiltration of outdoor air
6. Other miscellaneous heat gains

2.2 ASSUMPTIONS

1. Weather conditions are selected from a long-term statistical database. The conditions do not represent any actual year, but are representative of the location of the room. ASHRAE has tabulated such data.
2. The solar loads on the functions room are assumed to be those that would occur on a clear day in the month chosen for the calculations.
3. The building occupancy is assumed to be at full design capacity.
4. All equipment and appliances used in the room (except lightings) are considered to be operating at a reasonably representative capacity and are assumed the same for all the conditions under consideration.
5. Lights and appliances are assumed to be operating as expected for a typical day of design occupancy.
6. Latent as well as sensible loads are considered.
7. Heat flow is analysed assuming dynamic conditions, which means that heat storage in building envelope and interior materials is considered.
8. The latent heat gain is assumed to become cooling load instantly, whereas the sensible heat gain is partially delayed depending on the characteristics of the conditioned space. According to the ASHRAE regulations, the sensible heat gain from people is assumed 30% convection (instant cooling load) and 70% radiative (delayed portion).

9. The energy analysis program compares the total energy use in a certain period with various alternatives (in lighting use) in order to determine the optimum one.

Table 1: Heat production rate in a human body

Activities	Rate of heat production (W)	(W/m^2)
Sleeping	60	35
Resting	80	45
Sitting, Normal office work	100	55
Typing	150	85
Slow walking (3km/h)	200	110
Fast walking (6km/h)	250	140
Hard working (filing, cutting, digging, etc	More than 300	More than 170

Source: [21]

2.2.2 HEAT GAIN

The heat (sensible and latent) gain is computed according to information available in literature. The heat gain in this functions room is computed from roof, walls, solar load through glass, infiltration air, ventilation air, air supply, internal loads (thermal energy generated, internal loads from equipment, people and lights) and 5% of heat was added to the total sensible and latent heat as safety factor [19,20] . Table 1 and Table 2 show the heat output of human bodies for various activities.

Table 2: Rate of Heat Gain from Occupants at various activities (at indoor air temperature of 25.5°C)

Latent heat (W)				
Seated at rest	115	100	60	40
Seated, very light work, writing	140	120	65	55
Seated, eating	150	170	75	95
Seated, light work, typing	185	150	75	75
Standing. Light work or	235	185	90	95
walking Slowly	255	230	100	130
Light bench work	305	305	100	180
Light machine work, walking 1.34m/s	400	375	120	255
Moderate dancing	470	470	165	300
Heavy work, lifting, Athletics	585	520	185	340

Source: [25]

On the electrical lighting load, which is the obvious load consideration in this paper, the amount of electricity Q_c required for a light source to illuminate a given area is computed using equation 1

$$\frac{Q_c}{A} = \frac{E_{v,min}\ (lm/m^2)}{\varepsilon_{source}\ \ (lm/W)} \qquad (1)$$

This equation assumes that all light emitted from the source travels in equal amounts in the direction of the surface to be illuminated. Table 3 and Table 4 show the luminous efficacy of different light bulbs minimum luminous intensity for common environments respectively.

Table3: Luminous efficacy of select light sources

Fixture Type	Luminous Efficacy $\varepsilon\ (lm/W)$	Overall Lighting Efficiency, η (%)
Candle flame	0.3	0.05
Halogen	12	1.8
Incandescent	17	2.5
White LED bulb	34	5.0
Compact fluorescent	63	9.2
Tube fluorescent	88	13.0
High pressure sodium	130	19.0

Source [20]

Table 4: Minimum luminous intensity for common environments

Environment/ Activity	Minimum lighting $E_{v,min}\ (lux)$
Storage	0 to 150
Residential living room	50
Kitchen	300
Office	400 to 500
Television studio	1000
Detailed work	1000 to 1500

Source [20]

Equation 1 is applied to the space under consideration with minimum luminous intensity of 450 lux, as in Table 4 to obtain the capacity and quantity of light bulb needed for both incandescent and compact fluorescent lamps (CFLs).

Supposing a light source shines towards a flat 1 m x 1 m square in this room:
The capacity of incandescent bulb required on this 1 m x 1 m square surface, is obtained as

$$\frac{Q_c}{A} = \frac{450(lm/m^2)}{17\ (lm/W)} \approx 26.5W/m^2$$

From Table 4 it is found that 26.5 W of electricity is required to illuminate the area to the proper level instead of the 100 W incandescent bulb installed. Since this room comprises many 1 m x 1 m squares, (with an area of $161m^2$), then each square requires this amount of electricity. Overall, this functions room will require a total power demand (lighting) of 4266.5 W when the 26.5 W incandescent bulbs are installed. With this result, the standard size of incandescent lamps available in the market that would have been installed is shown in Table 5.

Table 5 shows the quantity of standard size incandescent lamps needed in the functions room.

Capacity (W)	Quantity
25	≈170 units
40	≈107 units
60	≈71 units
100	≈43 units

The number of lighting point required to achieve the intended power demand is obtained by using equation 2

$$Number\ Incadescent\ lamp\ required = \frac{Total\ Power\ Demand\ (with\ incandescent\ lamp)W}{Lamp\ Capacity\ (W)per\ unit} \quad (2)$$

Similarly, applying equation 1 theory to capacity and quantity of compact fluorescent (energy saving) bulbs to be used in this space,

$$\frac{Q_c}{A} = \frac{450(lm/m^2)}{63\ (lm/W)} = 7.14\ W/m^2 \approx 8\ W/m^2$$

Then, a total power demand of 1149.54 W of the 7.14 W CFLs is required to make the lighting conditions in the room energy efficient with improved human comfort. With the various standard sizes of CFLs in the market, Table 6 shows the quantity of energy saving lamps required to be installed in the functions room with improvement in level of human comfort.
The heat gain considers the situation when all the light bulbs are incandescent type and energy saving type.

2.2.3 OPERATING/INPUT PARAMETERS

The operating parameters used in the course of the calculations are as follows:

- **i.** Location: Akoka, Yaba, Lagos, Nigeria
- **ii.** Type of Building: A functions room within University of Lagos Guest Houses and Conference Centre
- **iii.** Floor area: 11.5 m x 14 m = 161 m^2
- **iv.** Floor height = 4 m
- **v.** Window area = 0.75 m^2
- **vi.** Number of windows: 6
- **vii.** Wall: Material: Wall number. U value = 0.630 $W/m^{2}\ {}^{0}C$
- **viii.** Roof: MaterialU value = 0.693 $W/m^{2}\ {}^{0}C$
- **ix.** Windows: U value = 6.2 $W/m^{20}C$
- **x.** Occupancy: 60 persons
- **xi.** Working: time of use of the space is 10 hrs
- **xii.** Location: Latitude of the Guest House is 6^0 30’
- **xiii.** Outdoor design dry-bulb: 35^0C
- **xiv.** Outdoor design wet-bulb: 18^0C
- **xv.** Indoor design dry-bulb: 25^0C
- **xvi.** DailyRange: 10^0C
- **xvii.** Relative humidity: 50%
- **xviii.** Wind velocity: 2m/s
- **xix.** Occupancy hours for people from 8 A.M. to 6 P.M. (10hrs)
- **xx.** Light remains on from 8 A.M. to 6 P.M.
- **xxi.** Total power demand of the 100 W incandescent bulbs: 9180 W
- **xxii.** Total power demand of the equal number of 8 W Compact Fluorescent Lamps: 734.4 W
- **xxiii.** Total power demand of the mixture of the 100 W and 8 W lamps currently in use: 4488 W
- **xxiv.** Total wattage of all the appliances within the space: No appliance
- **xxv.** Roof number one (check Table 31t page 28-42 and U value for the roof from ASHRAE 2007 handbook).
- **xxvi.** Wall number four (4) (check Table 31t page 28-42 and U value for the wall from ASHRAE 2007 handbook).
- **xxvii.** Values of Cooling Load Temperature Difference (CLTD) for roof taken from Table 30, page 28-42 of ASHRAE 2007 handbook.
- **xxviii.** Values of Cooling Load Temperature Difference (CLTD) for wall taken from Table 32, page 28-45 of ASHRAE 2007 handbook.
- **xxix.** Values of Cooling Load Temperature Difference (CLTD) for glass taken from Table 34, page 28-49 of ASHRAE 2007 handbook.

xxx. Values of Shading Coefficient (SC) are taken from Table 11, page 29-25 of ASHRAE 2007 handbook.

xxxi. Values of Solar Cooling Load (SCL) are taken from Table 36, page 28.50, zone Type C of ASHRAE 2007 handbook.

xxxii. Values of Cooling Load Factor (CLF) for lighting are taken from Table 37 based on 10hours in space, page 28.51, zone Type C of ASHRAE 2007 handbook.

xxxiii. Rates of Sensible Heat Gain (SHG) and Latent Heat from people are taken from Table 3, page 28.8 of ASHRAE 2007 handbook.

3.0 RESULTS AND DISCUSSION

The results as shown in Table 7 gives the heat gain in the functions room under the three different conditions;

Table 7 shows the heat gain by the room before retrofitting i.e. incandescent lamps only, with this condition, a total load of **23.23 kW** is needed to be cooled, for human comfort. The table also shows the total load after replacing all of the incandescent lamps with compact fluorescent lamps (CFLs). It is apparent that savings of **9 kW** is made after the exercise.

Table 7. Heat gain from the functions room at the three different conditions

	Heat gain by the functions room before replacement of lamps	Heat gain by the functions after replacement of lamps
LOAD SOURCE	WATT (W)	WATT (W)
Lights	9180	734.4
People	9078	9078
Ventilation	3865.656	3865.656
Sub Total Load	**22123.6566**	**13,678.056**
Safety Factor* (5% of Sub Total Load)	1106.1828	683.9028
Total Load	**23229.8394**	**14361.9588**

Fig. 1 shows the cooling load by the various sources of heat considered in the functions room under the conditions of heat gain from the building with all incandescent lamp and with all energy saving lamps. The lighting source accounts for 39.52% of the cooling load considered when all the incandescent are in place.

The savings achieved with the implementation of energy efficiency measures (the energy saving retrofitting) in this functions room is obvious in Fig.1.

Total retrofitting of incandescent lamps with energy saving lamps offer a saving of **8,867.88 W** in the cooling load. This shows a saving of 62%.

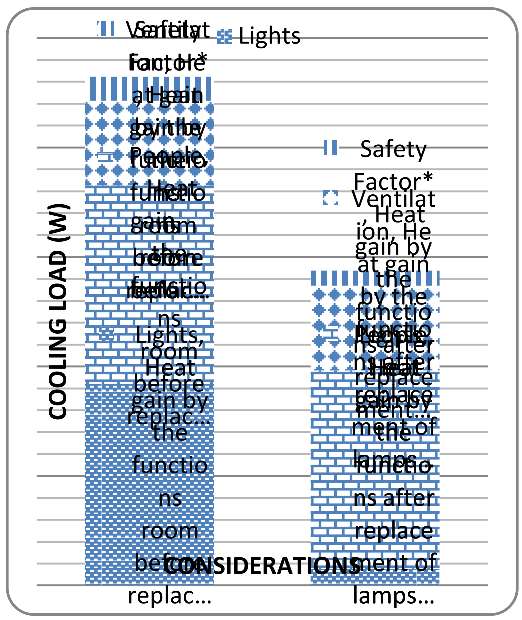

Figure 1: The graph of the Cooling Loads resulting from the two conditions

The numbers of standard size of air conditioning Units of 7 kW capacity required in the functions room under the two conditions are presented in Table 8.

Similar studies [22] on an overview of compact fluorescent lamp retrofitting and Abolarin et al [23] on energy (lighting) savings in students' hostels, also concluded that savings are achievable when inefficient light bulbs are retrofitted with energy efficient ones. This energy efficiency implementation results in a friendly environment as reported in [24] that over 45% of pollutant emission is prevented from the atmosphere.

Table 8. Quantity of ACs required for installation under the three conditions

Conditions	Cooling Load (W)	Quantity of ACS
Heat gain by the functions room before replacement of lamps	**23229.8394**	≈4 units
Heat gain by the functions after replacement of lamps	**14,361.958**	≈2 units

4.0 CONCLUSION

This study shows that energy efficient technologies when deployed in buildings will help cut down on building energy use and improve human-occupancy comfort. In this paper, selected cooling load of the room was calculated with a focus on replacing the inefficient lightings with efficient ones. Cooling load of the room under consideration amount to **23.23 kW**, this requires four (4) units of 7 kW free blow stand-alone air conditioners. When all the incandescent lamps are replaced, the load reduced to **14.36 kW**, this required two (2) units 7 kW free blow stand-alone air conditioners to condition the room, instead of the initial four 7 kW air conditioner before the exercise. From this retrofitting exercise, a saving of 9 kW is achieved from the total cooling load demand of the functions room. This automatically reduced the number of air conditioners from four (4) to two (2). This analysis clearly shows that a 34.41% savings is achievable from lighting alone. This study, therefore, recommends that energy efficiency technologies should be adopted right from the design stage to reduce the energy demand of buildings.

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