



UNIVERSITY OF NAIROBI

INFLUENCE OF BUILDING DESIGN ON RUNNING COSTS OF LIGHTING IN OFFICE BUILDINGS.

(CASE STUDY: NAIROBI CENTRAL BUSINESS DISTRICT)

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**A research project submitted in part fulfillment for the award of
B.A. (BUILDING ECONOMICS) degree in the Department of Real
Estate and Construction Management, School of the Built
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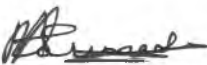
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DECLARATION

I, ASUMA R. ISOE, hereby declare that this project is my original work and has not been presented for a degree in any other University.

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DEDICATION

This work is dedicated to the entire Isoe family who inculcated in me family and community values that I will always treasure in my life. Their contribution to my smooth learning in my entire University life will always be appreciated. I also dedicate it to my very close friends Odindo and Pauline for their very valuable support all through my campus life. God bless you all. Thank you.

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LIST OF ABBREVIATIONS AND ACRONYMS

- i. **CBD** Central Business District.
- ii. **IES** Illuminating Engineering Society.
- iii. **IESNA** Illuminating Engineering Society of North America.

DEFINITION OF TERMS

BALLAST: A device used to operate fluorescent and HID lamps. The ballast provides the necessary starting voltage, while limiting and regulating the lamp current during operation.

COMPACT FLUORESCENT: A small fluorescent lamp that is often used as an alternative to incandescent lighting. The lamp life is about 10 times longer than incandescent lamps and is 3-4 times more efficacious. Also called CFL lamps.

CONTRAST: The relationship between the luminance of an object and its background.

DIFFUSE: Term describing dispersed light distribution. Refers to the scattering or softening of light.

DIRECT GLARE: Glare produced by a direct view of light sources. Often the result of insufficiently shielded light sources.

EFFICACY: A metric used to compare light output to energy consumption. Efficacy is measured in lumens per watt. Efficacy is similar to efficiency, but is expressed in dissimilar units. For example, if a 100-watt source produces 9000 lumens, then the efficacy is 90 lumens per watt.

FLUORESCENT LAMP: A light source consisting of a tube filled with argon, along with krypton or other inert gas. When electrical current is applied, the resulting arc emits ultraviolet radiation that excites the phosphors inside the lamp wall, causing them to radiate visible light.

GLARE: The effect of brightness or differences in brightness within the visual field sufficiently high to cause annoyance, discomfort or loss of visual performance.

ILLUMINANCE: A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly called light level. It is expressed as lumens per square foot (footcandles), or lumens per square meter (lux).

INDIRECT GLARE: Glare produced from a reflective surface.

LIFE-CYCLE COST: The total costs associated with purchasing, operating, and maintaining a system over the life of that system.

LUMINAIRE: A complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source; also called a fixture.

LUMINANCE: A photometric term that quantifies brightness of a light source or of an illuminated surface that reflects light.

LUX (LX): The metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter. One lux equals 0.093 footcandles.

OCCUPANCY SENSOR: Control device that turns lights off after the space becomes unoccupied; it may be ultrasonic, infrared or other type.

REFLECTANCE: The ratio of light reflected from a surface to the light incident on the surface. Reflectances are often used for lighting calculations.

T12 LAMP: Industry standard for a fluorescent lamp that is 12 one-eighths (1 inches) in diameter. Other sizes are T10 (1 inches) and T8 (1 inch) lamps.

VCP: Abbreviation for visual comfort probability. Is a rating system for evaluating direct discomfort glare. This method is a subjective evaluation of visual comfort expressed as the percent of occupants of a space who will be bothered by direct glare. VCP allows for several factors: luminaire luminances at different angles of view, luminaire size, room size, luminaire mounting height, illuminance, and room surface reflectivity.

ABSTRACT

This is a study of office building design and running costs of lighting in an urban setting. The hypothesis of this study is that architectural design parameters have an influence on running costs of lighting.

It has been established in the literature review that the design indicators for running costs of lighting are façade character, window size, position of window, floor area, partitions, shape of building, room height, use of space and colour of room surfaces.

The analysis of data collected indicated that most buildings with adequate provision of natural lighting during the day to support basic office functions still had their lights on even though not required. The need for automatic lighting controls was revealed by this trend of space users forgetting to switch lights off using manual controls.

The study concludes that a relationship exists between running costs of lighting and design parameters. Thus designers should design for economy in terms of lighting costs among other factors.

The study recommends that, for future developments, provision of lighting in office buildings should be considered at the design stage and modern technology in terms of use of automatic lighting controls put into consideration.

CHAPTER ONE

1.1 INTRODUCTION

Light and sight are two words that rhyme and work together; one is meaningless without the other. We need light to see, but light can never be an end in itself, there must be something to light up (The architects' journal information library; 4th January, 1967pg 35).

The Architects' Journal Information (A.J.I) library isolates four main functions of lighting in buildings as follows:

- i) Is an amenity – It reveals the shape, size and colour of each element, proportions of each separate space and relationships between elements and spaces of which the building is composed.
- ii) Is a pre requisite for the satisfactory performance of almost any visual task - In the U.S.A., and Russia, a lot of emphasis is laid upon the relationship between performance and illumination. Over the range of values studied by Weston, (H.C. Weston, England), (A.J.I. Library, 1967) the proportions of mistakes decreased as illumination increased.
- iii) Aids in the safe movement of people in and about the building without risk of falling or collision.
- iv) Can be used in special; areas like bars, restaurants and discotheques to achieve a deliberate aesthetic effect.

It is in view of the above basic functions of light that this research is being undertaken since from a look at the many structures that are coming up, there seems to be no serious consideration being given to the concept of reducing costs of lighting in office buildings.

This research paper will act as an eye opener to various stakeholders in the construction industry and will also provide a quick reference to students and government authorities who might want to get a collection of well documented information on running costs of lighting in office buildings. This study is based on office blocks but the findings are also applicable to several other buildings including industrial, residential, retail, schools and hospitals.

The sample size of the research will be 48 office buildings within the Central Business District of Nairobi City.

The sources of information include existing literature, visits to case study offices, the internet and interviews with landlords, tenants and the architects. This research has used both qualitative and quantitative methods to analyse collected data from the field.

This research project constitutes five chapters. Chapter one consists of a brief introduction of the study, the problem statement, the objective, hypothesis, significance of the study and scope of the study. Chapter two presents an analysis of lighting and lighting systems in office buildings and their controls. It also discusses the design principles and design parameters as well as the relationship between running costs of lighting and the building design.

Chapter three elaborates on the research methodology with special emphasis on the research planning, data collection and data analysis procedures. Chapter four presents a quantitative and qualitative evaluation of the data obtained from the sample. The last chapter dwells on conclusions and

recommendations based on the data analysis. Potential areas of future research are also suggested.

1.2 Problem Statement

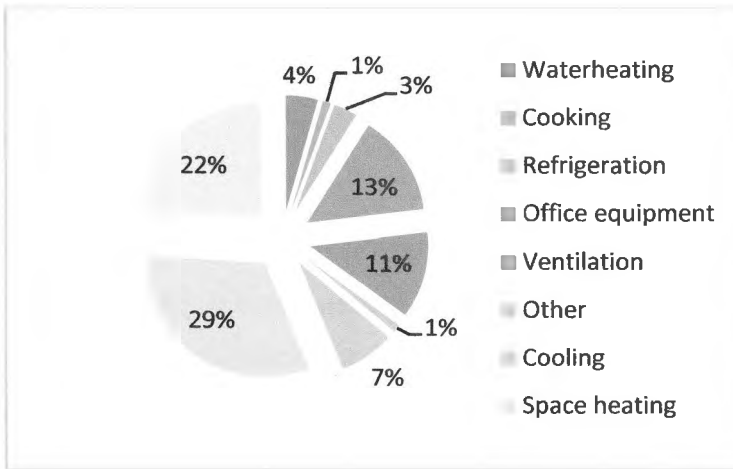
Bell (1995), notes that an important policy problem facing African countries and indeed all the developing countries is that of identifying the appropriate technology for their industries. Hopkinson (1969) in his book “Daylighting of Buildings” aptly captures this problem and states: The worst buildings in the tropics import the traditions of colonising countries with little or no intelligence applied to modify this alien tradition to the totally different climatic conditions (page 232).

Unfortunately, a casual look at buildings in Kenya will confirm that we are equally guilty of this accusation of blind importation. Most high rise structures are set up without a careful consideration of the cost implications of the adopted designs on running cost of lighting, maintenance, heating, ventilation, water provision and other engineering services.

As per a research carried out by the U.S Department of Energy (1994), lighting is the largest cost component of a commercial building’s electricity bill (Figure 1) and a significant portion of its total energy bill.

This makes the lighting component an important consideration when trying to control electricity costs of a given office block building or even an office space within a given building.

Figure 1: Lighting Share of Office Building Electricity Use



Source: U.S. Department of Energy, Energy Information Administration, *Energy End Use Intensities in Commercial Buildings*, Sept. 1994.

From the above analysis conducted by the U.S. Department of Energy, it is apparent that lighting is a cost component that cannot be ignored in commercial buildings. Considering that Nairobi and Kenya in general is within the tropics, space heating that accounts for 29% of electricity use in commercial buildings in the United States is not a consideration in our situation thus making lighting the highest consumer of electricity in office buildings in the tropics.

The two fold reasons that have prompted this research are the high costs of lighting in office buildings and the design errors/decisions made by designers which may, among other things, contribute to the high costs of lighting in commercial buildings.

Researches conducted by both the Building Research Establishment and the U.S. Department of energy indicate that lighting in commercial buildings constitutes 25 – 30% of energy use. However, in most cases, office lighting design is based on how pleasing the design is to the designer and the building owner. Unfortunately both of them won't work in the space and may also not

incur the high costs of lighting. Thus these costs will be transferred to the tenants who will have to shoulder unnecessary high costs in terms of electricity bills and extra costs to modify the internal lighting environment to fit their various requirements.

The Good Practice Guide 245 (1998) notes that it goes without saying that without light we cannot see. It emphasizes that without good lighting however, we cannot see well and its absence means both human and electrical energy can be wasted. It further states that sadly, many lighting installations are designed by non-specialists, and too often only some of the requirements are considered, usually the illumination of tasks and the capital cost of the installation.

The above statement is a reality in the Kenyan situation and introduces another angle of non employment of professional services in the design and commissioning of electrical and other services in commercial buildings. It is of paramount importance for developers to appreciate the value of incorporating the right professionals right from the inception stage of their buildings; especially for commercial buildings where tenants are very sensitive about the building's performance efficiency.

However, in some situations, the right professionals are engaged but designers end up making design errors. These include non consideration of the building's environment in design of various services, irregular and complicated design shapes of the buildings, expanse floor areas that are very deep and building space without adequate natural ventilation and light.

Osas (2005) notes that we can make full use of artificial lighting if from the Architectural design stage adequate and deliberate provisions are put in place to naturally light up walk-ways, staircases, bathrooms and toilets etc during day time. He further indicates that you will find corridors, toilets, and staircases

including fire escape routes that are completely dark during daytime. This necessitates use of artificial lighting, which could be avoided.

Following is a discussion of the design errors and their influence on lighting costs.

1.2.1 Non consideration of the building's environment in design of various services – Osas (2005) has noted that for third world countries geographically located in regions with plentiful sunshine most of the day, there is no reason why natural lighting should not be used in most of our offices, classrooms, Hospital wards, Outpatient Departments and Lecture rooms in order to reduce the ever rising cost of Electricity. He concludes that artificial lighting should only be used as a supplement. It is therefore imperative that designers take into account the prevailing environment and use their experience and expertise to achieve a good balance of both artificial and natural lighting in office spaces. Thus, costs that would have been avoided are incurred hence raising the overall lighting charges of an office building.

1.2.2 Irregular and complicated design shapes of the buildings – Seeley (1996) has pointed out that office buildings with complicated and irregular design shapes require a large number of service points in a building. This is expressed by the large amount of plumbing and electrical works which have to be installed. Conversely, the large number of electrical works will incur higher costs that would have been avoided had the design been simple.

1.2.3 Expanse floor areas – Joedicke (1962) observes that expanse floor area in office buildings is a design error because the building has to depend permanently on artificial lighting and ventilation. This maybe remedied by using excessive lighting fittings and fixtures to make the spaces conducive to functions they are intended for. Considering that the estimated cost of lighting is between 25% and 30% of electrical energy spent in office buildings, any factor

that will contribute to an increase in this cost will have a negative impact on the market competitiveness of the final structure.

1.2.4 Inadequately ventilated and lit areas – Rukwaro (1990) observes that designers of some office buildings in Nairobi have made errors by providing inadequate or no natural lighting in some building spaces. Osas (2005) also observes that corridors, toilets, and staircases including fire escape routes are completely dark during daytime in some buildings in Nairobi. This necessitates use of artificial lighting, which could be avoided thus attracting unnecessary high costs of lighting.

Rea (1999) notes that, the choice of using either artificial or natural lighting in a given space or a combination of both is at the designer's discretion. Kohn (1990) observes that Daylighting is the controlled admission of natural light into a space through windows to reduce or eliminate electric lighting. He further notes that by providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as one-third of total building energy costs.

It is therefore important that designers, especially in tropical regions such as Kenya where there is adequate sunlight during day time, understand the benefits of sunlight and incorporate its use wherever possible. These benefits as noted by the National Institute of Building Sciences (2001) include:

- i. **Improved Life-Cycle Cost:** At an estimated incremental first cost increase of from \$0.50 (Ksh 35) to \$0.75 (Ksh 53) per square foot of occupied space for dimmable ballasts, fixtures and controls, daylighting has been shown to save from \$0.05 (Ksh 4) to \$0.20 (Ksh 14) per square foot annually [in 1997].

- ii. **Increased User Productivity:** Daylight enlivens spaces and has been shown to increase user satisfaction and visual comfort leading to improved performance.
- iii. **Reduced Emissions:** By reducing the need for electric consumption for lighting and cooling, the use of daylight reduces greenhouse gases and slows fossil fuel depletion.
- iv. **Reduced Operating Costs:** Electric lighting accounts for 35 to 50 percent of the total electrical energy consumption in commercial buildings. By generating waste heat, lighting also adds to the loads imposed on a building's mechanical cooling equipment. The energy savings from reduced electric lighting through the use of daylighting strategies can directly reduce building cooling energy usage an additional 10 to 20 percent. Consequently, for many institutional and commercial buildings, total energy costs can be reduced by as much as one third through the optimal integration of daylighting strategies.

Evans (1999) notes that overlooking opportunities for skylights is a major defect of many building designs, but lack of coordination of interior light banks with indirect sunlight is an even more common error. He argues that at a minimum, the building design should offer sufficient independent light banks so that building occupants may select the most suitable combination of natural to augmented light. He further indicates that very frequently entire floors of office buildings are designed with only one switch, so that perimeter areas near natural light are illuminated with the same level of man-made light as the dimmest interior zones.

Bell (1995) observes that this lack of independent controls also would require an entire office floor of say 10,000 square feet (1,000 m²) to be fully illuminated if one office worker stays late for evening work. He further notes that this can

occur with even the most eminent of architects. He quotes Frank Lloyd Wright as having designed Marin County Civic Center in 1957 with only one or two switches serving very large floor footprint office pools. This cost Marin County several thousands of dollars per annum in unneeded electricity costs.

The Good Practice Guide 160 (1997) indicates that designers have the responsibility to advise clients on the use of lighting controls so as to ensure that they only pay for light that they actually need. It further notes that research has been conducted showing worker productivity gains in settings where each worker selects his or her own lighting level. Osas (2005) observes that although such a design may look costly initially, the life cycle cost of such a venture is worthwhile to both the developer and the tenants in the longrun. It would thus be advisable that the professionals inform their clients of the advantages of such a system.

Bell (1995) notes that for a daylighting strategy to be successful, the designer must effectively design the electric lighting system and specifically, an effective controls strategy.

1.2.5 Electric Lighting Design: The Good Practice Guide 272 (1999) indicates that the key is to have an overall vision of how the lighting system and lighting controls integrate with the daylighting scheme.

Harris (1998) also observes that lighting is a tremendously important architectural element that has far-reaching impacts on energy consumption, operating costs, aesthetics and ambience, user satisfaction, worker productivity,

and the environment. He further notes that lighting is often relegated to low-priority status within the design/build process, when in reality it should be considered upfront and incorporated into the entire building design for maximum effect and benefit.

From the foregoing quotes, it is clear that electric lighting and daylighting systems should be designed so that they are integrated and complementary.

There should be adequate measures taken before hand to ensure that all necessary factors are taken into consideration during the design process so as to produce a final product that meets not just the basic requirements but one that goes a step further to improve user satisfaction (Bell 1995).

The Good Practice Guide 300 (2002) identifies lighting controls as a major area of integration. It further notes that daylighting entails the use of daylight as a primary source of illumination. It emphasizes that since daylight is generally available during hours when most commercial buildings are occupied, daylighting is often feasible.

Bell (1995) argues that, if the lights are operating at full output when there is ample daylight available, then no energy is being saved and the owner is wasting money. He further indicates that if the building is heated or cooled, daylighting may even result in a net increase in energy consumption if daylighting controls are not present. He notes that lighting controls make a daylit space an energy saving opportunity. He concludes that daylight harvesting means simply making use of daylight and reducing electric light

intensity in the building; since daylight is in plentiful supply, its harvesting should be a top priority of any designer.

Finally, Wise design choices can meet lighting needs and save energy. This is what the designers in our situation should be encouraged to follow.

The aim of this study is to highlight the high costs of lighting in our commercial buildings which have either been ignored or have not been given serious consideration by stakeholders in the construction industry and for which designers are mostly responsible. Designers should consider the concept of minimizing lighting costs as one their priorities in office building design.

1.3 Objectives of Study

The main objective of this study is to establish the relationship between building design and the cost of lighting in office buildings by:

- i) Establishing the responsiveness of the buildings designed and set up in Nairobi to measures aimed at lowering operating costs of lighting.
- ii) Establishing the role of the building designers in regard to designing and implementing building designs appropriate to our economic situation.

1.4 Hypothesis

The hypothesis to be tested in this study is that the design considerations of a building have an effect on running costs of lighting in office buildings.

1.5 Significance of Study

This study will undertake to act as an eye opener to both clients and professionals in the construction industry of the need to consider the prevailing climatic conditions in their design and to look at all the necessary factors at the design stage of construction before making decisions that may have great financial consequences in future.

It will also add to some of the already existing academic knowledge considering that not much study has been done by scholars on this subject.

1.6 Scope of Study

Due to financial and time constraints, the study will be limited to office buildings in Nairobi's Central Business District. This region has been selected due to the large number of high rise office buildings available there.

1.7 Research Methodology

The research adopts both primary and secondary methods of data collection. Secondary data has been collected through reading books and accessing the internet. Some data has also been collected through actual observation. Interviews have also been conducted with several groups of people including architects, building developers, tenants and other stakeholders in the construction industry.

Questionnaires were administered to collect primary data; these were given to architects, tenants and landlords.

CHAPTER TWO

LITERATURE REVIEW

This chapter gives a critical review of design principles and design parameters in buildings as well as giving an introductory analysis of light and lighting design in office buildings. It concludes by giving an insight on considerations made by various designers in the industry and points out where the designers should give more emphasis on future designs.

2.1 Introduction

Hopkinson (1969) notes that after the development of the fluorescent, an abundance of light for little energy was made easily available. Cheap energy led to the concept that, "More light is better light," which unfortunately became an industrial standard.

Osas (2005) observes that in commercial interiors, the general practice has been to fill the ceiling with evenly distributed area type luminaires sometimes supplemented with incandescent down lights to cover the difficult areas.

Sorca (1990) also notes that this practice continued unchallenged throughout the early seventies. He further notes that with the energy crunch at that time, a major change occurred in the style of lighting design. Harris (1998) concurs and states that as energy costs skyrocketed, the flaws in the "more light is better light" concept became painfully apparent. He further notes that in a renewed form it was felt that merely reducing the level of the light to save energy (which proved counter productive) wasn't necessarily the answer.

Evans (1999), notes that in the commercial atmosphere, work is constantly regulated by many factors which include; visual, aesthetical, psychological, physiological et al. He observes that this dynamic workforce cannot be effectively controlled by a static lighting level. He concludes that the system must be flexible with provisions for fine tuning to specific needs.

The Illuminating Engineering Society (IES-2005) notes that lighting is often relegated to low-priority status within the design/build process; when in reality it should be considered upfront and incorporated into the entire building design for maximum effect and benefit. It recommends that this should change because of the huge cost implications such a move has especially in large building projects.

2.2 Lighting design

Rea (2000) notes that the process of designing anything is about solving a problem, or perhaps a series of problems. He notes further that the problem might be the design for a supermarket trolley, the cover for a new book or a lit environment for a modern office, but whatever it is, the starting point is the same i.e. to identify all aspects of the problem.

He further notes that in terms of lighting, whether it is daylighting, electric lighting or as is more usual, a combination of the two; it means analysing all the requirements and the constraints for the particular application, including the people and the building it applies to. Further, the designer also needs to consider the positive benefits good lighting can bring, such as creating a pleasantly lit space with a level of visual interest appropriate for the application in a way that complements the architecture.

Energy efficiency is also a vital consideration to minimise the emission of greenhouse gases and the resulting climate changes, which could damage the environment for future generations (Illumination Engineering Society of North America- IESNA, 2003).

Bell (1995), notes that an artificial lighting system must work with a daylight system when natural illumination falls below recommended levels. He recommends that this is a factor that designers should always put into consideration when designing lighting for various spaces.

Sorca (1990) notes that office designers and builders can reduce lighting energy use by selecting light fixtures and sources that use energy more efficiently, and by installing controls to reduce the amount of time lights are on.

2.3 Types of Lighting Systems in Office Buildings

Hopkinson (1969) notes that the lighting systems generally available to most designers are natural and artificial. He further notes that the use of either of them or both depends on mostly the availability and reliability of the system under consideration as well as the requirements of the developer. He indicates that in the tropics however, there is plenty of natural light all year round which makes use of natural light in office buildings a very viable consideration.

He also notes that however, there are situations where the designer might not incorporate natural lighting even in situations where it is in plentiful supply and therefore eliminating it as an option to be considered. This is mostly in the case where the building is to be used for highly sensitive purposes and hence requires total blockage of the outside. This is mostly in cases of highly sensitive security matters or very delicate researches.

2.3.1 Artificial Lighting

Evans (1999) states that, "The simple and basic need of artificial lighting is to provide illumination to read fine print." He further notes that it has been established beyond reasonable doubt that the provision of more light enables people to do finer visual work and to appreciate color in greater richness. This shows that the significance of artificial lighting in office buildings cannot be over emphasized in that, in offices, most of the work being done has a great effect on whether the particular entity remains competitive in its respective market or not. Hence, sufficient lighting of whichever kind is always needed in office spaces.

The I.E.S. (2001) notes that artificial lighting is required for the following purposes:

- i. To light the building after dark.
- ii. To supplement day light where necessary.
- iii. To provide special lighting on difficult visual tasks.
- iv. To maintain attention on the work.
- v. To ensure safety and alertness.

The I.E.S further notes that the first two requirements demand a general distribution of light about the building in sufficient quantity. The last three requirements can only be met by a combination of suitable building lighting and localized lighting controlled strictly with reference to the points where it is needed. The last requirement also demands the provision of an emergency lighting system to be brought into action should the main lighting fail.

Artificial lighting in most office spaces is provided by fluorescent and incandescent lamps. These are discussed further below.

2.3.1.1 Incandescent lighting

The Lamp guide (2001) notes that incandescent lighting has traditionally delivered about 85% of household illumination. Their use in office spaces is however limited to stores and sometimes washrooms. Incandescent lamps operate without ballast, are dimmable and instantly controllable, and light up instantly. Most familiar are the standard pear-shaped, screw-in "A"-type incandescent light bulbs. They produce a warm light and provide excellent color rendition. They have a low efficacy compared to all other lighting options (10 to 17 lumens per watt) and a short average operating life (750 to 2500 hours).

Incandescent lamps can be made in other shapes and variations.

Tungsten halogen lamps provide excellent color rendition. Reflector (R) and parabolic aluminized reflector (PAR) lamps direct light in a desired direction. All three are slightly more efficient than standard bulbs, have longer operating lives (2000 to 4000 hours), and are often used for accent lighting (I.E.S, 2001).

2.3.1.2 Fluorescent lighting

According to the Lamp Guide (2001), these use 25 to 35 percent of the energy used by incandescent lamps to provide the same amount of illumination (efficacy of 30 to 110 lumens per watt) and last about 10 times longer (7,000 to 24,000 hours). Improvements in technology have resulted in fluorescent lamps with color temperature and color rendition that are comparable to incandescent lamps. Fluorescent lamps require a ballast to regulate operating current and provide a high start-up voltage.

Electronic ballasts outperform standard and improved electromagnetic ballasts by operating at a very high frequency that eliminates flicker and noise. They are also more energy-efficient. Special ballasts are needed to allow dimming of fluorescent lamps. Two general types of fluorescent lamps are available. The traditional tube-type fluorescent is usually identified as T12 or T8 (12/8 or 8/8 of

an inch tube diameter, respectively) and is installed in a dedicated fixture with built-in ballast.

The newer compact fluorescent lamps (CFLs) and circlines have smaller diameters and are usually bent or twisted into compact shapes. These are frequently sold with built-in or separate electronic ballasts and screw thread adapters for application in fixtures designed for incandescent bulbs. Dedicated fixtures that are equipped with electronic ballasts and that use plug-in (pin) CFLs are also available.

The CFLs and circlines have been found to be more efficient in energy utilization compared to the traditional T8 or T12 tubes. They are also better in directional lighting and thus more appropriate to current needs (Lighting technologies.com).

2.3.2 Natural Lighting

Sorca (1990) defines daylighting as the controlled admission of natural light into a space through windows to reduce or eliminate electric lighting. He further notes that by providing a direct link to the dynamic and perpetually evolving patterns of outdoor illumination, daylighting helps create a visually stimulating and productive environment for building occupants, while reducing as much as one third of total building energy costs.

The Good Practice Guide 300 (2002) notes that there are however several factors that have to be put into consideration to enable effective and efficient natural lighting of a given space. It indicates that this involves more than just adding windows or skylights to a space. It explains that it is the careful balancing of heat gain and loss, glare control, and variations in daylight availability. For example, successful daylighting designs will invariably pay close attention to the use of shading devices to reduce glare and excess contrast in

the workspace. Additionally, window size and spacing, glass selection, the reflectance of interior finishes and the location of any interior partitions must all be evaluated.

In most buildings, the most frequently used daylighting strategies are toplighting and sidelighting strategies. These are further discussed below.

2.3.2.1 Toplighting Strategies

Good Practice Guide 245 (1998) notes that large single level floor areas and the top floors of multi-storey buildings can benefit from toplighting. It identifies the general types of toplighting as including skylights, clerestories, monitors, and sawtooth roofs. These are further discussed below.

i. Skylights

Lighting Guide LG10 (1999) states that horizontal skylights can be an energy problem because they tend to receive maximum solar gain at the peak of the day. The daylight contribution also peaks at midday and falls off severely in the morning and afternoon. It further notes that there are high performance skylight designs that incorporate reflectors or prismatic lenses that reduce the peak daylight and heat gain while increasing early and late afternoon daylight contributions.

It also indicates another option as lightpipes where a high reflectance duct channels the light from a skylight down to a diffusing lens in the room. These may be advantageous in deep roof constructions.

ii. Clerestory Window

Lighting Guide LG10 (1999) defines a clerestory window as vertical glazing located high on an exterior wall. It further notes that South-facing clerestories can be effectively shaded from direct sunlight by a properly designed horizontal overhang. In this design, the interior north wall can be sloped to better reflect the light down into the room.

It recommends that Light-colored overhangs should be used with adjacent roof surfaces to improve the reflected component. If exterior shading is not possible, interior vertical baffles ought to be considered to better diffuse the light. A south-facing clerestory will produce higher daylight illumination than a north-facing clerestory. East and west facing clerestories have the same problems as east and west windows: difficult shading and potentially high heat gains.

■ Clerestory window

Here stepped clerestory windows provide daylight for the interior workspace.



Plate 2.1: Clerestory window

Source: Lighting technologies.com

iii. **Roof Monitor**

Lighting Guide LG10 (1999) states that a roof monitor consists of a flat roof section raised above the adjacent roof with vertical glazing on all sides. It notes that this design often results in excessive glazing area, which results in higher heat losses and gains than a clerestory design. The multiple orientations of the glazing can also create shading problems.

iv. **Sawtooth Roof**

Lighting Guide LG10 (1999) notes that a sawtooth roof is an old design often seen in industrial buildings. Typically some sloped surface is opaque and the other is glazed. A contemporary sawtooth roof may have solar collectors or photovoltaic cells on the south-facing slope and daylight glazing on the north-facing slope.

2.3.2.2 Side lighting strategies

This is the controlled admission of natural light from the sides of buildings. This is mostly through the use of windows and lightshelves which are further discussed in depth below.

i. **Windows**

Bell (1995), notes that a standard window can produce useful illumination to a depth of about 1.5 times the height of the window. He further notes that with lightshelves or other reflector systems, this can be increased to 2.0 times or more. He also indicates that as a general rule-of-thumb, the higher the window is placed on the wall, the deeper the daylight penetration.

Window Design Considerations (Bell, 1995)

The daylight that arrives at a work surface comes from three sources:

- i. The exterior reflected component - This includes ground surfaces, pavement, adjacent buildings, wide windowsills, and objects. The designer should however remember that excessive ground reflectance will result in glare. He should thus get a way to avoid this.
- ii. The direct sun/sky component - Typically the direct sun component is blocked from occupied spaces because of heat gain, glare, and Ultra Violet degradation issues. The sky dome, due to its reflectance, then becomes an important contribution to daylighting the space.
- iii. The internal reflected component - Once the daylight enters the room, the surrounding wall, ceiling, and floor surfaces are important light reflectors. Using high reflectance surfaces will better bounce the daylight around the room and it will reduce extreme brightness contrast. Window frame materials should be light-colored to reduce contrast with the view and have a non-specular finish to eliminate glare spots. The window jambs and sills can be beneficial light reflectors. Deep jambs should be splayed (angled toward the interior) to reduce the contrast around the perimeter of the window.

According to the Good Practice Guide 245 (1998), the most important interior light-reflecting surface is the ceiling. Tilting the ceiling plane toward the daylight source increases the daylight that is reflected from this surface. In small rooms the rear wall is the next important surface because it is directly facing the window. This surface should also be a high reflectance matte finish. The sidewalls followed by the floor have less impact on the reflected daylight in the space. Major room furnishings such as office cubicles or partitions can have a significant impact on reflected light so light-colored materials should be selected.

For office materials, the I.E.S recommended surface reflectances are:

Ceiling 80-90%

Walls 40-60%

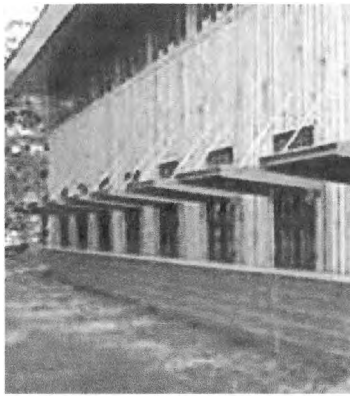
Floors 20-40%

Furnishings 25-45%

ii. Light Shelves

The Installer's Lighting Guide 004 (2001) indicates that since luminance ratios or brightness is a major consideration in view windows, it is often wise to separate the view aperture from the daylight aperture. This allows a higher visible transmittance glazing in the daylight aperture if it is out of normal sight lines. Since the ceiling is the most important light-reflecting surface, using this surface to bounce daylight deep into the room can be highly effective. Both of these strategies are utilized in light shelf designs.

A light shelf is a horizontal light-reflecting overhang placed above eye-level with a transom window placed above it. This design, which is most effective on southern orientations, improves daylight penetration, creates shading near the window, and helps reduce window glare. Exterior shelves are more effective shading devices than interior shelves. A combination of exterior and interior will work best in providing an even illumination gradient.



Light bounces off the top of the light shelf into the ceiling of the first floor offices.
The overhang shades the window below it.

Plate 2.2: Light shelves

Source: [Lighting technologies.com](http://lightingtechnologies.com)

Heschong (2005) identifies skylights combined with daylighting controls as the baseline efficiency standard for big box-type spaces. She further notes that a prescriptive provision requires skylights in these big box buildings, specifically skylights with controls to shut off the lights when daylight is available. The provision applies to buildings greater than 25,000 square ft with more than 15 ft. high ceilings, and to spaces directly under a roof and with general lighting power density of more than 0.5W/square ft. For these spaces, at least one-half of the floor area must be daylit using skylights. The skylights must have a glazing material or diffuser that effectively diffuses the skylight.

She further adds that, for daylit areas larger than 250 square feet, at least one control is required to either, control 50% of the power, control fixtures in vertically daylit areas separately from horizontally daylit areas, or maintain uniform levels by means of dimming or alternating lamp/fixture switching. For daylit areas over 2,500 square feet, she recommends that general lighting has

to be controlled separately with either automatic multi-level daylighting control or multi-level astronomical time switch.

2.4 Design Principles and Design Parameters of Buildings

This section discusses the pertinent guiding principles used by designers to form an enclosure which is served with these lighting systems. The design principles guide the designer in his decision making process. The ultimate tangible aspects which the designer may consider while designing constitute the design defined below.

Rukwaro (1990) in his MA Thesis quotes Pye (1978) and Raman (1980) as having identified that design is a problem solving activity and the designer always has the freedom of choice in deciding the central issue. Pye (1978) in particular states that design involves rejection of many tentative versions of design before one is found that satisfies exact sensibility.

He further points out that Pye (1978) stresses that the designer has to understand, master, be systematic, analytical and rational in making decisions involved in design. Rukwaro (1990) also quotes Philpott (1975), Hartkopt (1973), and Manasseh and Cunliffe (1968) who have hypothesized that a decision made during the early stages of a design ultimately affects the future building cost.

Stone (1980), in explaining the concept of design says that a designer tries to achieve several goals, among them: appearance, soundness of construction, internal comfort and convenience to the client; the contract price and effective maintenance cost of design.

Rukwaro (1990), quoting Gasson (1973) identifies visual perception, visual dominance, static and dynamic effects, colour, unity and composition, continuity, rhythm, balance, line, shape, proportions and form as design principles. Hence, the design principles used by designers are within this range.

All these design principles, as conveyed in these studies, are devoid of lighting system design appropriate for a given type of building. It seems as if designers consider lighting systems in buildings as being a secondary factor that need not be incorporated in building design right from the first step of design. This in itself is a design error as noted by Hopkinson (1969).

He further notes that the consequences of relegating lighting design to after completion of the building has the effect of setting up structures that don't take advantage of available resources in their natural environment such as daylight which contributes eventually to unnecessary high costs of lighting especially in office buildings.

He regrets that it is unfortunate that most designers think that after achieving a functional and aesthetically sound building design, their responsibility to the client is complete. This is a wrong attitude in that the efficiency of the building in terms of resource utilization is also a very important factor to the building owner and his tenants. This is because it will affect the building's marketability in that, if the owner is to meet the high electricity costs, then he will have to pass them on to the tenants through high rent rates.

Alternatively, if the tenants are to meet these costs on their own, they might opt for other buildings where they will pay lower rates since they are business

people and they won't want to incur unnecessary expenses. Thus the designer should design buildings with such factors as economy on lighting costs in mind as this might determine whether or not the building owner will get clients.

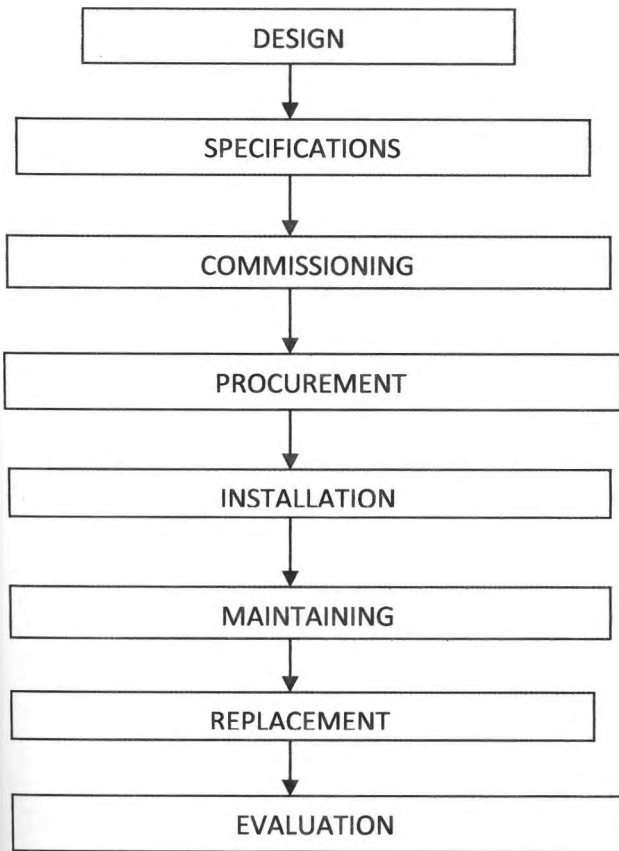
Bell (1995) notes that lack of a proper and elaborate building lighting system in the early stages of design may mean that the building is destined to be unsatisfactory; it may, for example, be very expensive for the occupants to keep up with the remedial measures required to contain the designers' errors.

He further notes that it would be advisable that, for any design principle that the designer wants to accentuate and execute properly, the concept of an effective and appropriate lighting system is considered too. This is because lighting costs within a building are great determinants of its competitiveness in the market as earlier noted.

Rukwaro (1990) quoting Carpenter (1975), states that the terotechnology concept should be effectively pursued by designers and clients in present day organization of building services. He suggests that designers should relate design to maintenance and operational costs. This statement cannot be over emphasized in that lighting costs are part of operational costs which in the longrun affect the life cycle costs of a building; which might end up making a potentially viable investment in construction uneconomical and hence be abandoned totally.

The adapted chart model from Rukwaro's thesis presents terotechnology life cycle (Figure 2.1). The model identifies the effective stages that the building

design team should follow for proper integration of design and maintenance of various building services.



Legend



Life cycle phases



Flow of information

Figure 2.1 Terotechnological life cycle

Source: Harvey, G. (1978)

The model however does not give the quantitative presentation of how to relate building costs to design variables.

Lucey, T. (2002) notes that the life cycle costing concept is the time over which the life cycle cost of an asset, including the cost of ownership is analysed. He further states that it is concerned with planning to achieve the optimum assets' life cycle costs. Rukwaro (1990), quoting Kline (1971), identifies design as one of the stages of lifecycle costing. He notes that as design progresses, decisions are made at critical points and they are effective only if relevant information is available at the appropriate time.

The above discussion acts as a powerful pointer towards taking effective steps during design of, in our case, the lighting considerations of the various spaces within the office building. This will have a long term impact on the life cycle costs of the building and research by the Building Research Establishment has shown that where lighting design is done at initial stages, the costs are lower than a case where lighting design is done during construction or on completion of the structure.

The design principals discussed in this research mainly revolve around the aspects of organization and geometry of the designed buildings. These aspects are considered to have a strong influence on the running costs of lighting in office buildings. The design variables depicted are organization of space, unity of composition, shape, rhythm, proportion and form.

These principles have been selected because they have a relationship with the measured design parameters such as height, floor area, window areas, shape and perimeter of the building. This relationship is discussed below.

Organization of space – Rukwaro (1990), quoting Isaac (1971), defines the organization of space as the valid spatial arrangements which can only be devised from adequate consideration of the creation of internal and external volumes and interrelationship and behavior of objects, elements and people within the defined field of vision.

From these definitions of space, one can infer that space is physically defined by its size and shape. The space maybe measured by use of height, area, perimeter and number of storeys. It should be put in mind that room dimensions and finishes also affect the required light output and thus the energy consumption of all interior lighting systems. Hence, they should be put into serious consideration during the design process.

Research has shown that light penetrates up to 1.5 times the height of the opening as noted earlier. Hence, the organization of a particular space will determine the amount of natural light the given space receives.

Unity of composition – Gasson (1982) describes unity of composition as the relationship among all the parts of a designed building. Such relationship must seem natural, whole and pleasant to the eye. To achieve unity of composition, the designer is guided by an accepted contemporary style. This is the single most important design principle.

It can be concluded that unity of composition is related to both size and shape of a building which are themselves design parameters.

Shape of building – Gasson (1982) defines shape as the area of a space enclosed by more than two lines. Thus, the shape of a building is the area in

space enclosed by the building elements. The basic geometrical shapes are triangles, rectangles, squares and circles.

Rukwaro (1990), quoting McGuinness (1971), notes that proportion will often determine the spacing and mounting of luminous sources.

2.5 Running Costs of Lighting and Building Design Parameters

This section discusses the relationship between design parameters and running costs of lighting in office buildings. The design parameters reviewed in this research have been used by other authors to give either a quantitative or descriptive explanation of the total cost of a building.

Seeley (1996) has identified the following design variables as indicators of building costs: shape, size, storey height, total height, circulation ratio and fenestration of a building. These are also some of the design parameters that the researcher has established to have an effect on running costs of lighting in buildings.

Stone (1980) has established that the price of a building may be based on the following design parameters: building type, floor area, number of storeys, shape and form. It is likely that these factors used to cost a building can also be indicators of the cost of lighting the structure under consideration since they are defining a given building.

This review confines itself to the following design parameters as listed below:

- i) Façade character (Recessed or plain)
- ii) Window sizes

- iii) Position of windows
- iv) Floor area
- v) Partitions within various spaces in the building
- vi) Room height
- vii) Use of space
- viii) Color of room surfaces

These parameters are considered as surrogates of office building design. The following is a discussion on each of these factors.

Façade character: Bell (1995) notes that the façade character of a building has the effect of either increasing or reducing the surface area of a building exposed to daylight. The Illuminating Engineering Society of North America (IESNA-2001) recommends increase of perimeter daylight zones by extending the perimeter footprint to maximize the usable daylighting area.

Seeley (1996) has observed that different plans can be compared by examining the ratio of their enclosing wall to floor (perimeter/floor area ratio). He argues that the lower the wall/floor area ratio, the more economical the building's initial and running costs. One can infer that the lower the wall/floor area ratio, the lower the lighting cost of the various spaces within the building.

Hence, there is a relationship between the façade character of the building and the lighting cost of the building. It can thus be assumed that the façade character of a building varies directly with the costs of lighting in a building.

Floor area: Stone (1980) notes that the more the lighting fittings used per unit area of the floor, the greater the cost of cleaning tubes, replacing fittings and electricity used. Thus, the larger the floor area, the more the number of lighting fixtures which have to be installed to serve the large spaces that need to be lit. However, it is also true that a single luminaire can serve large areas especially a fluorescent tube luminaire. In this case, there will be less energy used to cover a large area. Alternatively, if the same area is subdivided into smaller units, each unit will require its own independent luminaire which will translate to higher lighting charges.

Area of windows: The layout of the building affects the amount of daylight entering the room through the glazed surfaces. Rukwaro (1990), quoting Koeningsberger (1980), notes that the amount of electrical lighting in the spaces during the day relates to the amount of daylight received in the spaces; which in turn relates to the amount of glazed areas.

Stone (1980) has noted that buildings with deeper spaces are not adequately lit through the openable windows. This, in effect, raises the capital and running costs of lighting appreciably. Seeley (1996) concurs with Stone (1980) by noting that increasing the depth of the space in the building may result in increased operational cost through higher artificial lighting charges because no ample natural light penetrates through the window areas. He further notes that as the window area increases, more sunlight penetrates the rooms and less electrical lighting is needed.

The area of windows is a continuous variable. It can be derived from the above argument that the area of windows in multi storey buildings varies directly with the running cost of lighting.

Position of windows: Bell (1995) notes that as a general rule-of-thumb, the higher the window is placed on the wall, the deeper the daylight penetration. He further notes that windows located high in a wall or in roof monitors and clerestories will result in deeper light penetration and reduce the likelihood of excessive brightness.

The IESNA (2001) design requirements further recommend that the position and shape of the fenestration must be planned to complement the surroundings and increase workers' efficiency.

The IES (2005) recommends that the sizes and locations of windows should be based on the cardinal directions rather than their effect on the street-side appearance of the house. Giving temperate climates as an example, it notes that South-facing windows are most advantageous for daylighting and for moderating seasonal temperatures because they allow most winter sunlight into the home but little direct sun during the summer, especially when properly shaded.

It further indicates that North-facing windows are also advantageous for daylighting because they admit relatively even, natural light, producing little glare and almost no unwanted summer heat gain. Further, it states that although east- and west-facing windows provide good daylight penetration in the morning and evening, respectively, they should be limited because they may cause glare, admit a lot of heat during the summer when it is usually not wanted, and contribute little to solar heating during the winter.

It thus can be derived from this analysis that location of windows varies directly with running costs of lighting.

Room height: The IESNA (2001) recommends that pendant-style direct/indirect fixtures should not be used if the ceiling height is less than 2.75 m. It further notes that for best light distribution, pendants should be hung at least 0.46 m from the ceiling. The amount of light in the room is also influenced by the height of a given space in that, if the room height is very high, the designer has to provide more luminaires so as to provide sufficient illumination in the given space.

It can thus be derived that the higher the room height, the higher the energy requirement of the given space.

Shape of the building: Seeley (1996) notes that the shape of the building is determined by aesthetics, function, natural daylighting hours and cost. He further notes that the shape of the building has an influence on cost. He argues that a narrower and longer building or a complicated and irregular floor area outline has higher perimeter/floor area ratio and this increases the building cost. It thus can be reasoned that a complicated and irregular shape or a narrower and longer shape of a building increases the running costs of lighting.

Space partitions: Installer's Lighting Guide 004 (2001) notes that the number of partitions in a given space will have an effect on the distribution of light within the space. The more the number of partitions in a space, the more the number of luminaires needed to ensure sufficient light for various activities to be carried out within that space. The partitions also have the effect of limiting the amount of light reaching spaces beyond the light source even though these would have been lit effectively if the partition(s) were not there.

Bell (1995), notes that the overall brightness of a room is greatly influenced by the luminance of vertical surfaces, including walls as well as cubicle partitions.

In general, people prefer well-lighted walls to dark ones, so long as the wall is not so bright that it becomes a secondary glare source. Thus, the surface finishes of the various partitions should be chosen in such a way that they reduce the amount of light that will be provided in that space.

He further notes that the locations of partitions and other tall furniture should not interfere with penetration of daylight. This may require re-orienting partitions or using translucent panels rather than opaque. Thus the designer should consider the light sources and lighting system in use when locating and specifying the type of partitions.

It can thus be derived that the lighting costs vary directly with the number of partitions in a given space.

Use of spaces: Evans (1999) notes that the use a given space is put into determines the amount of light that will be provided in the particular space. Standards of illumination level on the work recommended by the I.E.S. (2005) range from 300lux (30lm/ft²) for general offices to 600lux (60lm/ft²) for drawing offices and business machine operation and 1000lux (100lm/ft²) for work that requires great visual effort. Circulation spaces like corridors and staircases as well as toilets have minimum recommended illumination levels of about 150lux.

The I.E.S. (2005) further recommends that the Glare Index in offices should not exceed a value of 19. It states that to achieve this degree of freedom from glare, lighting fittings must be designed to restrict the amount of light emitted sideways in the direction of the observer's eyes. It continues to suggest that greater visual comfort would result if the Glare Index can be reduced to 16.

The IESNA (2001) notes that it is important to note that these are average maintained target levels for the task and should not necessarily be applied uniformly as the ambient light level for the entire space. It further recommends that lighting levels should be customized through the use of supplemental task lighting in areas requiring higher localized levels. Further, target lighting levels should be the sum of the ambient and task lighting levels. This task and ambient lighting design approach creates flexibility to accommodate individual tasks or worker requirements, creates visual interest, and can save considerable energy in comparison to a uniform ambient level approach.

Table 2.1: Recommended Light Levels (lux)

| | |
|-------------------------------|--------|
| Average Reading and Writing | 500 |
| Offices with Computer Screens | 250 |
| Task Lighting | 250 |
| Ambient Lighting | 250 |
| Hallways | 100 |
| Stockroom Storage | 300 |
| Loading and Unloading | 100 |
| High-Volume Retail | 100 |
| Low-Volume Retail | 300 |
| Roadway Lighting | 3 – 16 |
| Parking Lots | 8 – 36 |
| Building Entrance | 8 – 36 |

Source: IESNA Lighting Handbook.

Colour of room surfaces – The IES recommends the following reflectance percentages for various room surfaces.

Ceiling 80-90%

Walls 40-60%

Floors 20-40%

Finishes 25-45%

According to the IES (2005), as much as one-third of the energy use of a lighting system depends upon the surrounding interior features, such as the ceiling height, windows, and color and reflectivity of room surfaces and furnishings. Thus, where possible, the lighting designer should work with both the architect and interior designer to ensure that features that significantly enhance lighting levels, such as large windows and light-colored finishes, are utilized wherever possible. This helps minimize the required light output and therefore the energy consumption of the lighting system.

The nature of the task also should be put into consideration when deciding on the reflectances of the wall. People prefer lower wall brightness for computer tasks and higher brightness for reading or writing. The IES (2005) recommends a minimum CVP of 80 where computers (visual display units) are in use and a CVP of 70 in case of general work offices. The VCP index provides an indication of the percentage of people in a given space that would find the glare from a fixture to be acceptable.

Brightness ratios in the field of view should not exceed the following values according to the IESNA (2001) recommendation.

Brightness ratio in offices

| | |
|---|-------------------------------|
| Between task and surround | Maximum brightness ratio 3:1 |
| Between task and remote surfaces | Maximum brightness ratio 10:1 |
| Between luminaire/windows and adjacent surfaces | Maximum brightness ratio 20:1 |
| Anywhere within normal field of view | Maximum brightness ratio 40:1 |

According to the Good Practice Guide 272 (1999) in order to maintain the designed performance of the lighting system, the person responsible for interior finishes and furnishing must be aware of the desired reflectance values. It

further insists that dark interior finishes can compromise an otherwise great lighting design.

According to the Lamp Guide (2001), whatever type of luminaire selected, ambient lighting is largely dependent on surface reflectances. The higher the surface reflectances, the greater the amount of light in that space. It goes further to recommend that colors must therefore be selected to provide the maximum reflectance that will optimize lighting efficiency.

Running costs of lighting: These are the costs that are incurred to maintain the illumination gadgets in good working order and to generally pay for the electricity charges that the organization uses. Lucey (2002) notes that costs will always be an important issue but the capital cost of an installation, in combination with the operating costs, over the likely life of the installation will need to be considered to ensure a good economic solution.

He further notes that it will be a false economy to have a cheap installation, which is expensive to run. He further states that the total cost and operation of a building, including the lighting, will be small compared to the cost of the employees. Therefore he recommends that lighting costs should be seen with respect to the productivity of the staff otherwise money will be wasted.

Lighting controls: Good Practice Guide 160 (1997) notes that reducing the connected load (wattage) of the lighting system represents only half of the potential for maximizing energy savings. The other half is minimizing the use of that load through automatic controls. It further notes that automatic controls switch or dim lighting based on time, occupancy, lighting-level strategies, or a combination of all three.

The Guide (1997) further provides that in situations where lighting may be on longer than needed, left on in unoccupied areas, or used when sufficient daylight exists, the designer should consider installing automatic controls as a supplement or replacement for manual controls.

Time-Based Controls: Kohn (1990) notes that the most basic controlling strategies involve time-based controls; which are best suited for spaces where lighting needs are predictable and predetermined. He further notes that time-based controls can be used in both indoor and outdoor situations. He classifies common outdoor applications to include automatically switching parking lot or security lighting based on the sunset and sunrise times.

Typical indoor situations noted include switching lighting in production, manufacturing, and retail facilities that operate on fixed, predefined operating schedules. He further notes that time-based control systems for indoor lighting typically include a manual override option for situations when lighting is needed beyond the scheduled period.

Occupancy-Based Controls: Rea (2000) notes that occupancy-based strategies are best suited to spaces that have highly variable and unpredictable occupancy patterns. He elaborates that occupancy or motion sensors are used to detect occupant motion, lighting the space only when it is occupied.

He further notes that for both initial and sustained success in using occupancy sensors, the sensor must be able to see the range of motion in the entire space while avoiding either on or off false triggering. He emphasizes that this requires proper product selection, positioning, and testing. He concludes that occupancy sensors should first be selected based on the range of body motion expected to occur throughout the entire lighted space.

Lighting Level-Based Controls: The Good Practice Guide 160 (1997) notes that these strategies take advantage of any available daylight and supply only the necessary amount of electric light to provide target lighting levels. It further notes that in addition to saving energy, lighting level controls can minimize over lighting and glare and help reduce electricity demand charges.

The two main strategies for controlling perimeter fixtures in daylit areas as noted by the Installer's Lighting Guide 004 (2001) are daylight switching or daylight dimming. Daylight switching involves switching fixtures off when the target lighting levels can be achieved by utilizing daylight. Several levels of switching are commonly used to provide for flexibility and a smooth transition between natural and electric lighting.

Daylight dimming involves continuously varying the electric lighting level to maintain a constant target level of illumination. Dimming systems save energy by dimming fluorescent lights down to as low as 10 to 20 percent of full output, with the added benefit of maintaining consistent lighting levels according to the Code of Lighting (2001).

The above discussion has highlighted the various lighting controls available in the market which the designers could incorporate during building design to significantly lower the cost of lighting in office buildings. Their consideration will definitely have a positive impact on any office building project.

A designer makes decisions on all these design parameters that have been discussed in depth. The question is whether he considers the running costs of lighting as he makes choice on the extent of application of the stated parameters.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter describes the procedures that were followed in conducting the study. It discusses the study area, the population, sampling techniques and data collection methods used by the researcher. Data collection is used to test the study hypothesis as well as to fulfill the objectives of the study.

3.2 Research design

Kothari (2004:31) citing Selltiz, et al. (1962:50) defines research design as the arrangement of conditions for collection and analysis of data; in a manner that aims to combine relevance to the research purpose with economy in procedure. It is the conceptual structure in which research is conducted; it constitutes the blueprint for the collection, measurement and analysis of data. Research design can be classified by the approach used to gather primary data into two broad categories: observation and communication approaches.

Observation includes the full range of monitoring behavioral and non-behavioral activities and conditions such as listening, reading, visual data collection, smelling and touching. In other words, information is sought by way of the investigator's own direct observation without asking from the respondent (Ibid).

According to Cooper and Schindler (2003:319), the communication approach involves surveying people and recording their responses for analysis. It is the most reliable method of learning about opinions, attitudes, motivations,

intentions and expectations. These attributes can be effectively harnessed using the questionnaire, being the most effective instrument for collecting survey data. The communication approach is the most effective method for collecting the survey data. The communication approach is also an effective method for eliciting issues that are exclusively internal to the respondent, as the most qualified person to provide such information (Cooper and Schindler, 2003:322).

3.3 Background of the area of study

Nairobi is the capital city of Kenya. It has the highest urban population in East Africa, with a population of over 3.5 million. The city centre has an area of over 700 square kilometers and stands at an altitude of 1,675 meters above sea level. It is 140 kilometers south of the equator and some 480 kilometers west of the Indian Ocean (Wikipedia, 2008).

Nairobi was founded in 1899 as a supply depot for the Uganda railway, which was being constructed between Mombasa and Uganda. It was named after a water hole known in Maasai as *Ewaso Nyirobi*, meaning, "cool waters". It was totally rebuilt in the early 1900s after an outbreak of plague and the burning of the original town. Nairobi replaced Mombasa as the capital of the British East Africa Protectorate in 1905. The railway brought wealth into the city, which made it grow dramatically. In 1919, Nairobi was declared a municipality, and in 1954, was granted city status (Wikipedia, 2008).

After Kenya got its independence in 1963, Nairobi grew rapidly. This rapid growth put pressure on the already existing buildings. High-rise buildings slowly replaced the low-rise buildings to maximize on space in the city centre and create buildings with a higher floor area out of a relatively small ground area.

3.3.1 Nairobi Central Business District

Nairobi grew around the Central Business District (CBD). This is the area bounded by Uhuru Highway to the west, Haile Selassie Avenue to the south, Tom Mboya Street to the east and University way to the north taking a rectangular shape (Kiongoriah, 1987). It is the centre of many important activities including commerce, administration, education, religion, culture as well as recreation. Some of the buildings found within this area include: Kenyatta International Conference Centre (K.I.C.C.), Parliament buildings, City Hall, Holy Family Basilica and the Times Towers complex to mention just a few.

3.4 Investigation methods

The two major methods of investigation are as follows: quantitative and qualitative. The qualitative is concerned with obtaining an in-depth understanding of a subject. It includes designs, techniques and measures that do not produce continuous numerical data; the data is mostly in the form of words often grouped into categories (Abwunza, 2006). Such data is generally captured from a smaller number of respondents using open-ended questions.

The quantitative method is used to measure things discreetly and numerically and is based on a representative sample of the population, within estimated levels of accuracy. This method places emphasis on methodology, procedure and statistical measures of validity.

The study adopted both the quantitative and qualitative methods of investigation. While perception is a subjective concept, there is evidence from past studies of its application and measurement (Ibid).

3.5 The Population

The Board of Registration of Architects and Quantity Surveyors (BORAQS) require all practicing architectural and quantity-surveying firms to register not only with the Registrar of Companies but also with the Board. The Board, therefore, was the best source for the most comprehensive list of consulting firms in the country. A list of consulting firms obtained from the Board in October 2003 (which was the most recent) indicated that there were 139 registered architectural firms in the country.

High-rise office buildings over four storeys within the CBD were chosen. The CBD has a large population of high-rise office buildings hence justifying it as an ideal case study area on the influence of building design on running costs of lighting. It was found that there are 138 high-rise buildings over four storeys in the CBD (Field survey, 2008).

3.6.0 The Sample

3.6.1 Sampling size and technique for the architects

The target population consisted of 139 architectural firms. When determining the sample size, it is assumed a confidence level of 95% of the target population and that the response achieved from the sample will be within -ve 5 or +ve 5 of the true state of the population targeted.

$$n = \frac{Z^2 pq N}{e^2(N-1) + Z^2 pq}$$

(Chava & Nachmias, 1996)

Where N = Population size

n = Sample size

p = Sample population estimated to have characteristics being measured. Assume a 95% confidence level of the target population

$$q = 1-p$$

e = Acceptable error ($e = 0.05$, since the estimated should be 5% of the true value).

Z = The standard normal deviate at the required confidence level = 1.96

Hence:

$$n = \frac{1.96^2 \times 0.95 \times (1-0.95) \times 139}{0.05^2 \times (139-1) + 1.96^2 \times 0.95 \times (1-0.95)}$$

= 48 architectural firms.

The architectural firms on the BORAQS list to be sampled were selected using the random sampling technique. This was done by writing numbers from 1-139 on small pieces of paper with each firm being assigned a number and putting the pieces of paper in a container where they were shuffled and picked randomly without replacement and the chosen number noted down for research purposes.

3.6.2 Sampling size and technique for high-rise buildings

The high-rise buildings in the CBD were constructed at different times. Some were built in the early 1960's and 1970's, a time when the need to contain costs of lighting was not necessary since electric power was in plentiful supply in

Nairobi and the general demand for electricity were even lower due to a few number of industries and an even fewer number of office buildings.

The sample size for the high-rise buildings:

$$n = \frac{1.96^2 \times 0.95 \times (1-0.95) \times 138}{0.05^2 \times (138-1) + 1.96^2 \times 0.95 \times (1-0.95)}$$

= 48 buildings.

The buildings chosen for the study were grouped according to the decade in which they were constructed. Various buildings constructed in each decade from 1970 to date, were selected using stratified random sampling. A total of 48 buildings were surveyed. The existing buildings that were constructed between 1970 and 1990 were surveyed to see if any alterations to the building or retrofitting of various devices were done to consider lowering the costs of lighting. Existing buildings constructed between 1990 to date were studied to see if they had incorporated automatic lighting control devices to try and reduce unnecessary costs of lighting in office spaces.

A list of some of the high-rise buildings in Nairobi Central Business District:

High-rise Buildings (completed)

| Building Name [Complex Name] | Height | Year |
|---|---------------|-------------|
| 1. Times Tower [New Central Bank Complex.] | 140 m | 1997 |
| 2. Kenyatta International Conference Centre | 105 m | 1974 |
| 3. Kenindia House | | 1984 |
| 4. I & M Bank Tower | 99 m | 2001 |

| | | |
|---|------|------|
| 5. Government Office Conference Hall | 98 m | 1972 |
| 6. Provincial Headquarters (<i>Nyayo house</i>) | 84 m | 1982 |
| 7. Cooperative Bank House | 83 m | 1981 |
| 8. National Bank House | 82 m | 1976 |
| 9. Anniversary Towers | 80 m | 1992 |
| 10. Lonrho House | 80 m | 1990 |
| 11. Reinsurance Plaza | 77 m | 1982 |
| 12. Uchumi House | 71 m | 1972 |
| 13. ICEA Building | 69 m | 1981 |
| 14. International House | 66 m | 1971 |
| 15. Hilton Hotel | 61 m | 1969 |
| 16. Electricity House | 60 m | 1974 |
| 17. Treasury Building | 48 m | 1980 |
| 18. Union Towers | 48 m | 1977 |
| 19. Hotel 680 | 47m | 1972 |
| 20. Bima House | 45 m | 1973 |
| 21. Ministry Of Works Building | 43 m | 1968 |
| 22. Office Of The President | 43 m | 1967 |
| 23. NHC House | 40 m | 1975 |
| 24. Harambee House | 40 m | 1962 |
| 25. Development House, West Tower | 39 m | 1972 |
| 26. KCS House | 38 m | 1975 |
| 27. Posta House | | 1999 |
| 28. Hazina Towers | | 1993 |
| 29. AmBank House | | 1994 |

| | |
|--|------|
| 30.View Park Towers | 1991 |
| 31.Fedha Towers | 1983 |
| 32.Nation Centre | 1997 |
| 33.Posta Sacco Plaza | 1986 |
| 34.Maendeleo House | 1977 |
| 35.City Hall Annex [City Hall Complex] | 1981 |
| 36.Victoria Towers | 2000 |
| 37.Harambee Plaza | 1987 |
| 38.IPS Building | 1967 |

Source: Skyscraper.com-last updated 2004.

3.7.0 Data collection instruments and procedures

Primary data was collected by use of the following instruments:

3.7.1 Observation

This was aided by use of a checklist to see the various measures taken within office spaces to avoid incurring unnecessary costs of lighting, their effectiveness and also the internal spatial arrangement of the buildings and respective office spaces.

3.7.2 Questionnaires

This was the main method of data collection that was used. The questionnaires were self-administered and the researcher administered to the following people:

- Architects
- Building owners/property managers
- Tenants

3.7.3 Photography

According to Kothari (2004), photography is an indirect way of data collection. It was used to capture the existing conditions of the various spaces in the high-rise office buildings with respect to aspects such as amount of daylight penetrating a given space, the general lighting of a given space, position of windows, window size among others.

3.8 Data presentation and analysis

The data collected was analyzed by use of descriptive statistics such as frequency distribution tables and percentages. The data is presented in the form of graphic presentation such as charts and tables. Plates are also used.

CHAPTER FOUR

DATA ANALYSIS AND PRESENTATION

4.1 Introduction

The field study set out to study the various office building designs and determine their appropriateness to our economic and climatic conditions with regard to the costs of lighting in high-rise office buildings in Nairobi's Central Business District. Its prime aim was to establish the responsiveness of design parameters in the high-rise office buildings towards lower costs of lighting in various spaces within these buildings through successful integration of artificial lighting with natural lighting within their environment.

The findings form the basis of the analysis and the presentation to follow and serve as a basis on which conclusions and recommendations were made. Both qualitative and quantitative methods of analysis were used. Simple descriptive statistics such as, tables, charts, percentages and photographs have been used to display, describe and present the research findings through the classification of the raw data into some purposeful and usable categories.

Qualitative data have been presented as narratives. Tabulation and percentages were preferred since they present data in an orderly manner and conserve space while reducing the explanatory statements to a minimum. They also allow easy and fast interpretation of the results through drawing of statistical inferences. Photographs were used since images help present data in a manner that as much as possible reflects the existing state on the ground at the time of research and can be understood without too much explanation.

Table 4.1 shows the response rate of the questionnaires administered:

Table 4.1: Response rate

| Respondent | Total number posted | Response | Percentage Response(%) |
|-------------------|----------------------------|-----------------|-------------------------------|
| Architects | 48 | 40 | 83 |
| Building Owners | 24 | 17 | 71 |
| Tenants | 24 | 19 | 79 |

Source: Field survey, 2008.

Mugenda (1999) has stated that; while administering questionnaires, a response rate of 50 percent is adequate for analysis and reporting, 60 percent is a good response while 70 percent is very good.

4.1.1 Survey of selected buildings

The high-rise buildings surveyed were all office blocks. The physical survey was carried out in four categories. A checklist was used to check whether the lighting system in the building met the requirements of various users of different spaces within the office building.

The categories were as follows:

- a) Circulation spaces within the buildings.
- b) Quantity and quality of light within respective office spaces.
- c) Availability of lighting controls.
- d) Internal spatial arrangement of the various spaces.

A total of 40 out of the 48 buildings were surveyed due to various technicalities giving a success rate of 83%.

4.1.1.1 Circulation spaces within the buildings.

This section was mainly concerned with the circulation spaces within the building. These were the entrance lobbies, lift lobbies, staircases, corridors and escalator ramps where they were present. The main area of focus being the light supply to these spaces and the lighting system employed. The plate below shows a staircase lit by natural means.

Plate 4.1: Well lit Staircase



Source: Field Survey, 2008.

4.1.1.2 Quantity and quality of light.

This section was concerned with the general illuminance in the respective spaces and whether the amount was adequate to perform specific tasks or not. It was also concerned with quality of light in terms of glare, presence of shadows and color rendering properties of the various luminaires employed.

4.1.1.3 Presence of lighting controls

The main aim of the researcher was to check out whether the building in question employed any system of lighting control. The target controls were both manual and automatic lighting control devices.

4.1.1.4 Internal spatial arrangement

The main area of concern in this case was the number, type and height of partitions in a given space and their effect on light distribution in that space. The partitioning material that is whether transparent, translucent or opaque; was also put into consideration.

4.1.2 Qualitative Analysis

This section gives a qualitative analysis of functions of Nairobi office buildings, lighting systems in these office buildings, costs attributable to these lighting systems, and the common office building design concepts used and their errors.

4.1.2.1 Functions of Nairobi Office Buildings

As Kenya's capital city, Nairobi is the commercial, administrative and cultural centre of the country. It is also a major international communications and organizations centre in Africa. The Central Business District (CBD) is the heart of Nairobi City. Here, one finds the greatest concentration of offices, retail stores and shops.

Most of the Nairobi office buildings sampled in this study had ground floors designed for possible multi-use. The functions present in the ground floors ranged from shops and banks to cafeterias and bookshops.

The shops varied from specialised stockists of jewellery, clothes, shoes, electronics to butcheries; reflecting 22%, 24%, 7%, 11% and 2% respectively. These shops were lit by natural means augmented by electricity. The upper floors of the buildings usually accommodated conference rooms, government offices, consultants' bureaux, embassies and local and regional offices of international organizations and associations. These buildings had a combination of the above activities. They accommodated both small businesses and large international agencies.

Of the 40 buildings sampled, 80% had conference rooms, 40% had government offices, 52% had consultants' bureaux, 43% housed embassies, 49% housed international agencies and 42% had associations.

Generally, the offices of most buildings had lift lobbies and stair cases lit naturally and augmented by electricity with few exceptions like View Park towers and having lift lobbies almost lit entirely by artificial lighting. Kenindia house in particular had staircases and its washrooms served exclusively by artificial means. Most other buildings could easily do away with electric lighting during the day at their stair cases and lift lobbies with the best examples being Cianda house and Utalii house.

4.1.2.2 Types of Lighting Systems Used In Office Buildings

It was observed that most office buildings used fluorescent lighting tubes to light up most spaces. The only spaces using incandescent lamps being store rooms and some washrooms. It was noted however that very few office buildings use Compact Fluorescent Lamps (CFLs) which are more energy efficient and have a longer lifetime than the traditional T12 and T8 tubes in most common use. This trend was noted even in very new office buildings.

This is also a factor that contributes to increase in running costs of lighting in office buildings since incorporation of Compact Florescent Lamps has been found to decrease lighting costs by as much as 35% compared to incandescent lamps and by 25% compared to T8 and T12 tubes according to the Building Research Establishment (2001). The designers should therefore make a point of informing clients of the current technology available in the market which they can take advantage of to reduce unnecessary expenditure.

It was also observed that some office spaces used exclusively natural lighting during the day. This was observed at Utalii house and Cianda house where the window size and building orientation enabled adequate supply of sunlight. Presence of an atrium at Loita house and the Bazaar building also enabled about 70%-80% use of natural lighting in most office spaces within the two buildings. At Electricity house, most offices near windows could use natural lighting exclusively but the large number of partitions in most office spaces made some spaces very dark during the day and thus have to be lit exclusively by artificial means such as the secretaries' pads.

Corridors in almost all buildings were lit by artificial means almost exclusively such that in case of a power black out, one cannot find themselves within the

building. This was prevalent because of deep spaces within office buildings and designers' lack of consideration to incorporate atriums into their designs so as to increase the amount of natural light available to any given space. This was most prevalent at View Park towers which could be attributed to the complicated design of the building which makes most spaces within the building dark even on very sunny days.

However, there were buildings that almost successfully incorporated natural lighting with artificial lighting in their corridors. This was by providing glazed 300mm x 100mm fanlight-like sections along the corridor near the ceiling level throughout the entire corridor length on both sides. This enabled light to filter into the corridor from adjacent office spaces that could have been used to lower lighting costs in such office buildings; unfortunately, there were no automatic light controls that could have adjusted the lighting system to provide just the needed amount of light.

The stair cases were mostly lit by a combination of natural and artificial light. This was noted even in situations where there was adequate natural lighting to support basic movement within the building without any problems.

Thus, the availability of adequate natural lighting within these building does not contribute to lower lighting costs within the office building. Unfortunately, this trend was noted in 95% of the buildings surveyed. With the large number of storeys in most office buildings, this translates to a high lighting cost that could be avoided. This emphasises the need for automatic lighting controls in office blocks. Thus, designers have an important role to play by advising clients on the longrun savings they could make by incorporating lighting control measures in their office buildings.

Respondents interviewed were of the view that lighting costs were a major component of their rent payable to the landlords and blamed the designers for not taking due consideration of availability of excess natural lighting that could have reduced their lighting costs considerably.

Plate 4.2 Fluorescent lighting in lift lobby



Source: Field survey, 2008.

4.1.2.3 Types of Lighting Controls Used In Office Buildings

The absence of automatic lighting controls was noted in all buildings sampled and surveyed despite the fact that costs of lighting have been rising over the years. The reason for this could be attributed to lack of information regarding the use and benefits of automatic lighting controls; with most landlords passing the extra electrical lighting charges to their tenants either through high rent charges or the tenants having to pay for their power usage within their respective space(s).

Most tenants did not have any information on automatic lighting control devices and they only knew about the manual control of putting the lights on or off i.e.

the traditional on-off toggle. This contributed to the high lighting costs in such spaces as it was noted that in 90% of the spaces, lights were left running even when the space was adequately lit by sunlight to enable carrying out of most office tasks effectively.

However, some new buildings have installed automatic lighting controls with the Kenya Re towers at Upper hill having dimmer controls in most office spaces. This is an effective control in that it has the capacity to lower energy consumption by as much as 40% depending on the use of the particular space as per a research conducted by the Building Research Establishment (2001).

Some informed tenants at about 10% of the new buildings had incorporated photo sensors and occupancy sensors in their office spaces. This was especially prevalent in office spaces where a single organization had let either almost or the entire floor area and they used open office system. These controls have the capacity to reduce the lighting costs within such office spaces considerably since control is much stricter and hence more effective.

Some office spaces incorporated timers to automatically switch lights off at a given time of day. This proved very effective in lift lobbies, staircases and office spaces that are either adequately lit or don't require the lights to be on at that particular time of day. This is an effective means of control in that the tenants reported a 40% decrease in their lighting costs.

Most respondents interviewed seemed to have little or no knowledge of presence of automatic lighting controls in the market and were eager to learn

from the researcher of the various types available, their advantages and recommended areas of use.

4.1.2.4 Types of Lighting Used In Office Buildings

It was observed that most office buildings used ambient lighting in lighting the various office spaces. 78.9% of all buildings surveyed employed only ambient lighting in all office spaces within the building. This shows the lack of consideration by designers of the different types of uses the various office spaces could be put into. This was especially clear where a given space was taken over by a doctor operating a clinic. Of the buildings surveyed, 55% of them had doctors' clinics. Of these, no space had specific task lighting for the doctors forcing them to incur extra expenses by purchasing portable lamps to perform their work efficiently.

Accent lighting was however noted in spaces that were used for retail purposes mostly at ground floors of most buildings surveyed.

4.2 Responses from Architects

Of the architectural firms interviewed, 100% of them were aware that Nairobi's climate is conducive for use of daylighting in office buildings. Most architects noted however that the need to design deep offices to accommodate more tenants and to maximize land use in the CBD compromised total dependency of sunlight in office spaces. They therefore stated that use of artificial lighting during the day in some office spaces is inevitable. They however recommended that this should be kept to a minimum and use should only be in cases where there is no option other than artificial lighting.

4.2.1 Frequency of use of local climatic data in lighting design

Among the architects interviewed, 60% of them often considered local climatic data during lighting design of buildings while 40% of them rarely did. Those who rarely considered local climatic data felt that following basic design standards was sufficient to develop a building that was functional enough to meet the necessary requirements. Those who often considered the local climatic data during lighting design argued that considering the local climate during design enables development of a final product that is both cost effective and most responsive to most design requirements.

4.2.2 Reasons for limited use of automatic lighting control devices

The architects interviewed indicated that automatic lighting control devices were in very limited use in most office buildings because of the restrictive high initial costs associated with these devices. 80% of those interviewed indicated this as the main reason for lack of automatic lighting control devices in office buildings.

20% of the architects interviewed cited ignorance about the contribution of automatic lighting controls to lower cost of lighting as the main reason why they are not incorporated in most office buildings. They claimed that most building owners did not know the importance of such devices and convincing them to incorporate the devices in their buildings is a difficult task.

The architects however concurred that incorporation of automatic lighting control devices could be a very cost effective strategy in most office buildings; particularly in our climate due to the availability of adequate sunlight all year round.

Table 4.2: Consideration given to various qualitative factors in lighting design of office buildings.

| Item | A lot of consideration | Little Consideration |
|--------------------|-------------------------------|-----------------------------|
| Energy consumption | 20% | 80% |
| Occupants comfort | 60% | 40% |
| Maintenance | 60% | 40% |
| Fashion | 80% | 20% |

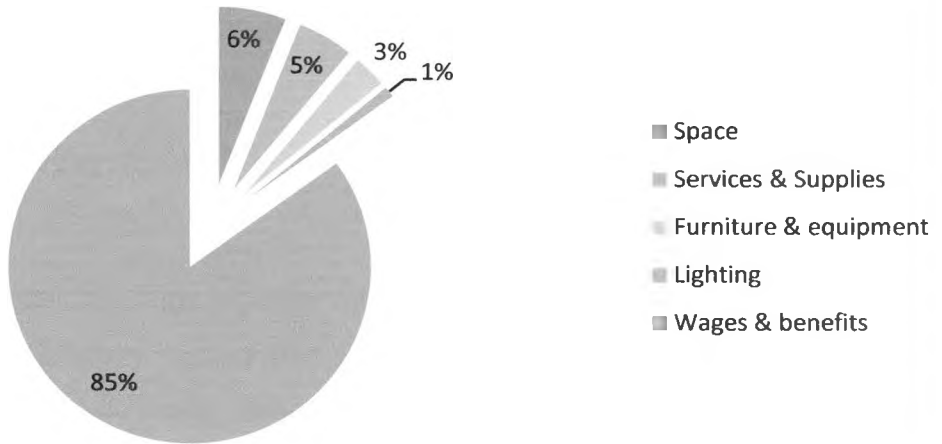
Source: Field Survey, 2008.

The architects were also requested to provide insight on their consideration of some qualitative factors in their design of buildings. A large proportion of them, 80%, did not consider the energy efficiency of the lighting systems they recommended for installation in office buildings. This is a very dangerous trend in that it is the architects who many at times are responsible for advising the client as well as leading the design team in decision making. The result, as seen in most office buildings was installation of lighting systems that are inefficient in their light provision and high in maintenance and running costs.

Occupants' comfort was also another factor that received a 60% consideration according the architects interviewed. The Lighting Management Handbook (2005) provides that the most important resource in any given organization is its work force. This is because the highest expense for any organization is its workers which according to the Lighting Management Handbook, accounts for 85% of any given organization's expenditure. Comfort of occupants should thus be given more consideration by architects.

The Lighting Management Handbook research results are shown in the chart below.

Figure 4.1: Annual Operating Costs Per Square Foot, Typical Office Space



Source: Lighting Management Handbook.

Other factors considered in the questionnaires were maintenance and style of architecture which received 60% and 80% consideration during design by the architects respectively. The architects argued that style of architecture is a major influence on their part in design of office buildings since they have to design technologically ready and efficient buildings.

To attract the necessary clientele, the buildings should also be aesthetically appealing in terms of what the market considers fashionable at the particular time.

Table 4.3: Reasons why high rise buildings are lit artificially during the day

| Item | Number of firms | Percentage |
|--|-----------------|------------|
| Inadequate regulatory standards | 13 | 33.33% |
| Style of architecture | 0 | 0.00% |
| Blocking of light by other high rise buildings | 0 | 0.00% |
| Disregard of basic design standards | 27 | 66.67% |

Source: Field Survey, 2008.

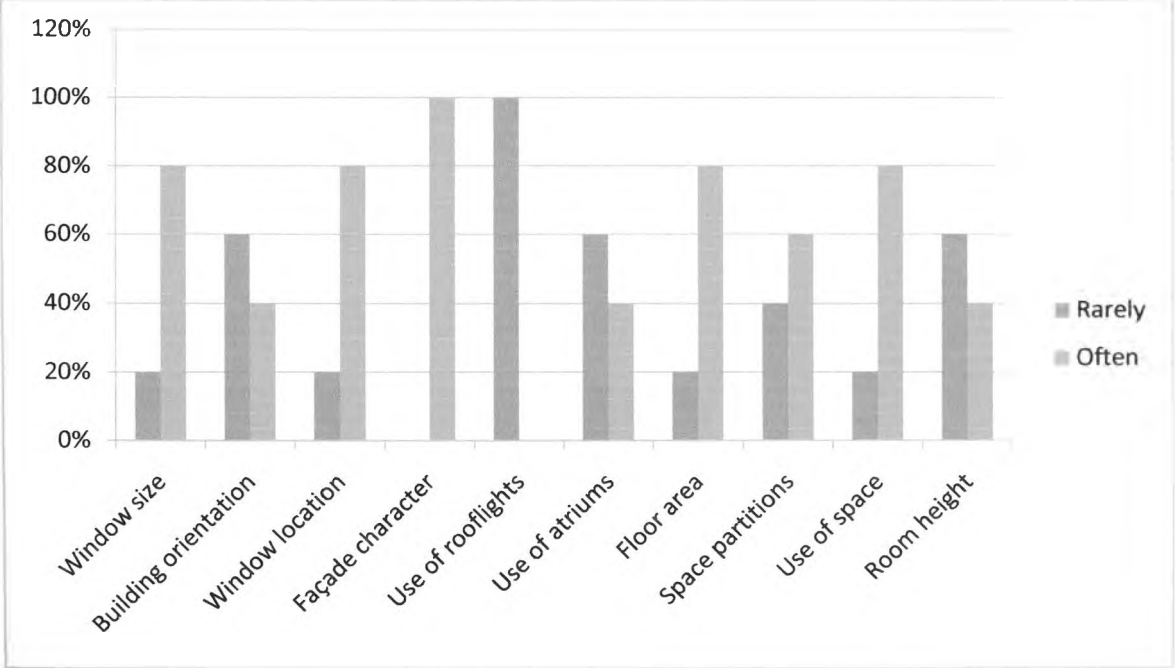
There were several buildings sighted within the Central Business District (CBD) which were lit artificially during the day. The architectural firms interviewed noted disregard of basic design standards as being the main reason for the high prevalence of the practice. This amounted to 66.67% of all those surveyed which gives a strong indicator that design is the main culprit in as far as inefficient buildings are concerned.

Inadequate regulatory standards were also noted by 33.33% of the firms surveyed as being the reasons behind inefficient buildings in terms of lighting design within the CBD. Some architects were particularly critical of the Building Code which they argued has never been revised ever since it was adopted so as to accommodate changes in design and urban growth over the years.

Lack of research to develop local solutions to existing local problems, quack professionals, financial limitations, poor designs and client difficulties were also cited as being part of the reasons why high rise buildings were artificially lit during the day. The architects who noted these were especially critical of quack professionals and they blamed their continued stay in the market on lack of adequate laws and regulations that could punish offenders and enable the

industry to be better regulated hence ensuring that at least the basic minimum standards are met during building design.

Bar Chart 4.1: Degree of consideration given to various design parameters during lighting design



Source: Field Survey, 2008.

Among the architects issued with questionnaires, 80% often considered **window size** during lighting design of buildings as opposed to 20% who did not feel that window size was an important factor to put into consideration during lighting design. Those who considered window size argued that the window is the fundamental element both for view and daylighting in buildings and hence its size is of fundamental importance. The window size determines the level of lighting that a space receives with the amount of light increasing with window size.

They however, noted that factors such as privacy and glare were some of the challenges concerned with window size and hence require greater attention to obtain a final product that would meet most if not all of the client's requirements. They also noted that other concerns on window size included insulation of windows against moisture and thermal gain whose costs increase with window size and thus determine to some extent the window size for various office buildings. Other concerns for window size were ventilation and solar heat gain; they recommended sun shading devices, special glazing and building orientation as some of the options available in the market to counter these problems.

Plate 4.3 French window lighting lift lobby



Source: Field Survey, 2008.

Building orientation with regard to climatic factors was also another section that the architects gave their opinion on. 60% of the architects gave this design element little consideration during the design process. Most of these architects indicated that many at times, site characteristics, client requirements and use of the building determined the orientation of the building.

40% of architects however gave this factor serious consideration and they indicated that the main factors they considered were façade design where they considered the sun's path and tried as much as practicable to orient buildings in such a way that they reduced the adverse effects of direct sunlight with glare in mind. Space layout within the building was also a consideration under building orientation with use of spaces being a bearing factor. Prevailing winds with regard to ventilation and lighting were also noted as major factors to be put into consideration during building design as regards orientation of the building.

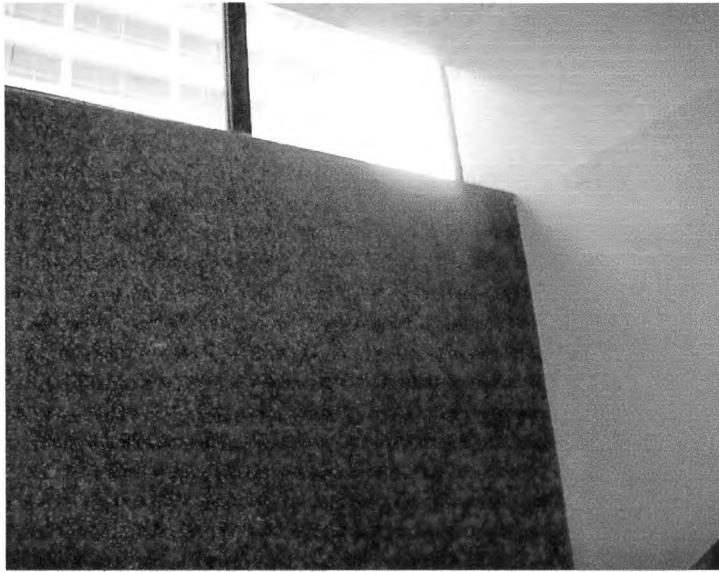
The architects recommended that building orientation should be done with the aim to maximize the advantages of natural lighting while reducing thermal gain. They indicated that buffer spaces such as stair cases, lift lobbies, toilets and stores should be located in the Western façade while useful spaces being located in the Southern façade incase of Nairobi.

Window location height came out as one of the design elements that the architects put into consideration during building lighting design with 80% of them indicating that they many at times put this into serious consideration. They argued that this factor determined the depth to which light penetrated in a given space and the general distribution of light within the particular space.

It was also noted that window location heights had an influence on illumination and glare which necessitated extra provisions to be made to prevent the negative effects of glare. Window location also determined location of most tasks within office spaces. Clerestory windows were noted to be in use where light was required to penetrate deep into a given space. Thus these were mostly used in staircases and corridors. In cases where French windows are used, sufficient amount of sunlight was supplied in the space in question.

They recommended that for proper distribution of light within a given space, windows should be located in accordance with the need of the space.

Plate 4.4 Clerestory window lighting staircase.



Source: Field Survey, 2008.

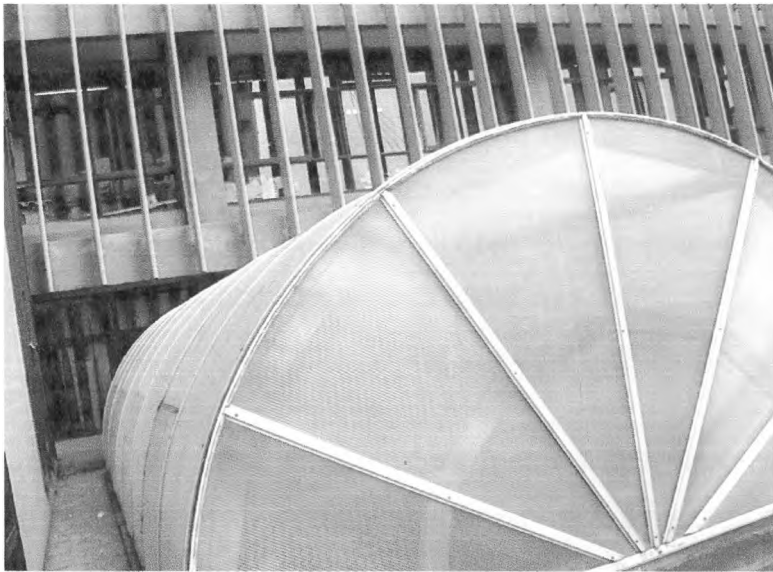
Façade character was given 100% consideration by all architects surveyed. These architects indicated that materials used for the façade and their colour were some of the factors put into consideration during façade character determination. In this case, they considered the reflectivity of the material used on the external façade as these determined glare considerations to the surroundings of the structure as well as heat gain of the structure itself.

Another element considered was the sun shading strategy where the architect makes decisions on whether to use sun shading devices or not and the strategy to employ in these circumstances with options being to use recessed openings, to incorporate double walling or to use vertical and horizontal elements.

Use of roof lights was given little consideration by architects with 100% of them responding that they hardly consider it as an option when it comes to tropical climates where Nairobi is located. They argued that roof lights are especially discouraged because of their high maintenance costs and their unsuitability for flat roofed buildings since there will be a glare problem for at least eight hours every day. They recommended use of atriums instead.

Atriums were given 60% consideration by architects designing in Nairobi. They argued that for offices with large floor areas, atriums were the most feasible option to distribute diffuse lighting to office spaces. They also noted that the incidence of glare is greatly reduced when atriums are employed which ensures good lighting quality.

Plate 4.5 Atrium (Loita House)



Source: Field Survey, 2008.

Floor area was a major point of consideration during office building lighting design with 80% of the architects surveyed giving it a lot of priority. They noted that they put into consideration depths of task spaces from facades; with

rectangular shape being preferred to all other shapes when it came to adequate light provision within office buildings during the day.

Space partitions was put into consideration during office lighting design by 60% of the architects according to the field data collected. Most of the architects who put it into consideration claimed that the problems involved in this case included politics and bureaucracy in most organizations where the senior managers felt that they could not share office spaces with their juniors. This necessitated setting up of permanent partitioning walls although the space could have been conveniently served with temporary partitions and thus enabled sharing of light from windows.

The architects indicated that in terms of lighting considerations, they put into consideration the heights of partitions since these determined the positioning and number of luminaires to be incorporated in a given space. They also determined whether or not light could be shared between spaces and to what extent. The other factors they put into consideration were the nature of partitioning materials; i.e., opaque, translucent or transparent and this was determined by the use of spaces as well as client requirements.

Number of partitions was also an important factor which determined whether artificial lighting was necessary in a given space or not. This was determined by the size of the space and client requirements. However, the architects recommended few partitions to enable better sharing of light between the various spaces.

Use of space was considered a very important factor with 80% of the architects interviewed putting it into serious consideration during lighting design of various office spaces. They recommended that use of space should be paramount since design should aim to meet the needs of the user as much as possible. They concluded that standards of lighting for various tasks as stipulated by the IES (2005) should be adhered to as this will result in satisfaction of the user as well as in economical lighting costs.

Room Height this was one of the factors that few architects put into consideration during lighting design of office buildings with only 40% of those surveyed claiming to often consider it. Those who considered it argued that it was an important consideration in situations where the ceiling is to be used as a reflective surface. One architect recommended that the standard ceiling height for such a situation would be 3 m high; any higher or lower than that would be inappropriate with lower heights causing glare and light distribution in the space not being uniform while higher heights would not reflect the light appropriately.

From the above analysis, it is clear that the various design parameters noted above have an influence on the running costs of lighting albeit to different degrees. The office building designer should therefore put each of them into consideration while putting greater emphasis on those with more influence on lighting costs. This will enable generation of a final product that is both cost effective and meeting most requirements of the user.

4.3 Responses from tenants

The tenants surveyed mostly indicated that the lighting of the spaces they occupied had influenced them to choose the spaces they were currently occupying. Most tenants indicated that they would move from their spaces to

spaces that had a higher provision of daylighting if they had such an option. They argued that such spaces could provide them with an option to reduce their general dependence on electricity and the view they provided was very good.

The influence of the lighting system on the space to occupy is clearly shown by the results of the questionnaire where 100% of all surveyed felt that the lighting system had an influence on their choice of office space. Some tenants who were in very poorly lit spaces claimed not to have had a better choice.

100% of the buildings had their office spaces lit through windows during the day with a few exceptions being some lift lobbies and stair cases where in some cases there was exclusive lighting of the spaces with artificial lighting. This was seen at View Park towers lift lobbies and Shankardass house staircases. The main area of concern as indicated by most tenants was inadequacy of light supplied to their spaces especially where there were partitions. They would have preferred light adequate to cover the entire office space instead of some spaces being well lit while others were left in semi- darkness.

The buildings surveyed lacked automatic lighting controls with most of the tenants unaware of automatic lighting controls. They admitted that they would welcome automatic lighting controls in their office spaces if they were to be given an option to choose. They complained of high costs of lighting in their office spaces as it was difficult to always use manual means to control electricity use.

The researcher also observed that the lights were left running even in office spaces where there was adequate natural light to support the basic office tasks.

This trend was very prevalent and the main cause was forgetting by the tenants to switch off the lights using the manual control devices available at their disposal.

4.3.1 Percentage of tenants inconvenienced by power failure

55% Of the tenants surveyed indicated that they experienced lighting inconveniences during repair, maintenance or power failures of the lighting system employed in their office spaces. Some noted that they could hardly work incase there was a power failure of the system since the space became totally dark even if there was plenty of sunlight outside. This clearly showed that the designers had not put into consideration the use of sunlight for performance of basic office functions. This lack of incorporation of sunlight was most prevalent in corridors which were in pitch darkness during the day if one just switched off the lights.

30% of those who intimated that they did not experience inconveniences during power failure or maintenance of the lighting system indicated that if it was not for the stand by generators installed into the system by the landlords, there would have been no meaningful activities taking place in their respective spaces during such times. They concurred with their counterparts in other buildings who felt like the lighting systems in their offices were not designed to be fully complementary of each other with the designs in most spaces, 85% to be precise, leaning towards artificial lighting use almost exclusively during the day.

15% of the tenants who were not affected irrespective of the lighting system in use were in buildings which incorporated good use of and location of windows, window size and atriums in their buildings. This enabled adequate supply of

sunlight throughout the day which ensured continued carrying out of various activities by occupants of the space. The general productivity of such spaces was high on average compared to spaces with unreliable supply of light throughout the day.

The tenants in the 85% of the spaces who could either not work effectively or not work at all in cases of power failures considered their costs of lighting as being high and they felt like these could have been more manageable had the designer made an effort to supply adequate sunlight to their respective spaces.

Those in 15% of the spaces considered their lighting costs affordable while some felt that incorporation of automatic lighting control devices could have even made their lighting costs cheaper since sometimes lights were left on for unnecessarily long hours during the day.

Table 4.4 shows the field results collected from tenants and their own assessment of the lighting systems employed in their various spaces and the appropriateness of the internal environment the system(s) created.

The tenants had various reasons for their rating of the system employed in their space. Some believed that location of the space they occupied deep into the building made the space they currently occupied to be poorly lit. They recommended that designers should have designed the building with an atrium to enable better sharing of light between various office spaces.

Some tenants felt that the main undoing of their building was the positioning of windows where by they did not take full advantage of the available natural light. One tenant whose office directly had a window but was in darkness incase he switched his lights off during the day questioned the competence of the designers who had designed the windows and also rated every lighting aspect of his space as being poor.

Table 4.4: Rating of various lighting aspects by tenants

| Item | Good | Fair | Poor |
|------------------|------|------|------|
| Light quality | 10 | 3 | 6 |
| Light quantity | 6 | 6 | 7 |
| Lighting control | 0 | 3 | 16 |
| Spatial comfort | 6 | 3 | 10 |

Source: Field Survey, 2008.

The results from table 4.4 above are better presented in bar chart 4.2.

Bar chart 4.2 indicates that 50% of the tenants surveyed felt that the light quality in their respective spaces was good. However, it should also be noted that a significant number, 33%, felt that the lighting quality in their spaces was poor. This shows that there is a large proportion of tenants whose overall output will not be optimum because of poor quality of light in their spaces. Considering that employees consume 85% of an organization's budget in salaries as noted earlier, the overall effects of the various design errors with regard to lighting will have a very big impact on the success or failure of an organization.

I.E.S. (2005) defines Light quantity as the amount of light falling on the task plane, measured in lumens. It further states that the visibility of a task depends on both the light quality and quantity. Hence the importance of a sufficient

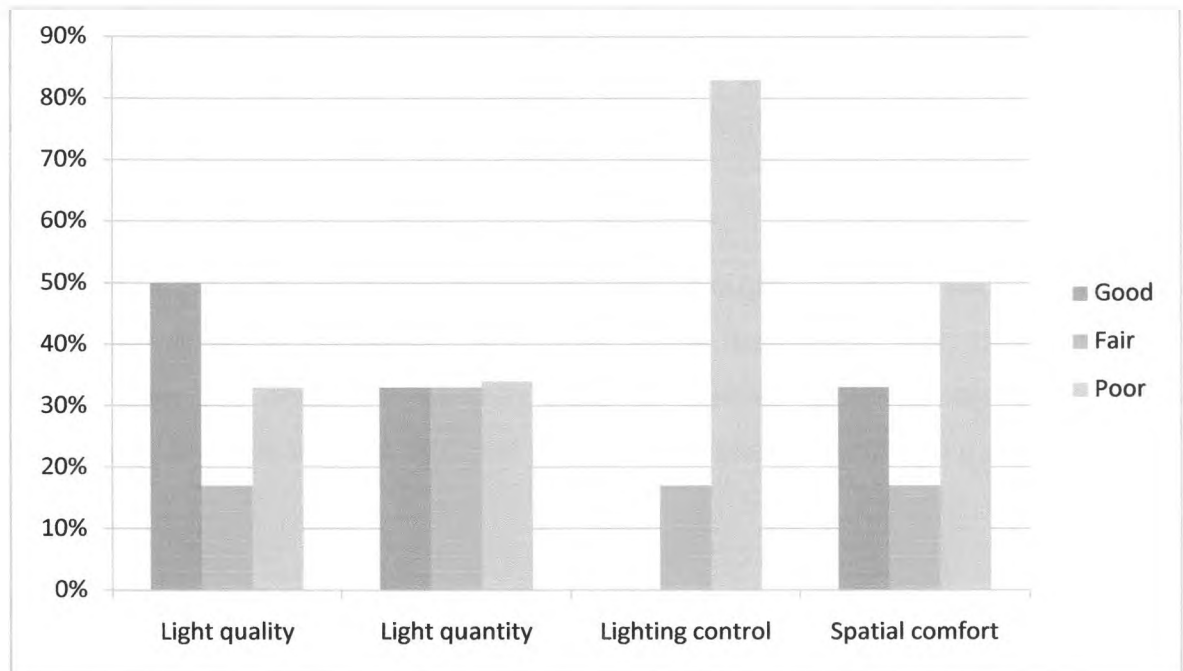
amount of light cannot be over emphasized. Surprisingly, most tenants surveyed, 34%, felt that the lighting quantity in their spaces was not adequate to enable them perform all the necessary duties. 33% considered the light quantity fair while 33% considered it good. This is a trend that clearly shows how wanting our lighting systems are and that designers need to give lighting design more consideration during office building design.

Lighting control was one of the factors where most tenants surveyed showed alot of ignorance with only 10% of those interviewed knowing of existence of automatic lighting control devices. Further still, the tenants only had a general existence of the devices and they did not understand the contribution they could give towards reducing their overall lighting costs. Most tenants only knew of the manual control devices of turning the lights on or off which they actually did not consider a control device as they had no choice but to either let the lights remain on or just switch them off completely.

On the basis of this knowledge, 83% of the tenants indicated that their buildings had poor lighting control with 17% indicating that the lighting control in their spaces was fair. They encouraged the designers to start incorporating automatic lighting control devices in their designs so that the market could become aware and introduce the same into their buildings.

Spatial comfort in lighting terms was also another factor where 50% of the tenants felt the designers had let them down. With a further 17 % considering that their spaces were neither good nor bad but just fair, makes this a factor that cannot be ignored. Only 33% of those interviewed felt that the lighting in their spaces was comfortable.

Bar Chart 4.2: Rating of various lighting aspects by tenants



Source: Field Survey, 2008.

4.4 Responses from Landlords

Most landlords interviewed incorporated both artificial and natural lighting in their buildings and they felt that their buildings were adequately lit. This was so even in cases where the tenants had observed that the lighting was poor. Some landlords however felt that the lighting in their office buildings was not the best in terms of taking advantage of natural lighting. This was so with View Park towers where the landlord felt that the design compromised the amount of light that could penetrate into the building.

40% of the landlords indicated that they were not informed by designers that their buildings could use natural lighting almost exclusively during the day. They noted that had they been armed with this knowledge, they could have made a

concerted effort to set up structures that could take full advantage of the existing natural environment. They further argued that they strongly felt that use of natural lighting almost exclusively in their buildings during the day could have definitely given their buildings a marketing advantage.

The rest of the other landlords indicated that although they were informed of the possibility of using daylighting for most areas during the day, they had no control over the designers as they believed that as professionals, designers were the ones who were in the best position to make such design decisions.

The other area where most landlords were unaware of was about automatic lighting controls. 80% of the landlords indicated that they had no clue about their existence or the value they could add to their office buildings. They noted that their building designers had not indicated of their importance in lowering lighting costs. They also noted that they were not aware of the various automatic lighting control devices available in the market.

The other 20% of the landlords who were aware of lighting controls noted that they were informed by their designers that the automatic lighting control devices were not only unnecessary but also expensive. They were told that use of manual controls was good enough and highly cost effective.

However, on being informed more about automatic lighting controls by the researcher, they expressed their desire to have designers encouraged to be supplying more information to the landlords regarding such devices so that they can make more informed decisions.

4.5 Interpretation of Data analysis

It has been shown from the above analysis that most office buildings within the CBD are inefficient in terms of their lighting energy consumption. Further, the designers have let the users of the office buildings down in most areas of design in the sense that they have failed to take into consideration basic design standards in their lighting design of office buildings.

The above inferences have tested the following study hypothesis and proven it to be true:

“The design considerations of a building have an effect on running costs of lighting in office buildings.”

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents conclusions and recommendations of the study made in the light of the study objectives.

The objectives of this study were as follows:

- i. Establishing the responsiveness of the office buildings designed and set up in Nairobi to measures aimed at lowering operating costs of lighting.
- ii. Establishing the role of the building designers in regard to designing and implementing office building designs appropriate to our economic situation.

5.2 Challenges faced during Field work.

There were various problems that were encountered during the field survey. These included:

- i. Unwillingness of the respondents to provide information - Some respondents claimed they were too busy and they could not have time to attend to the questionnaires. Others claimed they had no knowledge in lighting requirements and could thus be of no help. The researcher was forced to explain to the respondents that the questionnaires were not technical and that everyone could handle them. In some circumstances, the researcher had to take the respondents through the questions one by one.

- ii. Excessive bureaucracy in a number of places - This resulted in the researcher spending a lot of time before being directed to the concerned persons. This was the case in most buildings as access was denied by security guards despite the researcher having the necessary identification documents. The researcher had to at times go to great lengths to convince the security men to allow him into the premises. Some times the researcher had to lie that he was to see somebody in the building in order to be allowed entry.

- iii. In some buildings, the researcher was not allowed to get any information, the main reason being security. In other buildings, the photographing activity was faced with mixed security reactions. The researcher was allowed to take photos of only specific areas of the buildings according to the discretion of the property managers. In some situations the researcher had to take photos without permission by timing when the security men had relaxed a bit.

5.3 Conclusions

From the findings presented in chapter four, most of the office buildings surveyed were inefficient in their utilization of electricity for lighting purposes. This was so because the lights were either running when not needed or there was darkness when lights were needed. Incorporation of the necessary lighting control devices and the appropriate lighting system for a particular space will create a highly productive environment which will profit both the tenant and the building owner in the longrun.

5.4 Summary of Findings

Following is the summary of findings that were established from the data collected in the field:

- i. Floor areas have an influence on the amount of light available in a given space.
- ii. Window size determines the amount of light getting into a space
- iii. Location of windows determines the depth of light penetration in a given space.
- iv. Façade character will determine the general illumination available to various spaces within the building.
- v. The type of controls employed in a given space, have an influence on the total lighting cost of that space.
- vi. Light quality has an influence on the total productivity of persons using the space in question.
- vii. The amount of light in any given space should be adequate for the function(s) to be performed
- viii. Partitioning material and number of partitions in a space have an influence on the quantity of light available in that space and thus on the cost of lighting as well.
- ix. Atriums are an important consideration for diffuse light distribution especially for buildings with expanse floor areas.
- x. Building orientation takes into consideration the sun's path and use of respective spaces.
- xi. Regulatory standards in place do not reflect modern requirements and developments.
- xii. The prevailing climate of a place has an influence on the designs of buildings that can be set up in that place.
- xiii. Task lighting used together with ambient lighting presents the best lighting design.
- xiv. Surface finishes have an influence on the amount of light to be supplied to a given space.

5.5 Recommendations

Energy-efficient lighting design focuses on methods and materials that improve both quality and efficiency of lighting. Energy-efficient lighting design principles include the following:

- i. Keep in mind that more light is not necessarily better. Human visual performance depends on light quality as well as quantity.
- ii. Match the amount and quality of light to the performed function.
- iii. Install task lights where needed and reduce ambient light elsewhere.
- iv. Use energy-efficient lighting components, controls, and systems.
- v. Maximize the use of daylighting.

From the findings and conclusions that have been made, the following measures are recommended;

- i. Future developments for high-rise office buildings should consider the incorporation of automatic lighting control devices in these buildings. These considerations should be made in the design stage to avoid the high costs of future modifications and alterations. Manual controls currently in use in most office buildings have proved ineffective to contain costs of lighting because people tend to forget switching off the lights in the spaces they are using.
- ii. Office designers and builders can reduce lighting energy use by selecting light fixtures and sources that use energy more efficiently. There should be a deliberate effort made to educate the clients on the long run cost savings they will get by incorporating lighting efficient fixtures and sources.
- iii. Maximize the use of daylighting – Designers should take advantage of sunlight which is in plentiful supply in Nairobi and use it more so as to reduce significantly the cost of lighting.

- iv. Designers should come up with ways of designing office buildings that, although having a large floor area, should still be able to take advantage of daylighting and their total costs of lighting should at least be economical in the longrun. They could stagger the plan of the building or incorporate roof lights into their design. This has been used effectively at Jubilee Insurance Building (use of roof lighting) and Chester House (Staggered plan).
- v. Designers should design the lighting system in such a way that there is a good balance between ambient lighting and task lighting. This will ensure that only the required amount of electricity is consumed since the user will only use one at a time thus the unnecessary lighting will be eliminated which will contain the lighting costs.
- vi. Designers should use light room surface colours to minimize the need for artificial lighting – Since the room surfaces are important reflection surfaces, designers should choose colours that will generally require less amount of light to be used to light up the space in question.
- vii. Use a lighting strategy that integrates with daylight – The designer should make daylight integration part of lighting design from the beginning. Lighting strategy, fixture selection, and method of control are all affected by the goal of daylight integration. For buildings primarily occupied during the day (schools, commercial, etc) that do not have tasks requiring higher illumination at night, the electric lighting should be designed to augment daylight and not the other way round.
- viii. Incorporation of atriums – Designers should consider use of atriums in situations where they deem impossible to take advantage of the available natural lighting. This will enable efficient sharing of light among various spaces of an office building. This has been used effectively at *Loita House and Utalii House*.
- ix. Designers should choose partitioning material that does not compromise the ability of the space to share the available light. They should also keep the number of partitions to a minimum so as to minimize lighting cost.

- x. Maximize Visual Comfort – The designers should aim at designing a lighting system that will maximize the output of the users of the respective space. They should thus follow the recommended practice guidelines regarding lighting design as stipulated by the I.E.S (2001).
- xi. Window location – Designers should put the use of space in mind when deciding on the location of the window. They should try as much as possible to match the use of the space with the amount of daylighting they will provide to that space.
- xii. Window size – Designers should try as much as possible to put into consideration all aspects of window design when choosing the size of window to use for a particular space. They should keep in mind the tasks to be performed within the space for which they are designing. They should also consider the problem of glare and sound and thermal insulation so that the final product meets most of the user requirements.
- xiii. Façade character – This should be selected so as to maximize the amount of natural lighting available to a given space. Use of curtain walling should be an important consideration as this will maximize the amount of natural lighting available to the various spaces within the building. Some building such as Shelter Afrique House and Harambee Plaza, have used this to achieve a well lit internal atmosphere.
- xiv. The city council of Nairobi should consider reviewing its building code so that it can be more responsive to current construction needs. It should also enforce its rules and regulations more strictly so as to ensure that designers adhere to basic design standards.
- xv. The designers of office building should also self regulate themselves while designing office buildings in that they should design buildings that take advantage of their surrounding environment and maximize the use of resources at their disposal.
- xvi. Lighting quality comes before energy efficiency. Designers should ensure that they do not reduce occupant comfort or satisfaction for higher energy

savings. They should remember that an occupant's productivity is far more expensive than the energy he/she uses.

- xvii. Include calibration and maintenance plans in the construction documents. Designers should develop a set of recommended procedures and schedules for control system calibration, other lighting system commissioning, operation, maintenance and replacement, and format in a clear and easy to use package. They should make this documentation part of the lighting construction documents. They should also provide documentation that can be passed along to the ultimate occupants of the space so that they can understand how to best use the lighting systems and controls.
- xviii. Public awareness campaigns should be done to emphasize the need to conserve electrical energy and to maximize the light resources at the users' disposal as well as embracing current technology in their various office spaces.

Thus, the designers should put into consideration all the factors discussed above so as to present the end user with a final product that will meet most of his/her lighting needs.

5.6 Areas of further study

- i. A study on the effects of using automatic lighting on overall lighting costs in both residential and commercial buildings should be carried out.
- ii. This study was done mainly in commercial buildings. A further study may be done on the running costs of lighting in residential buildings.
- iii. Due to time and financial constraints, the study was limited to the study of office buildings whose geographical coverage area was confined to the Nairobi CBD. A study should be done to cover the entire city and if possible the whole country so as to bring a better understanding of the

problem at hand and hence enable all encompassing decisions to be made.

- iv. Due to time and resource constraints, the researcher was not able to develop a cost model. Further research should be done on the topic so that a cost model can be developed that can be used by various stakeholders within the industry in decision making on the lighting system to use in their buildings.

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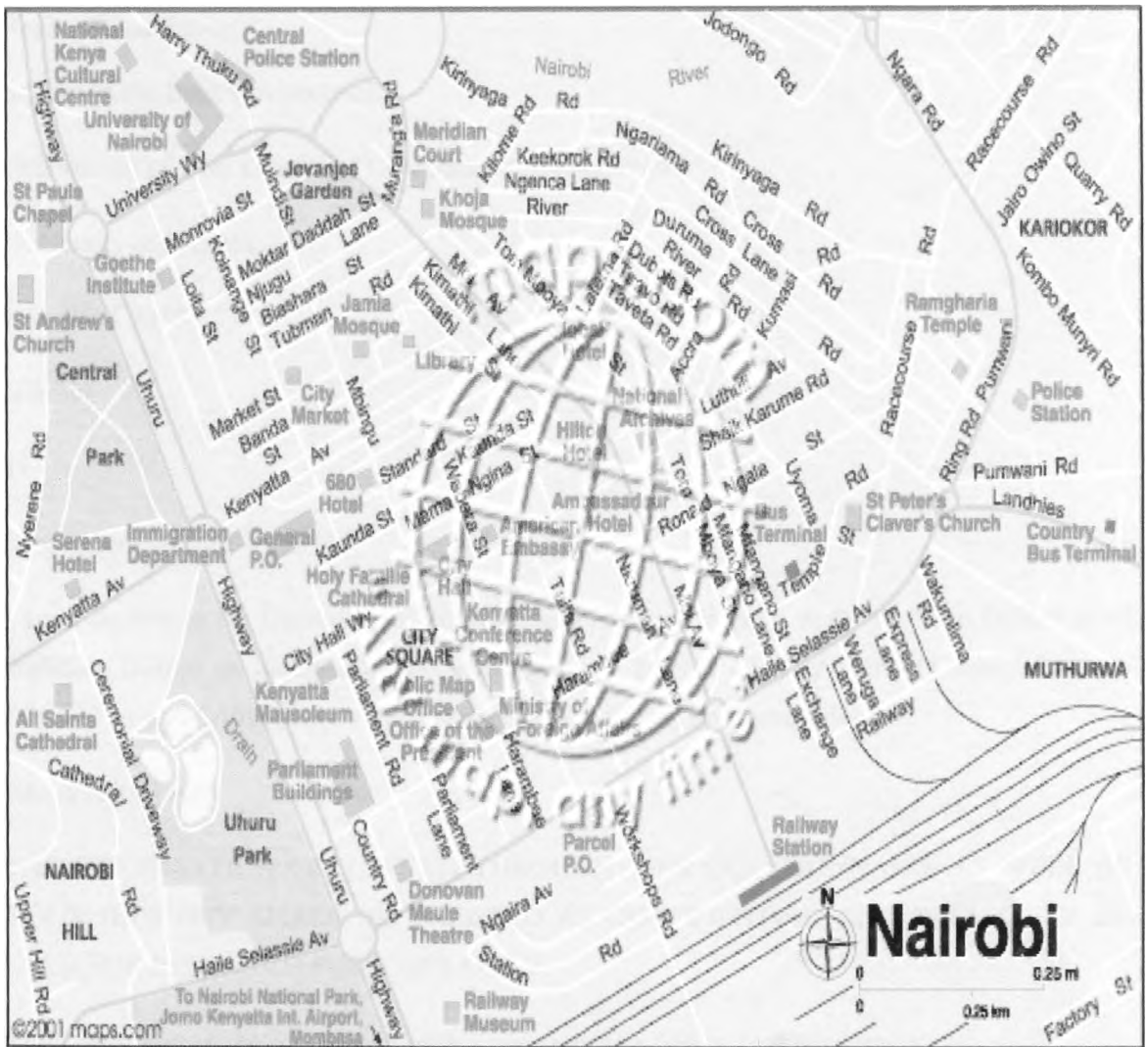
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Appendix 1: Map of Nairobi Central Business District



Source: nairobi.com

Appendix 2: Questionnaire to the architects

LETTER OF INTRODUCTION TO THE ARCHITECTS

Asuma Ronald Isoe,
School of the Built Environment,
Department of Real Estate and Construction Management,
University of Nairobi,
P.O. BOX 30197.
Nairobi.

To

Respondent,

I am a student at the University of Nairobi conducting a research study on **“The Influence of Building Design on the running costs of lighting”** (*A case study of Nairobi Central Business District*) as part fulfillment for the award of B.A Building Economics degree.

DECLARATION

THE INFORMATION COLLECTED THROUGH THIS QUESTIONNAIRE AS WELL AS YOUR IDENTITY SHALL BE TREATED AS CONFIDENTIAL AND WILL ONLY BE USED FOR RESEARCH PURPOSES ONLY.

Your assistance *in the completion of this questionnaire* will be highly appreciated.

INSTRUCTIONS:

Please tick {✓} and/ or state the appropriate answer in the space(s) or box (es) provided. More than one answer may be ticked or stated where applicable.

Your assistance will be highly appreciated.

Thank you.

Asuma Ronald Isoe,

RESEARCHER.

UNIVERSITY OF NAIROBI

DEPARTMENT OF REAL ESTATE AND CONSTRUCTION MANAGEMENT

QUESTIONNAIRE TO ARCHITECTS

1. Are you aware that Nairobi climate is suitable for daylighting?

Aware { } Partly aware { } Unaware { }

2. How often is the local climatic data used during lighting design of office buildings?

Never { } Rarely { } Often { }

3. How much consideration is given to the following during lighting design?

| | Item | A lot of consideration | Little consideration | No consideration |
|---|-------------------------------|------------------------|----------------------|------------------|
| a | Energy consumption efficiency | | | |
| b | Occupants comfort | | | |
| c | Maintenance | | | |
| d | Style of architecture | | | |
| e | Space use | | | |

4. How much consideration is given to automatic lighting control devices during design of office buildings?

No consideration { } High consideration { } Little consideration { }

5. Why are high-rise buildings within the CBD artificially lit during the day?

- (a) Inadequate regulatory standards { }
- (b) Fashion influenced by developers preference { }
- (c) Obstruction by other high rise buildings blocking light { }
- (d) Disregard of basic design standards by designers { }
- (e) Others reason(s) (specify).....

6. Why are very few buildings using automatic lighting control devices in office buildings despite their contribution to lower lighting costs?

Restrictive high initial costs { } Ignorance about the devices { }

7. What is the frequency of consideration given to natural lighting in office building based on the following design aspects? (*Tick where appropriate*)

| | Item | Never | Rarely | Often |
|---|----------------------|-------|--------|-------|
| a | Window size | | | |
| b | Building orientation | | | |
| c | Window location | | | |
| d | Façade character | | | |
| e | Use of roof lights | | | |
| f | Use of atriums | | | |
| g | Floor area | | | |
| h | Space partitions | | | |
| i | Use of space | | | |
| j | Room height | | | |

Thank you.

Appendix 3: Questionnaire to the tenants

LETTER OF INTRODUCTION TO THE TENANTS

Asuma Ronald Isoe,

School of Built Environment,

Department of Real Estate and Construction Management

P.O. BOX 30197-00100,

Nairobi, Kenya.

To

Respondent,

I am a student at the University of Nairobi conducting a research study on “**The Influence of Building Design on the running costs of lighting**” (*A case study of Nairobi Central Business District*), as part fulfillment for the award of B.A Building Economics degree.

DECLARATION:

THE INFORMATION COLLECTED THROUGH THE QUESTIONNAIRE(S) OR INTERVIEW(S) AS WELL AS YOUR IDENTITY SHALL BE TREATED AS CONFIDENTIAL AND WILL ONLY BE USED FOR THE PURPOSE OF THIS RESEARCH.

Your assistance in the completion of this questionnaire will be highly appreciated.

INSTRUCTIONS:

Please tick (√) and/ or state the appropriate answer in the spaces(s) or box (es) provided. More than one answer may be ticked or stated where applicable.

Your assistance will be highly appreciated.

Thank you.

Asuma Ronald Isoe,

RESEARCHER.

UNIVERSITY OF NAIROBI

**DEPARTMENT OF REAL ESTATE OF AND CONSTRUCTION
MANAGEMENT**

QUESTIONNAIRE TO TENANTS

1. Did the lighting system of the building influence your choice of the space you currently occupy?

Yes []

No []

2. Is the building lit through the windows during day time?

Yes []

No []

3. If yes in 2 above, is the lighting adequate?

Yes []

No []

4. Is the lighting automatically controlled in any way?

Yes []

No []

5. Do you experience lighting inconveniences during power failures, maintenance and repair of the system?

Yes []

No []

6. How is the cost of lighting managed?

(i) Is it factored in the rent []

(ii) Is paid by the building owner []

7. What is the cost of lighting to the tenant?

a) High []

b) Affordable []

c) Low []

8. What makes the office space you occupy poorly lit?

(i) The space location is deeply within the building where natural lighting isn't possible []

(ii) The building is completely sealed from external environment by surrounding buildings []

(iii) The building has poorly positioned windows []

(iv) The building is poorly oriented []

(v) The size of the windows is inadequate for sufficient lighting []

(vi) Use of the space was not taken into consideration during lighting design []

9. In your own assessment, how do you rate the following?

| | Good | Fair | |
|------------------|-------------|-------------|-----|
| Poor | | | |
| Light quality | [] | [] | [] |
| Light quantity | [] | [] | [] |
| Lighting control | [] | [] | [] |
| Spatial comfort | [] | [] | [] |

Thank you.

Appendix 4: Questionnaire to the Land lord/Property manager:

LETTER OF INTRODUCTION TO THE LAND LORD/ PROPERTY MANAGER

Asuma Ronald Isoe,
School of Built Environment,
Department of real Estate and Construction Management,
P.O. BOX 30197-00100,
Nairobi, Kenya.

To
Respondent,

I am a student at the University of Nairobi conducting a research study on, “**The Influence of Building Design on the running costs of lighting**” (*A case study of Nairobi Central Business District*), as part fulfillment for the award of B.A Building Economics degree.

DECLARATION:

THE INFORMATION COLLECTED THROUGH THE QUESTIONNAIRE(S) OR INTERVIEW(S) AS WELL AS YOUR IDENTITY SHALL BE TREATED AS CONFIDENTIAL AND WILL ONLY BE USED FOR THE PURPOSE OF THIS RESEARCH.

Your assistance in the completion of this questionnaire will be highly appreciated

Questionnaire No.....

INSTRUCTIONS:

Please tick (√) and/ or state the appropriate answer in the spaces(s) or box (es) provided. More than one answer may be ticked or stated where applicable.

Your assistance will be highly appreciated.

Thank you.

Asuma Ronald Isoe,

RESEARCHER.

UNIVERSITY OF NAIROBI

**DEPARTMENT OF REAL ESTATE OF AND CONSTRUCTION
MANAGEMENT**

QUESTIONNAIRE TO LAND LORD/ PROPERTY MANAGER

1. Is the building during day time:-

- (i) Lit by sunlight []
- (ii) Lit by electricity []
- (iii) Combination of both []

2. Does the factor(s) in above, give the building a marketing advantage over competitors?

- Yes []
- No []

3. Was it ever brought to your attention by consultants that Nairobi zone can use natural lighting almost exclusively during the day if the building is properly designed in relation to its environment?

- Yes []
- No []

4. Did you advocate for incorporation of automatic lighting control devices to avoid unnecessary cost due to lights running when not needed?

- Yes []
- No []

5. Have there been cost savings achieved due to use of automatic lighting controls?

- Yes []
- No []

6. Is the building faced by any or all of these problems?

- (i) Poor lighting []
- (ii) Completely sealed from external environment []
- (iii) Use of the space was not taken into consideration during lighting design []
- (iv) The building has poorly positioned windows []
- (v) Poor orientation of the building []
- (vi) Imported design not meant for Nairobi climate []

Thank you.