THE INFLUENCE OF ARCHITECTURAL DESIGN PARAMETERS ON THE MAINTENANCE COSTS OF BUILDING SERVICES OF OFFICE BUILDINGS IN THE CITY OF NAIROBI

BY

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A Thesis submitted in part fulfilment for the degree of Masters of Arts in Building Management.

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ACKNOWLEDGEMENTS

I am indebted to the following people for their sincere help, without which I could not have managed to write this thesis: John Mbaya and Abel Mugenda, my supervisors; Staff in the Department of Building Economics and Management, Dr. P.G. Ngunjiri of Department of Architecture, and my second year Masters colleagues. My gratitude also goes to Mr. Kariuki, Chief Mechanical Engineer in the Ministry of Public Works; Mr. Muhia, Nairobi Provincial Mechanical Engineer; Mr Mwandini, Depot Maintenance Works Officer-in-Charge and to Mr. Otieno and Miss Mugo of Tyson and Town Property Estate Agents.

Finally, I wish to thank Leah W. Machira for typing this thesis with a lot of patience.

DEDICATION

To my dear parents; Mary Nyakiambi Wambugu and Ignatius Wambugu Githinji.

DEFINITIONS

Maintenance of Building Services: Work undertaken to keep and restore building services to currently acceptable standards, to sustain services and value of the facility.

Design Parameters: The characteristics or determinant features of designed buildings.

ABBREVIATIONS

CBD - Central Business District

MOPW - Ministry of Public Works

NCC - Nairobi City Commission

ABSTRACT

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

It has been established in the literature review that the design indicators for maintenance cost are height, perimeter, shape, area of windows, area of floors, number of storeys and the age the of building. These seven independent variables are regressed against maintenance cost of engineering services; the dependent variable.

The analysis of the data collected revealed that more maintenance cost is expended in the mechanical services than electrical services. The analysis further indicated that maintenance cost of mechanical services is determined by the following design variables: height, shape and perimeter of the building. It was also found that height is a determinant of maintenance cost of electrical services. The overall maintenance costs of engineering services were found to be a function of height and perimeter of the building.

This study concludes that a relationship exists between maintenance costs of building services and design parameters. Thus designers should design for maintainability of office building services among other factors.

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CHAPTER ONE

INTRODUCTION

Building services in office blocks are essential because they make internal environments more comfortable. They facilitate communication and transportation of goods and services. They also ease the supply of water and drainage within the buildings.

The Kenya Government has attached a lot of importance to maintenance of the existing building stock. In the 1984-1988 Development Plan[1], for example, it was stipulated that "Proper maintenance procedures will be given high priority and be streamlined. This will be done by establishing a system of information monitoring on the state of building and maintenance work that gets carried out". The aim of the present study is to establish a maintenance model which may serve as an information system which will assist building designers and maintenance team during the design stage and the building-in-use-stage.

This research is an investigation of the influence of design parameters on maintenance costs of office building services. The sample size of the study is 45 office buildings within the Commercial Business District of Nairobi City.

The sources of information include existing literature, visits to the case study offices and interviews with maintenance staff and estate agents. This research has used quantitative and qualitative methods to analyse the data collected from the field. The maintenance cost model developed in this research is expected to benefit the clients, designers and maintenance staff in predicting the maintenance costs of the office building services.

This thesis constitutes five chapters. Chapter one consists of a brief introduction of the study, the problem statement, the objective, hypothesis, significance, limitations of the study and finally the assumptions of this study. Chapter two presents an analysis of services in the building system and their maintenance. It also discusses the design principles and design parameters as well as the relationship between maintenance cost of building services and design parameters.

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.

1:1 Statement of the Problem

McGuiness[2], Phillpott[3] and Carpenter[4] have identified that the ever-increasing engineering services in buildings have received little attention in terms of research on their space design and maintenance costs. Carpenter[5] has noted that "building services installations are poorly maintained, ... and hurriedly designed....". Casual observation in Kenya generally indicates rapid deterioration of installed office building engineering services and large maintenance expenditure. One is tempted therefore to infer that these are the results of inappropriate design for building services-in-use.

The two-fold reasons that have prompted this research are the high maintenance expenditure on the building services and the design errors made by designers and which may, among other things, contribute to high maintenance cost of building services.

Previous researches by Gibson and Martin have shown that the maintenance of building services is a major component of the maintenance budget. For example, Gibson[6] has established that the maintenance expenditure on building services is 27 percent of total maintenance of building fabric and services. Figure 1.1 below shows Gibson findings.

Martin[7] has identified, as shown in Figure 1.2,

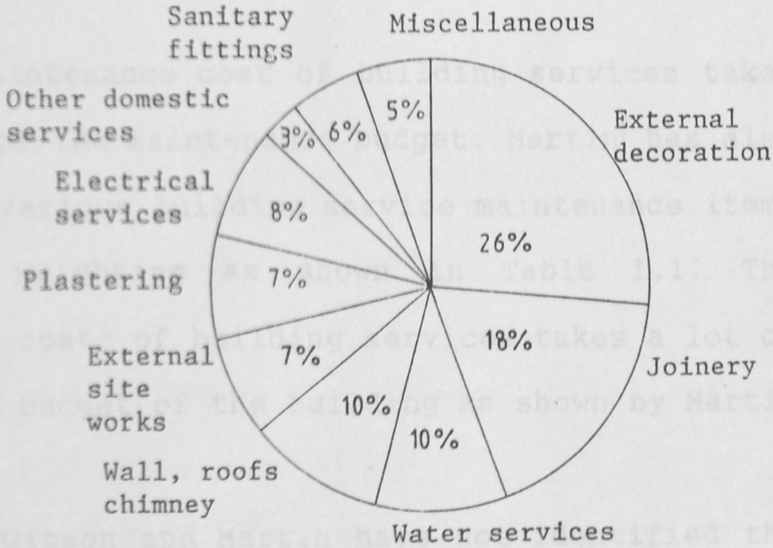

Figure 1.1: The maintenance cost apportionment to each building component. Note that Gibson's research on three local authorities excludes the internal decoration.

Source: Gibson, E.J. (1977)

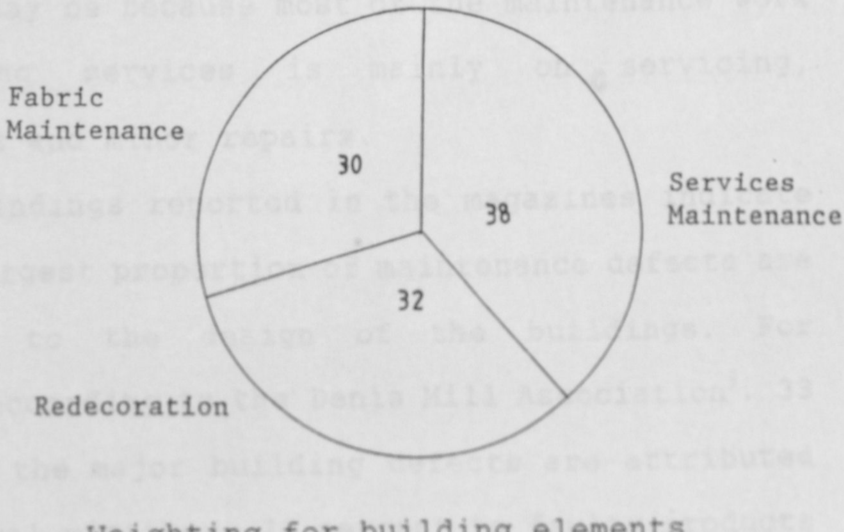

Figure 1.2: Weighting for building elements indices for general maintenance.

Source: Martin J.L.N. (1987)

that the maintenance cost of building services takes 38 percent of the maintenance budget. Martin[8] has also identified various building service maintenance items and their weighting as shown in Table 1.1. The maintenance costs of building services takes a lot of maintenance budget of the building as shown by Martin and Gibson.

Both, Gibson and Martin have not identified the types of buildings they studied even though their studies have given a general idea of how the maintenance cost is distributed among different building components. Martin has further established maintenance indices for each item in building services. Moreover, the proportions given by Martin indicate that the labour cost is higher than the material cost in the maintenance expenditure.

This may be because most of the maintenance work of building services is mainly on servicing, inspections and minor repairs.

The findings reported in the magazines indicate that the largest proportion of maintenance defects are attributed to the design of the buildings. For instance, according to the Denis Mill Association[9], 33 percent of the major building defects are attributed to designers' mistakes, 26 percent to faulty products from manufacturers, 41 percent to poor workmanship from contractors. A similar survey carried out by the

Table 1.1: The building service maintenance items and their weighting.

ITEM	WEIGHTING
Plastic building material	1.5
Copper tube	1.0
Sanitary Ware	2.5
Plumbers brass	2.0
Electrical materials	10.5
Mechanical engineering materials	17.5
Materials total	35.00
Labour total	65.00
TOTAL	100.00

Source: Martin J.L.N.(1987)

<u>Building Research Establishment</u>[10] identified that designers' errors account for 50 percent of defects, while contractors' workmanship contributes 40 percent and finally faulty manufacturers' products constitute 10 percent.

These researches, nevertheless, have not identified the types of buildings with the above composition of defects nor the building components that accounted for the defects. Against the background of these studies, one can conclude that defects in building services are more likely to originate from designers' faults, contractors' workmanship and faulty products from the manufacturers.

Designers' errors include inappropriate location of 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. These design errors adversely affect the finished buildings and escalate the maintenance costs of building services. Below is a discussion of these design errors and their influence on maintenance costs.

<u>Inappropriate location of services</u>: Feldman[11] has noted that in buildings where the designers have not ensured that the location of lighting fixtures are easily accessible for relamping, cleaning and other

general repairs, it is highly expensive to maintain the buildings' electrical installations. He has also observed that office buildings with high-ceiling areas are very difficult and expensive to relamp, clean and maintain since special provision has to be made for work to be carried out. That is, scaffolding has to be done before. He has also noted that it is not only difficult and time consuming but also unsafe to replace stairwell lights which tend to be very high in office buildings.

According to Feldman[12] the designer should, among other things, provide empty conduits from recessed electrical panels to junction boxes to handle future requirements for electrical outlets and fixtures. This reduces the chances of exposed wiring and the associated high maintenance attention.

Irregular and complicated design shapes of buildings: Seeley[13] has pointed out that office buildings with complicated and irregular design shapes require a large number of service points in a building. This is more expressed by the large amount of plumbing and electrical works which have to be installed. Conversely, as much maintenance work is required during the use of the plumbing services and electrical services in the building.

Expanse floor areas: Joedicke[14] 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 may be remedied by using excessive lighting fittings and fixtures to make the spaces conducive to functions they are intended for. This error increases the maintenance costs of office building services.

Inadequately ventilated and lit spaces: The present researcher has observed that designers of some office buildings in Nairobi have made errors by providing inadequate ventilation in some building spaces especially stairways, stores and toilets. The remedy for this error is to install mechanical ventilation or air-conditioning systems to make building spaces functional.

The second case observed is where a building has inadequate or no natural lighting in some building spaces. This error is only rectified by use of excessive supplementary lighting or permanently artificial lighting to make the spaces conducive to their intended purposes.

Designer's error may also influence the allocation, size and specifications of space for office building service components. The process of designing space for engineering services demands that the space be appropriately located for installation of those services. The size of the space left for engineering services must both be adequate for equipment and circulation during the maintenance work. The designed areas for building services need proper specifications. For example the types of equipment supports, ducts and their openings. This is because the space allocation, its size and specification, are determined by the design principles which include organization of space, unity of composition, shape, rhythm, proportion and form.

Design principles affect the way the service components, pipes, cables and fittings are distributed throughout the building. The design principles, therefore, have a relationship with the maintenance cost of building services. If, for instance, a principle like rhythm is the dominant design concept,then it might be noted that the locations of lighting fittings, ventilation outlets (grilles) and fire-fighting equipment follow the rhythm of the building fabric.

It is from these design principles that the parameters are derived. This study has used the design parameters as surrogates to measure design.

In all the building design problems noted above, there is no suggested model that shows the relationship between maintenance cost and design parameters. Thus this study aims at establishing a model that could assist designers in determining exactly what they ought to consider when designing.

The aim is to minimise future maintenance costs arising from common design errors. Designers should consider the concept of minimising maintenance on services as one of their priorities in office building design.

1.2 Objective of Study

The main objective of this study is to establish the relationship between design parameters and maintenance cost of office building engineering services by:

(i) Examining designs of various office buildings with a view to identifying appropriate design variables.

(ii) Identifying designers' errors in office buildings.

(iii) Examining the maintenance cost of various buildings with a view to apportioning costs to various elements of building engineering services.

1.3 Hypothesis

The hypothesis to be tested in this study is that architectural design parameters have an influence on maintenance costs of office building services.

1.4 Significance of Study

Within the Kenyan context, there is scarcity of maintenance models to help the building maintenance team, especially in the area of building engineering services. It is envisaged that the cost model developed in this study will assist the client, designers and maintenance staff to forecast, at an early stage, the maintenance cost of building services.

The landlords want to be assured that they are investing their money in viable projects in terms of their maintainability. The model developed in this research will help designers evolve tentative designs and then choose those which give optimum investment returns to the clients.

This study will examine the factors that influence the design of office buildings. Designers can take these factors into account in order to avoid unnecessary high maintenance costs that arise from avoidable design errors.

1.5 Limitations of Study

This research deals with the design principles of office buildings with respect to organization of space, shape, rhythm, proportion, form and unity of composition. It limits itself only to the above principles because the author feels they are the most appropriate in illustrating the relationship between maintenance cost of the office building services and design parameters considered. This study is restricted to only six design parameters namely: height, floor areas, window areas, perimeter, number of storeys and shape of the building. These are physical design variables of a building and can easily be measured either on site or from the building plans, sections and elevations.

The study also confines itself only to the maintenance cost of labour and materials related to the building services.

It also limits itself to office buildings above four storeys where most of the service components are more or less constant. Moreover, only a sample of 45 buildings out of 135 were considered since, statistically the sample has to be large enough for clear interaction of variables especially when the analysis is done using multiple regression.

The research limits itself only to tall urban office buildings in the same geographical zone so that other variables such as climate remain constant.

The study also concentrates only on engineering services for tall office buildings whose maintenance costs are most affected by design errors. In most of their designs, the designers seem not to have given enough consideration to allocation, size and specifications of space for the services. In addition, most designers allocate more time to the aesthetics and spatial organization of the building and often forget to design appropriately for the building services.

Although this study concentrates only on the design, the other factors which affect maintenance costs of office building services include organisation and qualification of maintenance personnel, type of occupants and efficiency of utilities.

Finally, the constraints of time and money have hindered a wider range of data collection. Wide use is made only of relevant literature and data collected from the 45 office buildings in Nairobi city.

The field data consists of measurements taken from plans, sections and elevations of the buildings. It also consists of interviewees' responses and the researcher's own observations of design parameters and engineering services from the sampled office buildings.

1.6 Assumptions

This research holds that some design decisions are unique to the specific building types like offices, warehouses, museums, hospitals etc. For example, in a hospital, circulation takes the first priority whereas in a museum, it is the lighting. As a result, this study concentrates on office buildings only. Hence the research assumes these buildings have similar services and users.

The data collected on maintenance costs is for five years (1984-1988). Previous research done by Janicki and Zaleski[15] and a pilot study done on this research have shown that the data collected have adequate information regarding the variation of maintenance cost over the years. It is difficult to obtain the maintenance costs of the building services from the time of construction to the present day. It is therefore assumed that an average cost of each building over a life time of five years is representative of expected annual maintenance costs over the life of the building. The figure computed are then divided by the area of respective buildings. The maintenance cost of engineering services for each building for the years 1984-1988 was raised to 1988 constant prices using the Central Bureau of Statistics construction cost indices, before computing their mean over five years.

Footnote

1. Kenya Development Plan 1984-1988, (Nairobi: Government printer, 1984), p.131
2. William McGuiness, Mechanical and Electrical Equipment for Buildings (New York: John Wiley and Sons, Inc, 1971 5th ed.) p.v.
3. B. Phillpott, "Designing with terotechnology in Mind". Building Service Establishment, vol.43 (1975), pp.76-80.
4. I. K. Carpenter, "The commercial aspects of terotechnology and planning for maintenance "Building Service Establishment, Vol.43 (1975), pp.71-75
5. Ibid., p.75
6. E. J. Gibson, "Maintenance Research", British Research Establishment. vol.37 (1977) p.8.
7. J.L.N. Martin, "Monitoring the movement of maintenance costs," in Building Maintenance Economics and Management. ed. Alan Spedding (London: E.& F.N. Spon, 1987), p.183
8. Ibid., p.183
9. Trade News, "Blame for Defects now swings to Products" Building Today, vol.195 No. 5753 (April, 1988), p.16
10. Ibid., p.16

11. Edwin B. Feldman, Building Design for Maintainability. (New York: McGraw-Hill Book 1968). p.166.

12. Ibid., p.161

13. Ivor H. Seeley, Building Economics (London: MacMillian, 1972), p.18.

14. J. Joedicke, Office Buildings (London: Crosby Lockwood & Son Ltd, 1962),p.22

15. S. Janicki and S. Zaleski, "Bases for Maintenance and Modernisation of Buildings," in Renewal, Rehabilitation and Maintenance Volume 1b, CIB 83, Stockholm, 1983. p.191

CHAPTER TWO

LITERATURE REVIEW

This chapter gives a critical review of the historical background of building services in tall buildings with emphasis on office buildings. It also stresses the importance of building services in an office building system. In discussing the types of office building engineering services, the sections considered are mechanical and electrical services, as has been identified by Sidwell[1], and their maintenance. This review also deals with design principles and design parameters. Finally, the chapter dwells on the maintenance costs of building services and their relationship to architectural design parameters of office buildings.

2.1 Historical Background of Building Services in Tall Office Buildings

Intensive design of building services is a recent phenomenon in the field of architecture. Early architecture, including the Hellenic, Roman, Gothic and Renaissance Architecture mainly concentrated on the function and the structure of a building. The massive structure as noted by Maver[2] provided security and protection from climatic extremes; openings in the structure provided light and ventilation. The dominant building types were public buildings like agora, temples, castles, forts and churches; these mostly consisted of one large functional space.

During the industrial revolution in the eighteenth and nineteeth centuries, there evolved the modern architecture with different and more complex building types. Maver[3] has postulated that the functions of security and climatization have been taken over by electronic control devices. For example, monitor television sets and burglar alarms are installed in banks while air-conditioning plants now moderate climatic variation. Artificial lighting also performs some functions of the window. The massive structures also have been substituted by steel frames, portal reinforced concrete frames and by plastic reinforced concrete structures. These technological advances have facilitated the use of intensive engineering services in the building system.

Ozguner[4] concurs with the above statement on technology and he notes that the recent technical innovations have made the tall buildings more economical and functional. The technological developments pointed out by Ozguner include the invention of concrete, steel, precast elements, skeletal construction as loadbearing wall and the elevators as vertical transportation systems. Ozguner[5] has also put forward that the main technical innovations include the elevators, sanitary blocks and equipment shafts. The modern office building design has to respond to these technical innovations. Hence, the vertical circulation elements, services, wet core areas, emergency staircases and mechanical shafts are all arranged in office building plans in such a way that they are strongly expressed on the building elevations. The inner space of the office building is also free and flexible with a main facade elegantly expressed with the created service cores.

Finally, the concept of engineering services in tall buildings seems to have evolved out of the necessity of man's increased and/or varied functions and subsequent economy of space.

2.2 Importance of Building Services in Building Systems

Building services form part of the elements of the building system. Others are substructures, superstructures, finishes and fittings. In his research on the breakdown of capital expenditure of different building types, Maver[6] established the apportionment of building elements among different types of buildings. The buildings considered were; house, factory and hospital. His analysis shows that the importance of engineering services changes with the type of the building. For instance, building services are 12 percent in a house, 18 percent in a factory; and 50 percent in a hospital. (Figures 2.1, 2.2 and 2.3).

In recent years building services have become major items in the construction budget. McGuiness[7] points out that building services are now taking "half the construction budget" although he has not identified the type of the building construction nor the building type which does so. However, Maver[8] has shown the breakdown of the capital investment of hospital services. (Figure 2.4)

Phillpott[9] has established that about 37 to 43 percent of the building volume is occupied by building services but he too does not specify what type of building has these proportions.

However, Tarmohamed[10] has put forward that in some Nairobi Office buildings such as Uchumi House, Extelcoms Building and Bruce House, about 13 to 15 percent of the built up office space is occupied by services and auxilliary spaces.

Fussel, as quoted by Sidwell[11] has given a more concise descriptive analysis of mechanical and electrical costs for different building types. The costs are percentages of total building cost. (Table 2.1).

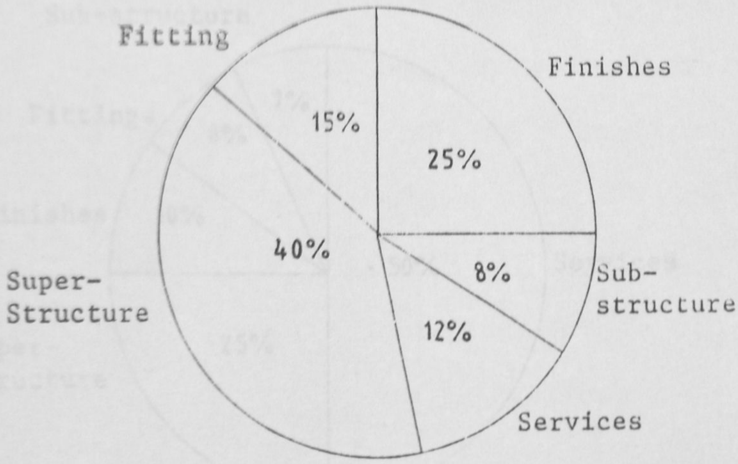

Figure 2.1: Apportionment of building elements in a house.

Source: Maver, Thomas W.D. (1971)

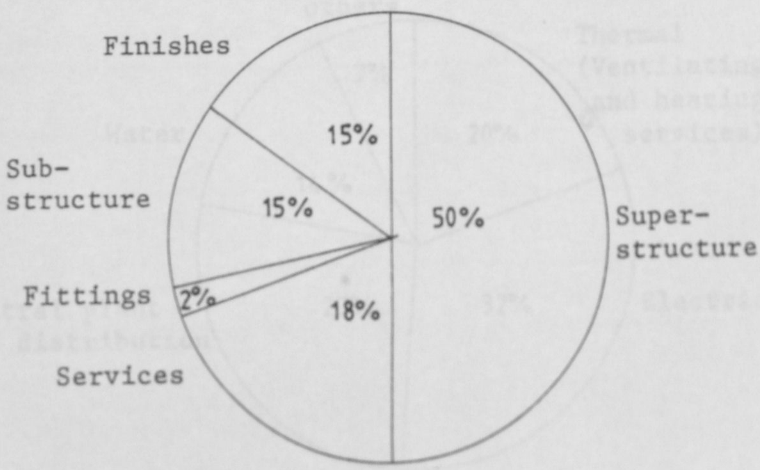

Figure 2.2: Apportionment of building elements in a factory.

Source: Maver, Thomas W.D. (1971)

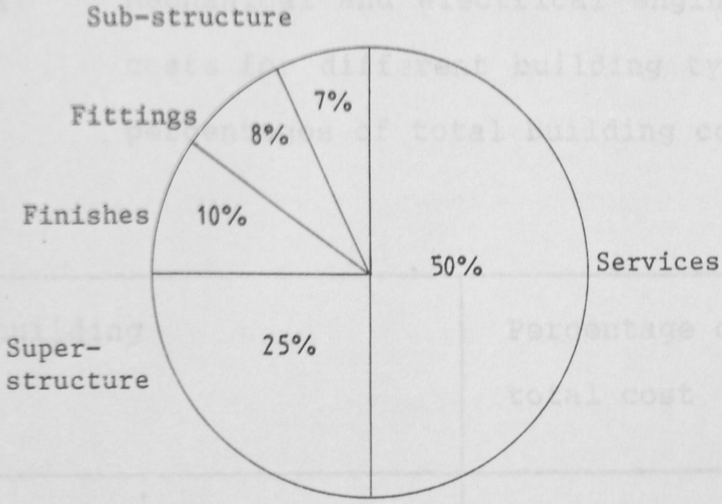

Figure 2.3: Apportionment of building elements in a hospital.

Source: Maver, Thomas W. (1971)

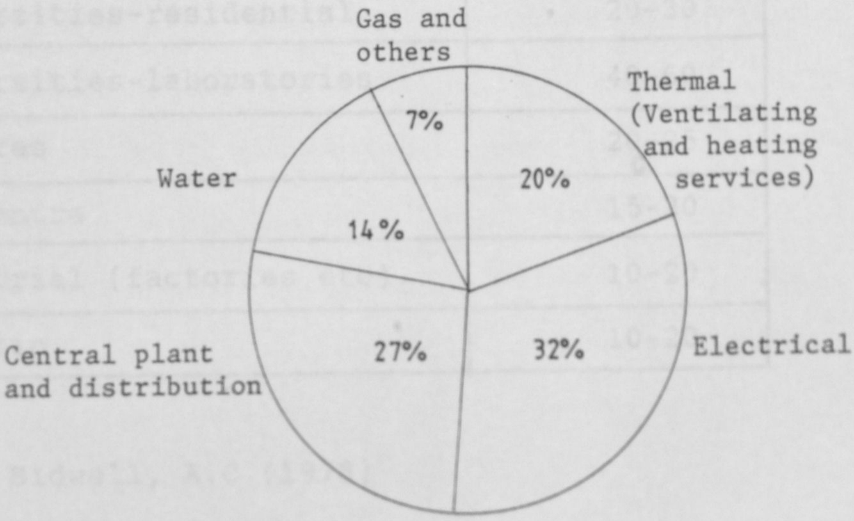

Figure 2.4: The breakdown of the capital investment of hospital engineering services.

Source: Maver, Thomas. W.(1971)

Table 2.1: Mechanical and electrical engineering costs for different building types in percentages of total building cost

Type of building	Percentage of total cost
Offices-not air conditioned	15-20
Offices-air conditioned	25-33
Hospitals	30-45
Schools	20-30
Universities-residential	20-30
Universities-laboratories	40-60
Theatres	20-25
Art Centre	15-20
Industrial (factories etc).	10-20
Domestic	10-20

Source: Sidwell, A.C.(1978)

It can be inferred from the above that building services are as important as any other building element in the building system;and that different types of buildings have different requirements with regard to building services. Maver and Fussel go further to reaffirm that capital expenditure on building services varies with the type of building. Finally, it can be deduced from the above analysis of capital expenditure that the maintenance cost of these building services would vary among different types of buildings.

2.3 Type of Office Building Engineering Services and Their Maintenance

Office building services are those systems and their components which provide a building with plumbing, sewerage, heating, ventilation, air-conditioning, lighting power, vertical transport and fire protection as established by Miles[12]. All these services can be classified into two main groups, namely, electrical and mechanical services.

It is accepted that maintenance tries to keep the design of office buildings within acceptable standards as stipulated by Kenyan Laws. The Laws include: the Public Health Act (Chapter 242), The Registered Land Act (Chapter 300), the Rent Restriction Act (Chapter

301) and the Local Authorities Adopted Building By-Laws 1968. These requirements are used to make sure that the building is not injurious to health of the users; thus quaranting the safety of all occupants.

A building has to be maintained continually because of the concept of normal wear and tear, as forwarded by Syagga[13]. Feldman[14] has noted that to have a reasonable maintenance cost of building services, the maintenance planning should include: maintenance inspection, preventive maintenance activities such as lubrication and rodding; corrective maintenance such as repair and replacement of broken or worn out items and, lastly, cleaning and sanitation.

Feldman assertion concurs with studies carried out by Miles[15] which have identified the following three maintenance classifications:

(i) Planned maintenance, also known as planned preventive maintenance, refers to inspection, cleaning, servicing or work done to avoid failure of any of the building elements. Janicki and Zaleski[16] have also noted that planned preventive repairs are performed "in order to maintain proper physical and technical characteristics of aging materials" used for the construction of the building within required level. The planned corrective maintenance is done by replacing a component that has failed.

(ii) Contingency maintenance is the maintenance work resulting from unforeseen breakdown of the components. The component having a defect is repaired or replaced depending on its condition. This type of maintenance work includes power failure and burst pipes. This type of maintenance may also be referred to as emergency repairs which, by their nature, call for priority action to avoid serious consequences. Repair work is defined by Grover and Grover[17] as reduction of deterioration by a constant factor or by a factor that varies according to the age of the item when the repair is undertaken.

(iii) Cyclic maintenance results from cyclic breakdown of the component. This type of maintenance work includes replacement of light fittings and leaking taps or pipes.

(vi) The fourth category of maintenance is termed as running maintenance. This is defined by Colston[18] as the "work required to help the operation of mechanical plant, lifts, ventilation equipment, pumped water services and others which require regular servicing and inspection over a period of time, during the whole life of the property".

The section that follows briefly discusses the mechanical and electrical services and their maintenance.

2.3.1 Mechanical Services

According to Estmancode,[19] the mechanical services include; piped services, air-conditioning and ventilation systems, fire-fighting equipment, gas services and lifts. These mechanical services are discussed below.

2.3.1.1 Piped Services

These are services involved with hot and cold water supply, drainage and sewerage of soil and waste water.

Cold and hot water services: Maver[20] emphasizes the supply and distribution of hot and cold water in office building to ensure an adequate standard of hygiene for office users, of the equipment and utensils used in the tea rooms and of the building fabric itself. Closely associated with hygiene is the necessity of waste disposal which is facilitated by adequate supply of water.

Manasseh and Cunliffe[21] have noted that water in office building is also used to contain and extinguish fires which could otherwise destroy the contents and the building fabric.

The National Building Agency[22] has identified that the maintenance work done on hot and cold water systems includes repairing leaking taps and pipes, replacement of burst and furring pipes, rugging the hot water cylinder, replacement of faulty ball valves, broken sinks and wash-hand basins.

Drainage Services: This applies to installations of pipes which help in the disposal of both soil and waste water.

Soil water is drained from water closets and urinals whereas waste water is disposed from sinks, wash-hand basins and from basements when water seeps through during rainy seasons. Manasseh and Cunliffe[23] have emphasized that the buildings with deep basements must have pumps for pumping waste water from the basement level to the public sewer level. This implies that more cost is incurred in the maintenance of motors and pipes used to pump the waste water out of the basement.

The maintenance work done on drainage system involves rodding the internal sewerage pipes, replacing broken water closets and covers, faulty ball valves, broken pipes and unblocking the drainage pipes.

2.3.1.2 Ventilation and Air-conditioning Systems

Barton[24] notes that "the effect of air on health and comfort of occupants depends on a variety of factors; these include its temperature, humidity and velocity". The main purpose of air-conditioning and ventilation systems in office spaces is to provide them with controlled levels of environment. Joedicke[25] has identified the following conditions for comfort in office building: temperature 20-28^{0}C; humidity 30-70%; air-change 30m^3/hr/person; and air-movement 0.20m/s. Following is a discussion of ventilation and air-conditioning systems.

Ventilation System: Ventilation is necessary in order to prevent unduly high concentrations of carbon dioxide and moisture and to provide for the removal of bacteria as has been stressed by Barton[26]. The provision of local fans either on desks or ceilings and ductwork on ceilings creates sufficient air movement to give relief in conditions which would otherwise be very oppressive.

A considerable degree of air change occurs in most buildings even if no mechanical system of ventilation is provided. This is due to infiltration of air around the windows and doors. Mechanical ventilation is only used when a definite rate of ventilation is necessary or when it is desired to have the conditions within the building under control.

The maintenance cost of a ventilation system is incurred in servicing, repairing and in replacement of components such as fans, ducts, grilles and motors as the need arises.

Air-Conditioning System: Air-conditioning is the production and maintenance of suitable conditions of atmospheric temperature and humidity. Air-conditioning is done in an enclosure to enhance human comfort, regardless of the outdoor climatic fluctuations.

According to the Nuffield Provincial Hospital Trust (NPHT)[27], an air-conditioning system also increases the level of air hygiene by removing from the air dust particles, bacterial gases and other matter of noxious or unpleasant nature.

The maintenance cost of an air-conditioning system is incurred during the servicing, repair and replacement of components such as: pipes, tanks, valves and ducts.

2.3.1.3 Fire-Fighting Equipment

Fire-fighting equipment are yet another type of mechanical service components. They are integrated in the office building system to prevent and control outbreak of fire. Manasseh and Cunliffe[28] has hypothesized that this has an effect on the shape, planning, construction of the building and pattern of use.

The local authorities have guidelines in the Building Code[29] on planning and protection systems of the building. They stipulate the location and specification of fire fighting equipment and escape staircases in a building. They also standardise the types of fire-extinguishers according to categories of fire they can extinguish.

The maintenance cost is incurred in keeping portable extinguishers, hose reels and sprinklers, water tanks and pipes in good working condition. These components need thorough planned maintenance based on inspection. This ensures that the facility is always in working condition. Maintenance cost is mainly expended in the installation of the fire-fighting equipment in case it is used or it has become redundant. This would mostly apply to fire-extinguishers and alarms. The main maintenance cost incurred here is labour for inspection; minimal cost for material is used for replacing fire-extinguishers.

2.3.1.4 Gas Services

An office building in tropical regions is unlikely to need an intensive gas layout although where there are catering facilities, gas is often used for cooking and for heating water. In case the office building uses gas, then there is need for planned vents, meter cupboard, location for hot and cold water storage tanks and pipe work. The maintenance cost is incurred in the replacement of faulty apparatus; for example, leaking gas pipes, burners, storage cylinders and regulators.

2.3.1.5 Lifts

Lifts also constitute the services needed in office building systems. Saleh[30] notes that lifts are installed in commercial buildings to facilitate quick vertical transportation of human traffic and goods; thus they increase building efficiency by saving occupants' space and time. Lifts are an expensive installation and thus they should be functionally and economically sound. The components of the lift are also delicate; it is estimated that a lift for a population of 250-300 people serving 2787-3252 square metres takes about 11 percent of the construction cost and this has been established by McGuiness[31]. As such, Feldman[32] adds that a lift requires equally high level of maintenance.

Lifts are, therefore, fully integrated into circulation pattern. The lift installation (traction type) has the following components: motors, continuous chain of the car, doors, alarms, bells and telephone. (Figure 2.5).

The lift components need planned maintenance which is based on inspection to ensure that the lift's mechanical services are always in good working condition.

2.3.2 Electrical Servcices

Electrical services are distributed in office buildings by means of conduits, cables, switchboards (switchgears), panel boards and service points. The whole distribution system of electrical wiring requires varied equipment and auxilliaries for adequate, safe and efficient operation.

McGuiness[33] has classified electrical services according to the functions each equipment performs. His categories include "the service switch for main control, protection and metering; the main switchboard for control and protection of main feeders; the

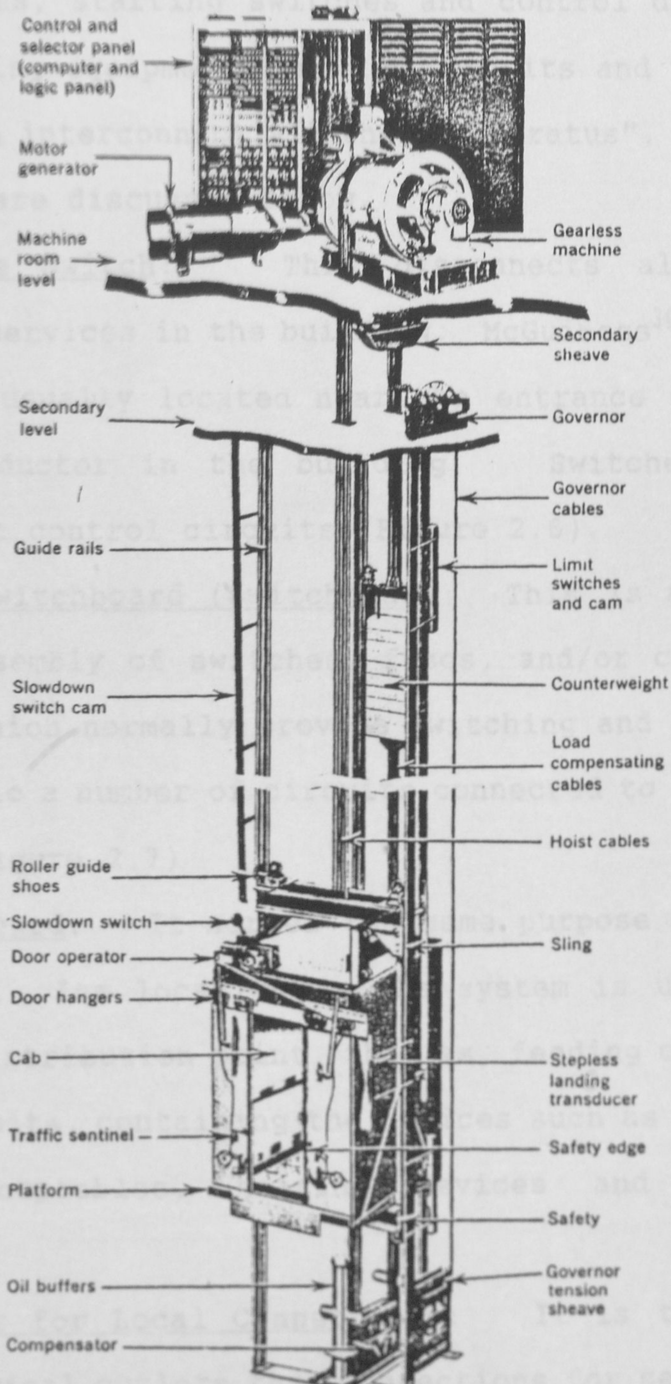

Figure 2.5: Components of a typical gearless lift installation.

Source: McGuiness, William. (1971)

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panelboard for connections to the lamps, motors and their devices, starting switches and control devices for motorizing equipment; and the conduits and wiring system which interconnect all these apparatus". These components are discussed below.

Service Switch: This disconnects all the electrical services in the building. McGuiness[34] notes that it is usually located near the entrance of the service conductor in the building. Switches are devices that control circuits (Figure 2.6).

Main Switchboard (Switchgear): This is a free standing assembly of switches, fuses, and/or circuit breakers, which normally provide switching and feeder protection to a number of circuits connected to a main source. (Figure 2.7)

Panelboard: It serves the same purpose as the switchboard. Its location in the system is usually the final distribution point, that is, feeding out the branch circuits, containing the devices such as lamps, motors, receptables, heating devices and other equipment.

Outlets for Local Connections: It is through these electrical outlets that connections for services like lighting, ventilation and air-conditioning systems, vertical transportation, kitchen equipment and miscellaneous appliances are fed with electricity. The maintenance cost of lighting components is

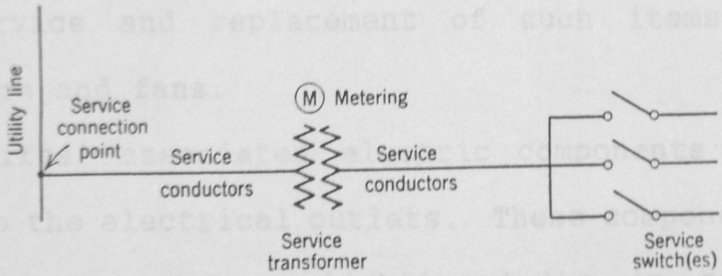


Figure 2.6: Electrical services arrangement.

Source: McGuiness, William.(1971)

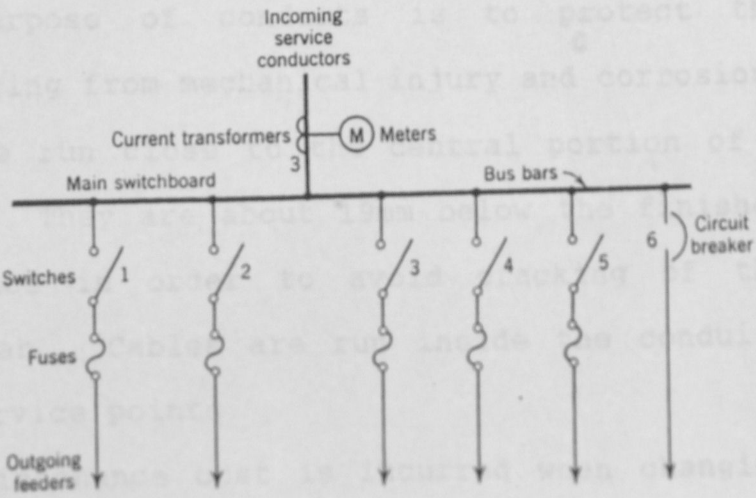


Figure 2.7: Arrangement of switchboard devices.

Source: McGuiness, William. (1971)

incurred during relamping of the blown bulbs; replacement of faulty socket outlets, switches, lampshades and lampstands. McGuiness[35] notes that the faulty electrical components for ventilation and air-conditioning systems incur maintenance cost during repair, service and replacement of such items as pumps, motors and fans.

The lifts' associated electric components are connected to the electrical outlets. These components include control machines, lighting bulbs in cabs, pumps and motors. The maintenance work is done during the inspection of the electrical components and during repair or replacement of the defective items.

The electric components involved in kitchen equipment are the electrical cookers; kettles, and refrigerators etc. The maintenance of these items is mainly through servicing and replacement.

The purpose of conduits is to protect the enclosed wiring from mechanical injury and corrosion. Conduits are run close to the central portion of a floor slab. They are about 19mm below the finished floor surface in order to avoid cracking of the concrete slab. Cables are run inside the conduits upto the service points.

The maintenance cost is incurred when changing the worn out cables, replacing faulty conduits or burnt cables due to overloads or short circuiting.

Most of the building engineering services discussed are specialized and are maintained, on contractual basis, by either the installer, supplier or a specialised company and this has been noted by Miles[36].

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 installed with these building services. The design principles guide the designer. The ultimate tangible aspects which the designer may consider while designing constitute the design defined below.

Pye[37] and Raman[38] have indentified that design is a problem-solving activity and the designer always has freedom of choice in deciding the central issue. Design, according to Pye,[39] involves rejection of many tentative versions of design before one is found that satisfies exact sensibility. Raman explains the design process thus:

> Idealisation and abstraction are devices which ....the designer employs for dealing with the complexity[40].

Idealisation involves simplifying the state of affairs. Abstraction is concerned with accentuating the dominant factors.[41]

Both idealisation and abstraction are attempts where selectivity is made explicit.[42]

Pye[43] points out that the designer has to understand, master, be systematic, analytical and rational in making decisions involved in design. Philpott[44], Hartkopt[45], and Manesseh and Cunliffe[46] have hypothesized that a decision made during the early stages of a design ultimately affects the future building cost.

In explaining the concept of design, Stone[47] 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.

It may be construed from Raman's argument that the dominant factors which the designer wants to express in buildings are the design principles. Isaac[48] has postulated that the design principle does exist and it is consistent and "derived from the basis of human perception." Gasson[49] has defined design principle as the "the principal source of aesthetics."

Isaac[50] goes further to suggest that design principles include planning sequence, massing, organisation of space, enclosure planes, elements within organised space, movement and scale, form, basic geometrical shapes, unit, contrast, pattern and texture, proportion and scale.

Similarly, other studies by Gasson[51] have considered the following as design principles: visual perception, visual dominance, static and dynamic effects, colour, unity and composition, continuity, rythm, balance, line, shape, proportions and form. These two studies have revealed that designers use similar 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 maintenance concept of building services. It seems as if the designers do not have a concept of the maintenance of buildings. It is unfortunate that most designers think that after achieving a functional and aesthetically sound building design, their responsibility to the client is finished. This is a wrong attitude since the life-span of a building and its maintainability are crucial for the building occupants. Lack of a proper maintenance concept of the building system in the early stages of design may probably 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.

It would be advisable that, for any design principle that the designer wants to accentuate and execute properly, the concept of maintenance is considered too. This is because maintenance is a client's responsibility after commissioning the building services and the owner would like to maintain the building within the minimum effective costs.

For instance, if the designer overlooks the maintenance of lighting and ventilation of inner spaces and only concentrates on the design principle of form, the designer ends up having installed engineering services which are expensive to maintain. Economically maintainable mechanical services are compromised for more conducive living spaces.

Thus although the designer achieves the form of the building, he fails to achieve a building with economical maintenance of its engineering services. This is because inadequately lit and ventilated inner building spaces created have to be installed with engineering services. The building owner might then be unable to meet their escalating maintenance costs in the long run. It is likely that this would lead to fast deterioration of those services due to neglect; eventually the end result would be inhabitable building spaces.

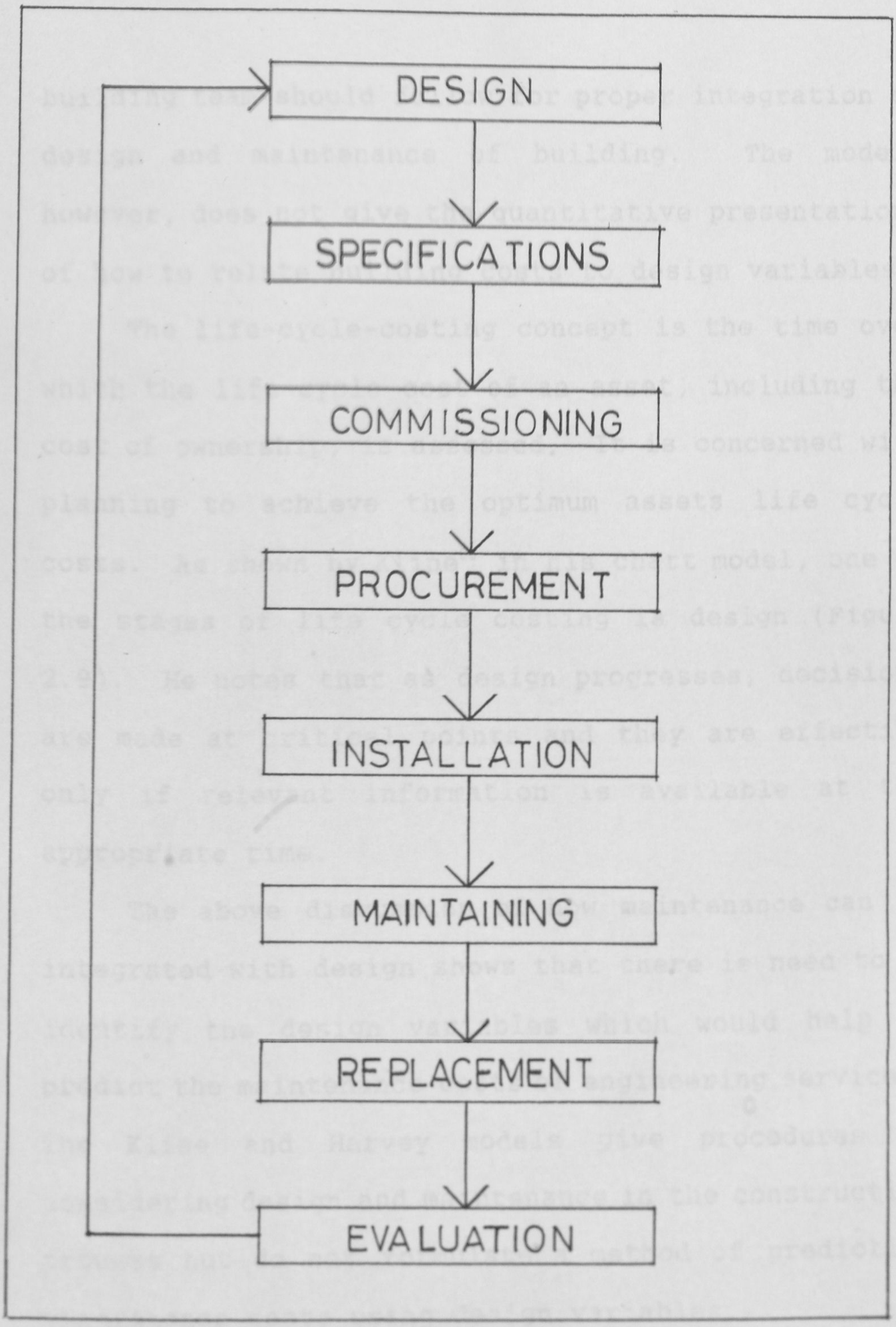
Thabit, Carpenter, Harvey and Kline have established ways of integrating the maintenance of building with the design using the concepts of terotechnology and life-cycle-costing.

According to Thabit,[52] terotechnology is concerned with the specifications and design for reliability and maintainability of plant, machinery, equipment, buildings, structures with their installation and replacement and with feedback of information on design performance and costs.

The feedback on building design performance and maintenance cost are crucial aspects for designers. It is these aspects that could help the designers to identify the repercussions or implications of their design errors hence avoid similar shortcomings in future.

Carpenter[53] wishes that the terotechnology concept would be pursued effectively by designers and clients in present day organisation of building services. He suggests that designers should relate design to maintenance and operational costs. He points out that the professional design team has negated the effective feedback approach to maintenance.

The adapted chart model from Harvey's work[54] presents terotechnological life-cycle (Figure 2.8). The model identifies the effective stages that the



Legend

Life cycle phases.

Flow of information.

Figure 2.8 Terotechnological life cycle

Source: Adapted from Harvey, G. (1978)

building team should follow for proper integration of design and maintenance of building. The model, however, does not give the quantitative presentations of how to relate building costs to design variables.

The life-cycle-costing concept is the time over which the life cycle cost of an asset, including the cost of ownership, is assessed. It is concerned with planning to achieve the optimum assets life cycle costs. As shown by Kline[55] in his chart model, one of the stages of life cycle costing is design (Figure 2.9). 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 of how maintenance can be integrated with design shows that there is need to identify the design variables which would help to predict the maintenance costs of engineering services. The Kline and Harvey models give procedures of considering design and maintenance in the construction process but do not formulate a method of predicting maintenance costs using design variables.

Design principles, at first glance, may seem to lack considerations for maintenance. It would therefore be necessary to discuss a few of these design principles to show how they relate to design parameters; which in turn, influence maintenance costs

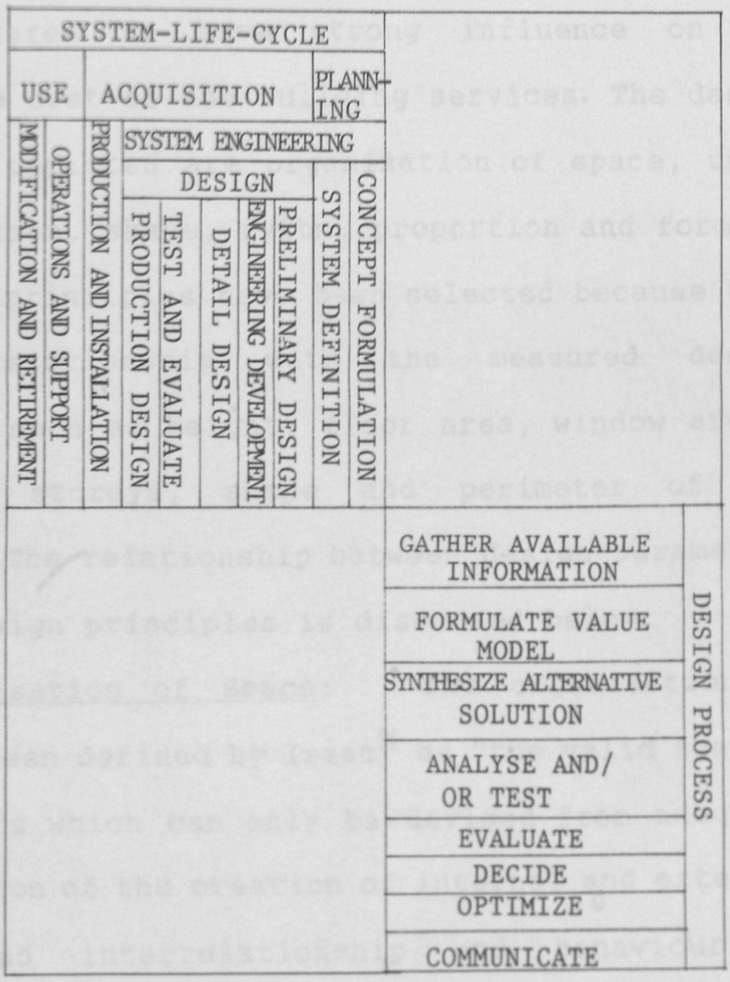


Figure 2.9: The life-cycle/design process matrix

Source: Kline M.B. (1971)

of buildings.

The design principles discussed in this research mainly revolve around the aspects of organisation and geometry of the designed buildings. These aspects are considered to have strong influence on the maintenance cost of the building services. The design principles depicted are organisation of space, unity of composition, shape, rythm, 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, number of storeys, shape and perimeter of the building. The relationship between design parameters and the design principles is discussed below.

Organisation of Space: The organisation of space has been defined by Isaac[56] as "the valid spatial arrangements which can only be devised from adequate consideration of the creation of internal and external volumes and interrelationship and behaviour of objects, elements and people within the defined field of vision." Isaac[57] has also established that the enclosure planes which define space in physical terms are determined by the shape and size of the space. (Figure 2.10)

From these definitions of space, one can infer that space is physically defined by its size and shape. The space may be measured using height, area, perimeter and number of storeys. The shape of the space is rated using classification of space configuration. Shapes of similar configuration are grouped in one category.

Burberry[58] has noted the relationship between space and building services. He points out that space planning of services is influenced by pattern layout of the building structure, a vertical or horizontal emphasis, access from circulation areas and within ducts themselves and space available in the building.

Unity of Composition: Gasson[59] has described the unity of composition as the relationships among all the parts of a designed building; such relationships must seem natural, whole, and pleasant to the eye. To achieve unity of composition, the designer is guided by an accepted contemporary style. Isaac[60] precisely says that the oneness or wholeness is the single most important design principle.

It can be concluded from the Isaac and Gasson arguments that unit of composition is related to both size and shape of a building. Size and shape are themselves design parameters. (Figure 2.11)

Shape of building: Mathematically, a line is taken to be locus of points in space. Gasson[61] has defined shape as the area of a space enclosed by more than two lines. And so the shape of the building is defined as the area in space enclosed by the building

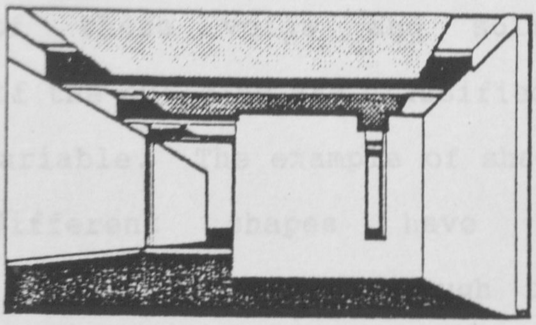


Figure 2.10: Space defined by horizontal and vertical planes.

Source: Isaac, ARG. (1971)

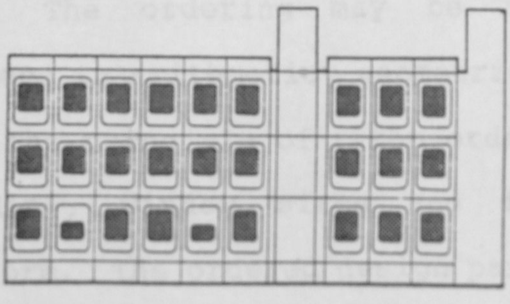


Figure 2.11: Unity of composition expressed by this multi- storey building.

Source: Isaac ARG. (1971)

elements. The basic geometrical shapes are squares, triangles and circles. (Figures 2.12, 2.13,2.14, 2.15).

The building shape may give the layout and impression of building in terms of perimeter and arrangement of the voids and solids in the buildings. It is out of these voids and solids that configurations of the building are classified. Shape is a discrete variable. The example of shapes below show that different shapes have different configurations and perimeters, although the floor areas might be the same. (Figures 2.16(a), (b), (c) and (d)).

Rythm: Isaac[62] has defined rythm in design as the elegant perfection whose resultant is the sheer beauty, precision and purity of shape that are associated with mathematically abstracted forms. Rythm orders variety in design; that is to say, distinguishable elements are given orderly arrangement. The ordering may be according to position or shape in arithmetic, geometric or harmonic progression. The principle of rythm orders the shape of the building, window sizes and facade in a mathematical form. The ordered design parameters thus do relate to rythm. (Figure 2.17)

Proportion: Isaac[63] has established that proportion systems are based on governing dimensions

Figure 2.12: Line

Figure 2.13: Square

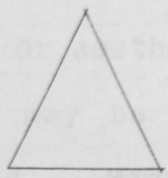


Figure 2.14: Triangle.

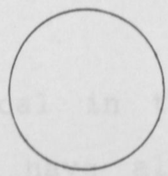


Figure 2.15: Circle.

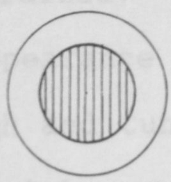


Figure 2.16(a) Curvilinear shape

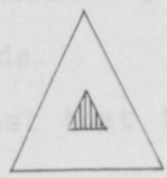


Figure 2.16(b) Triangular shape

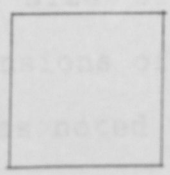


Figure 2.16(c) Rectangular shape

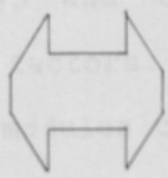


Figure 2.16(d): Polygonal shape

Source: Drawn by the author

and provide a method of relating spatial intervals to each other. Manasseh and Cunliffe[64] have noted that the governing dimensions identified above are referred to as module which is a form of dimensional rationalisation of a building design. Manasseh and Cunliffe[65] have found that designers use the module for flexible planning, economy and simplicity of construction or aesthetic.

Modules may be horizontal or vertical in the planning grid. Manasseh and Cunliffe[66] have also identified that the vertical module relates to floor height or storey height. Isaac[67] has found out that these storey heights allow columns, walls and services to be standardized. They also allow a consistency in scale and appearance of the building facade.

Manasseh and Cunliffe[68] further suggest that the horizontal module, which is based on the dimension of construction materials, is multiplied out into planning module and is arranged into squares or rectangles. The planning module depends on the area per person, size of the structural bays and the minimum dimensions of a room; among other factors.

Isaac has noted that a few dimension modules can be used to generate many shapes which have properties of economy and flexibility of size. (Figure 2.18)

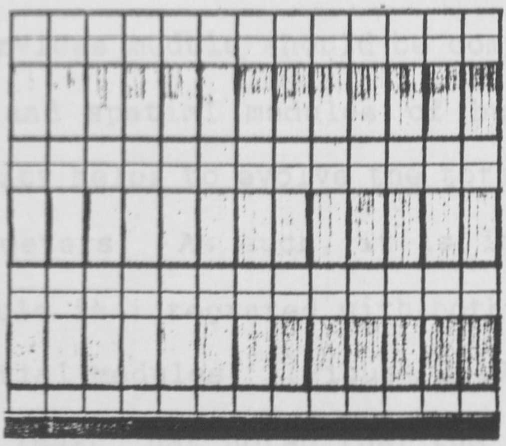


Figure 2.17: Building facade.

Source: Joedicke, Jurgen: (1962)

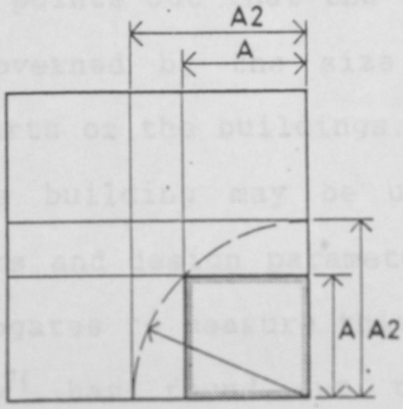


Figure 2.18: Nine shapes are derived from a square and only two dimensions A and 2A are used.

Source: Isaac, ARG:(1971)

McGuiness[69] notes that "... proportions will often determine the spacing and mountings of luminious sources ..." Ronner[70] and Obango[71] have also pointed out that the services module should be compartible to the structural and spatial modules of buildings. Such compartability helps to evolve the total effect of the design parameters. As such, it is important that a service module is integrated with both the structural and the spatial modules. (Figure 2.19).

<u>Form</u>: Isaac[72] has noted that the basic geometric forms are cube, pyramid and sphere and they are derived from basic shapes which are square, triangle and circle respectively.[72] Buildings which are multistorey may also take conical, rectangular, cylindrical and tubular forms (Figures 2.20(a), (b), (c), (d), (e), (f) and (g)).

Gasson[73] points out that the form of all applied design is governed by the size and shape of the functional parts of the buildings. Thus the size and shape of the building may be used to relate the building forms and design parameters and can also be used as surrogates to measure this principle.

Burberry[74] has found out that the efficient performance of building service is how well the form, building planning and service distribution are correlated. Burberry[75] has stressed that this efficient performance for building services is only achieved if

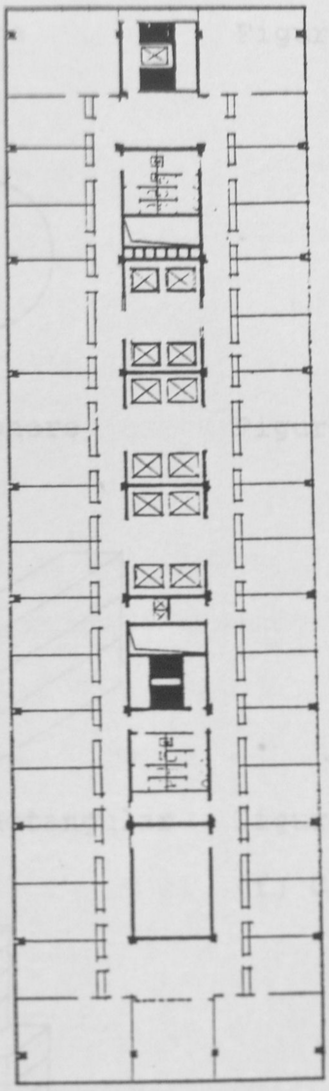


Figure 2.19: Service module integrated with structural and spatial modules.

Source: Joedicke, Jurgen: (1962)

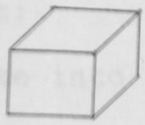


Figure 2.20 (a)Cube

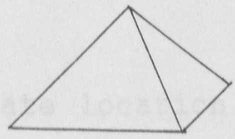


Figure 2.20 (b) Pyramid

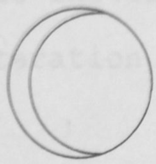


Figure 2.20 (c) Sphere

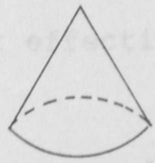


Figure 2.20 (d) Conical

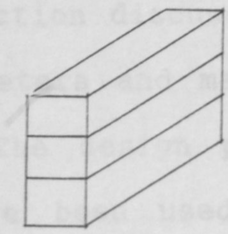


Figure 2.20 (e) Rectangular

Figure 2.20 (f) Cylindrical

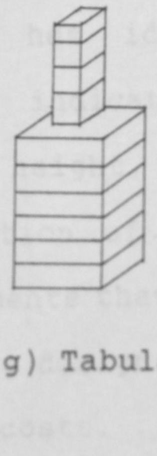


Figure 2.20 (g) Tabular

Figures 2.20(a), (b), (c), (d), (e), (f) (g) Illustrate, different forms of buildings.

Source: Drawn by the author.

the designers:

(i) take into account appropriate location for large volumes required to accommodate plants.

(ii) coordinate service distribution systems so that installation, maintenance and alteration can be carried out effectively.

2.5 Maintenance Costs of Building Services and Building Design Parameters

This section discusses the relationship between design parameters and maintenance costs of building services. 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[76] has identified the following design variables as indicators of building costs: shape, size, storey height, total height, circulation ratio and fenestration of a building. Since it is the building elements that are maintained, then it follows that the above design variables are also indicators of maintenance costs. Holmes[77] notes that the major determinants of maintenance expenditure by local authority dwellings include their age, height, building type, and construction type. These are also possible determinants of maintenance costs.

Stone[78] has found out 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 same factors used by Stone to cost a building could also be used to predict the maintenance cost of the building since the same priced building elements undergo maintenance thereafter.

Fujikami[79] has mentioned the following factors that affect repair characteristics of wooden houses in Japan: "location, neighbourhood, size of site, area and type of house, combination of materials and construction methods used, quality and specification; and the extent of usual cleaning and repairs". Since the repair characteristics depend on maintainability of the building elements then it would follow that these outlined determinants may as well be used to predict the maintenance costs of the building services.

A study carried out by Syagga[80] in Mombasa on maintenance cost of the local authorities dwelling estates used the following as the indicators of overall maintenance cost: age, number of housing units per estate, number of habitable rooms per hectare, and number of persons per habitable room.

Other indicators were building cost per room, rental value per room, building area, wall area, wall height, perimeter of building, room height, roof type, wall material, type of external finishes, facilities (shared/self-contained) and eaves (present/absent).

This study, carried out in Mombasa residential estates, indicated that the predictors of maintenance costs are more or less similar to the variables used to price the buildings or those used in estimating building costs.

This review confines itself only to one non design parameter (age) and six design parameters as listed below:

(1) perimeter
(2) floor area
(3) area of windows
(4) number of storeys
(5) the height of the building
(6) the shape of the building.

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

Perimeter: Hartkopt[81] has established that the maintenance costs of buildings are optimised when perimeter of the building is minimised. According to Manasseh and Cunliffe,[82] the compact office block provides more floor space per square metre of external wall. Hence, the perimeter of office building has an effect on the maintenance cost of the air-conditioning and heating services. Maver[83] has hypothesized that the heating and cooling of an office building will be greater in a dispersed layout than a compact layout.

Seeley[84] has observed that different plans can be compared by examining the ratio of their enclosing wall to floor(perimeter/area ratio). He argues that the lower the wall/floor ratio, the more economical the building's initial and running costs. One can infer that the lower the wall/floor area ratio, the lower is the maintenance cost of the building services.

Hence, there is a relationship between the perimeter length of a building and the maintenance cost of the building. However, these authors have not established the quantitative relation that exists between the maintenance cost and the perimeter of the building. Thus, from their works, it is not possible to establish the extent to which perimeter as a design parameter contributes to maintenance cost of the office building services. But the study carried out in Mombasa housing estates by Syagga[85] has revealed that the perimeter of a building is a significant predictor of future overall maintenance cost of the building.

The perimeter is a continuous variable. It can be assumed from literature that the perimeter of building directly varies with the maintenance costs of the building services.

Floor area: Holmes[86] established that the houses with lower building plinth area require lower maintenance compared to houses with large plinth areas. Holmes' study was to find out the influence of floor area on maintenance costs of small dwellings. Holmes noted that, although there was a relationship between the built area of a dwelling and the maintenance cost, the variable floor area was not so significant as to predict the overall maintenance cost of the building. The study done by Syagga[87] on housing estates in Mombasa also found that the area of the building was not a significant indicator of overall maintenance cost of buildings.

Seeley[88] has also noted that an increase in the size of the building usually leads to a reduction in the unit cost; that is cost per square metre of floor. He argues that, "with high rise buildings, a cost advantage may accrue due to lifts serving larger floor areas". Probably, it can be deduced from Seeley's concept that maintenance cost of building services may become less as the floor areas increase in multi-storey building because of cost advantages in some electrical and mechanical services.

The floor area is a continuous variable. It can be assumed that the maintenance cost of building services decreases with the increase in the floor area.

<u>Area of windows</u>: The layout of the building affects the amount of daylight entering the rooms through the glazed surfaces. Koeningsberger[89] has found out that the amount of the electrical lighting in the spaces during the day relates to the amount of daylight received in the spaces; this inturn relates to the amount of glazed areas. Thus, area of glazed windows relates to the electrical lighting services in an office building.

Stone[90] has pointed out that buildings with deeper spaces are not adequately lit nor naturally ventilated through the openable windows. This, in effect, raises the capital and running costs of lighting and ventilation appreciably. Seeley[91] concurs with Stone's view 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.

Morton[92] has found out that as the window area increases, more sunlight penetrates the rooms and less electrical lighting is needed. Stone[93] again hypothesizes that the more the lighting fittings used per unit area of the floor, the greater the cost of cleaning tubes and replacing the fittings. Finally, Manasseh and Cunliffe[94] argue that in order to reduce the maintenance of electrical lighting, glazed windows in multi-storey buildings must be high enough.

The area of windows is a continuous variable. It can be derived from the above argument that the area of windows in multi-storey office building directly varies with the maintenance expenditure on the electrical services.

<u>Height of the building</u>: Most electrical and mechanical services take the vertical dimension in the building. NPHT[95] has postulated that these services are grouped in service cores in order to minimise the maintenance cost of the building. Zamil[96] has established that among the services which are fitted in the service cores are the plumbing for the supply and disposal of water, lifts, electrical works and air-conditioning duct work. It is assumed or common sense dictates that the lower the height of the building, the more economical the maintenance cost of the services. This follows from the argument by NPHT[97] that if more building space is allocated on the lower floors of multi-storey buildings, then the height of the building will be less. In addition, Stone[98] has also identified that "..." costs per unit ..... for maintenance are often greater for taller than for

lower buildings."

Saleh[99] observes that some of the main design criteria for lifts is the height of the building and the number of floors in the building. The height of the building influences the maintenance cost of lifts installed in the building since the taller the building the more the lifts and service points are required for the lifts.

Seeley[100] notes that the cost of the buildings vary with storey height; holding total area constant. He argues that an increase in storey height may require longer services and waste pipes supply, more sanitary appliances and increased cost of constructing the lifts. It has also been observed that storey height increases the amount of space to be air-conditioned. The increase in space in a multi-storey building calls for larger air-conditioning plants and longer lengths of pipes and duct work. Thus these extra installed services arising from the increase in the height of a building result in increased maintenance expenditure.

Holmes[101] has found out that the height factor in multi-storey dwellings is important because of the wide variety of the special services in the building such as lifts, laundries and communal lighting. He has also established that the repairs of these installed services increase the maintenance cost.

Holmes had considered dwellings of 1-2 storeys and 3-4 storeys.

Finally, room height was found to be a significant variable in the study carried out on municipal housing estates in Mombasa. The model established by Syagga[102] in his study is shown below:

$$Ym = 193.12 + 22.63 X_{13}$$

where Ym is overall maintenance cost in Ksh/m^2/year.

X_{13} is height of room in metres.

Thus the height of a building was one of the variables used to predict the overall maintenance cost of a building.

The height of the building is a continuous variable. It is hypothesized that the height of a building directly varies with the maintenance costs of office building services.

Number of storeys: Stone[103] has observed that the ".. cost of the operation within a building is often related to the number of storeys." It has been established that the running cost of engineering services per square metre tends to increase with the number of storeys. It is argued by Stone[104] that the running cost increases because of additional services necessary in a multi-storey block. This means that the number of storeys in a building influences the maintenance expenditure of the office building services.

The number of storeys is a continuous variable. It can be assumed from literature that the number of storeys directly varies with the maintenance costs of the building services.

The shape of the building: Seeley[105] and Koeningsberger[106] have hypothesized that the shape of the building is determined by aesthetics, function, natural daylighting hours and cost. Burberry[107] has identified that "... building shape can dictate heating and cooling loads thereby governing both the internal and running cost of environmental control" of the the building. Manasseh and Cunliffe[108] have also postulated that the building shape relates closely to the floor layout. They further argue that "for economy, buildings should rise straight up with each floor the same size and shape".

Harpkopt[109] found out that the linear geometry of the buildings has a low maintenance cost. Seeley[110] gives the implication of shape on maintenance cost of building and he states that simple shapes (e.g. square) are economical to construct. Rectangular shapes are more expensive but are often used to fulfil the functional aspect of a building. 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 building floor outline has high perimeter/floor area ratio and this increases the building cost. From Seeley's argument it can be reasoned that a complicated and irregular shape or a narrower and longer shape of a building increases the maintenance cost of the engineering services.

Shape of a building is a discrete variable and buildings having similar configuration are categorised in the same group in this study.

Age of building: Stone[111] has established that cost of repair tends to increase with the age of the building. Grover and Grover[112] have also stressed that the "wear out failure increases with age". Grover and Grover[113] have also pointed out that "repair could reduce deterioration by a factor that varies according to the age of the item when the repair is undertaken".

In addition, Morton[114] has established that the life span of the building or parts thereof, should be carefully examined as this will fundamentally affect decisions regarding capital and future cost of the building. The issues raised by these researchers indicate that age may be a significant determinant of maintenance of building service components.

Moreover, Holmes'[115] study established that there is a relationship between maintenance cost of local authorities dwellings and their age. (Figure 2.21).

In his research, Holmes collected data from four local authorities of varying sizes covering a period of between five and ten years. Holmes notes that Skinner[116] had done similar research and he had considered the age/cost trend for a large number of dwellings. (Figure 2.21). They both found that there was a positive relationship between age and cost.

In Holmes' analysis, it was found that the age factor was only important when considering total housing stock in an authority. The age factor becomes insignificant when considering a specific housing area.

Still on dwellings, Mathur[117] observed that the age of the dwelling determines, to a large extent, its quality. He argues that older buildings are more likely to be "structurally unsound and functionally absolete". From the adapted graph, Fujikami's[118] curve of repair costs as years elapse, it can be stressed that the cost of repairs increases with time because the older the house, the more pronounced the appearance of decay. (Figure 2.22)

Botman[119] sums up the issue of maintenance and age by stressing that the needs for maintenance of building elements increases with age. Hence, the maintenance of office services probably needs to be increased with the age of the building.

From the adapted Bargh's[120] bath tub curve (Figure 2.23), it can be argued that a new building

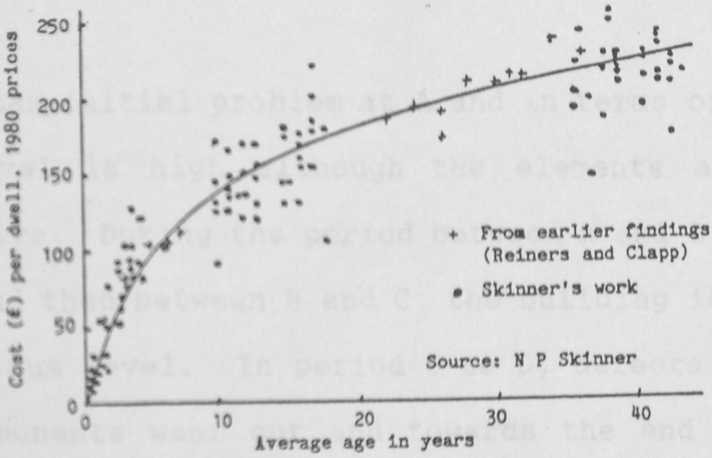


Figure 2.21: Age/cost relationship for 1-2 storey houses.

Sources: Holmes Roy; (1987)

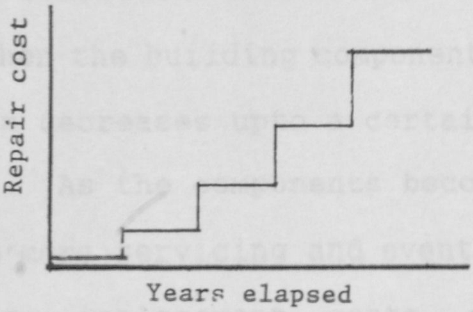


Figure 2.22; Curve of repair costs as years elapse.

Source: Adapted from Fujikami Teruyuki, (1983)

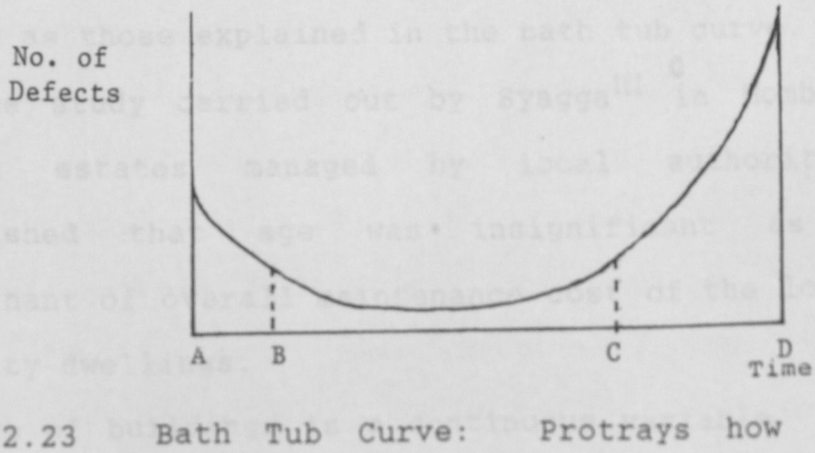


Figure 2.23 Bath Tub Curve: Protrays how the buildings perform in terms of number of defects over time.

Source: Adapted from Bargh John, (1987)

often has initial problem at A and in terms of defects the level is high although the elements are still effective. During the period between A and B, defects fall and then between B and C, the building is running at optimum level. In period C to D, defects increase as components wear out and towards the end of C the defects start to rise showing signs of wearing out and a reduction in effectiveness.

Thus from the adapted Bargh's bath tub curve, it can be concluded that servicing costs are high at first when the building components are newly installed and then decreases upto a certain level over a period of time. As the components become old, they start to require more servicing and eventual replacement, thus incurring replacement costs. Hence, it can be inferred that the maintenance cost of engineering service components have the same behaviour in their defects as those explained in the bath tub curve.

The study carried out by Syagga[121] in Mombasa housing estates managed by local authorities established that age was insignificant as a determinant of overall maintenance cost of the local authority dwellings.

Age of buildings is a continuous variable. It can be hypothesized that age directly varies with the maintenance costs of the building services.

Footnotes

1. A.C. Sidwell, "The measurement of Mechanical and Engineering services in the buildings", Quantity surveying, Vol. 35 (1978), p.316
2. Thomas W. Maver, Building Services Design (Oxford: Aden of Mowbray Ltd., 1971) p.10.
3. Ibid, p.10.
4. Orhan Ozguner, "Philosophy of Tall Buildings", in Tall Buildings in Urban Context ed. Dieter Ackehnecht and Sadi Asset (Dhahram: UPM Press, 1986), p.11
5. Ibid., p.12
6. Thomas W. Maver, Op. Cit., p.11
7. William McGuiness, Mechanical and Electrical Equipment for Buildings (New York: John Wiley and Sons, Inc. 1971 5ed.),p.v.
8. Thomas W. Maver, Op. Cit., p.12
9. B. Philpott "Designing with Terotechnology in Mind", Building Services Establishment (BSE), Vol.43,July, 1975), p.77
10. N. Tarmohamed, "Office and Commercial Facilities Complex, City Centre Nairobi", (B.Arch Thesis, University of Nairobi, 1974), p.96.
11. A.C. Sidwell, Op. Cit., p.317.
12. D. Miles and P. Syagga, Building Maintenance -

a Management Manual (London: Intermediate Technology Publications Ltd. 1987), p.187.

13. P.M. Syagga, "The Impact of Building Design on Maintenance Costs of Residential Housing Estates Owned by Mombasa Municipal Council", (Ph.D. Thesis, University of Nairobi, 1985), p.102.

14. Edwin B. Feldman, Building Design For Maintainability (New York McGraw - Hill Book Company, 1968), p.13.

15. D. Miles and P. Syagga, Op.Cit., p.4.

16. S. Janicki and S. Zaleski, "Bases for Maintenance, Repair and Modernisation of Buildings", in Renewal, Rehabilitation and Maintenance Vol.16, CIB 83, Stockholm, 1983. p.187.

17. Christine S. Grover and Richard J. Grover, "Conditions for Optimality in Periodic Preventive Maintenance", in Building Maintenance: Economics and Management, ed. Alan Spedding (London: E & N Spon Ltd., 1987), p.171.

18. A.E. Colston, "The Maintenance of Public Housing Assets, Practice and Development", in Building Maintenance: Economics and Management, ed. Alan Spedding (London: E & N Spon Ltd., 1987), pp.332-333.

19. Estmacode, "A System of Planned Preventive Engineering Maintenance", Operations and Maintenance Vol.2, April 1976, p.22.

20. Thomas W. Maver, Op. Cit., p.83.

21. Leonard Manasseh and Roger Cunliffe, Office Buildings (London: B.T. Batsford Ltd., 1962), p.58.

22. The National Building Agency, Common Building Defects (London: The Construction Press, 1979) pp.112-136.

23. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.58.

24. J.J. Barton, Heating and Ventilating (London: George Newnes Limited, 1964), p.417.

25. Jurgen Joedicke, Office Buildings (London: Crosby Lockwood and Sons Ltd., 1962), pp.114-135.

26. J.J. Barton, Op. Cit., p.417.

27. Nuffield Provincial Hospital Trust, Studies in the Functions and Design of Hospitals (London: Oxford University Press, 1955), p.144.

28. Leonard Manasseh and Roger Cunliffe, Op. Cit. p.60.

29. Building Code (Nairobi: The Government Printer, 1968), pp. 33-46.

30. Ridzuam M. Saleh, "Vertical Transportation in

Tall Buildings", in Tall Buildings in Urban Context ed. Dieter Ackekncht and Sadi Asset (Dhahram: UPM Press, 1986), p. 189.

31. William McGuiness, Op. Cit., p. 898.
32. Edwin B. Feldman, Op. Cit., pp.78.79.
33. McGuiness William, Op. Cit., p.475.
34. Ibid., p.542.
35. Ibid., pp. 368-391.
36. D. Miles and P. Syagga, Op. Cit., p.189.
37. D. Pye, The Nature and Aesthetics of Design (London: Barrie and Jenkins Ltd., 1978), p.90.
38. Pattabi G. Raman, "Synthesis in Design Interdisciplinary Essay", in Environmental Design Research, ed. Preiser Wolfgang (Pennsylvania: Dowden Hutchinson and Ross, Inc., 1973), p.506.
39. D. Pye, Op. Cit., p.91.
40. Pattabi G. Raman, Op. Cit., p.514.
41. Ibid., p.516.
42. Ibid., p.517.
43. D. Pye, Op. Cit., p.95.
44. B. Philpott, Op. Cit., p.76.
45. Volker Hartkopt, "An Economy model for generating Evaluation, and selecting Architectural Design Alternatives", in Environmental Design Research ed. Preiser

Environmental Design Research ed. Preiser Wolfgang (Pennsylvania: Dowden Hutchinson and Ross, Inc., 1973), p.359.

46. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.95.

47. P.A. Stone, "Economic Criteria and Building Decisions" in Value in Building, ed.Hutton, H. (London: Applied Science Publishers Ltd., 1973) p.31.

48. A.R.G. Isaac, Approach to Architectural Designing (London: Butterworth & Co. Ltd., 1971), p.9.

49. P. Gasson, Theory of design (London; B.T. Batsford Limited), 1973 p.34.

50. A.R.G. Isaac, Op. Cit., pp. 63-103.

51. P. Gasson, Op. Cit., pp.34-52.

52. Thabit, "Terotechnology", Msc. Thesis Manchester Institute of Science and Technology. 1978, p.6.

53. I.K. Carpenter, "The commercial aspects of terotechnology and planning for maintenance", Building Service Establishment, Vol.43 (1975), pp.71-72

54. G. Harvey, "A study into the practice and concept of terotechnology and life-cycle costing as applied to manufacturing industry", PhD. Thesis, 1978. Loughborough

University of Technology.

55. M. B. Kline et al., " The System Life-cycle." Journal of Systems Engineering, Vol. 2 No1, 1971, pp.3-22.

56. A.R.G. Isaac, Op. Cit., p.77.

57. Ibid., p.78.

58. P. Burberry, "Space for services, 5 distribution and sizing", Architectural Journal, Vol.5 (March 1986), pp.63-66.

59. P. Gasson, Op. Cit., pp. 38-39.

60. A.R.G. Isaac, Op. Cit., pp.95-99

61. P. Gasson, Op. cit. 41-43

62. Ibid., p. 39-40

63. A.R.G. Isaac, Op. Cit., p.84.

64. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.20.

65. Ibid., p.20

66. Ibid., p.21.

67. A.R.G. Isaac, Op. Cit., p.84.

68. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.739.

69. William McGuiness, Op. Cit., p.739.

70. Heiz Ronner, Jhavani Sharad and Vasella Alessandro Louis Khan. Complete Works (1935 - 1974) (Calorado: West View Press, 1974), p.117.

71. Obunga Odhiambo, "Office Spaces" (B. Arch.

Thesis, University of Nairobi, 1979), p.61.

72. A.R.G. Isaac, Op. Cit., p.85.

73. P. Gasson, Op. Cit., p.48.

74. P. Burberry, Op. Cit., p. 63.

75. Ibid., p.63.

76. I.H. Seeley, Quantity Surveying Practice (London: MacMillian, 1984), p. 217.

77. Roy Holmes, "The Evaluation of Determinants in Maintenance Expenditure on Local Authority Dwellings", in "Building Maintenance Economics and Management; ed. Alan Spedding (London: E. & N. Spon Ltd. 1987) p.235.

78. P.A. Stone, Building Evaluation Cost-in-Use (London: E & F.N. Span Ltd., 1980) p.200.

79. Teruyuki Fujikami,"A study of the cost of repairing wooden houses in Japan", in Renewal, Rehabilitation and Maintenance Volume 16, CIB 83, Stockholm, 1983. p.165.

80. P.M. Syagga, Op. Cit., p.57.

81. Volker Hartkopt, Op. Cit., 43.

82. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.44.

83. Thomas W. Maver, Op. Cit., p.128.

84. I.H. Seeley, Building Economics (London: McMillian 1972), p.24

85. P.M. Syagga, Op. Cit., p.327.

86. Roy Holmes, Op. Cit., p. 239.

87. P.M. Syagga,"Maintenance cost modelling for Residential Housing Estates in Mombasa, Kenya", in Building Maintenance: Economics and Management,_ ed. Alan Spedding (London: E. & N. Spon Ltd., 1987) p.208 -209.

88. I.H. Seeley, Op. Cit., p.21.

89. H. Otto Koeningsberger, et al, Manual of Tropical Building and Housing, (New York: Longman, 1980 4th ed.) pp. 131-149.

90. P.A. Stone, Op. Cit., p.19.

91. I.H. Seeley, Op. Cit., p.24.

92. Crawford W. Morton, "Life Cyle Costing and Resource Optimisation", in Building Maintenance: Economics and Management, ed Alan Spedding, (London: E & N Spon Ltd., 1987), p.195.

93. P.A. Stone, Op. Cit., p.132.

94. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.21

95. NPHT, Op. Cit., p.144

96. Mokrin A.R. Zamil, "Structural Considerations in The Design of Tall Buildings"; in Tall Buildings in Urban Context ed. Dieter Ackeknecht and Sadi Asset (Dhahram: UPM Press, 1986), p.195.

97. NPHT, Op. Cit., p.148.

98. P.A. Stone, Op. Cit., p.49.

99. Saleh M. Ridzuam, Op. Cit., p.193.

100. I.H. Seeley, Op. Cit., p.28.

101. Roy Holmes, Op. Cit., p.239.

102. P.M. Syagga, Op. Cit. p.334.

103. P.A. Stone, Op. Cit., p.49.

104. Ibid., p. 19.

105. I.H. Seeley, Op. Cit., pp. 18-21.

106. Otto H. Koeningsberger, et al, Op. Cit., pp.131-149.

107. P. Burberry, Op. Cit., p.63.

108. Leonard Manasseh and Roger Cunliffe, Op. Cit., p.23.

109. Volker Harpkopt, Op. Cit., p.361.

110. I.H. Seeley, Op. Cit., p.18.

111. P.A. Stone, Op. Cit., p.202.

112. Christine S. Grover and Richard J. Grover, Op. Cit., p.173.

113. Ibid., p.177.

114. Crawford W. Morton, Op. Cit., p.193.

115. Roy Holmes, Op. Cit., pp.236-237

116. N.P. Skinner, "House Condition, Standards and Maintenance," Housing Review. July/August, 1981. pp.106-109.

117. G.G. Mathur, "Conservation of Existing Housing Stock" in Renewal, Rehabilitation and Maintenance, Volume 1b, CIB83, Stockholm, 1983. p.396.

118. Teruyuki Fujikami, Op. Cit., p.163.

119. J. J. Botman, "A Model for Estimating the Maintenance needs of the Dwelling stock." in Renewal Rehabilitation and Maintenance Volume 1b, CIB83, Stockholm, 1983. p.133.

120. John Bargh, "Increasing Maintenance Needs on limiting Budgets. A Technique to Assist the Building Manager in Decision Making, in Building Maintenance: Economics and Management, ed. Alan Spedding (London: E & N Spon Ltd., 1987), pp.321-326.

121. P.M. Syagga, Op. Cit., p.335.

CHAPTER THREE

RESEARCH METHODOLOGY

This section discusses the conceptual definitions of design parameters, the techniques used to analyze the data, the cost model and finally the operational definitions of all the research variables.

3.1 Conceptual Definitions of Variables

The conceptual definitions are logical abstractions, and through them one seeks out principles that explain relationships between and among variables. These variables, which are design parameters, are elementary parts of a system and as such are capable of varying.

Heneman[1] points out that variables in theories and hypotheses require definitions which are precise enough to permit real-life definition, classification and measurements. There are two types of variables: dependent and independent variables. The dependent variable is what is sought to be explained; often a goal or objective. Independent variables, on the other hand, are those variables which are expected to provide an explanation; they are also called regressor variables.

Of the ten variables identified in the literature review in this research, seven are independent and three are dependent varibles. The conceptual definitions of the independent variables are given below:

(i) Perimeter of the building: The perimeter of building is the boundary of a closed plane of the building and it is the sum of the length of the line segments forming the building enclosure. This is measured in metres.

(ii) Total area of the building: An area of an office building is a definite bounded part of section of the building, set aside for a specific use or purpose. It is thus the enclosed space of which a building stands. The total area of a building is the aggregation of individual building levels. This is measured in square metres.

(iii) Total area of the windows in a building: An area of office building window is a definite glazed part of a building whether openable or fixed. The area of french windows and roof lighting are also included. The total areas are the aggregation of individual glazed window areas of a building. This is measured in square metres.

(iv) Total height of building: The total height of an office building is the distance extending from the lowest basement to the upper most part or region of an office building. The upper most part may be a lift tower or an air-strip. This is measured in metres.

(v) Shape of the building: The shape of an office building is the spatial form that is usually fixed by a relative constant spatial relation between the parts of the periphery or surface of the office building. The shape of the office building can be linear or curvilinear. Rectangular office buildings are coded 0 while non-rectangular buildings are coded 1.

(vi) Number of storeys of a building: The number of storeys of an office building is the set of rooms on one floor level and this excludes the attic level. This is measured in numbers.

(vii) Age of the office building: The age of the office building is the length of time during which an office building has existed commencing from the issue of certificate of occupation to the time of this study. This is measured in years.

The conceptual definitions of dependent variables are given below:

(viii) Total maintenance cost of office building services: This is the aggregate of labour and materials costs used to service, to repair and to replace the building's engineering services to the current acceptable standards and to sustain the utility and value of the building facilities. It is measured as an annual average in Kenya shillings per square metre over five years which is from 1984 to 1988.

(ix) Maintenance cost of electrical services: This is the aggregate of labour and materials costs used to service, to repair and to replace the building's electrical services to the current acceptable standard and to sustain the utility and value of the building facilities. It is measured as an annual average in Kenya shillings per square metre over five years which is from 1984 to 1988.

(x) Maintenance cost of mechanical services: This is the aggregate of labour and materials costs used to service, to repair and to replace the building's mechanical services to current acceptable standard and to sustain the utility and value of the building facilities. It is measured as an annual average in Kenya shillings per square metre over five years which is from 1984 to 1988.

3.2 Technique used to analyze the data

Allan[1] has noted that multiple linear regression analysis is the method used for cost modelling purposes and it is the most useful and popular, technique in predictive research. This statistical technique aims at developing a mathematical model that best fits the data.

Multiple linear regression analysis relates two or more variables and because of the complexities involved, it requires the use of a computer. Constructing a cost model using regression analysis involves the following:

(i) The choice of a single response or dependent variable. This is selected as the total maintenance cost of office building services, electrical maintenance cost and mechanical maintenance cost in this study.

(ii) The selection of several independent variables which determine the dependent variable. The variables chosen to predict the dependent variable are perimeter, total floor area, total window area, height of the building, number of storeys, age and shape of the building.

(iii) Allan[3] notes that the number of data points used in construction of a cost model must be greater than the number of variables fitted in the model. Ideally, two and half times the number of variables should equal to the number of data points required as suggested by Allan. Allan also recommends that the maximum number of variables included in the model should be twelve. This is done to reduce the amount of data required initially, the time and cost required in collecting the future data. The computer program used to analyse the data is the statistical package for social sciences (SPSS-X package).

Allan[4] has also recommended that the stepwise regression method be adopted for building a regression model. This method is based on the following procedure:

(i) The independent variables are added to the model, one at a time and the influence on the results is noted. The order of insertion is determined by the simple product moment correlation between each independent variable and the dependent variable.

(ii) Re-examination of each variable is incorporated in the model at every stage.

3.3 Analysis of The Cost Model

Carver[5] has identified the maintenance cost model is a mathematical statement of cost for a set of office projects with a common set of identified variables. The model seeks to explain changes or variations in the dependent variables. It gives information about which independent variables will produce signficant changes in the dependent variables.

The independent variables (X_i) considered in this maintenance cost model are:

X_1 = Perimeter in metres

X_2 = Total floor area in square metres

X_3 = Total window area in square metres

X_4 = Number of storeys

X_5 = The total height in metres

X_6 = Shape of the building

X_7 = Age of the building in years

The dependent variables (Y_i) considered in this maintenance cost model are:

Y_1 = Annual mean maintenance cost of building engineering services in Ksh per square metre

Y_2 = Annual mean electrical maintenance cost in Ksh per square metre

Y_3 = Annual mean mechanical maintenance cost in Ksh per square metre

Each of these dependent variables is regressed against all the independent variables. This is done to establish which independent variables are significant predictors for each dependent variable.

A general maintenance cost model adopted in this study will be as follows:

$$Y_i = a_0+b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5+b_6X_6+b_7X_7+e_i$$

where:

a_0 is the Y-intercept or the value of dependent variable without the independent variables within the given setting of this study.

b_1 to b_7 are regression coefficients. These regression coefficients indicate the amount of expected increase or decrease in the dependent variable for one unit change in the independent variable, controlling for other independent variables in the equation.

e_i is the error term; it indicates the difference between the observed value and the predicted values of the dependent variable.

The statistics used in the analysis include:

<u>Correlation Coefficient (r)</u>: Correlation coefficient, also referred to as simple product-moment correlation (Pearson rho) is the quantitative factor which describes the association between two variables. The value computed is used to check for multicollinearity among the independent variables. The correlation coefficient is a statistic whose value

lies between -1 and +1. The sign of the statistic indicates the direction of the relationship between the variables while absolute values indicate the strength of relationship.

Residuals: These are the deviations of observed values from the values predicted by the regression equation. These deviations are the amount by which the regression equation has been unable to predict the data. The residual is the indication of the degree of accuracy of the prediction equation or model. Therefore, the smaller the values of these residuals, the better the fitted model.

The coefficient of multiple correlation (R): This defines the relationship between all independent variables taken as a group and the dependent variable.

Coefficient of determination (R^2): This is the sum total or the cumulative explanation of the variation that has been explained by all the independent variables taken together. The value R^2 ranges from 0 to 1.

$$R^2 = \frac{\text{Explained variation}}{\text{Total variation}}$$

Test of statistical significance: The statistics that are used to evaluate the regression equations are R-squared and the regression coefficients or 'b'. The t-tests associated with the regression coefficients are used to assess the significance of the relationships. The F-test is used to determine the significance of R-squared. In this study the regression coefficients and the R-squared are considered significant if the probability is less than 0.05. This probability level has been pointed out by Koutsoyrannis[6]. Koutsoyrannis[7] has noted that researchers have often suggested that this confidence level has consistently given valid results. The 95 percent confidence level means that the researcher risks committing type one error 5 times out of 100.

3.4 Sampling and data collection

This section first gives how office buildings were selected as case studies, the reasons why they were selected as case studies, how they were sampled, how data was collected from sampled office buildings and finally the measurements of the regression variables in the field.

3.4.1 Sampling process

The population of office buildings in Nairobi CBD was determined by going around the Nairobi streets, following Nairobi cartographic maps and identifying all the buildings by their names. This exercise was limited to buildings with more than four storeys and built before 1984. It took six days to identify all the 135 office buildings in Nairobi CBD built before 1984. More information was also sought from Nairobi City Commission and Ministry of Public Works.

In sampling the buildings, the following procedure was followed:

(i) The investigator calculated the minimum sample size using Allan's guidelines of "two and half times the number of variables equal sample size".

2.5 x 10 variables = 25 Buildings.

(ii) Considering the population of 135 buildings,the above minimum sample size was too small. The researcher, therefore, opted to take a third of the buildings identified, which amounted to 45 buildings, as the minimum sample size. This had a mathematical rationale during random sampling since for every three buildings, one was supposed to be in the sample.

(iii) Before selecting the sample, names of the 135 buildings were written on small pieces of paper. The papers were put in a box labelled A and shuffled to ensure that there was no bais during sampling.

(iv) Three other pieces of paper were marked 1,2,3 and put in another box labelled B.

(v) Simple random sampling was used in two stages to select the 45 buildings for the sample. For every three building selected randomly from box A, one was supposed to be in the sample.

(vi) The first stage involved selecting randomly three papers from box A. But to determine which of three buildings would fall in the sample, a second stage of random sampling was carried out.

(vii) The second stage involved picking randomly one paper from box B. If, for example, the paper marked one was picked, the first of the three buildings selected from box A in stage one would fall in the sample.

The above process was repeated until the required 45 buildings were selected.

3.4.2 <u>Selection of case studies.</u>

This study focussed on office buildings in Nairobi CBD because of various reasons. These include: geographical location, variety of designs, age, size, maintenance management and similarity in compliance with statutory requirements.

<u>Geographical location:</u> All these office buildings are within the same geographical location. They are, therefore, exposed to the same climatic conditions, and the same economic zone, the (CBD).

Any variation in the maintenance costs of these buildings should not arise from climatic conditions nor economic activities in the area, but from other factors, mainly their design.

Variety of Designs: The office buildings in the CBD have different design responses whereas most other building types like schools, hospitals, housing estates, have prototype designs. The building services in these offices are more or less the same because of their mode of use. Thus, different building types could not have been selected because of the diversity of engineering services among the different designs. Allan[7] noted that cost models based upon a single category of building projects are likely to be more reliable when forecasting cost, than models seeking to embrace a wide variety of building types.

Age: The office buildings studied were more than five years old. This is done so as to have maintenance cost data for at least all engineering components and to help get annual means of maintenance costs.

Size: This study takes into account only those office buildings with more than four storeys. This is to ensure the presence, in all buildings sampled, of all engineering services that require maintenance including lifts. The facilities in office buildings in Nairobi CBD include shops, offices, stores, parking, banks, cafeterias and conference rooms. The population of office buildings in Nairobi is large enough for sampling.

Maintenance Management: The office buildings have a maintenance management set up by Ministry of Public Works in the public office buildings. Private buildings are managed by private estate management. The maintenance management assists in providing better accounting processes for maintenance system as compared to those which have ad hoc maintenance management. Most of the buildings had proper book keeping since they were business ventures where investment appraisal and accountability of public funds are fundamental. Hence, it was easy to get the cost of maintenance in elemental levels. Hence the maintenance costs for electrical and mechanical services were well distinguished.

Compliance with Statutory: The owners of office buildings within CBD have to comply with the legistations of urban planning Acts which include local authority Adopted By-Laws; which define zoning regulations - plot coverage, plot ratios and fire protection regulations.

3.4.3 Field Tools

The design parameters and maintenance costs were measured using structured questionnaires, unstructured interviews, tape measure, building plans, elevations and sections. These different field tools identified by Zeisel[8] were used to countercheck the validity of the data. Applications of these field tools are discussed below.

(a) Interviews: The unstructured interviews were used to find out what the maintenance staff thought, felt, did, knew and expected of maintenance of engineering services. Information on cost incurred and maintenance as it related to design parameters was also tapped. The maintenance staff of each office building were interviewed.

(b) Questionnaires: The investigator formulated the questionnaires (Appendix A) and used it to examine the effects of design on maintenance of building services. The individual buildings were visited with already prepared questionnaires. The investigator briefed the maintenance staff of the intention of the research, and thereafter, provided them with copies of questionnaires to answer. The structured questionnaire contained the following topics under which design parameters were investigated: historical background of the buildings, functions of office buildings, engineering services in office buildings, design variables, ventilation and lighting, space design for engineering services, maintenance policy and maintenance costs of engineering services.

(c) Photographs and drawings of office buildings: The photographs of each of the sampled buildings were taken. Drawings for these buildings were also checked either from the client, estate agents or architects.

It took about four to five days to gather the information using the above field tools for each of the sample buildings. Three research assistants were also engaged to help in the collection of data.

3.4.4 Measurement of the variables

A pilot study was done on ten buildings in the sample in order to find out how variables established in the literature review manifested themselves in a real life setting. The following sections give the procedures for the documenting maintenance information in both public and private sectors.

3.4.4.1 Documentation of maintenance cost of building services by public sector in Kenya

The government maintenance depot departments are under Ministry of Public Works. The buildings which are maintained by a depot may include:

(i) government pool houses,

(ii) government or rented offices,

(iii) government rented houses, and

(iv) educational institutions.

The work of a maintenance depot department is to attend to any defect that might be reported to them. The maintenance expenditure by these maintenance depot departments is met from the money allocated to each of the ministries by the government treasury every financial year.

The materials are brought from the supply branch and kept in depot stores. Before the material is taken to the depot store, the following forms are filled: Purchase requisition Note, Purchase Order Form, and Goods Inward Note. This is done by the storeman with authority from the Works Officer-In-Charge of the maintenance department.

The material cannot leave the depot until a defect is reported in the depot. The maintenance work in the depot is divided into three categories. These are:

(i) Electrical section; the workforce in this sections includes electrical inspectors and wiremen.

(ii) Mechanical section; the workforce here is composed of fitters, inspectors, and mechanics.

(iii) Building section; the workforce present in this category includes carpenters, masons, painters, plumbers, sign writers and sweepers.

Each of these categories of maintenance work is coded in elemental form, for example, electrical and mechanical works are coded F and E respectively. This coding helps in sorting out the maintenance records kept in the depot. Action is taken when a case is reported in any of the above sections of maintenance works. A building Inspector goes to inspect the reported defect, he then writes a work instruction (Appendix B).

Having identified the defect reported, the Inspector then requests the Works Officer-In-charge to send workers to the reported area to note whether the maintenance work needs material or not. If material is not needed, then the workers attend to the said defect as required. If on the other hand, material is needed, then the workers request the Officer-In-charge to fill a material issue voucher (Appendix C). The material voucher is then signed by the worker, the storeman and the Works Officer- In-charge and it is only after that the material leaves the store.

<u>Costing Maintenance Works:</u> The maintenance

department considers that maintenance cost is the aggregate of labour and the material costs of any maintenance work carried out.

Labour cost = rate per hour x time taken (hours) +
Transport charge (20% labour cost).

Material cost is the cost of material as from the hardware shop. Below is an illustration on how the maintenance cost was computed.

Mr. Musango Kilio who is a plumber Grade III was sent with a work instruction (Appendix D). Mr. Musango took three washers from the store costing Shs 7.50. His salary is Shs 2080.00 per month and the job took him five hours to complete. All this information is included in daily costing sheet (Appedix E).

Salary per month		per day		per hour
Shs 2080.00		$\frac{2080.00}{30}$		$\frac{69.33}{8}$
	Shs	69.33	Shs	8.66

Labour cost	= 8.66x5	= Shs	43.30
Transport charge	= 20% of labour cost		
	= 20/100 x 43.30	= Shs	8.66
Material		= Shs	7.50
Total		= Shs	59.46

Thus the maintenance works cost about Shs 59.50.

The above procedure is used to calculate the maintenance costs for both mechanical and electrical services by the maintenance department.

Work on contract: The Ministry of Public Works contracts the maintenance of lifts. Tenders for the maintenance of lift services are advertised in the public press. Private companies tender for this work. The ones who win the tender are appointed as the contractors of the maintenance work of lifts. The maintenance cost becomes the tender figure per year that the contractor offers and the government accepts.

3.4.4.2 Private estate management: Calculating the maintenance cost of building services.

The major duty of the estate management is the maintenance of building premises. The resposibility of estate management is to keep the building within acceptable standards.

The property manager mediates between the landlords and the tenants. He is expected to convene meetings with landlords and tenants so as to identify their maintenance and security problems of their premises.

The building caretaker reports to the property manager any maintenance works required in the building. The maintenance work is divided into four categories: building fabric, electrical services, mechanical services and decoration. The mechanical and electrical services in the office buildings include lifts, electrical installations, generators and water pumps. Each of the engineering services is maintained by contracting workforce. The following is the method used when contracting different services.

The estate agent for a particular building invites tenders for particular engineering services through the public press. The property manager liaises with landlord on what maintenance expenditure they may allow for each service. Normally, the contractor with the lowest tender is awarded the job: the property manager however is not bound to accept the lowest tender. This method is used for maintenance work of water pumps, generators, and electrical installations. Often the contract may only include the servicing and minor repairs of these engineering facilities. Otherwise, for a major breakdown of engineering services, the charge is done separately.

The lifts are serviced by the firms who install them in the office buildings. The manufacturers offer a six months guarantee period for free lift maintenance. After the guarantee period expires, the property manager and the landlord agree on the contract sum for lift maintenance per year which is then distributed on a monthly basis. This contract only includes normal servicing and minor repairs of the lift. In case of a major breakdown or replacement of worn-out chains, they are charged separately and the figure is eventually distributed into the monthly instalments for the remaining period of the contract.

The electrical components for daily maintenace are left open because of the inflation problem. The caretaker in the building is the one who replaces bulbs or any other components which are provided by the estate agent's store.

The purchase order form is filled when purchasing all these electrical components and the building caretaker and property manager have to sign any time an item is taken from the store. This process is strictly followed in order to have proper accounts of maintenance costs. The money spent on the engineering services is easily determined from annual account computer sheets from the Management Agents.

The money used for maintenance works in office building is mainly provided by the tenants of the building premises. The landlords levy the service charge from tenants. The charge mainly caters for the services like maintenance of lifts, electrical appliances, repairs and replacement of water pumps and generators, cleaning and security, sanitary services and general maintenance.

The landlord, through estate management, spends

£Y per month per square metre. This expenditure incurred is repaid by the tenant. The tenant when accepting the offer of taking over the office space agrees to a clause in a letter of intent which states that he has to pay £X per month per square metre.

The estate management firm receives £X/month/m^2 paid by, for example, tenants A, B, and C. The firm calculates the excess that the tenant might have to pay.

Excess charge = £(Y-X)/month/m^2 = £Z/month/m^2

The £Z is the excess paid by the firm management and so this excess expenditure is distributed proportionately to tenants A, B, and C according to the amount of the space they occupy. This is the method used to fund the maintenance of the private office buildings services.

3.4.4.3 <u>Computation of the maintenance cost for each building for private and public sector</u>

The maintenance cost data was collected for five years consecutively. That is, from 1984 to 1988. It was categorised as mechanical and electrical services maintenance. The year 1988 was used as the base to calculate maintenace cost per year within the five years. The maintenance cost of engineering services for each building for the years 1984 to 1988 was raised to 1988 constant prices using the Central Bureau of Statistics construction cost indices.

After calculating the average maintenance costs per year, the figure computed is then divided by the area of the respective building. Maintenance cost for building services is therefore given as Ksh/square metre/year.

3.4.4.4 <u>Measurement of independent variables</u>

The measurement of the independent variables for both private and public sectors are the same since in all cases only the architectural drawings are required and interviewees for respective office buildings.

The buildings were visited and the measurements in the architectural drawings ascertained. The building plans helped in measurement of the total floor areas and the perimeter using the relevant scales.

The building sections and the elevations were used in the measurement of the total window areas. Visits to the building premises also helped to confirm the presence of extra windows which might not have appeared from the available elevations. The scale rule was used to take measurements.

The building sections formed a basis for the measurement of the heights of the buildings. The building elevations and visits to the buildings helped in establishing the exact number of storeys for each building.

Drawing plans provided the shape of the building. The shape was assigned arbitrary units in such a way as to appropriate as best as possible the variations of a categorical factor which is expressed quantitatively. Shape is therefore a dummy variable; rectangular shaped buildings were code zero and non-rectangular shaped buildings were coded 1. Zero code was given to rectangular shaped buildings because it has been established in the literature that rectangular buildings incur less maintenance costs of installed engineering services compared to non-rectangular buildings.

The approximate ages of the sampled buildings were obtained from building records or building registers (Appedix F), Nairobi City Commission and the Estate Agents. The age of the building was also checked with maintenance staff during the interviews.

Footnotes

1. Herbert G. Heneman, "Toward a General Conceptual System of Industrial Relationss: How do we get there?" in Essays in Industrial Relations Theory. ed. Somen G. (Iowa: The Iowa State University Press, 1969) p.3-24
2. Ashworth Allan, "Cost Modelling for the construction Industry". The Quantity Surveyor Vol. 37, No.1-12, (July,1981). pp132
3. Ibid., P.133
4. Ibid., P.133
5. M. Carver, "Optimisation Techniques for use in the design of Building" in Quantity and Total costs in Building costs in Building Services Design, Ed.d D.J. Croome (Lancaster: The construction Press,1977) pp.103-117
6. A. Koutsoyrannis, Theories of Econometrics (London: Macmillan Eduation Ltd, 1986) pp.566-567
7. Ibid., p.563
8. .J. Zeisel, Inquiry by Design (Monterey: Brooks/cole Publishing Co., 1981) pp.89-195.

CHAPTER FOUR

DATA ANALYSIS

4.1 QUALITATIVE ANALYSIS

This section gives a qualitative analysis of functions of Nairobi office buildings, types of engineering services in these office buildings, maintenance cost of their engineering services, and lastly, the common office building design concepts used and their errors. The data used is in appendix G.

4.1.1 Functions of Nairobi Office Buildings

As the capital of Kenya, Nairobi is the commercial, administrative and cultural centre of the country. It is also a major international communications and organisations 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, shoes, electronics, clothes to butcheries; reflecting 22.2 percent, 6.6 percent, 11.1 percent, 24.4 percent and 2.0 percent respectively. These shops had wetcore and electrical facilities.

The upper floors of the buildings usually accommodated conference rooms, government offices, consultants' bureaux, embassies and local and regional offices of international organisations and associations. These buildings had a combination of the above activities. They accommodated both small businesses and large international agencies.

Of the 45 buildings sampled, 84 percent had conference rooms, 68.8 percent had government offices, 48.8 percent had consultants' bureaux, 33.3 percent housed embassies, 48.8 percent housed international agencies and 42.2 percent had associations.

Generally, the offices would have centralised wet core facilities for consultants and other users, but special considerations seemed to have been given to doctors' clinics which usually needed water in their individual offices because of the nature of the services they offered.

4.1.2 Types of Engineering Services in Office Buildings in Nairobi.

It was observed that the airconditioning and the ventilation systems were few in Nairobi's office buildings. It was noted that 11.1 percent of the sampled buildings had installed ventilation systems while 4.4 percent of sampled buildings had installed air-conditioning systems. The observations were also reflected in the maintenance cost of mechanical services apportionment. It was found that air-conditioning and ventilation only constituted 4.7 percent (Figure 4.1) of total maintenance cost of mechanical services.

The analysed field data is supported by the geographical location of Nairobi; it is near the equator and at a high attitude. Its climate data[1] indicate that the annual mean maximum temperature is 25.2^{0}C, whereas the annual mean minimum temperature is 13.6^{0}C. The annual relative humidity at 15.00 hours is 91% while the annual mean relative humidity at 06.00 hours is 48%; and finally the average annual rainfall is 873 mm. Nairobi City is therefore within the comfort zone.

4.1.2.1 Mechanical Services

The mechanical services in the sampled office buildings varied. They included lifts, air-conditioning and ventilation systems, fire-fighting equipment, gas services and boilers. Lifts, fire-fighting equipment and plumbing services were present in all the buildings. The gas services were only found where there were cafeterias.

The respondents interviewed pointed out that the inclusion of some services components like air-conditioning and ventilation systems were mainly because designers did not give due consideration to natural ventilation requirements of some spaces. The air-handling units were also used for partial mechanical ventilation in very deep spaces.

The fire-fighting services, like sprinklers, were rare and were mostly installed in buildings with basements. The basement space is a recent development in the field of architecture and thus only a few recent buildings have sprinkler systems. The other services installed in the basements included ventilation systems and sewerage pumps used to drain water seeping in during rainy seasons. The parking, machine storage and general storage were some of the functions accommodated in the basements. Boilers were only found where hot water was required especially in buildings with cafeterias.

4.1.2.2 Electrical Services

There was a variety of electrical services in the sampled office buildings like electrical installations, portable and fixed electrical apparatus, kitchen equipment, alarm systems, motors, generators and distribution systems. The electrical installations and distribution systems were found in all the buildings studied. The kitchen equipment were common where there were tea rooms and cafeterias. The sampled buildings which had standby generators for emergency purposes in case of a power failure included KICC, Ardhi House, Corner House and Magereza House. The electrical services were also provided in all sampled buildings which had motors for pumping water to separate tanks on rooftops, and those which had air-extracting fans and lifts. The electrical bells were present in all the buildings. All the buildings had security lighting.

The respondents in Afya House and Kilimo House noted that the inclusion of some service components like emergency lighting and batteries was due to designers' errors; that is the designers lacked consideration for some requirements as stipulated by the Adopted Building By-Laws.[2]

4.1.3 Maintenance Cost of Engineering Services

The annual mean maintenance cost of engineering services in the sampled buildings was KSh 24.60 per square metre. The annual mean for mechanical and electrical services were KSh 15.80 per square metre and KSh 8.80 per square metre respectively. Proportionately, the mechanical services and electrical services accounted for about 64 percent and 36 percent respectively of total maintenance cost of engineering services.

The range for annual maintenance cost of office engineering services was KSh 52.85 per square metre annually. Nyayo House, with ten lifts, had the higest annual maintenance cost of KSh 59.07 per square metre while Ex-community Building, with seven lifts, had an annual mean of KSh 6.22 per square metre.

It can be noted from Figure 4.1 that high maintenance of mechanical services expenditure was on lifts followed by plumbing services which included water supplies and sanitary services; these accounted for 84.2 percent of the maintenance cost of mechanical services. The maintenance of fire-fighting equipment was very low because of limited fire-outbreaks.

Figure 4.2 shows that the highest maintenance cost of electrical services expenditure was on the electrical installations, motors and generators which constituted 63.8 percent of the total maintenance cost of electrical services.

It can be concluded from Figure 4.3 that most of the maintenance expenditure went into lifts,

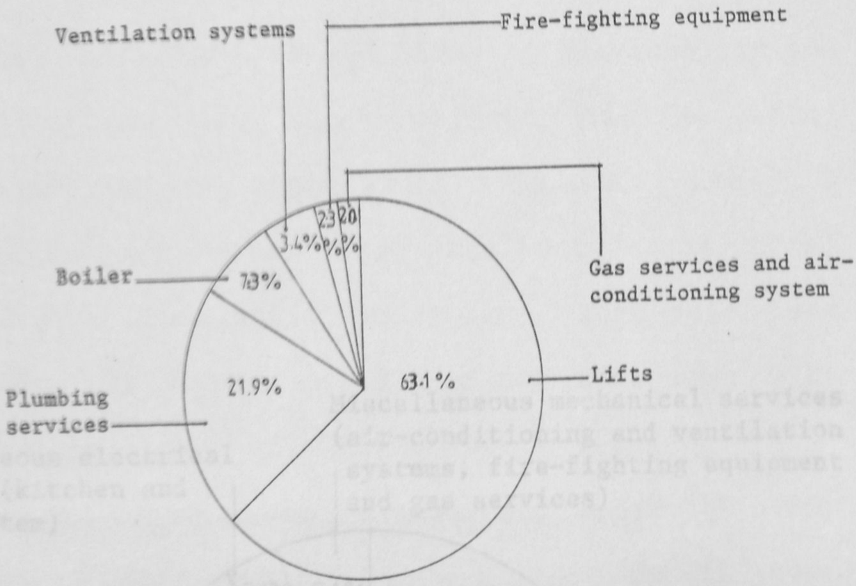


Figure 4.1. Apportionment of elemental costs of maintenance of mechanical services in sampled office buildings.

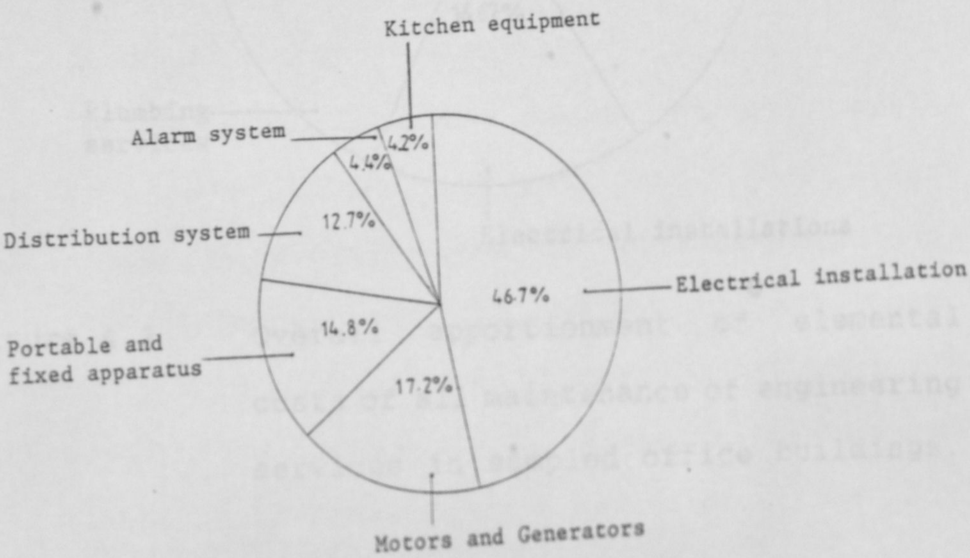


Figure 4.2. Apportionment of elemental costs of maintenance of electrical services in sampled office buildings.

Source: Compiled from author's field data.

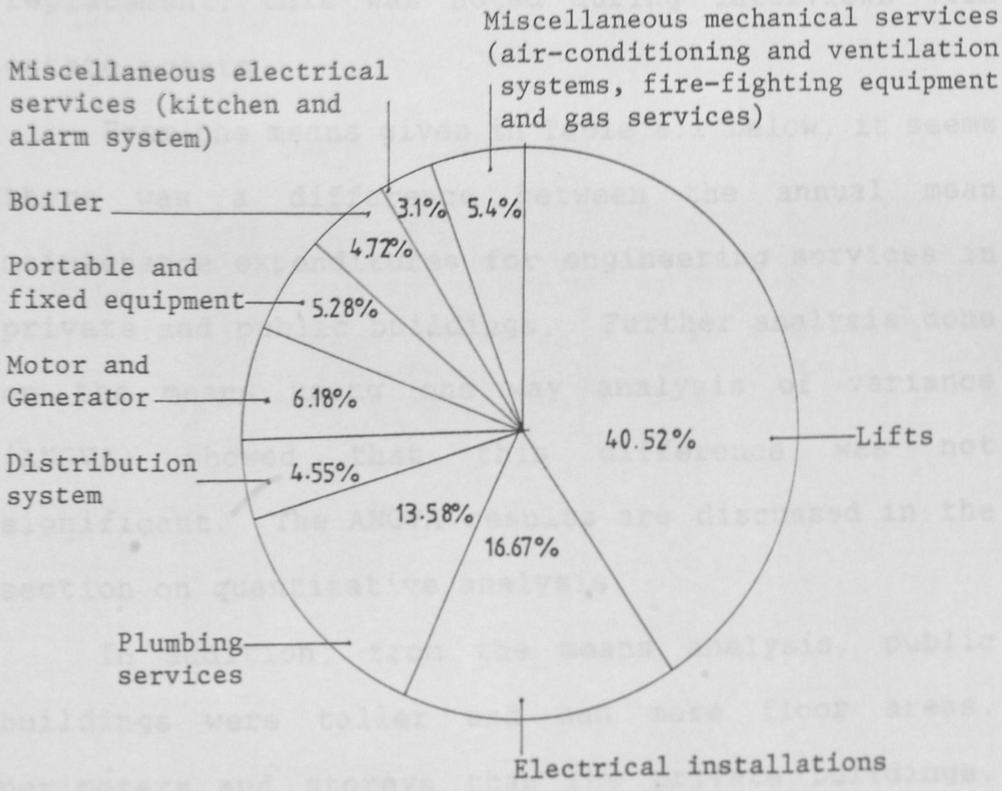


Figure 4.3 Overall apportionment of elemental costs of all maintenance of engineering services in sampled office buildings.

Source: Compiled from author's field data.

electrical installations and plumbing services; in all they accounted for 70.67 percent of the total maintenance cost of engineering services. The high maintenance cost arose from the fact that these services were frequently on repair, inspection and replacement; this was noted during interviews with estate agents.

From the means given in Table 4.1 below, it seems there was a difference between the annual mean maintenance expenditures for engineering services in private and public buildings. Further analysis done on the means using one way analysis of variance (ANOVA) showed that this difference was not significant. The ANOVA results are discussed in the section on quantitative analysis.

In addition, from the means analysis, public buildings were taller and had more floor areas, perimeters and storeys than the private buildings. This is because as a matter of policy, the government constructs its own office blocks and as such it optimises the available plot coverage and ratio.

Since the government has more resources than any individual developer, it is the most established in the construction industry. The private developers have limited construction resources, such as finance, land and skills. Because of these constraints, private buildings are limited in perimeter, area,

Table 4.1: The means and standard deviations of the design variables.

	ALL BDGS n=45		PUB BDGS n=21		PRIV BDGS n=24	
Var.	Mean	Std dev.	Mean	Std dev.	Mean	Std dev.
Hgt	36.74	18.24	39.03	22.22	34.74	14.08
F/A	9221.00	8482.40	12106.50	9910.20	6697.20	6164.2
W/A	2027.00	1590.70	2307.40	1603.20	1606.60	1486.8
Peri	190.60	123.00	225.70	135.70	159.90	104.1
Stoy	10.49	5.51	19.19	6.82	9.86	4.10
Shape	0.53	0.51	.48	.51	.58	.50
Plot	4.79	1.48	4.38	1.77	5.15	1.07
Age	19.11	9.49	16.38	8.56	21.50	9.78
T/Mte	24.60	11.21	21.98	13.43	27.33	8.35
M/Mte	15.80	7.98	15.03	10.40	16.54	5.15
E/Mte	8.80	4.59	6.94	4.14	10.49	8.35

Source: Compiled from the author's field data.

<u>Key:</u>

BDGS-buildings, PUB-public, PRIV-private.

VAR-variable, Std. dev.-standard deviation

Hgt-height in metres, F/A-floor area in square

metre, W/A-window area in square metre.
Peri-perimeter in metres, Stoy-Number of storeys, Plot-plot ratio, T/Mte-total maintenance cost in Kshs/M^2/year, M/Mte-mechanical maintenance cost in Ksh/M^2/year, E/Mte-electrical maintenance cost in Ksh/M^2/year.

number of storeys and height. This explains why some buildings on high plot ratio areas are not necessarily the tallest.

The mean age of the public buildings was less than that of private buildings. This is probably because after independence there was a major shift in government policy from renting spaces for its offices to constructing its own office blocks. Most of the public buildings sampled had been constructed after 1970.

On the average more private buidings had designs of non-rectangular shapes than public buildings. This can be explained in three ways. First, there are many architectural firms who design private buildings and as such there is bound to be a diversity of design concepts with a bias towards non-rectangular shapes. On the other hand, public buildings are all designed by the Ministry of Public Works which seems to emphasize rectangular shapes. Here, the design concept is found to be consistent.

The second explanation has to do with aesthetics. Since private buildings are purely commercial, designers will tend to emphasize beauty in order to impress potential tenants. And because non-rectangular shapes may look more attractive, potential tenants will naturally tend to prefer them. Public buildings, on the other hand, tend to be rectangular because they are mainly for use by government departments and not for commercial purposes. As such the question of aesthetics is not a major design concept. The third reason may be the maintenance cost. Previous research has established that rectangular shaped buildings are cheaper to maintain than the non-rectangular shapes.

Thus designers of private buildings may not seriously consider their future maintenance cost because it will always be passed on to the tenants. Designers of public buildings, to the contrary, will tend to prefer shapes that minimise the future maintenance cost simply because those building are not commercial.

4.1.4 Office Buildings Design Concepts

The government office buildings are designed by the Ministry of Public Works (MOPW). The private offices are designed by professional designers. The buildings are normally designed to a minimum life expectancy of 50 years.

Three of the office buildings sampled have used the concept of tower design. The tower block rises upward, keeping the horizontal line short while increasing in vertical height. These blocks are found where plot ratios are high. The examples of tower blocks in this study were Corner House, Nyayo House and Cooperative House, Plates 4.1, 4.2 and 4.3 respectively.

The Kenyatta International Conference Centre (KICC), represented by Plate 4.4, uses the concept of podium and tower. The tower springs from a low base ground of ancilliary blocks attached to it. The podium normally makes the tall buildings have a human scale and look structurally stable. The tower with a base, rises many storeys above the surrounding buildings.

The buildings which were organised using the courtyard concept were ten in the sample. These building blocks have either fully or partially enclosed courts. These buildings included Maji House, Gateway House and Ardhi House, which are represented by Figures 4.4 and 4.5, plate 4.5 respectively.

Two thirds of the buildings have used the concept of low rise rectangular blocks. These buildings included Ministry of Foreign Affairs and Salama House

Plate 4.1. Corner House: Tower block design concept.

Source: Photographed by the researcher

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Plate 4.2. Nyayo House: Tower block design concept

Source: Photographed by the researcher

Plate 4.3. Cooperative House:Tower block concept

Source: Photographed by the researcher

Plate 4.4. KICC: Tower block and podium design concept

Source: Photographed by the researcher

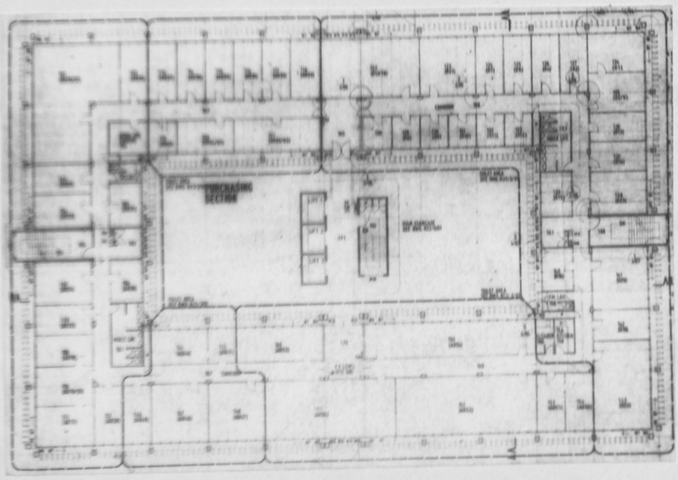


Figure 4.4. Maji House: Enclosed courts

Source: MOPW Records Office

Plate 4.5. Gateway House: Semi-enclosed courts

Source: Photographed by the researcher

as shown in Plates 4.6 and 4.7 respectively.

The layout of the offices was in accordance with the tenants' requirements. Except for Church house, the rest of the buildings in the sample, had circulation and service cores integrated to give greater freedom for multi-use of spaces. The partitions used to define spaces of sampled buildings, mostly fall on the columns and along the beams where possible.

All sampled buildings had dimensional coordination of their elements. This allows for flexibility during partitioning. About 97 percent of the sampled building structures, which were mainly of reinforced concrete frame with concrete block infill, were integrated with the services. This means that the service module followed the structural module. This integration is essential because the location of service points does not interfere with partitions of the building. The building slabs and beams were designed to support the ducted services as indicated in Hill Plaza (Figure 4.6) and in KICC (Figure 4.7) respectively.

About 82 percent of the office partitions in the sampled buildings were constructed of sound absorbing demountable panels. This allows for variation of office sizes. The ceiling was of exposed painted plaster or accoustic tiles with ducting spaces left

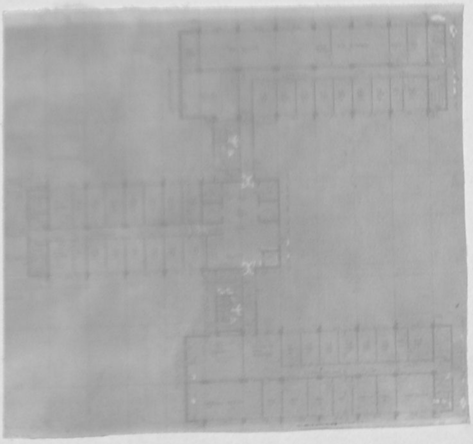


Figure 4.5. Ardhi House: Semi-enclosed courts

Source: MOPW Records Office

Plate 4.6. Ministry of Foreign Affairs: Low-rise rectangular block

Source: Photographed by the researcher

Plate 4.7. Salama House: Low-rise rectangular block

Source: Photographed by the researcher

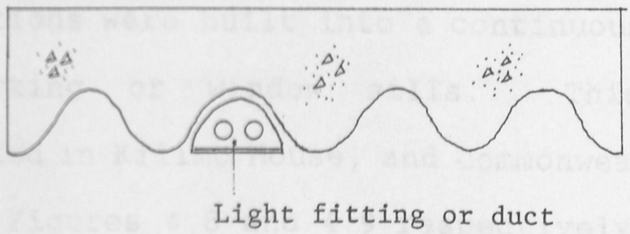


Figure 4.6 Hill Plaza building: Waffle slab design has been integrated with lighting and ducting services.

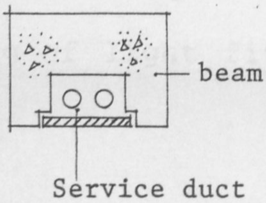


Figure 4.7 KICC: U-beam design has been integrated with the ducting services.

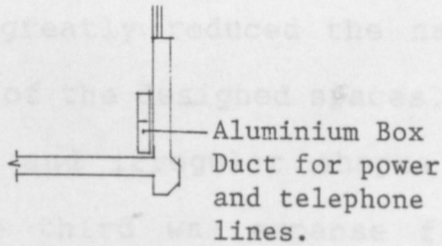


Figure 4.8 Kilimo House: Duct detail

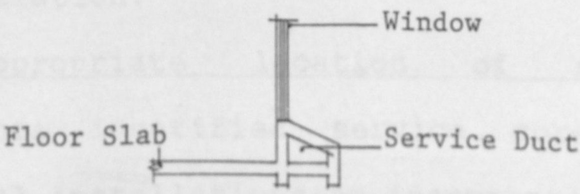


Figure 4.9 Commonwealth House: Duct detail

Source: Drawn by the author.

above for electrical fitting outlets. The electrical installations were built into a continuous duct along the skirting or window sills. This was well illustrated in Kilimo House, and Commonwealth House as shown in Figures 4.8 and 4.9 respectively.

In an interview, which was conducted at Parkroad Maintenance Depot, Kinyua[3] suggested that designers should, in the initial design stage, allow for flexible design of service points in the rooms to facilitate the fixing of light fittings during later partitioning.

4.1.5 Design Errors

Three common design errors were identified by the respondents. The first was inappropriate location of services which greatly reduced the natural lighting and ventilation of the designed spaces. The second was the complicated and irregular shapes of the office buildings. The third was expanse floor with deep spaces which resulted in inadequate natural lighting and ventilation.

Inappropriate location of services: The respondents identified service cores, ducts and electrical installations as inappropriately located.

The service cores are inappropriately located when the service spaces within them are not naturally lit or ventilated. The service cores with this problem are usually those situated in the centre of the building. The buildings having their services cores centrally placed accounted for 33.3% of the total sample. The service core spaces included the lift lobbies, stairways, toilets and ducts.

Apart from high maintenance expenditure, inappropriate location of service cores also results in stuffy toilets when the artificial ventilation system fails and dark stairways when there is a power failure. Inappropriate location of service core spaces was noted in Afya House and National Housing Corporation (NHC) House as shown in Figures 4.10 and 4.11 respectively.

It is a serious design error when engineering service ducts are not easily accessible during the maintenance period. This is commoly noted when ducts are wrongly located or the space provided for the ducts is not adequate for the repairer during the maintenance of such services. The spaces tend to be deep but very narrow.

An interviewer, Kinyua[4] has responded that this design error sometimes necessitates demolition of duct walls to create enough working space; an operation which interferes with the uses of adjacent spaces. Protection House and Nyayo House are used here to illustrate improper location of service ducts as shown

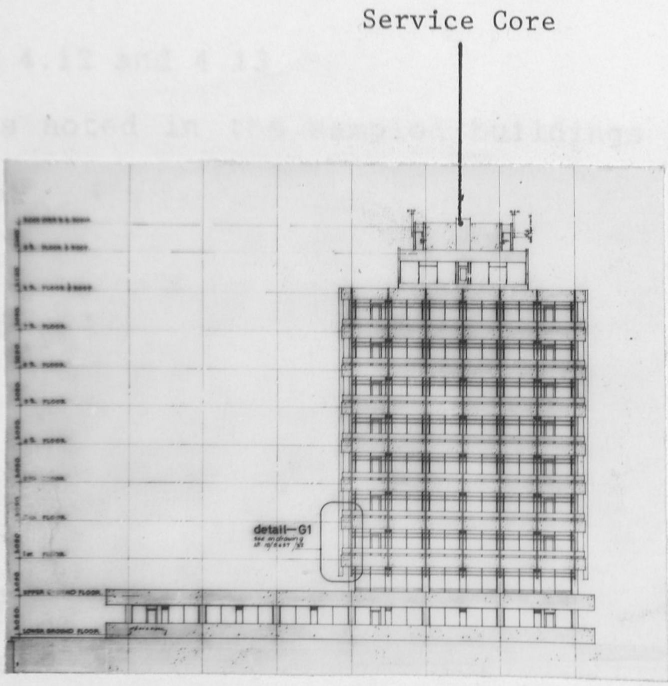


Figure 4.10 Afya House: Centrally located service core

Source: MOPW Record Office

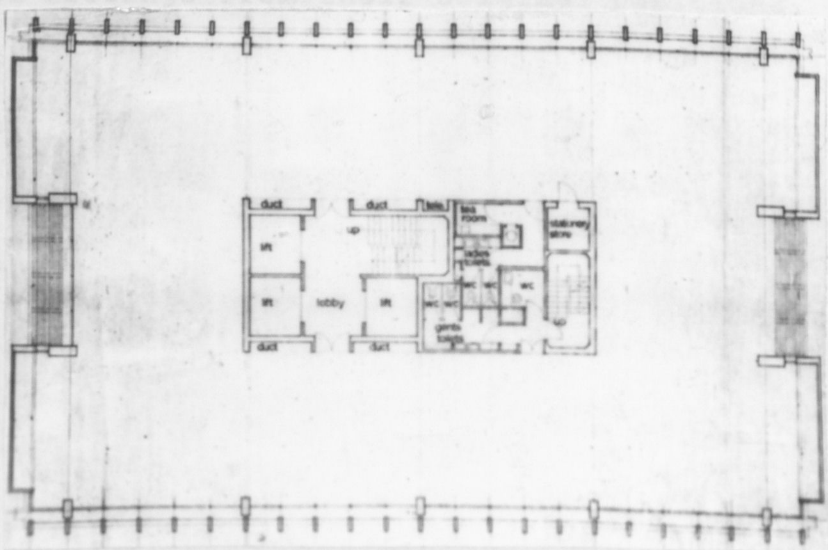


Figure 4.11 NHC House: Centrally located service core

Source: NCC Architectural Department

in figures 4.12 and 4.13.

It was noted in the sampled buildings that the conduits and the pipes were contained in vertical ducts. These pipes and conduits were in some cases embedded in the building structural elements such as beams, columns, walls and floor slabs. Some electrical cables and drainage pipes were passed in the false ceiling as in KICC while in other buildings the drainage pipes were exposed on the building inner court walls like Gateway House.

It is also considered designer error when the electrical installations like lighting fittings are not easily accessible. The designer may have put them too high making replacement difficult. Similarly, fixing specifications might overlook the removal of electrical fittings from their original positions. A case in point is the hidden lighting fittings at the lift lobby and staircase's handrails in the Kenyatta International Conference Centre.

It is noted that the pergola ceiling in KICC is perhaps not well integrated with the installed engineering services because scaffolding is always required during service maintenance operations. In addition, some portions of the ceiling are not demountable, thus complicating the maintenance of electrical components such as replacing fluorescent tubes.

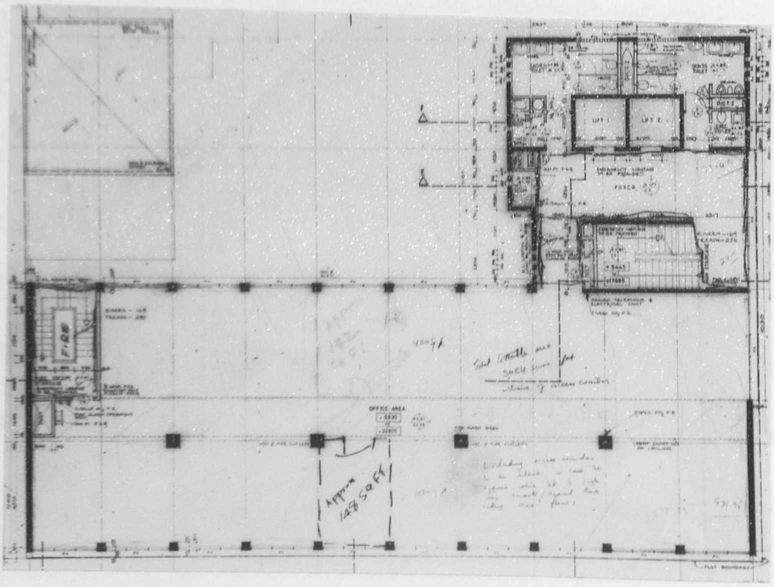


Figure 4.12 Protection House: Inappropriately located duct

Source: NCC Architectural Department

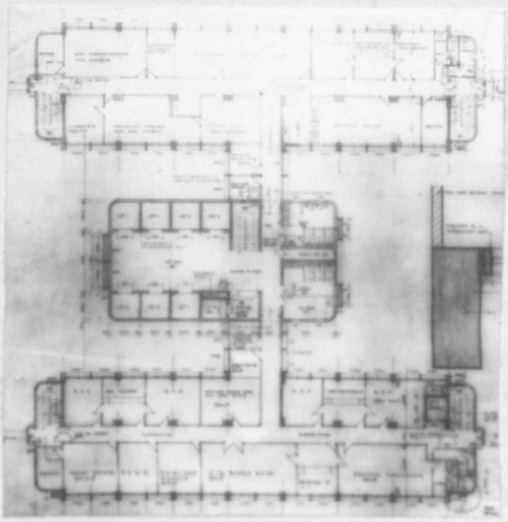


Figure 4.13 Nyayo House: Inappropriately located duct

Source: MOPW Records Office

An interviewee, Theuri[5], at KICC Maintenance Depot insisted on the provision of adequate space and size for the services. He stressed that designers should take into account the risk and difficulty involved in repairing and replacing electrical fittings. He added that high location of engineering services should be discouraged where possible. Finally, he noted that scaffolding in KICC was required where lighting was fixed high up in the stairways, lobbies, high ceilings and those concealled in high cantilevered structures (Figure 4.14).

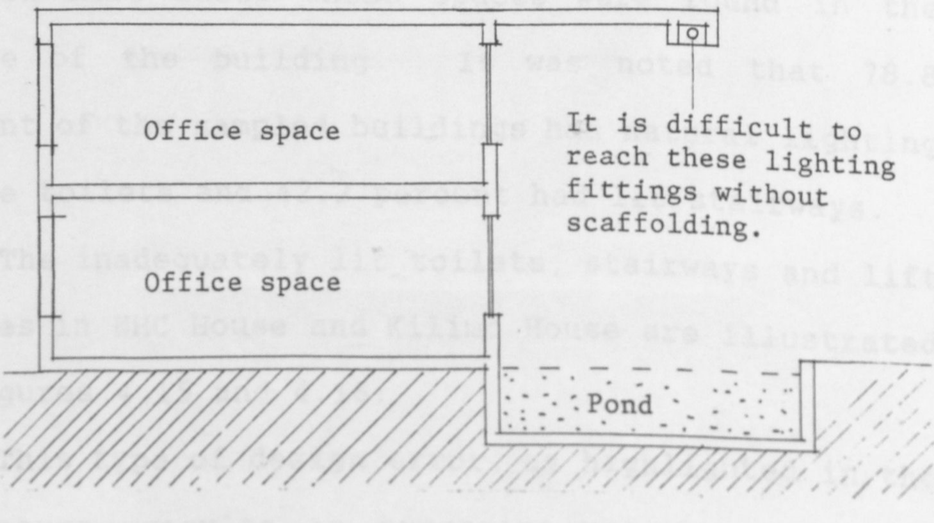


Figure 4.14 KICC: Sectional elevation showing cantilevered structure and lighting fittings.

Source: Drawn by the author.

Inadequate natural lighting of designed spaces: This is a design error because it is a requirement that all the spaces in the building should be given correct intensity of lighting. It is stated in the Building Code[6] that "every habitable room shall have a window or windows opening directly into external air which shall have for the purpose of daylighting, a total area exclusive of frames, equal to at least one-tenth of the floor area of such rooms".

The respondents in some of the buildings like NHC House and Kilimo House noted that some designed spaces had little or no natural lighting at all. These spaces were mainly for storage, circulation and toilets. Some office spaces, as in Kilimo House, had no frontage.

In most cases these spaces were found in the centre of the building. It was noted that 78.8 percent of the sampled buildings had natural lighting in the toilets and 42.2 percent had lit stairways.

The inadequately lit toilets, stairways and lift lobbies in NHC House and Kilimo House are illustrated in Figures 4.15 and 4.16.

This type of design error, as highlighted in the literature, results in excessive use of electrical lighting. Otherwise, the spaces would not be functional. This, in effect, calls for high maintenance costs.

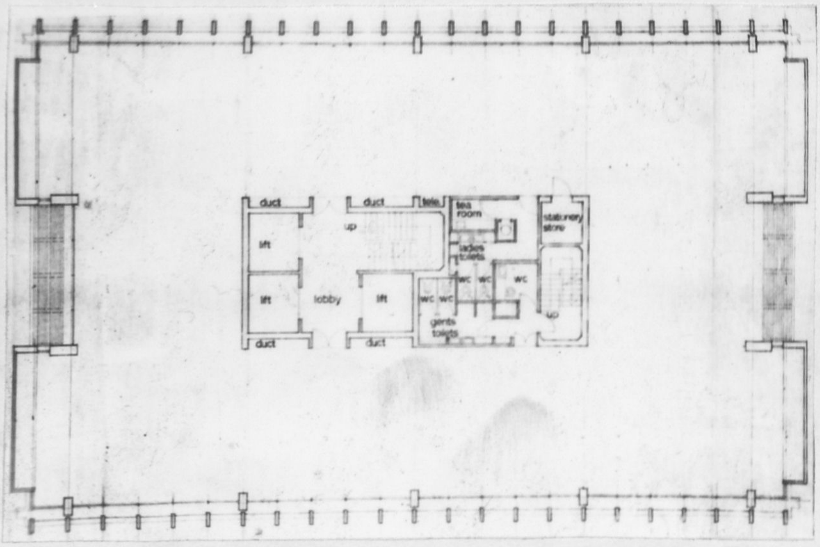


Figure 4.15. NHC House: Inappropriately located engineering service facilities

Source: NCC Architectural Department

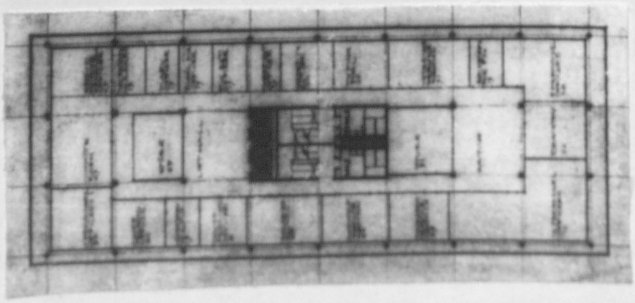


Figure 4.16. Kilimo House: Inappropriately located engineering services facilities

Source: MOPW Records Office

Inadequate naturally ventilated spaces: This is a design error because it is a requirement that all the spaces in the building should be given adequate air-infiltration. The respondents of some of the buildings such as National Social Security Fund (NSSF) and Kenyatta International Conference Centre noted that some designed spaces had little or no natural ventilation at all. These spaces were mostly used as storage and toilets; or offices and conference rooms in the basements as in KICC and NSSF. This is shown in Figures 4.17 and 4.18. In this study, naturally ventilated toilets were found in 80 percent of the buildings sample.

This design error, as noted in the literature, requires a mechanical ventilation system to make spaces functional. The mechanically installed systems raise maintenance cost of the building services considerably.

Use of irregular and complicated shapes in office buildings design: An analysis of the case studies established that 24 buildings (53%) had used non-rectangular shapes. Findings indicated that building services of non-rectangular shapes were more expensive to maintain than those of rectangular shapes. An obvious explanation here is that more plumbing and electrical installations works are involved. In addition, the findings show that cost of maintenance

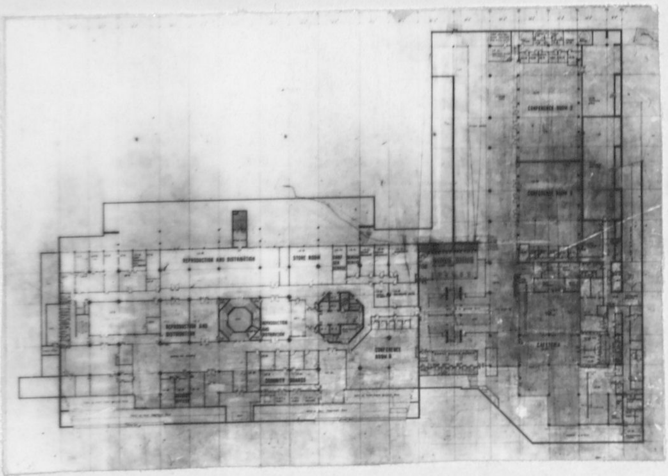


Figure 4.17 KICC: Inadequately ventilated basement conference rooms and stores

Source: MOPW Records Office

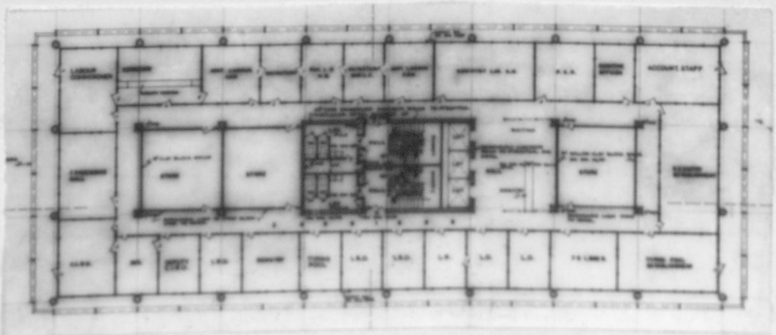


Figure 4.18 NSSF: Inadequately ventilated central service core

Source: MOPW Records Office

of mechanical services in both the rectangular and the non-rectangular buildings is twice as much compared to the maintenance cost of electrical services (Table 4.2).

Normally, the designers will designate the odd corner spaces of the irregular shapes as locations for the services. This is often done to make the office space into a better shape. The space assigned for services may not be adequate or in proportion to the electrical or mechanical equipment installed, hence a high future maintenance cost.

The designer, through his desire to achieve aesthetic ambitions, may choose irregular and complicated shapes thus neglecting future maintenance problems of the installed engineering services.

It can be concluded from this study that the rectangular shaped buildings installed with engineering services are easier to maintain than those in non-rectangular shaped buildings.

In the sample, the buildings which had irregular and complicated shapes were Hill Plaza, Church House and Jamia Towers (Figures 4.19, 4.20 and 4.21 respectively).

.<u>Expanse floor space:</u> Floor spaces in office buildings tend to be very deep and create a problem of lighting and ventilation. For instance, KICC, which had a big conference room, needed a lot of artificial

Table 4.2 Maintenance costs for building services in rectangular and non-rectangular buildings

	Rectangular n=21	Non Rectangular n=24
Engineering Maintenance KSh/m^2/Yrs	23.13	25.43
Mechanical Maintenance KSh/m^2/Yrs	15.88	17.29
Electrical Maintenance KSh/m^2/Yrs	7.25	8.14

Source: Compiled from author's field data

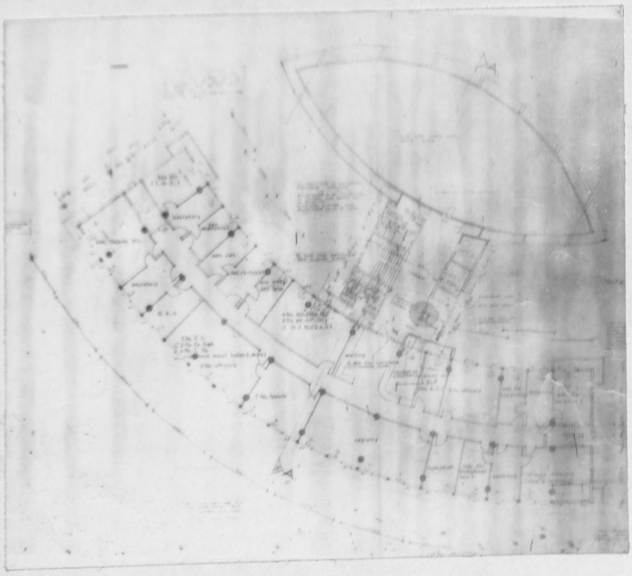


Figure 4.19. Hill Plaza: A complicated plan shape

Source: MOPW Records Office

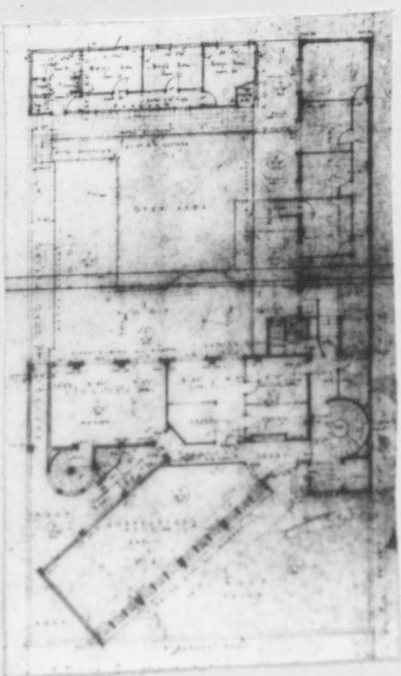


Figure 4.20 Church House: A complicated plan shape

Source: NCC Architectural Department

lighting and ventilation to make the spaces conducive to the purposes they were intended for.

The stores and office spaces without frontage introduced in the interior of Kilimo House to utilise the expanse floor area of the building requires artificial lighting and ventilation systems to make these spaces habitable. This inevitably has implications on the maintenance of building services. This type of design error is illustrated in figure 4.22.

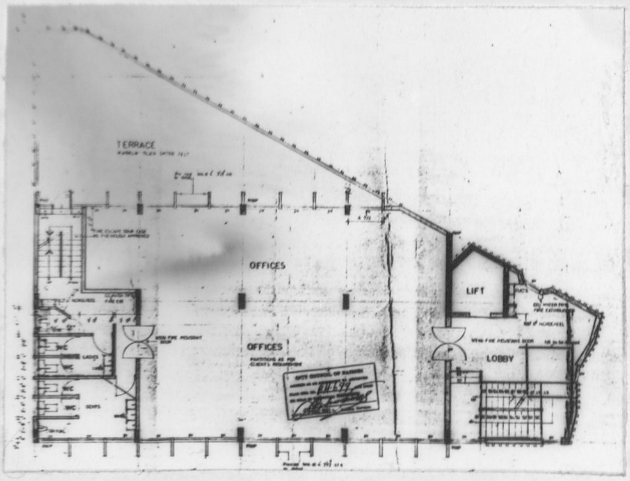


Figure 4.21 Jamia Towers: A complicated plan shape

Source: NCC Architectural Department

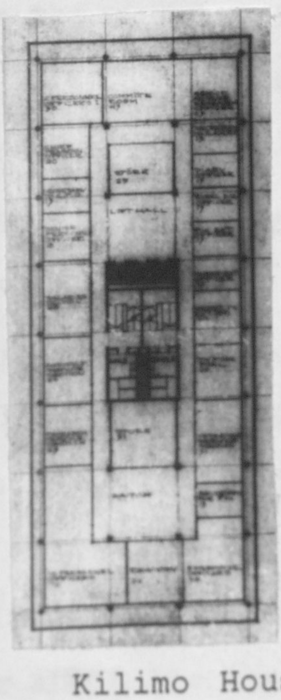


Figure 4.22 Kilimo House: Note that the central spaces have no frontage

Source: MOPW Records Office

4.2 QUANTITATIVE ANALYSIS

In this section the results of the quantitative analysis are presented. The method used for analysis is ordinary least squares regression. The independent variables are tested for their strength in predicting the dependent variables using the regression coefficients. Multicollinearity is assessed using pearson's product moment correlations to determine whether the independent variables are highly correlated among themselves (Table 4.3). This is necessary because any two independent variables having a correlation of more than 0.7 implies that one of the independent variables is redundant and hence should be dropped from the model. This dropping of redundant variables has been established by Pedhazur[7]. The data used is in appendix G.

The computed correlations on all the variables in the model show that there is a problem of multicollineality.

The following independent variables are found to be highly correlated: floor area and height (.820); window area and height (.718); storey number and height (.991); window area and floor area (.867); storey number and floor area (.818); storey number and window area (.714). This means that either of these variables can play the role of the other in the model.

Table 4.3 Simple product-moment correlation matrix for all variables.

Var	Hgt	F/A	W/A	Peri	Stoy No.	Age	Shape	Plot	Tot Mtce
Hgt									
F/A	.820								
W/A	.718	.867							
Peri	.528	.634	.504						
Stoy No	.991	.818	.714	.513					
Age	-.232	-.334	-.373	-.075	-.251				
Shape	.115	.195	.209	.318	.123	.040			
Plot	.221	.130	.181	.044	.218	.419	.229		
Tot.Mtc	.472	.275	.397	.031	.488	-.104	.202	.282	

Source: Compiled from author's field data

Key:

Hgt-height; F/A-floor area; W/A-window area; Peri-perimeter; Stoy No-storey number; Plot-plot ratio; Tot.Mtce-total maintenance cost, Var - variable

The product-moment correlation matrix was computed without the storey number. The following variables were still found to be highly correlated: floor area and height; and height and window area. It was only when the floor area and window area were dropped that the correlations between any pairs of independent variables were all less than 0.7.

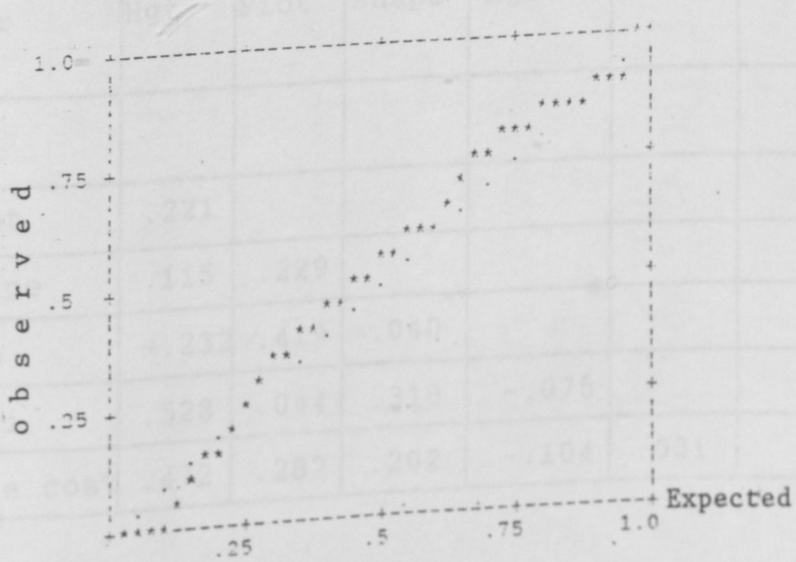
The height variable is retained because it is highly associated with the vertical dimension of building services in the service core. The other independent variables are plot ratio, shape, age and perimeter. The final simple product-moment correlation matrix is given in Table 4.4.

Having dropped the floor area, window area and storey number, it became imperative to consider a variable derived from floor area and storey number. The independent variable which was considered to have a bearing on floor area and storey number was the plot ratio (variable X_8). Plot ratio did not seem to have a high correlation with the other independent variables and it therefore, was included as a new variable in table 4.4.

Plot ratio is a constant in a given geographical urban region. It is the total floor area of a building divided by the plot size.

The selected independent variables were regressed on maintenance costs of building services using the step-wise regression method. In each case those variables with the highest correlation with maintenance cost were entered first as given in Table 4.5.

Testing of normality of the data: Normal probability P-P plot of standardized residual (Graph 1) is used to test normality of the data collected. It can be deduced from the plot that the data approximates normal distribution and hence the t-test and the F-test can be used in the analysis.



Graph 1: Normal probability (P-P) Plot. Standardized residual.

Source: Computed from author's field data

4.2.1 Final Regression Model for Annual Maintenance Cost of Engineering Services and Selected Design Parameters

Below is a discussion of the multiple regression model for total maintenance cost of building services and the selected design parameters.

Table 4.4. Simple product-moment correlation matrix for selected design variables and total maintenance cost of building services.

Var	Hgt	Plot	shape	Age	Peri	Mtce cost
Hgt						
Plot	.221					
Shape	.115	.229				
Age	-.232	.419	.040			
Peri	.528	.044	.318	-.075		
Mtce cost	.472	.282	.202	-.104	.031	

Source: Compiled from author's field data

Key:

Hgt-height; Plot-plot ratio; Peri-perimeter;

Mtce cost-total maintenance cost, var - variable

Table 4.5. Multiple regression for total maintenance cost of building services and selected design variables.

Var	Multiple-R	R^2	R^2 Change	b	t	t-test
Hgt	.47178	.22258	.22258	.35992	3.498	0.0012**
Plot	.50588	.25591	.03333	1.02431	.910	0.3682
Shape	.51827	.26860	.01269	5.00581	1.554	0.1284
Age	.52660	.27731	.00871	-.07382	-.411	0.6830
Peri	.59905	.35886	.08155	-.03314	-2.227	0.0318*
Const				11.21496	2.092	0.0430*

R^2 = .35886

F = 4.36577, Significant F = 0.0030**

* Significant at 0.05 level

** Significant at 0.01 level

Source: Compiled from author's field data

Key:

Hgt-height, Plot-plot ratio, Peri-perimeter, var-variable, Const-constant.

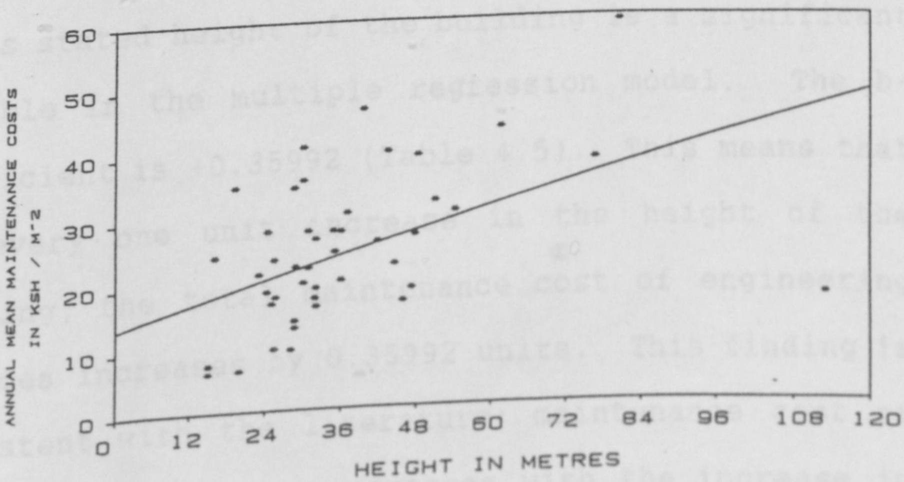
<u>Height of the building (X_5):</u> Simple correlation shows that total maintenance costs of services increased with the height of the building. The derived simple regression equation is:

$$Y_1 = 13.676 + .287X_5$$

where Y_1 is the annual mean maintenance cost in KSh per square metre.

X_5 is the height of the building in metres.

The unstandardised b-coefficient for the equation above is 0.287.



Graph 2: Plot of maintenance cost versus height of the building

Source: Computed from author's field data

This relationship between maintenance cost of engineering services and height of the building is significant at .05 level.

The plot of maintenance cost versus height of the building (Graph 2) shows that maintenance cost increases with an increase in the height of the building. The height and maintenance cost of building services are very correlated in the model (Table 4.4) having a correlation of 0.472.

Having computed the regression model, it was found that the height of the building was the most important variable; it explains about 22.26 per cent (Table 4.5) of the variation in maintenance cost of engineering services in office buildings.

As stated height of the building is a significant variable in the multiple regression model. The b-coefficient is +0.35992 (Table 4.5). This means that for every one unit increase in the height of the building, the total maintenance cost of engineering services increases by 0.35992 units. This finding is consistent with the literature; maintenance cost of the building services increases with the increase in height of the building. The most probable explanation for this relationship, therefore, is that engineering services components and fittings in office buildings increase with increase in height of the buildings. Design of such services may therefore require more input which is not always provided; hence durability is reduced. Ex-community Building and Nyayo House are good examples of this phenomenon.

The Ex-community building is 15 metres tall and only spends an annual mean of KSh 6.22 per square metre on the maintenance of engineering services, while Nyayo House, which is 80.4 metres tall spends an annual mean of KSh 59.07 per square metre. It can be concluded that the taller the building, the more the engineering services, and the more the maintenance works required. One would therefore expect higher maintenance costs in the future for tall buildings.

<u>Perimeter of the building (X_1):</u> Simple correlation though very weak at 0.031, shows that total maintenance cost of services increases with an increase in the perimeter of the building (Table 4.4). A simple regression equation is computed as:

$$Y_1 = 23.418 + 0.003X_1$$

where Y_1 is the annual mean maintenance cost in KSh per square metre.

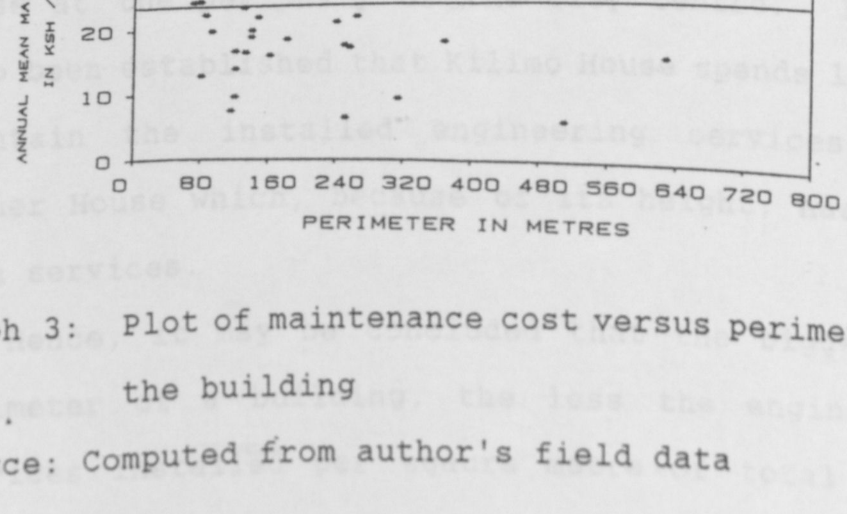
X_1 is the perimeter of the building in metres.

The unstandarised b-coefficient for the equation above is 0.003.

This relationship between maintenance cost of engineering services and perimeter of the building is not significant at .05 level.

The plot of maintenance cost versus perimeter of the building (Graph 3) shows that maintenance costs increases marginally with an increase in the perimeter of the building. The simple product moment correlation indicates the same trend.

In the computed the multiple regression model, it is found that the perimeter of the building is the second important variable accounting for nearly 8.16 percent of the change in maintenance cost of the office building services.



Graph 3: Plot of maintenance cost versus perimeter of the building

Source: Computed from author's field data

The perimeter of the building is a significant variable in the regression model. The b-coefficient for perimeter in multiple regression model is -0.03314 (Table 4.5). This means that for every one unit increase in the perimeter length of the building, the total maintenance cost of engineering services decreased by 0.03314 units.

This result is not consitent with the literature. The maintenance cost has been said to increase with the perimeter of the building. The most probable reason for this relationship is that there are more engineering services being installed in office buildings with smaller urban plots than the ones with large plots. This is also supported by the fact that buildings with small plot size will tend to be taller in Nairobi City than those with large plot size, which tend to be low rise. For instance, Corner House in the city centre has a smaller perimeter than Kilimo House at the periphery of the city centre. It has also been established that Kilimo House spends less to maintain the installed engineering services than Corner House which, because of its height, has more such services.

Hence, it may be concluded that the bigger the perimeter of a building, the less the engineering services installed per sqaure metre of total floor area and hence the less the maintenance works needed. Thus less expenditure is incurred in the maintenance of building services in low rise buildings. More often than not, most buildings with big perimeters are low-rise and have less expensive engineering services like lifts.

The sampling error is the other possible reason why the result is not consistent with the literature. Probably when perimeter is grouped together with other variables in multiple regression model, the sampling error interfered with the direction of the relationship between maintenance cost of engineering services and perimeter of the building.

Plot Ratio of Office Building (X_8): The plot of maintenance cost versus plot ratio of the building (Graph 4) shows that total maintenance cost of services increases with an increase in plot ratio of the building. The computed simple regression equation is:

$$Y_1 = 14.61 + 2.008X_8$$

where Y_1 is the annual mean maintenance cost in KSh per square metre.

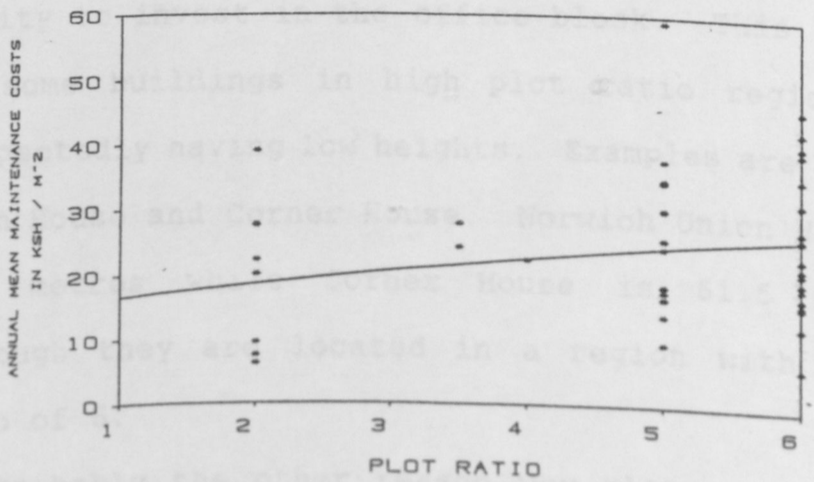
X_8 is the plot ratio of the building.

The unstandarised b-coefficient for the equation above is 2.008.

This relationship between maintenance cost of engineering services and plot ratio of the building is not significant at .05 level.

The computed multiple regression model shows that the plot ratio of the office building site is the third important variable accounting for nearly 3.33 percent of the change in maintenance cost of the office building services.

The product-moment correlation shows that the maintenance cost increases with plot ratio, and the correlation is 0.282 (Table 4.4). There is thus a positive relation between plot ratio and maintenance cost of engineering services. This is probably because plots of smaller sizes have buildings with high plot ratios. Thus buildings located on these



Graph 4: Plot of maintenance cost versus plot ratio of the building

Source: Computed from author's field data

areas tend to be high rise and have expensive engineering services like lifts which increase the maintenance cost of engineering services.

The high-rise building necessitates the use of many lifts to ensure efficiency in transport. It can be concluded from the simple product-moment correlation that the higher the plot ratio the more the possibility of having a high-rise building constructed on such a plot. Hence the taller the building the more the engineering services installed and the higher the maintenance costs.

The plot ratio of the building is not significant in the regression model for total maintenance cost of building services. This is probably because the buildings on plots of high ratios are not necessarily the tallest since it all depends on the developer's ability to invest in the office block. This is true for some buildings in high plot ratio regions but unexpectedly having low heights. Examples are Norwich Union House and Corner House. Norwich Union House is 30.8 metres while Corner House is 61.5 metres, although they are located in a region with a plot ratio of 6.

Probably the other reason why plot ratio is not significant is because the machinery involved with the monitoring and the implementing stages of developments in urban areas lacks adequate manpower to effect implementation. Laxity may also be a factor. As a result some clients construct buildings which cover more ground areas and more total floor areas than expected from the plot ratios and coverages as stipulated by the town planners.

Historically, planning of towns is a typical problem in most countries because it is done in piecemeal.

Shape of the Building (X_6): Simple product moment correlation shows that the irregular shaped buildings cost more to maintain the installed building services than regular shaped buildings. The computed simple regression equation is:

$$Y_1 = 21.485 + 4.623X_6$$

where Y_1 is the annual mean maintenance cost in KSh per square metre.

X_6 is the shape of the building.

The unstandardised b-coefficient for the equation above is 4.623. This relationship between maintenance cost of building services and shape of the building is not significant at .05 level. A graph of the relationship can not be drawn because shape is a dichotomous variable.

The simple product-moment correlation shows that shape of the building is the third most strongly related variable with maintenance cost having a correlation of .202 (Table 4.4).

After computing the multiple regression model, it is found that the shape of the building is the fourth important variable accounting for nearly 1.27 percent of the change in maintenance cost of the office building services.

The shape of the builidng is not significant in the regression model for the total maintenance cost of building services. This result though not statistically significant, is consistent with the literature on the relationship between the maintenance cost and the shape of a building. It is probably because Nairobi office buildings do not use intensively circumferential services like heating, air-conditioning and ventilation systems. Since such services must serve each space, the piping has to be placed at the perimeter. When the building has an irregular shape it complicates the plumbing and electrical works. Such buildings have many corners which make pipe work and conduits lengthy and difficult to maintain. In such a situation, it would be expected that shape would be statistically significant. Nairobi, as noted, does not need heating, ventilation or air-conditioning and hence the non-significance of this variable.

Age of the building (X_7): The plot of maintenance cost and age of the building (Graph 5) shows that total maintenance decreased with an increase in the age of the building. Computed simple regression equation is:

$$Y_1 = 26.246 - .122X_7$$

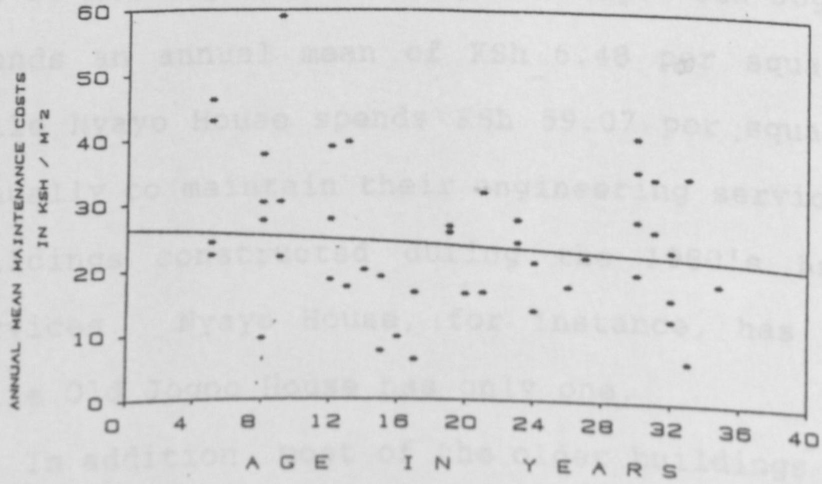
where Y_1 is the annual mean maintenance cost in KSh per square metre.

X_7 is the age of the building in years.

The unstandardised b-coefficient for the equation above is -0.122.

The relationship between maintenance cost of engineering services and age of the building is not significant at .05 level.

Simple product-moment correlation indicates that maintenance cost decreases with an increase in age of the building. The age is second least correlated in



Graph 5: Plot of maintenance cost versus age of the building

Source: Computed from author's field data

the correlation matrix with correlation of -0.104 as shown in Table 4.4.

The calculated multiple regression model shows that the age of the building is the least important variable accounting for only 0.87 percent of the change in maintenance cost of the office building services.

The age of the building is not significant in the multiple regression model for total maintenance cost of building engineering services. This result does not support the literature on how the maintenance cost relates to the age of a building. The most probable explanation for this relationship is that there are more installed engineering services in the newer buildings than in older buildings. Good illustrations of this are the Old Jogoo House and Nyayo House which are 34 and 9 years old respectively. Old Jogoo House spends an annual mean of KSh 6.48 per square metre while Nyayo House spends KSh 59.07 per square metre annually to maintain their engineering services. The buildings constructed during the 1980's have more services. Nyayo House, for instance, has 10 lifts while Old Jogoo House has only one.

In addition, most of the older buildings are low-rise and are equipped with few engineering services.

Age is not significant in the regression model probably because, despite their age, old buildings are kept at a very high level of maintenance. Their ages can therefore not be reflected in their maintenance cost.

Age can also be a measure of durability of materials used. Thus engineering services in older buildings can be more durable and require less repair or replacement than in newer buildings. The other possible reason is that the workmanship is of high quality than in the newer buildings.

The most significant variable is height which accounts for 22.26 percent of the variation in maintenance cost; the least is age which accounts for only 0.87 percent. All the design variables considered in this study account for 35.89 percent of the variation in maintenance cost of building services. This is significant at 0.05 level.

Thus the final model in respect of maintenance cost of building engineering services in Nairobi City may be given by the prediction equation below.

$$\widehat{Y}_{mtce} = 11.21496 + .35992H - 0.03314P.$$

where $\widehat{Y}_{mtce}$ is the predictive annual mean maintenance cost of office building services in KSh per square metre.

H is the height of a building in metres

P is the perimeter of a building in metres

Note: The variables, plot ratio, age and shape do not appear in the model because their b-coefficients are not significant at 0.05 level, (Table 4.5).

The above model has a standard error of +/-9.84298 which is the confidence interval for the results obtained.

4.2.2 The final regression model for maintenance cost of electrical services and selected design variables

Only height is significant in the regression model. It accounts for 15.18 percent (Table 4.7) of the change in maintenance cost of electrical services. The other variables, which are plot ratio, shape, age and perimeter account for only 6.1 percent. These are not statistically significant.

As has been predicted, the height of the building had a high correlation, of 0.39 (Table 4.6), with maintenance cost of electrical services. This is because of the vertical orientation of electrical installations in service cores. For instance, the

Table 4.6 Simple product-moment correlation matrix for maintenance cost of electrical services and selected design variables.

Var	Hgt	Plot	Shape	Age	Peri	Mtce
Hgt						
Plot	.221					
Shape	.115	.229				
Age	-.232	.419	.040			
Peri	.528	.044	.318	-.075		
Mtce	.390	.223	.021	-.047	.024	

Source: Computed from the author's field data

Key: Hgt-height, Plot-plot ratio, Peri-perimeter, Mtce-maintenance cost of electrical services, var - variable

electrical distributing cables, junction boxes and switchboards are all within the service core. Tall buildings also have more floor levels and these increase the number of lighting fittings required in the buildings. Moreover, tall buildings have more electrical installations for lifts; all these increase the maintenance costs cosiderably.

Table 4.7 Multiple regression for maintenance cost for eletrical services and selected design variables.

Var	Mult-R	R^2	R^2 Change	b	t	t-test
Hgt.	.38964	.15182	.15182	.12219	2.608	.0128*
Plot	.41415	.17152	.01970	.36384	.710	.4818
Shape	.41775	.17452	.0030	.13253	.090	.9285
Age	.41890	.17548	.00096	-.00224	-.027	.9783
Peri	.46121	.21271	.03723	-.00920	-1.36	.1822
Const				4.35424	1.784	.0822

R^2 = .21271

F = 2.10746 Signif F = .0850

* - signif at .05

Source: Computed from author field data

<u>Key</u>: Hgt-height; Plot-plot ratio; Peri-perimeter; Var-variable, Const-constant.

4.2.3 Final regression model for maintenance cost of mechanical services and selected design variables

There are only three significant design variables for maintenance cost of mechanical services. The most significant variables are height; which accounts for 19.87 percent of variation in maintenance cost of mechanical services, perimeter; which accounts for 8.72 percent and shape, a dichotomous variable which accounts for 3.82 percent. The other two variables, age and plot ratio are not statistically significant; they only explain 4.28 percent of change in maintenance cost of mechanical services (Table 4.9).

Height of the building(X_5): The plot of maintenance cost of mechanical services versus height of building (Graph 6) indicates that maintenance cost of mechanical services increases with the increase in the height of the building. The relationship is given by:

$$Y_3 = 8.435 + 0.190X_5$$

where Y_3 is the annual mean maintenance cost of mechanical services in Ksh per square metre.

X_5 is the height of building in metres.

The unstandardised b-coefficient for the equation

Table 4.8 . Simple product-moment correlation matrix for maintenance cost of mechanical services and selected design variables.

Var	Hgt	Plot	Shape	Age	Peri	Mtce
Hgt						
Plot	.221					
Shape	.115	.229				
Age	-.232	.419	.040			
Peri	.528	.044	.318	-.075		
Mtce	.446	.269	.277	-.119	.032	

Source: Computed from the author's field data

<u>Key</u>: Hgt-height, Plot-plot ratio, Peri-perimeter, Mtce-maintenance cost of mechanical services, Var-variable.

Table 4.9. Multiple regression for maintenance cost of mechanical services and selected design variables.

Var	Mult R	R^2	R^2 Change	b	t	t-test
Hgt	.44576	.19870	.19870	.23941	3.342	.0018**
Plot	.47878	.22923	.03053	.62533	.798	.4295
Shape	.51717	.26746	.03823	4.92492	2.195	.0341*
Age	.52887	.27971	.06225	-.06724	-.538	.5434
Peri	.60575	.36693	.08722	-.02401	-2.318	.0258*
Const				6. 8850	1.845	.0727
$R^2 = 0.36693$ F = 4.52098 Significance F = 0.0024						

* Significant at 0.05 level

** Significant at 0.01 level

Source: Computed from author's field data

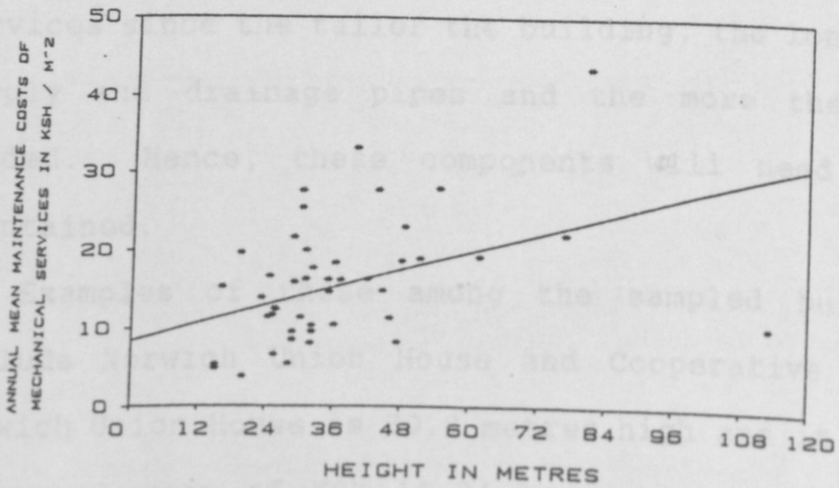
Key: Hgt-height; Plot-plot ratio; Peri-perimeter; Var-Variable; Mult-Multiple-R, Cont-constant.

above is 0.190.

The relationship between maintenance cost of mechanical services and height of the building is significant at 0.05 level.

The correlation between maintenance cost of mechanical services and height is +0.446 (Table 4.8). This means that there is a positive relationship between height and maintenance cost of mechanical services.

The computed multiple regression model shows that height is the most important variable accounting for 19.87 percent of the change in the maintenance cost of mechanical services.



Graph 6: Plot of maintenance cost of mechanical services versus height of the building

Source: Computed from author's field data

The height of the building is significant in the regression model for maintenance cost of mechanical services in the building. The b-coefficient for height is +0.23941 (Table 4.9). This means that for every one unit increase in the height of the building, the maintenance cost of mechanical services increases by 0.23941 units.

The height variable is therefore an important determinant of the future maintenance cost of mechanical services. This is probably because the service core usually has a vertical dimension and most pipes are within a given area of the core. Most of the buildings have the toilets near the ducts in the service core. The vertical orientation of a building causes variation in maintenance cost of mechanical services since the taller the building, the longer the supply and drainage pipes and the more the lifts needed. Hence, these components will need to be maintained.

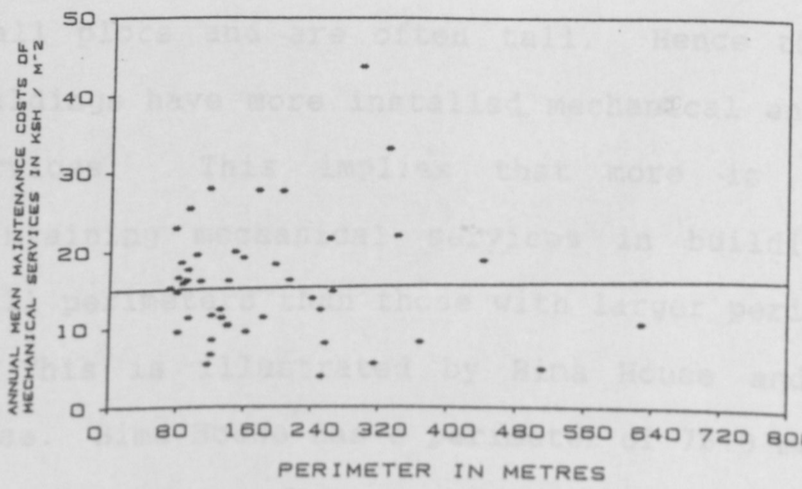
Examples of these among the sampled buildings include Norwich Union House and Cooperative House. Norwich Union House is 30.8 metres high and it spends an annual mean of KSh 16.24 per square metre while Cooperative House is 76.6 metres high and it spends an annual mean of KSh 22.11 per square metre on mechanical services.

Perimeter of the building (X_2): Maintenance cost of mechanical services increases marginally with an increase in the perimeter of the building (Graph 7). The simple product moment correlation indicates the same trend (Table 4.8). A simple regression equation is computed as:-

$$Y_3 = 14.858 + 0.002X_2$$

where Y_3 is the annual mean ofmaintenance cost of mechanical services in Ksh per square metre.

X_2 is the perimeter of the building in metres.



Graph 7: Plot of maintenance cost of mechanical services versus perimeter of the building

Source: Computed from author's field data

The unstandardised b-coefficient for the equation above is 0.002.

The perimeter of the building is significant in the multiple regression model for maintenance cost of mechanical services in the building. The b-coefficient for the perimeter is -.02401 (Table 4.9). This means that for every one unit increase in the perimeter length of the building, the maintenance cost of mechanical services decreases by .02401 units. This means that perimeter is a major predictor of maintenance cost of mechanical services.

This results is not consistent with the literature regarding the relationship between maintenance cost of mechanical services and the perimeter of a building. The most likely reason for this relationship is that buildings with small perimeters are constructed on small plots and are often tall. Hence those tall buildings have more installed mechanical engineering services. This implies that more is spent on maintaining mechanical services in buildings with small perimeters than those with larger perimeters.

This is illustrated by Bima House and Gateway House. Bima House has a perimeter of 76.0 metres and it spends an annual mean of Ksh 23.05 per square metre while Gateway House has a perimeter of 250 metres and it spends an annual mean of Ksh 12.40 per square metre.

<u>Shape of the building (X_6)</u>: A simple regression equation shows that buildings with non-rectangular shapes require more maintenance of mechanical services than rectangular-shaped buildings. The relationship is given by:

$$Y_3 = 12.860 + 4.459X_6$$

where Y_3 is the annual mean maintenance cost of mechanical services in Ksh per square metre.

X_6 is the shape of the building (rectangular or non-rectangular)

The unstandardised b-coefficient for the equation above is 4.59.

The relationship between maintenance cost of mechanical services and shape of the building is significant at 0.05 level. A graph of the relationship can not be drawn because shape is a dichotomous variable.

The calculated multiple regression model shows that shape is the third important variable accounting for 3.82 percent of the change in variation maintenance cost of mechanical services.

Simple product-moment correlation shows that the shape of a building has a high association with the mechanical services. The correlation between maintenance cost of mechanical services and shape is

+0.277 (Table 4.8)

The shape of the building is significant in the regression model for maintenance cost of mechanical services in a building. The b-coefficient for this variable is +4.92492 (Table 4.9). This means that for a non-rectangular shaped building, the maintenance cost of mechanical services increases by 4.92492 units.

Shape is statistically significant probably because mechanical services like plumbing and ducting work become difficult when a building has complicated and irregular shapes. This increases the maintenance cost of mechanical services.

Examples of this include Hill Plaza and Foreign Affairs House. The Hill Plaza House is a non-rectangular building and it consumes an annual mean of Ksh 18.32 per square metre while Foreign Affairs House, which is rectangular, spends an annual mean of Ksh 11.41 per square metre in the maintenance of mechanical services.

<u>Age of the building(X_7)</u>: Simple product-moment correlation coefficient shows that the age of the building is negatively related to the maintenance cost of mechanical services. The correlation coefficient between maintenance cost of mechanical services and age of the building is -.119 (Table 4.8). The possible reason for this result is that more services

are installed in the recent buildings than older ones. Since these services need more maintenance work, more is therefore spent in their maintenance.

The age of the building is statistically insignificant probably because most of the mechanical services in the old buildings are durable and only need routine inspection and repair.

Plot Ratio of building(X_8): Plot ratio of the building relates positively with the maintenance cost of mechanical services (Table 4.8). This is probably because tall buildings are the most likely to be constructed on plots with high plot ratios. These high-rise buildings are installed with more mechanical engineering services than low-rise building, hence high maintenance cost.

The plot ratio of the building is not statistically significant probably because some of the buildings which are located in the high plot ratio areas do not have buildings as tall as would be expected.

4.2.4 Analysis of variance

Further analysis were done using one way analysis of variance (ANOVA). Annual means of total maintenance cost of public and private buildings were compared. Below is the obtained ANOVA table. (Table

4.10).

A variable status was created; this was dichotomous. Public buildings were coded 0 and private buildings were coded 1. The rationale for this analysis of variance was to test whether designers of both public and private buildings adhere to design principles that minimise maintenance costs. It also sought to establish whether either category in the dichotomy manifested a particular neglect in the maintenance of building services.

The results of the analysis of variance shows that there is no statistically significant difference in maintenance costs between public and private buildings. Hence, these findings disputed the commonly held notion that installed engineering services in public buildings are not as well maintained as in private buildings.

Table 4.10 Analysis of variance: Total mean maintenance costs for public and private buildings

ANOVA Table					
Source	DF	SS	MS	F-ratio	(Prob)
Between GPS	1	321.4	321.4	2.65	.11
Within GPS	43	5209.5	121.2		
Total	44	5530.9			

Source: Computed from authors field data

Key: DF-degrees of freedom, SS-sums of squares, MS-mean squares, F(Prob)-F(probability), GPS-groups of private building and public buildings.

Footnotes

1. Climatic data for Dagoretti Meteorological Station Nairobi.
2. <u>Building Code</u>: (Nairobi: The Government Printer, 1976)
3. Interview with Mr. Kinyua, Building Inspector, Parkroad Maintenance Depot, September 1989.
4. Interview with Mr. Kinyua, Building Inspector, Parkroad Maintenance Depot, September 1989.
5. Interview with Mr. Theuri, Electrician, KICC Maintenance Depot, September 1989.
6. <u>Building Code</u>: (Nairobi: The Government Printer, 1976)
7. E.J. Pedhazur, <u>Multiple Regression in Behavioral Research</u>: (New York: Holt, Rinehart and Winston. 1982)

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to evaluate the relationship between the maintenance cost of electrical services, mechanical services, the total engineering services, and selected design parameters. Height, perimeter, plot ratio, shape and age were used as determinants of the dependent variables. The maintenance costs of public and private buildings were also analysed to establish whether there exists a significant difference between them.

5.1 Maintenance cost of electrical services

Height was the only design variable that significantly explained the maintenance costs of electrical services in a building. As the height increased, maintenance cost of electrical services increased.

The results confirmed the hypothesis that height is positively related to the maintenance cost of electrical services. This might be because more electrical installations are present in taller buildings than in low-rise buildings. This study has identified that electrical services took about 36 percent of total maintenance cost of engineering services. The sampled buildings had an annual mean of Ksh 8.80 per square metre for electrical services.

5.2 Maintenance cost of mechanical services

Among the design variables, height, perimeter and shape were strong predictors of the maintenance costs of mechanical services. Tall buildings are likely to have more mechanical installations than low-rise buildings. The use of more mechanical installations result in more maintenance work. This implies more expenditure on maintenance of mechanical services.

Maintenance cost of mechanical services increases with a decrease in the perimeter of the building. Smaller perimeters in buildings may indicate high maintenance costs of mechanical services because the buildings are likely to be high-rise. Tall buildings would tend to have more mechanical installations like lifts. The design of office building with small perimeter is also likely to be within regions of high plot ratios.

Mechanical services in non-rectangular shaped buildings cost more to maintain than those in rectangular shaped buildings. The non-rectangular shaped building designs are likely to have irregular and complicated geometry. This may lead to inappropriate location of service cores, ducts and servicing points. It may therefore need more time and labour to carry out the maintenance tasks. This implies more maintenance costs.

The results for height and shape confirmed the hypothesis that these design parameters positively relate to the maintenance cost of mechanical services. The results did not support the hypothesis that there is a positive relationship between perimeter and the maintenance cost of mechanical services.

The probable reason why a negative relationship was expressed is because of site constraints. It has been noted that tall buildings will normally have high plot ratios but small perimeters.

This study has also identified that mechanical services took about 64 percent of total maintenance cost of engineering services. The sampled buildings had an annual mean of Ksh 15.80 per square metre for mechanical services.

5.3 Total Maintenance Cost of Engineering Services

The design parameters, height and perimeter has a significant relationship with the total maintenance costs of building services. Taller buildings are likely to have more electrical and mechanical services than low-rise buildings. This implies that maintenance costs of building engineering services increase with floor areas and storey numbers. Hence, where the building's floor area and storey numbers are more, it is expected that more expenditure will be incurred on the maintenance of engineering services.

It was expected that the perimeter of a building would have a positive relationship with maintenance cost of engineering services. This would have inferred that as the building perimeter increases, maintenance cost of engineering services increases in the building. This hypothesis, however, was not supported by the results. The negative relationship may be because of the land factor in Nairobi City.

Since the plots are small, then it can only be viable if the developer constructed a tall building. This is the only way a building investment would be viable. Thus the developer has to be ready to meet the cost of extra engineering services like lifts, pipes, cables and conduits, and water storage tanks. These extra engineering services have implications on future cost-in-use.

Hence, tall buildings will normally have smaller perimeters and more engineering services which demand high maintenance costs.

The results indicate that there is a strong association between maintenance of building services and design. There is a need to design for maintainability of the building services. The results shows that the height of the building was the most significant design parameter. The results also seems to explain the townscape of the city in relation to the maintenance of buildings. Townscape in this context refers to the architectural art of achieving beauty in the design and spatial relationships created by the disposition and juxtaposition of structures (as in government and private buildings) in a city. The townscape in this case is expressed by a steady increase in height of buildings towards town centre where plot ratios are high. Simply put, the sky-line of the city approximately resembles the shape of a normal curve.

Further, this is shown by the relationship between the maintenance cost of engineering services and plot ratios; and the plot ratios and building heights. These findings emphasize that the engineering services installed in the buildings on high plot ratio areas are more expensive to maintain than in those on low plot ratio areas. This study has indicated that currently engineering services need an annual mean of Ksh 25.60 per square metre as maintenance cost.

5.4 Recommendations and practical implications

This study set out to: identify design errors, apportion the maintenance cost of engineering services and establish the design variables that are important in predicting the maintenance cost of building services. Below are the recommendations made in this study in relation to above objectives and derived from the data analysis.

5.4.1 Design Errors

In order to avoid the design errors identified earlier, the observations made below are worth noting.

Service cores are appropriately located when they are at the end of the building as in Stanbank (Figure 5.1) or when they are a link between the building blocks as in Hill Plaza (Figure 5.2) and Ardhi House (Figure 5.3). The ducts are well located when they are along the circulation space, and when the longest side of the duct is accessible as in National Housing Corporation (NHC) House (Figure 5.4) and Norwich Union (Figure 5.5).

The pipes carrying water inside the building should be contained in ducts with access panels which should be removable over the full length of the duct. Spring catches should be used when fixing

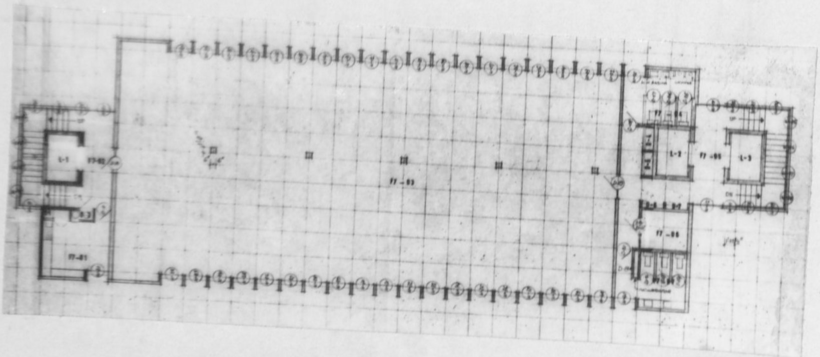


Figure 5.1 Stanbank House. Service cores appropriately located.

Source: NCC, Architectural Department

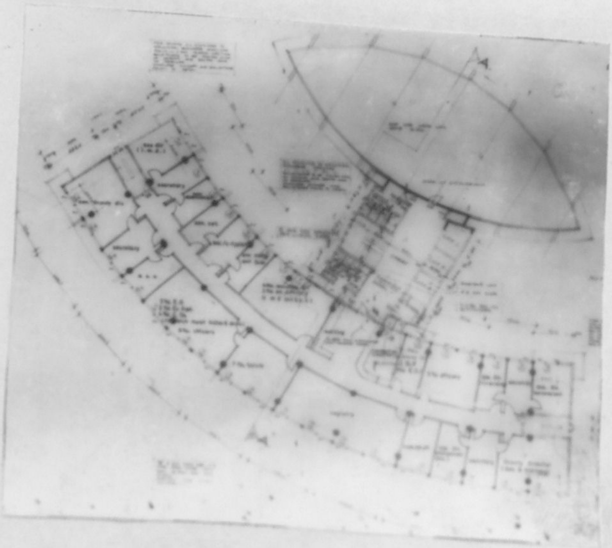


Figure 5.2 Hill Plaza. Service cores appropriately located

Source: MOPW, Records Office

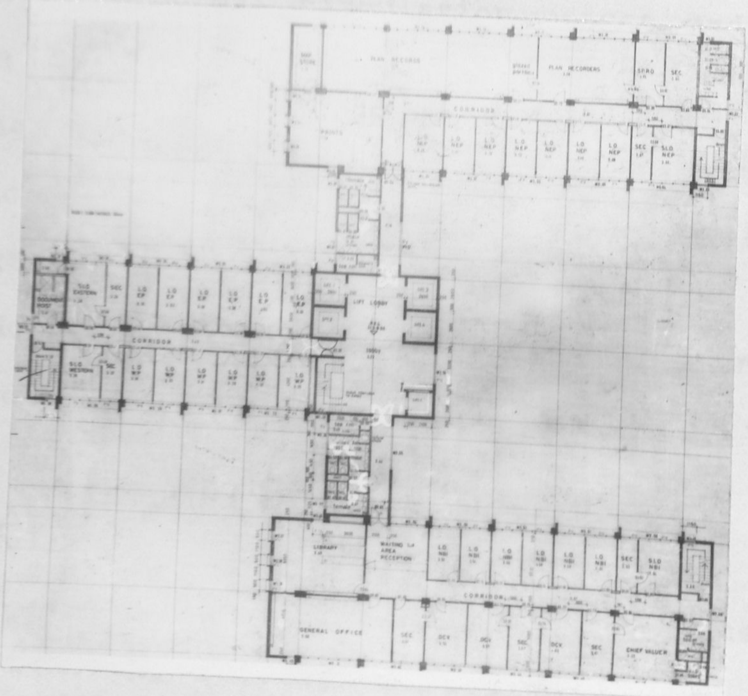


Figure 5.3 Ardhi House: Service cores appropriately located

Source: MOPW, Records Office

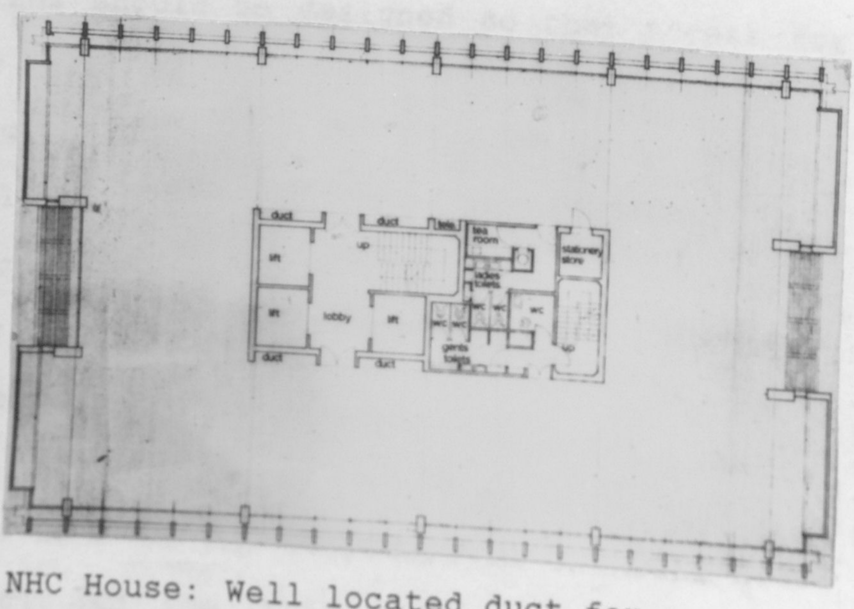


Figure 5.4 NHC House: Well located duct for accessibility.

Source: NCC, Architectural Department

them and not locks. The service ducts should be accessible from normal circulation spaces and from inside the rooms. When service pipes are placed in the ceiling spaces, the panels below should be hinged to drop down out of the way, if possible over the whole length of the pipes.

Pipe ducts in floors should be self draining or constructed with sumps at intervals to facilitate removal of surplus liquid.

The access of services is appropriate when fittings are not very high, and the specifications for fixing or removing fittings should allow for easy removal without disturbing the rest of the adjacent building elements.

It is recommended that the lighting fittings in high ceilings should be designed so that access for repair or replacement is simple and expensive scaffoldings not necessary. Fittings should be easy to dismantle for cleaning.

Artifical lighting in the service cores can be avoided by proper planning. All building spaces should have frontage rooms, thus reducing artificial lighting. The lighting along the corridors should be done at the ends of the corridors as in Ardhi House (Figure 5.6) and the lift lobbies should be lit directly from the outside as in Stanbank (Figure 5.7)

All building spaces should have permanent vents at

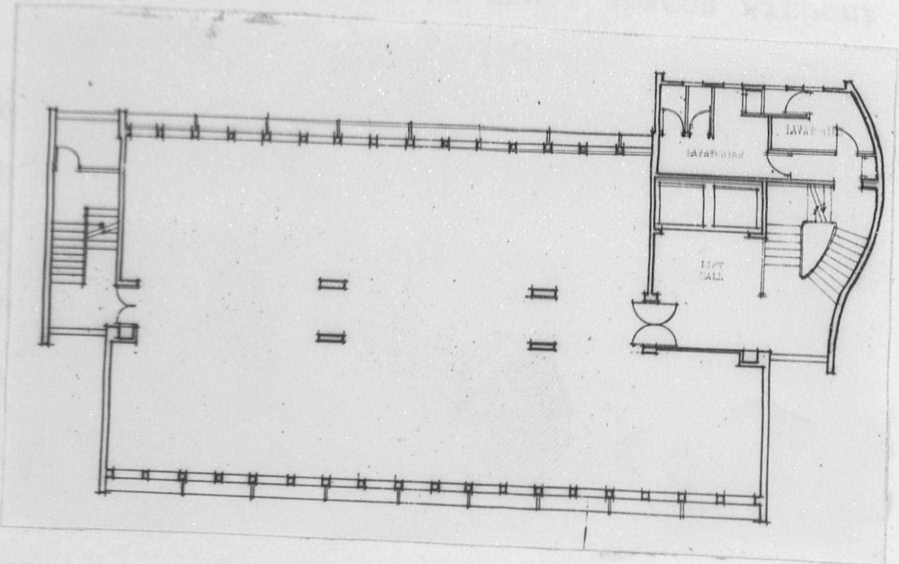


Figure 5.5 Norwich Union: Well located duct for accessibility.

Source: NCC, Architectural Department

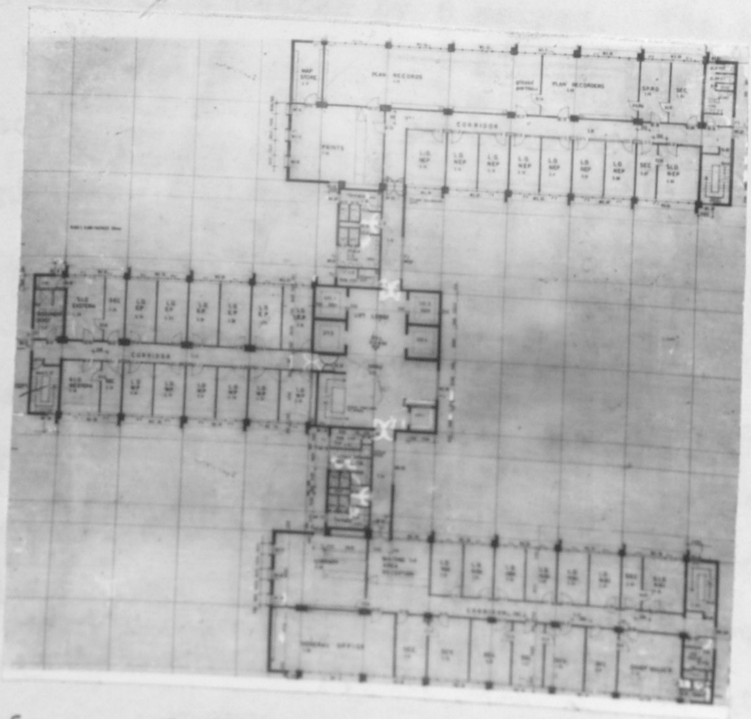


Figure 5.6 Ardhi House: Well lit corridors and service facilities

Source: MOPW, Records Office

the frontage to ensure natural ventilation in all the rooms. The design should avoid inner spaces without frontage or habitable rooms in the basement. This minimises the use of artificial ventilation. This feature has been achieved in Commonwealth House (Figure 5.8).

The designer should avoid expanse space in office buildings. In Stanbank (Figure 5.9), the designer seems to have considered the engineering services during the planning stage. The designer adapted a central corridor with service cores at the ends of the building. It is an economical layout because mechanical ventilation problems are miminal. The planning grid is 6 metres by 6 metres. The two main facades have enough natural lighting. The service core also has adequate natural lighting and offices are adequately illuminated.

An interviewee, Otieno[1] recommended that to avoid expanse office spaces, the depth of the office should have a maximum of 5-6 metres. The planning should be such that the layout ensures that all the spaces have a frontage (Figure 5.10). In this type of design, ventilation machinery would rarely be required. Therefore clients would not incur heavy maintenance expenditure in the servicing and replacement of such services especially in the event of breakdowns. In case of lighting, less electrical installations are

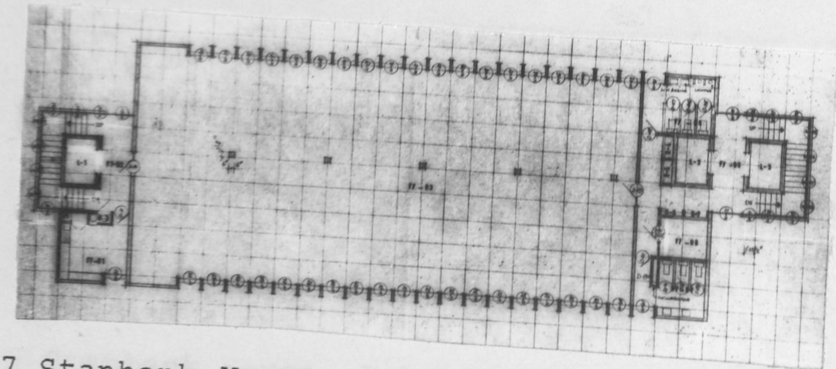


Figure 5.7 Stanbank House: Well lit service core facilities

Source NCC, Architectural Department.

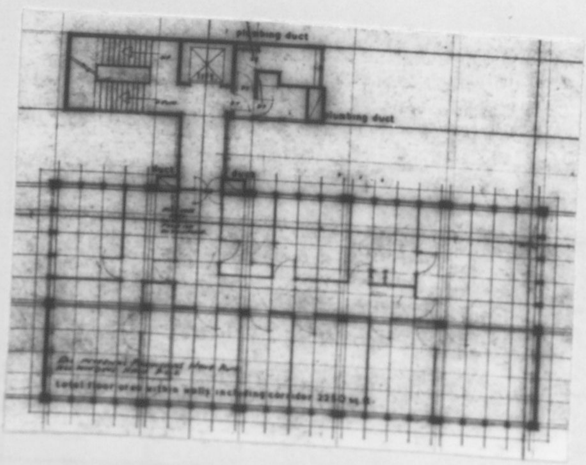


Figure 5.8 Commonwealth House: Well lit office spaces and service core facilities.

Source: NCC, Architectural Department

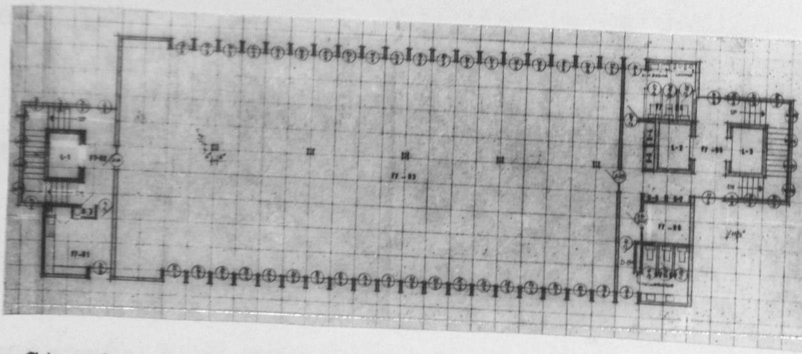


Figure 5.9 Stanbank House: A building with minimum problems associated with expanse space.

Source: NCC, Architectural Department.

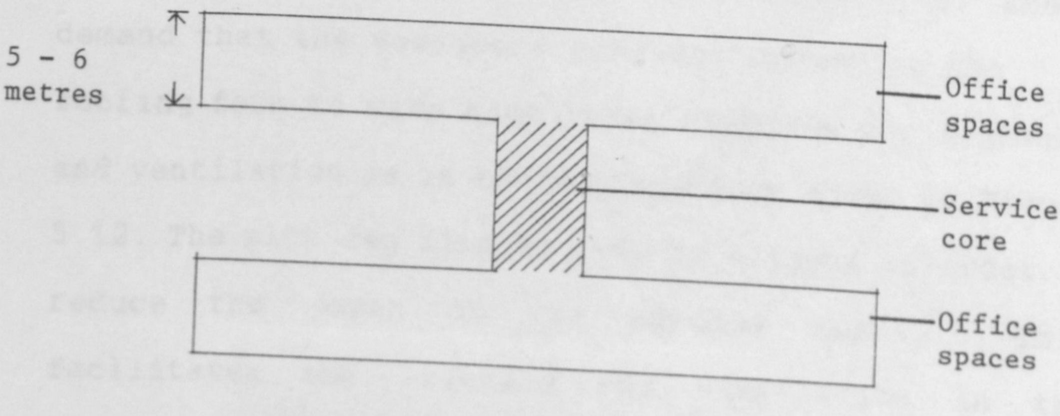


Figure 5.10: Office layout concept

Source: Drawn by the author

used since there is sufficient daylighting in the office spaces. This cuts down the maintenance cost of electrical services of the building considerably.

The service core, as well should be naturally lit and ventilated since this means that less money would be spent on the maintenance of engineering services. Magereza House (Figure 5.11) is a good illustration of this design concept.

Roof lighting and ventilation are the other possible solutions for expanse floor areas. This design concept has been used effectively in the library space of Kilimo House. Similarly, at Jubilee Insurance Building the designer has effectively introduced roof lighting in the central core to naturally light and ventilate the lift lobby and stairway.

The buildings which must have large floor areas demand that the designers consider cascading the roofing form to make high level openings for lighting and ventilation as in the roofing form shown in Figure 5.12. The plan can also be made to stagger in order to reduce the depth of the expanse space. This facilitates the lighting and ventilation in the spaces. Figure 5.13 below illustrates this type of layout.

The design of office building should also cater for aesthetics, spatial quality and engineering

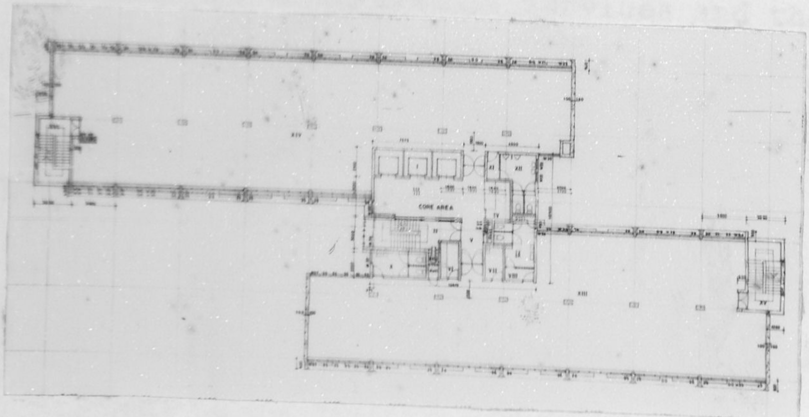


Figure 5.11 Magereza House. Juxtaposition of building plan to create adequate lighting for service core facilities.

Source: MOPW, Records Office

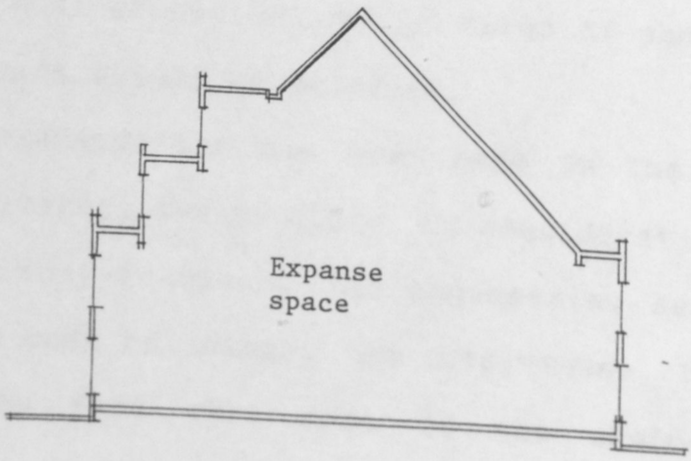


Figure 5.12: Cascading roof form concept for expanse space to allow adequate lighting and ventilation.

Source: Drawn by the author

services of buildings. The office functions which go with rectangular shaped spaces should be encouraged in order to have easy installations of services and their maintenance. Ardhi House (Figure 5.14) is an example of a building where the designer has achieved a high level of architectural requirements.

5.4.2 Apportioning maintenance cost of engineering services

The allocation of costs to maintain the services in a building should be minimal. This can be achieved by comparing alternative designs and components and their maintenance costs before taking a decision to go ahead. The most economical one in terms of short and long term costs should be selected.

This recommendation has been made on the basis that in the initial design stage, no consideration may be given to cost-in-use of the engineering services installed in most buildings. An interviewee, Theuri[2] supported the fact that most of the engineering fittings are imported and this increases future maintenance costs.

One interviewee, Otieno[3], noted that where a lift attendant is employed, the lifts maintenance problems are minimal. The lift attendant's responsibility is to make sure that the lift is effectively used. The lift

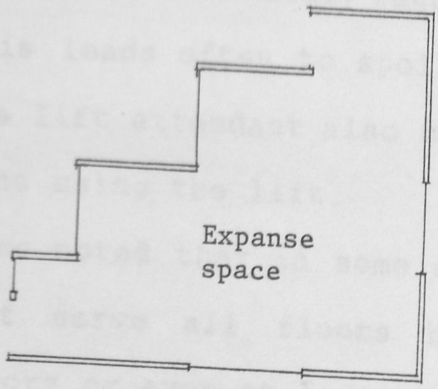


Figure 5.13: Staggered plan concept to reduce the depth of expanse space

Source: Drawn by the author

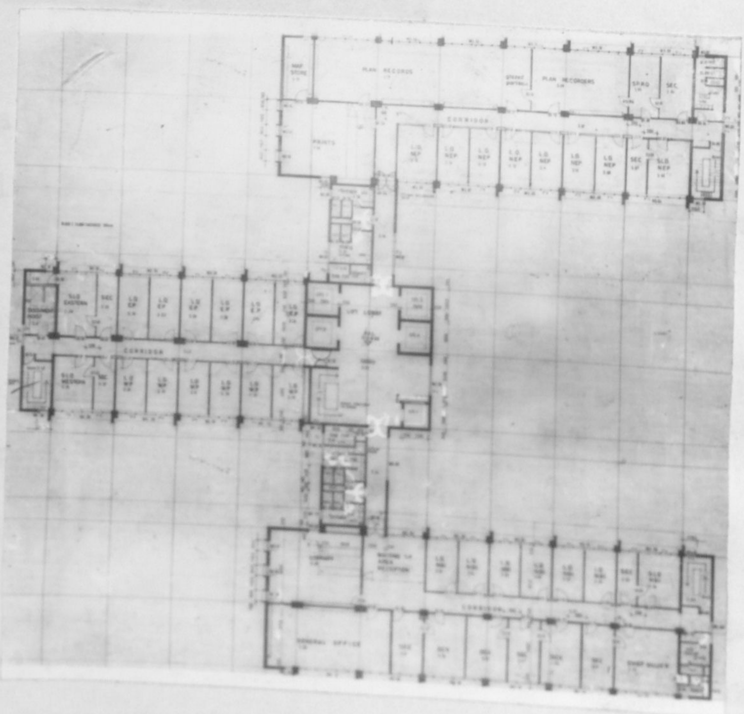


Figure 5.14 Ardhi House: Space design for engineering services well considered by designer.

Source: MOPW, Records Office

attendant ensures that the users do not misuse or overuse the lift. Some users misuse the lifts by using the keys indiscriminately regardless of intended purpose. This leads often to spoilt buttons or lift jamming. The lift attendant also controls the number of the persons using the lift.

It is also noted that in some sampled buildings, lifts do not serve all floors but only stop at alternate floors or even at large intervals. This is the case at the Ministry of Public Works Building and Nyayo House.

5.4.3 Cost Maintenance Model

The variables which were found to be very important in predicting the future maintenance costs of office engineering services were height and perimeter of the building. These variables explained about 31 percent of the variations in the maintenance cost as compared to 36 percent when all variables were used. The other insignificant variables were age, plot ratio and shape. The cost model that designers may use to make decisions regarding the extent of maintenance cost for different design variables is given as:

$$\hat{Y}_{mtce} = 11.21496 + 0.35992H - 0.03314P$$

where $\hat{Y}_{mtce}$ is predictive annual maintenance cost of engineering services in KSh per square metre.

H is the height of the building in metres

P is the perimeter of the building in metres.

The confidence interval of the results given by the cost model is +/-9.84298.

The designers should, therefore, be critical on the height and perimeter of the building since these are the variables that seem to be predictors of the maintenance cost of office building engineering services.

5.5 Suggestions for future research

Further research in the determinants of maintenance cost ought to focus on the proper relationship between architectural design parameters. These parameters include perimeter, height, areas of windows and floors of the building. This would help future researchers in identifying more easily and precisely which variables are less correlated and those with stronger interrelationships. Those variables which are less correlated are better predictors of maintenance costs than those which are strongly interrelated.

Further research should also consider using non-design variables such as intensity of use; qualification of personnel; efficiency of equipment etc. in predicting maintenance costs of building services.

Although this research concentrated on the office building designs only, it can be inferred that the same design parameters can be applied to other types of buildings such as schools, hostels, factories, etc. Hence, further research should be done to find out which parameters are significant predictors of maintenance cost of engineering services in other types of buildings.

Footnotes

1. Interview with Mr. Otieno, Estate Manager of Tyson Limited, October 1989
2. Interview with Mr. Theuri, KICC Maintenance Depot: Mr. Kinyua, Parkroad Maintenance Depot; and with Mr. Otieno of Tysons Limited, November 1989.
3. Interview with Mr. Otieno, Estate Manager of Tyson Limited, October 1989.

REFERENCES

Allan, Ashworth. "Cost Modelling for the Construction Industry." The Quantity Surveyor. Volume 37, No 1-12. (July, 1987).

Bargh, John. "Increasing Maintenance Needs on limiting Budgets. A Technique to Assist the Building Manager in Decision Making", in Building Maintenance, Economics and Management. (ed. Alan Spedding). London, E & F N Spon, 1987.

Barton, J.J. Heating and Ventilating. London, George Newness Limited, 1964.

Building Code. Nairobi: The Government Printer, 1976.

Burberry, P. "Space for services, 5 distribution and sizing". Architectural Journal. Vol.5 (March, 1986).

Botman J.J. "A Model for Estimating the Maintenance needs of the Dwelling stock," in Renewal Rehabilitation and Maintenance Volume 1b, CIB83, Stockholm, 1983.

Carpenter, I.K. "The Commercial aspects of terotechnology and planning for maintenance". Building Service Establishment, Vol. 43 (1975).

Colston, A.E. "The Maintenance of Public Housing Assets, Practice and Development", in

Building Maintenance Economics and Management, (ed. Alan Spedding), London:E & F N Spon, 1987.

Carver, M. "Optimisation Techniques for use in the design of Building", in Quantity and total costs in Building costs in Building Services Design, (ed. D.J. Croome), Lancaster: The Construction Press, 1977.

Estmacode. "A System of Planned Preventive Engineering Maintenance". Operations and Maintenance Vol.2, (April, 1976).

Feldman, Edwin B. Building Design For Maintainability. New York: McGraw - Hill Book Company, 1968.

Fujikami, Teruyuki. "A study of the cost of repairing wooden houses in Japan", in Renewal Rehabilitation and Maintenance. Volume 16, CIB 83, Stockhom, 1983.

Gasson, P. Theory of design. London; B.T. Batsford Limited, 1973.

Grover, Christine S. and Grover, Richard J. "Conditions for Optimality in Periodic Preventive Maintenance", in Building Maintenance,Economic and Management. (ed. Alan Spedding), London: E & F N Spon, 1987.

Gibson, E.J. "Maintenance Research." British Research Establishment. Vol. 37 (1977).

Hartkopt, Volker. "An Economy model for generating Evaluation, and selecting Architectural Design Alternatives", in <u>Environmental Design Research</u>.(ed. Preiser Wolfgang), Pennsylvania: Dowden Hutchinson and Ross, Inc., 1973.

Heneman, G. Herbeit. "Toward a General Conceptual System of Industrial Relations: How do we get there?" in <u>Essays in Industrial Relations Theory.</u> (ed. Somer), G. Iowa, the Iowa State University Press, 1969.

Holmes, Roy. "The Evaluation of Determinants in Maintenance Expenditure on Local Authority Dwellings", in <u>Building Maintenance, Economic and Management</u>, (ed. Alan Spedding), London: E & F N Spon, 1987.

Harvey, G. "A study into the practice and concept of terotechnology and life-cycle costing as applied to manufacturing industry." PhD. Thesis, 1978. Loughborough University of Technology.

Kenya Development Plan 1984-1988, Nairobi: Government Printer, 1984.

Kline, M.B. et al "The system life-cycle." <u>Journal of Systems Engineering</u>, vol.II No.1, 1971.

Koeningsberger, H. Otto. et al, <u>Manual of Tropical Building and Housing</u>. New York: Longman, 1980.

Koutsoyiannis, A. Theories of Econometrics. London: Macmillan Education Ltd., 1986.

Isaac, A.R.G. Approach to Architectural Design. London: Butterworth & Co. (Publishers) Ltd., 1971.

Janicki, S. and Zaleski, S. "Bases for Maintenance and Modernisation of Buildings," in Renewal, Rehabilitation and Maintenance, Volume 16, CIB 83, Stockholm, 1983.

Joedicke, Jurgen. Office Buildings. London: Crosby Lockwood and Sons Ltd., 1962.

Leonard, Manasseh and Roger, Cunliffe. Office Buildings. London: B.T. Batsford Ltd., 1962.

Martin, J.L.N. "Monitoring the Movement of Maintenance costs," in Building Maintenance, Economic and Management. (ed. Alan Spedding), London: E & F N Spon, 1987.

Mathur, G.G. "Conservation of Existing Housing Stock", in Renewal, Rehabilitation and Maintenance, Vol.1b. C1B83, Stockholm, 1983.

Maver, Thomas W. Building Services Design. Oxford: Aden of Mowbray Ltd., 1971.

McGuiness, William. Mechanical and Electrical Equipment for Buildings. New York: John Wiley and Sons, Inc. 1971.

Miles, D. and Syagga, P., Building Maintenance - a

Management Manual. London: Intermediate Technology Publications, 1987.

Morton, Crawnford W. "Life Cyle Costing and Resource Optimisation", in Building Maintenance, Economic and Management. (ed Alan Spedding), London: E & F N Spon, 1987.

Nuffield Provincial Hospital Trust. Studies in the Functions and Design of Hospitals London: Oxford University Press, 1955.

Lapin, L. Statistics for Modern Business Decision. London: Harcourt Brace Jovanovich Inc., 1982.

Odhiambo, Obunga. "Office Spaces." B. Arch. Thesis, University of Nairobi, 1979.

Ozguner, Orhan. "Philosophy of Tall Buildings", in Tall Buildings in Urban Context. (ed. Dieter Ackehnecht and Sadi Asset), Dhahram: UPM Press, 1986.

Pedhazur, E.J. Multiple Regression in Behaviour Research. New York: Holt Rinehart and Winton, 1982.

Philpott, B. "Designing with Terotechnology in Mind". Building Services Establishment (BSE), Vol.43 (July, 1975).

Pye, D. The Nature and Aesthetics of Design. London: Barrie and Jenkins Ltd., 1978.

Raman, G. Pattabi. "Synthesis in Design

Interdisciplinary Essay", in Environmental Design Research, (ed. Preiser Wolfgang). Pennsylvania: Dowden Hutchinson and Ross, Inc., 1973.

Ronner, Heiz. Sharad, Jhavani and Alessandro, Vesella. Louis Khan. Complete Works (1935 - 1974) Calorado: West View Press, 1974.

Saleh, Ridzuam M. "Vertical Transportation in Tall Buildings," in Tall Buildings in Urban Context. (ed. Dieter Ackekncht and Sadi Asset). Dhahram: UPM Press, 1986.

Seeley, I.H. Quantity Surveying Practice. London: MacMillian, 1984.

__________. Building Economics. London: McMillian, 1972.

Sidwell, A.C. "The measurement of Mechanical and Engineering services in the buildings", Quantity surveying, Vol. 35, 1978.

Skinner, N.P. "House Condition, Standards and Maintenance," Housing Review. July/August, 1981.

Stone, P.A. "Economic Criteria and Building Decisions" in Value in Building. (ed. Hutton, H.). London: Applied Science Publishers Ltd., 1973.

__________. Building Evaluation Cost-in-Use. London: E&F.N. Span Ltd., 1980.

Syagga, P.M. "The Impact of Building Design on Maintenance Costs of Residential Housing Estates Owned by Mombasa Municipal Council". Ph.D. Thesis, University of Nairobi, 1985.

________. "Maintenance cost modelling for Residential Housing Estates in Mombasa, Kenya," in Building Maintenance, Economics and Management. (ed. Alan Spedding). London: E&F N Spon, 1987.

Tarmohamed, N. "Office and Commercial Facilities Complex, City Centre Nairobi." B.Arch Thesis, University of Nairobi, 1974.

Thabit. "Terotechnology", Msc. Thesis Manchester Institute of Science and Technology, 1978.

The National Building Agency. Common Building Defects. London: The Construction Press, 1979.

Trade News. "Blame for Defects now Swings to Products." Building Today. Vol. 195 No. 5753 (April, 1988).

Zamil, A.R. Mokrin. "Structural Considerations in The Design of Tall Buildings", in Tall Buildings in Urban Context (ed. Dieter Ackeknecht and Sadi Asset). Dhahram: UPM Press, 1986.

Zeisel, J. Inquiry by Design. Monterey: Brooks/Cole Publishing Co., 1981.

APPENDIX A

QUESTIONNAIRE

Title: INFLUENCE OF ARCHITECTURAL DESIGN PARAMETERS ON MAINTENANCE COSTS OF SERVICES IN BUILDING OFFICES IN THE CITY OF NAIROBI.

I. HISTORICAL STUDY:

Please fill in the following information on the office building required on:

i) Name of the building..............
ii) The year the office building was constructed ....
iii) Name of the Estate Agents for office building...........................
iv) The status of the building: Private/Public.........................

II. FUNCTIONS OF OFFICE BUILDING

Please check whether the following functions are present in the building:

Shop - Jewellery Yes No
- Shoes Yes No
- Electronics Yes No
- Butchery Yes No
- Clothes Yes No

and others:
.... Yes No

o Bank Yes No
o Cafeteria Yes No
o Cinema Hall Yes No
o Conference room Yes No
o Office - Governmental Yes No
- Professionals Yes No
- Embassy Yes No
- Agents of organisation Yes No
- Association Yes No

Others
.... Yes No
.... Yes No

and others
.... Yes No

III. ENGINEERING SERVICES IN OFFICE BUILDINGS

Please check whether the following mechanical services are present in your office building:

A. Lifts and their appliances Yes No

B. Air-conditioning system Yes No

C. Ventilation systems (extracting fans in toilets and lifts) Yes No

D. Fire-fighting equipment
- hose reel Yes No
- splinkers Yes No
- buckets Yes No
- Alarm Yes No

and others: Dry risers Yes No
Carbon dioxide Yes No
Foam Yes No

E. Gas services and their appliances Yes No

F. Plumbing (for drinking, cold and hot water) Yes No

G. Internal drainage (waste and soil drainage) Yes No

H. Boiler Yes No

I. And others
.... Yes No

ii) Please check whether the following electrical services (for power and lighting) are present in your office building:

A. Electrical installations (cables, switches, sockets, bulbs e.t.c.) Yes No

B. Portable equipment
- mopper Yes No
- computer system Yes No
- and others
.... Yes No

C. Fixed apparatus permanently connected (Refrigerator/ heater) Yes No

D. Kitchen equipment (Refrigerator/ cooker) Yes No

E. Alarm systems
- horns Yes No
- bells Yes No
- sirens Yes No

F. Motor and generator including starting and regulation equipment Yes No

G. Distribution system
- High voltage Yes No
- Medium Yes No
- Low Yes No

H. And others
.... Yes No

IV. DESIGN VARIABLES

a) Please fill in the following information required on the office buildings:

i) Number of storeys....................

ii) Total height of the building in meters ....

iii) Average perimeter of the building in meters ....

iv) Total floor areas in square metres ....

v) Total window areas in square metres....

vi) Plot ratio of the building............

vii) Number of lifts in the building.......

viii) The shape of the building

- Rectangular Yes No
- Non-rectangular Yes No

V. VENTILATION AND LIGHTING

a) Please check whether the toilets are;

i) Naturally ventilated Yes No

ii) Artificially ventilated Yes No

iii) Naturally lit Yes No

iv) Artificially lit Yes No

b) Please check whether the stairways are:

i) Naturally lit Yes No

ii) Artificially lit Yes No

VI. SPACE DESIGN FOR ENGINEERING SERVICES

a) Please select the materials used to construct the following elements in the office building from the listed possible materials below:-

	Possible materials
i) Walls	1. Quarried stones
ii) Floors	2. Concrete blocks
iii) Roofs	3. Overburnt clay
	4. Timber
	5. Reinforced concrete
	6. Name others ....

b) Please check the materials used to make the piped services:

- metal (cast iron, copper) Yes No
- plastics Yes No

c) Please check where the engineering services are concealed in the:-

i) Beams Yes No

ii) Slabs Yes No

iii) Columns Yes No

iv) Falsed ceilings Yes No

v) Trenches Yes No

vi) Embedded in the walls Yes No

vii) Service floor Yes No
viii) Exposed along building elements (e.g. walls, columns) Yes No

d) Please check the following:

i) Is the location of the engineering services appropriate? Yes No
ii) Is the size and space allocated for engineering services adequate? Yes No

e) Location of the central service is
- in the middle of the building Yes No
- in the side of the building Yes No

f) Comment on the maintenance standard of the office building engineering services:

	Electrical Services	Mechanical Services
Excellent		
Best		
Good		
Fair		
Poor		

g) Please check which of the following aspects of building office design for services you would like to be given more attention in future design for effective maintenance of office building services
1. Location
2. Size
3. Specification

VII. <u>MAINTENANCE POLICY</u>

i) Please check whether you use the
a) Maintenance policy Yes No
b) Maintenance manual Yes No

ii) Please fill below the procedures involved in getting maintenance work executed in the office building services.
a) employed labour force Yes No
b) contract labour force Yes No

iii) Please state how you budget for maintenance work.
a) Is it from the past maintenance expenditure Yes No
b) Based on inspection of distinguishable maintenance need of elements of building Yes No

iv) Please note the source of funds for maintenance of office building engineering services:

a)	Rent	Yes No
b)	Grant	Yes No
c)	Service charge	Yes No

VII. **MAINTENANCE COSTS OF ENGINEERING SERVICES**

Please state the amount spent per year on maintenance work in the office building on engineering services from 1984-1988.

MECHANICAL SERVICES

Mech. services \ Year	1984	1985	1986	1987	1988
Lifts					
Air conditioning system					
Ventilation system					
Fire fighting equipment					
Gas services					
Plumbing					
Internal drainage					
Boiler					

ELECTRICAL SERVICES

Elect. services \ Year	1984	1985	1986	1987	1988
Electrical installation					
Portable equipment					
Fixed apparatus permanently connected					
Kitchen equipment					
Alarm					
Motor & Generator					
Distribution system					

REPUBLIC OF KENYA

The House Holder/Officer-in-Charge

....

MINISTRY OF WORKS & HOUSING
PROVINCIAL WORKS OFFICER
P.O. BOX 42267,

NAIROBI

Date ....

WORKS INSTRUCTION

Building No. ....
The bearer is sent to carry out the following ....

....

On completion of the work kindly sign in the space below and return to the bearer.

Work completed - Date .... Signature ....
House Holder/Officer-in-Charge

Note: It is requested that the workmen will not be asked to do any other work other than that stated above.

for ....
Depot Works Officer,
Authorizing Works Instructions

work completed
....
Supervisor-in-Charge

APPENDIX B: WORK INSTRUCTION

Form S 11

DUPLICATE

H 3291

J 186516

REPUBLIC OF KENYA

COUNTER REQUISITION AND ISSUE VOUCHER

Ministry ______ Dept. Branch ______ Unit ______
To (issue point) ______ Please issue the stores
listed below to (point of use) ______

Code No.	Item Description	Unit of Issue	Quantity Required	Quantity Issued	Value	Remarks Purpose
				1	171	

Account No. ______ Date ______
Requisitioning Officer ______ Designation ______ Signature ______
Issued by ______ Signature ______ Date ______
Received by ______ Designation ______ Signature ______

APPENDIX C: COUNTER REQUISITION AND ISSUE VOUCHER

Work Instruction MOW 312

OLD JOGOO HOUSE
3rd Floor kitchen
The bearer is sent to check and repair leaking kitchen taps

Date completed

Sign Occupant

for: DEPOT WORKS OFFICER
[illegible]/1988

APPENDIX D: COMPLETED WORK INSTRUCTION

DAILY COSTING SHEET

DEPOT................................. DATE...................

W.I.NO.	MAN'S NO	HRS	RATE	VALUE	TOTAL WAGES	TOTAL WAGES B/F	TOTAL WAGES TO DATE	STAFF WAGES B/F	D.S.R. NO	VALUE	MATERIAL COST B/F

APPENDIX E: DAILY COSTING SHEET

BUILDING REGISTER DETAIL SHEET

LOCALITY	HOUSING NUMBER	REGISTER NUMBER
BUILDING DESCRIPTION		DATE OF REGISTRATION
		MINISTRY/DEPARTMENT

DETAILS OF ORIGINAL AND SUBSEQUENT ADDITIONS AND ALTERATIONS	TYPE	WALLS	FLOOR	ROOF	FINISH	WTR.	SANI.	ELECT.	VALUATION CODE	PLINTH AREA BY FLOOR(M^2)

DATE OF CONST.	COST	JOB NUMBER	RATE VALUE	LIFE SPAN	RENTAL CLASSIFICATION

DESCRIPTION OF PLANT AND EQUIPMENT INSTALLED

VALUATION CODE	PLINTH AREA	PRICE	VALUE	DESCRIPTION	COST OR VALUE

NAMES OF MEMBERS OF DESIGN TEAM AND THEIR ADDRESSES OF CONTACT INCLUDING THEIR CONCERN	LIST OF DRAWINGS FOR FUTURE REFERENCE

RECORD FOR MAJOR CYCLICAL BUILDING MAINTENANCE REQUIRED

PAINTING AND REDECORATION		REWIRING		RE-ROOFING	
CYCLE	DUE IN YEAR	CYCLE	DUE IN YEAR	CYCLE	DUE IN YEAR
1ST		1ST		1ST	
2ND		2ND		2ND	
3RD		3RD		3RD	
4TH		4TH		4TH	
5TH		5TH		5TH	
6TH		6TH		6TH	
7TH		7TH		7TH	
8TH		8TH		8TH	
9TH		9TH		9TH	
10TH		10TH		10TH	
11TH		11TH		11TH	
12TH		12TH		12TH	
13TH		13TH		13TH	
14TH		14TH		14TH	
15TH		15TH		15TH	
16TH		16TH		16TH	
17TH		17TH		17TH	
18TH		18TH		18TH	

APPENDIX F: BUILDING REGISTER DETAIL SHEET

APPENDIX G: THE DATA FOR SELECTED 45 OFFICE BUILDINGS

NAME OF THE OFFICE	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	K	Y_1	Y_2	Y_3
1 Old Jogoo House	251.60	7776.00	827.00	5.00	19.90	1	33.00	6.00	0	6.48	2.59	3.89
2 Prudential Assurance House	202.80	4748.00	1365.60	8.00	30.00	1	30.00	6.00	1	40.73	13.08	27.65
3 Hill Plaza	194.90	5944.90	1296.60	11.00	36.00	1	8.00	2.00	0	27.53	9.21	18.32
4 Bima House	76.00	3720.00	1170.00	14.00	48.20	0	12.00	2.00	1	39.00	15.95	23.05
5 MOWP Headquarters Buildings	132.40	7519.20	2293.20	14.00	45.80	0	20.00	6.00	0	16.59	5.27	11.32
6 Salama House	101.40	3024.00	1008.00	5.00	19.20	0	33.00	5.00	1	34.84	15.21	19.63
7 Agriculture House	80.40	2721.20	849.60	8.00	28.60	0	32.00	6.00	0	12.92	3.37	9.55
8 Impala House	85.30	1760.40	511.90	8.00	28.80	1	5.00	3.50	1	22.41	6.55	15.86
9 Kilimo House	139.60	8289.60	1646.69	10.00	36.00	0	14.00	2.00	0	20.07	9.61	10.46
10 Gateway House	250.00	2560.00	825.00	8.00	25.60	1	26.00	5.00	1	17.79	5.39	12.40
11 Sheria House	120.00	8299.40	2738.00	7.00	25.40	0	16.00	5.00	0	9.71	3.05	6.66
12 Protection House	106.60	5559.60	792.70	10.00	37.00	0	9.00	5.00	1	30.37	14.21	16.16
13 NHC House	368.00	9000.00	1948.80	14.00	47.20	0	12.00	5.00	1	18.57	10.29	8.28
14 KICC	627.40	41858.20	4933.30	32.00	113.00	1	17.00	5.00	0	16.63	5.92	10.71
15 Commission House	256.00	3208.50	987.40	9.00	31.80	1	13.00	6.00	0	17.47	9.34	8.13
16 Corner House	157.10	18092.90	6030.70	16.00	61.50	1	5.00	6.00	1	42.85	23.62	19.23
17 Quran House	80.00	1556.00	336.50	7.00	24.40	0	30.00	3.50	1	27.88	11.27	16.61
18 Labour House	264.30	5838.00	2340.00	13.00	44.50	1	27.00	2.00	0	22.30	8.22	14.80
19 Tumaini House	130.00	6364.20	2182.60	7.00	25.40	1	32.00	6.00	1	23.55	11.13	12.42
20 Magereza House	146.90	10870.20	2504.30	9.00	30.80	1	9.00	6.00	0	22.09	2.11	19.99
21 Town House	161.20	10589.30	1304.20	10.00	32.00	1	32.00	6.00	1	16.16	6.60	9.56
22 NSSF	139.00	13171.80	2919.00	10.00	32.00	0	15.00	6.00	0	19.03	8.67	10.36
23 Development House	440.00	12500.00	4771.80	14.00	51.00	1	21.00	6.00	1	31.91	12.96	18.95
24 Cotts House	260.00	2400.00	680.00	8.00	28.60	1	31.00	5.00	1	34.50	12.80	21.70
25 Afya House	139.60	8289.60	1646.69	9.00	34.80	0	12.00	2.00	0	27.69	11.51	16.18
26 Silopark House	91.50	4650.00	915.00	10.00	32.00	0	31.00	6.00	1	26.51	8.85	17.66
27 Norwich Union House	90.00	3574.80	770.80	8.00	30.80	0	23.00	6.00	1	27.79	11.55	16.24
28 Ex-Community House	510.00	15201.00	2440.00	4.00	15.00	1	17.00	2.00	0	6.22	1.31	4.91
29 Jamia Towers	70.50	1319.00	270.00	5.00	16.00	1	5.00	3.50	1	24.32	9.04	15.28
30 Cannon House	120.80	4313.40	2392.60	8.00	28.60	0	24.00	5.00	1	14.04	5.50	8.54
31 New Treasury Building	116.00	25000.00	5752.00	16.00	54.20	1	8.00	5.00	0	30.25	2.29	27.96
32 Church House	78.60	3300.00	649.40	10.00	35.00	1	23.00	5.00	1	24.46	9.84	14.62
33 New Jogoo House	212.00	9783.40	1956.70	12.00	41.40	0	19.00	5.00	0	25.86	9.58	16.28
34 Cooperative House	340.00	27500.00	4337.10	23.00	76.60	0	8.00	5.00	1	37.81	15.70	22.11
35 Madini House	116.00	2340.00	587.70	4.00	15.00	0	15.00	2.00	0	7.52	2.11	5.41
36 Maji House	314.00	15694.00	3337.60	7.00	28.00	0	8.00	2.00	0	9.54	4.01	5.53
37 Stanbank House	83.20	8400.00	1354.30	14.00	47.80	0	19.00	6.00	1	26.78	8.17	18.61
38 Nationwide Finance House	120.00	14000.00	2600.00	7.00	25.00	1	21.00	5.00	1	16.78	5.12	11.66
39 Foreign Affairs Building	181.40	4621.50	996.00	5.00	24.20	0	34.80	5.00	0	18.67	7.26	11.41
40 Jubilee House	92.50	4800.00	890.00	8.00	30.00	1	30.00	6.00	1	19.87	8.51	11.36
41 Ardhi House	328.80	17168.60	4032.00	12.00	39.50	1	5.00	6.00	0	46.20	13.11	33.09
42 Commonwealth House	240.00	2300.00	510.80	7.00	23.00	1	24.00	6.00	1	21.41	7.54	13.87
43 Jubilee Insurance Hôuse	92.00	4700.00	940.00	8.00	30.00	1	30.00	6.00	1	35.64	10.14	25.50
44 Nyayo House	296.00	31330.00	6310.20	26.00	80.40	1	9.00	5.00	0	59.07	15.29	43.78
45 Transcom House	174.00	9312.50	2289.10	12.00	43.40	0	13.00	6.00	0	39.64	11.94	27.70

UNIVERSITY OF NAIROBI
ADD LIBRARY

X_1 - Average parimeter of the building in metres.
X_2 - Total floor area of the building in square metres.
X_3 - Total window area of the building in square metres.
X_4 - Number of storeys of the building.
X_5 - Height of the building in metres.
X_6 - Shape of the building:- (rectagular -0; non-rectagular - 1).
X_7 - Age of the building in years.
X_8 - Plot ratio of the building.
K - Status of building : - public-0; private-1.
Y_1 - Annual mean maintenance cost of engineering services in Kenya shillings per square metre.
Y_2 - Annual mean maintenance cost of electrical services in Kenya shillings per square metre.
Y_3 - Annual mean maintenance cost of mechnical services in Kenya shillings per square metre.