UNIVERSITY OF NAIROBI

THE IMPACT OF DESIGN PARAMETERS ON ENERGY CONSUMPTION IN OFFICE BUILDINGS IN NAIROBI

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DECLARATION

I, **Thomas Ng'olua Ntarangui**, hereby declare that this thesis is my original work and has not been presented for a degree in any other university.

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DECLARATION OF THE SUPERVISORS

This thesis has been submitted for examination with my approval as University Supervisor.

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ABSTRACT

The prime objective of this study is to investigate the impact of design parameters on energy consumption in office buildings. The study is restricted to office buildings found in the Nairobi Central Business District. The Nairobi Central Business District (CBD) has the highest concentration of office buildings in Kenya. The study is concerned about the impact of floor areas, shape, height, perimeter, orientation, shading and extent of glazing on energy consumption.

It is recognised that the above design parameters have (a) significant effect(s) on energy consumption in office buildings. These design parameters are the resultant characteristics of the design solution provided by the designer in response to various design requirements and constraints. The effect of each of the design parameters on energy consumption is disaggregated to show its relative contribution to energy consumption in office buildings.

It is realised in the study that other factors as climate and occupancy variables also influence energy use in buildings. The effects of these are assumed constant and are not accommodated in this study.

To measure the degree of association between each design parameter and energy consumption, multiple regression analysis is used. The study uses a simple stochastic model expressed as $E=f(X_1, X_2, \ldots\ldots X_n)$ as the basis of analysis. The dependent variable is the mean annual energy consumption and the seven independent variables are floor areas, glazed area, shading, height, perimeter per floor area ratio, orientation and perimeter. Data is collected from a random sample of 26 building, from a population of 128 buildings.

The study is organised in four chapters. The first chapter sets out the problem statement, the study objectives, conceptual definitions of the design parameters, the research methodology and the scope of the study. It is shown that the office buildings and small businesses consume over 40% of the total electricity in Kenya. The need to reduce this level of energy consumption through the design of energy efficient building is emphasised.

The second chapter sets out the theoretical background from the known principles relating to the influence of design parameters on energy use. The various energy determinants in buildings are discussed. Literature is reviewed on the possibility of producing energy efficient designs by paying attention to particular design parameters during the design stage. The possible influence of factors other than design parameters is discussed. Earlier attempts to model energy use in buildings are highlighted.

The third chapter generally shows the results of the field survey. It discusses the study area and the measurement of the characteristics of various parameters. The impact of the design parameter on energy use is quantitatively analysed. It is found that the glazed area and the height of the building explain over 70.68% of variation in energy consumption per year. It is found that only window area and building height are significant at 95% confidence level. The other parameters i.e. floor areas, perimeter, shading and orientation are not significant at 95% confidence level.

Finally the fourth chapter discusses the possible conclusions and recommendations derived from the data analysis in the third chapter. It is concluded that glazed areas and building heights have significant impact on energy consumption in office buildings. It is observed

that designers should control these parameters in order to minimise energy use in office buildings. It is noted however that many other considerations should be taken into account to achieve low energy consuming office buildings without compromising the internal environmental standards.

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CHAPTER ONE

PROBLEM STATEMENT

1.1.00 Introduction

Energy is an important input in industrial, commercial, and domestic processes. Human being has always harnessed energy from various sources for his survival. Energy has become the cornerstone of economic growth and development.

Energy is generally classified into three broad categories. These are primary, secondary and tertiary energy. Primary energy is the gross calorific value of the fossil fuel, coal, oil and natural gas or the equivalent of nuclear and hydro-electricity. Secondary energy is the energy contained in coal-gas, coke, electricity, or any other form of energy manufactured from a primary energy source. Secondary energy will be less than the primary energy from which it is manufactured due to conversion losses. Finally tertiary energy is the energy needed to perform a required task and differs from the delivered energy by the amount equal to transmission losses[1].

Kenya's commercial energy sources are oil, hydropower, geothermal power, wood, coal and solar power. The traditional sources of energy are fuel wood, charcoal, dung and crop residues. The traditional sources of energy are more prevalent in the domestic and rural sectors of the economy.

The current development plan (1987-1993) estimates that Kenya's energy demand will grow at 4.4% over the plan period. The report further indicates that the demand for electricity will grow at 6.7% per annum while supply will expand at 6.6% per annum in the short run. It implies that in the short run, the demand for electricity will outstrip supply. There exists a problem of balancing energy supply and demand. The Government aims at alleviating the electrical energy supply deficit by developing more hydro and geothermal power stations to exploit the untapped hydro and geothermal power generation potential in the country. This is however constrained by lack of adequate capital, technology. There also adverse environmental factors, especially in the case of hydropower generation. Thermal generation is the other alternative for reducing the energy supply deficit however this option has been constrained by the fact that oil imports consume over 50% of Kenya's foreign exchange earnings[2]. Thermal generation of electricity would therefore lead to increased oil importation thus widening the balance of payment deficit.

Increased foreign borrowing to finance the deficit would subsequently increase the debt burden[3].

Kenya's wood fuel supplies are becoming depleted at an increasing rate. There is continued over exploitation of wood fuel supplies due to the rising population and urban growth. This is likely to lead to increased soil erosion and other environmental problems resulting from massive deforestation.

The country's economy is threatened by an energy crisis. The Government has formulated a national energy policy to avoid the looming crisis. The backbone of this policy is energy conservation. Energy conservation is viewed as the `other resource'. Adoption of energy conservation measures in all sectors of the economy would generate considerable payoff. It is estimated that conservation in oil consumption would yield up to 10% payoff in five years and 75% payoff in 20 years whereas in wood consumption, use of energy saving stoves would result to a reduction of 30-40% in the use of fuel wood or charcoal[4].

Energy conservation however has its limitations and it is only a short term solution. There is need to develop an energy efficient economy by developing transport networks, agricultural systems, manufacturing systems and buildings that use less energy.

1.2.00 Problem Statement

Kenya's commercial sector which consists of both private and public buildings including small businesses, consumed 433 MWH of electricity in 1986. This was about 42% of the total electricity used in all sectors of the economy[5]. The electricity is generally used in lighting, heating and cooling, communication and running the equipment in the buildings. Office buildings use about 20% of the total energy used in the commercial sector per annum[6].

In a typical office building in warm climates most energy is used for lighting, cooling and electrical equipment respectively. Studies in Kenya by Schipper et al, for example have shown that Kenyatta Conference Centre consumes over 2.7×10^6 KWH of electricity per annum. This is used to operate its extensive internal chilled water cooling systems. This amounts to roughly, one fifth of the total energy used by private offices in Nairobi[7].

This is a relatively high level of energy consumption by a single building. However, it is now apparent that more office buildings that are larger and more elaborate will be built. It is therefore quite clear that the proportion of energy consumed by buildings in the commercial sector will increase.

The only way to reduce the relative increase in energy consumption by buildings is to embark on the design of energy efficient buildings from the outset, by paying attention to design parameters that significantly influence energy consumption patterns of office buildings.

Studies by Kusuda, et al have shown that design parameters like floor area, shape, height of buildings, orientation, extent of glazing and shading of buildings have a significant impact on energy use in the office buildings. Most of these studies have been concerned with buildings in temperate climates. Due to climatic differences that exist between the tropics and temperate regions, these findings cannot be applied in the Kenyan setting without modification.

1.3.00 Objectives of the Study

The study aims at evaluating the impact of design parameters on energy use in tropical climates. It is concerned with energy use in buildings with the aim of identifying aspects of building design that influence energy consumption. The study is achieved through observation and analysis of existing office buildings design parameters and their existing energy consumption patterns.

The objectives of the study are:-

(a) to establish the relationship between design parameters of office buildings and energy consumption.

(b) to make various recommendations based on the findings, on designing energy efficient buildings.

1.4.00 Study Hypothesis

The hypothesis of the study is that a strong relationship exists between the design parameters and energy consumption in office buildings.

1.5.00 Study Model

The expected relationships between design parameters and energy consumption can be represented as a simple stochastic model expressed:-

$E = f(X_i, X_2 \ldots\ldots\ldots X_n + ei)$

Where E represents annual mean energy use in the building.

$X_i..X_n$ represents the respective design parameters.

E is the dependent parameter and X_i ...... X_n are the independent parameters.

e_i - represents the error term and accounts for the variation in energy use attributed to other factors not covered in the study. It represents the variation of mean energy consumption in office buildings that cannot be explained by the design parameters but can be attributed to climatic factors, occupancy and all other factors outside the designer's control.

The design parameters are defined conceptually as:-

X_1 = Total floor area measured in square metres. It covers all the floors and basements but excludes the external covered areas like verandas etc.

X_2 = Perimeter per floor area ratio - This is the ratio of the perimeter to total floor area. It is used as a measure of shape. Complex shapes will generate higher perimeter/floor area ratios.

X_3 = Glazing area. This is the total glazed area of the building.

X_4 = Total internal height of the building from the basement to the ceiling of the top habitable room. It is measured in linear meters.

X_5 = Existence of shading and sun breakers. It is measured using a dummy variable, One defined as integer 1 for the presence of any form of shading sun breakers and zero defined as integer 0 for lack of the same.

X_6 = Orientation. This is the angle of the longest axis of the building from north expressed as a ratio of 360°.

X_7 = Mean perimeter. This is the average perimeter of all the floors in the building.

1.6.00 Limitations of the Study

The study is restricted to the Central Business District to discount climatic differences which can have a significant effect on energy consumption.

Only office buildings are considered in the study. Buildings housing different activities would generate different energy consumption patterns. For example, energy use pattern in hospitals is generally different from the energy consumption use patterns in offices or residential buildings due to their distinct uses.

The study is based on electrical energy consumption. Limitation to electrical energy is because most office buildings use this form of energy. Use of oil and gas in office buildings is almost non existent in Kenya.

Electrical bills used in the study can only span a maximum of three years (1988 - 1990). Data is not available for longer periods from the Kenya Power and Lighting Company Ltd.

1.7.00 Research Methodology

1.7.10 Sources of data

The study is based on a population of 128 office buildings. The sample forms the basis of the survey. Primary data is obtained from various sources. Energy consumption data is obtained from the Kenya Power and Lighting Company. The data is abstracted from 1988-1990, utility bills. The design parameters are measured and computed from architectural plans. These are compared with the existing building to take account of any modifications. The main source of architectural plans for private buildings is the Lands Department, Ministry of Lands and Housing. Architectural drawings for Public buildings are obtained from Ministry of Public Works. The design parameters obtained are the glazed areas, floor area, average perimeter, height of the building, shading and orientation.

Secondary data on energy demand and supply in Kenya is obtained from the Central Bureau of Statistics (CBS) and the Ministry of Energy. The data comprise of energy demand and supply statistics.

1.7.20 Data Analysis and Presentation

The SPSS-PC® statistical analysis program is used to analyse the data.

Descriptive analysis of the data is performed. At this stage the mean, maximum, minimum and modes for all the variables are computed. Generally the descriptive analysis is exploratory. The results of the analysis are presented using histograms and tables.

Inferential analysis is done in various stages. First the partial correlation coefficient of the dependent and all the independent variables is done. In the analysis the dependent variable is the mean annual energy consumption and the independent variables are the design parameters. The purpose of computing the partial correlation coefficients is twofold:-

i) To explore the strength of association between the variables.

ii) To detect collinearity among the variables.

The result of the partial correlation analysis is presented as a correlation matrix.

Secondly, simple regression analysis is performed between the dependent parameter, mean annual energy consumption and each of the seven design parameters (independent parameters). Regression analysis is performed to determine the strength of the relationship between the dependent and independent parameters. The results of this analysis are presented in form of regression coefficients and scatter plots.

Finally multiple regression analysis is done using the 'stepwise' regression procedure. The main aim is to determine the extent to which the design parameters acting together could explain the variation of the dependent variable.

1.8.00 Significance of the Study

The study is evaluative in nature and seeks to reveal the latent relationship between office buildings design characteristics, that is, design parameters and energy consumption patterns.

Kebathi has emphasised the need to design buildings that do not rely heavily on artificial lighting and ventilation to conserve energy[9]. This study provides some insight on how office buildings with certain design characteristics (parameters) use energy. Energy efficient buildings can only be achieved if steps are taken at the design stage to design energy efficient buildings. A clear understanding of the relationship between the buildings' design parameters and energy consumption would enable the designer to interpret energy consumption patterns of the building being designed.

1.9.00 Organisation of the study

This study is organised in four chapters. The first chapter has generally set out the research problem, hypothesis, model and the methodology. The significance of the study and its limitations are set out.

The second chapter of the study discusses the theoretical framework of the study. Energy use in buildings is discussed. This is done in reference to energy consumption determinants in buildings and the impact of design parameters on energy consumption.

The third chapter sets out the data analysis and its presentation using descriptive statistics, correlation and statistical analysis. Finally the fourth chapter discusses the conclusions and recommendations drawn from the study.

REFERENCES

[1] Leach S.J. and Desson R.A., ***Energy Consumption in Buildings in UK and Possibilities of Energy Conservation.***In ***Energy Conservation in Built Environment*** ed. Roger G. Courtney, Construction Press, London 1986. p4.

[2] Central Bureau of Statistics, ***Statistical Abstract 1989***, Government Printer, Nairobi, 1989, p12.

[3] Saitoti, George, ***Nation Newspaper 3rd,October 1990***, Nairobi 1990,p12

[4] Ministry of Energy and Regional Development, ***Kenya National Energy Policy,***(Nairobi, Energy Development International, 1993).Passim.

[5] Central Bureau of Statistics, ***Statistics Abstract 1988*** (Nairobi, Government Printer, 1988). p150.

[6] Co-operation for Development in Africa (CDA), ***Designing and Implementing National Energy Conservation Programs*** (Seminar held at Nairobi Vol. 1 May 1984). Passim.

[7] Schipper, L. and Mbeche O., ***Energy Demand and Conservation in Kenya,*** Beiger Institute of Energy and Ecology (Berkerly, University Of California, 1978).

[8] Nie, N.H., Hull et al. ***SPSS - Statistical Package for Social Sciences,*** (New York, McGraw Hill, 1975).

[9] Kebathi, S., ***Urban Design and Energy Conservation for Nairobi,*** (Berkerly, University of California, 1978).

CHAPTER TWO

ENERGY USE IN BUILDINGS

2.1.00 Introduction

Energy consumption in buildings has been a topic discussed in various fora. The aim has always been to reduce energy consumption in buildings through adoption of energy conservation measures and energy conscious designs.

Energy conservation refers to the steps taken to reduce energy use and increase efficiency in an existing stock of buildings. Energy conservation can achieve significant reduction in energy consumption. It has been shown that energy saving of about 25% or more can be achieved through the adoption of energy conservation measures[1]. However energy conservation programmes may require complete refurbishment of buildings involving modification of the building fabric and other installations which lead to high capital investment.

Energy conscious design on the other hand refers to attempts made at the design stage to produce a low energy consuming building. This is achieved by taking into account various design parameters that result to high levels of energy consumption in buildings[2]. Energy conscious design process should produce a low energy consuming building without necessarily resulting to extra investment. To understand the energy conscious design process it is important to examine how buildings use energy and the effect of design parameters on energy use. This is the aim of this chapter.

2.2.00 Energy Consumption in Buildings

The ultimate goal in the building process is to fulfil a basic human need by providing a building which will provide protection from adverse external environmental factors. The built environment must also provide internal environmental conditions that support human activity. These conditions are thermal comfort, lighting, acoustics, ventilation and communication. It is due to the need for maintaining these internal environmental conditions that buildings use energy.

Throughout the ages, architecture has been significantly influenced by the availability of energy application technologies in buildings. Burberry observes that the real history of architecture is not based on visual styles but on the development of effectively functional environmental design[3]. The need to provide adequate lighting and ventilation apart from aesthetics, style, structural and economic considerations has governed the recorded architectural history. The same view is held by Banham when he argues that though architectural history has been devoted to the study of stylistics, environmental management tended to dominate architects' design decisions[4]. For example the development of massive structural systems like massive walls were built to fulfil the physiological and psychological environmental needs of the occupants. Physiologically the massive walls maintained the internal environmental conditions constant due to the slow transfer of heat into the building. Psychologically the massive walls provided a sense of security.

In the traditional African architecture, environmental conditions were maintained by use of mud and dung as a walling and sometimes roofing material. The excellent thermal properties of mud and dung maintained constant internal thermal conditions. Psychologically the structures were clustered and grouped together for security. The clustering still offered distinct environmental management advantages.

Modern architecture has employed mechanical systems to provide the required internal environmental conditions. Air conditioning and ventilation are required to provide the necessary thermal comfort level, electric lighting to provide light and lifts to provide vertical transportation in the building. These new modes of internal environment control evolved in the era of cheap energy.

The era of cheap energy is seemingly over. Gupta cautions that due to the prevailing energy crisis, techniques and materials should be used to aid energy conservation through proper design techniques[5]. He further suggests that energy requirements in buildings can be reduced by proper combination of climatic design and usage factors in design[6]. This suggestion emphasizes the use of passive methods for internal environmental control similar to those used in traditional architecture. This calls for greater understanding of climatic conditions, materials and occupancy requirements.

Designers' influence on energy consumption in buildings cannot be underestimated but several writers have expressed pessimism on their ability to control energy use under the prevailing circumstances. Forwood et al argue that there has been a tendency of modern architecture to separate the design of building fabric and the design of the internal environmental services with designers replacing most of the functions of the fabric with service systems[7]. This makes buildings more energy intensive. The separation of the design of fabric and services denies the designer that unity of approach which is required to produce an energy efficient building. The designer's ability to employ passive methods of environmental control is seriously constrained.

Banham also asserts that the present design process might not put emphasis on environmental services since architects have handed over environmental management to specialists[8]. This is the prevailing situation in the study area. Electrical services are designed by electrical engineers and mechanical services by mechanical engineers. The architects contribution is reduced to approval of the engineering services design.

The handing over of environmental control in buildings to specialists has produced buildings that are not adaptive to the environment. The environmental specialist should closely coordinate with architects to solve this problem. Knowles argues that the design of building form and aesthetics should be adaptive to the cyclical variation in the external environment enabling the designer to use design parameters like geometry, shape and size of the building to reduce the need to use mechanical systems for environmental control[9]. The architects should re-examine the proposed environmental systems from the engineers and ensure their compatibility with energy standards of the design.

Energy consumption in buildings will vary depending on the mode of environmental management adopted by the designer. Banham identifies three different modes of environmental management. These are the conservation mode, selective mode and regenerative mode. These modes of environmental control have different effects on energy consumption patterns of the respective buildings. The conservation mode of environmental management relies on passive design of the structure to achieve its environmental objectives. In passive design; aspect, orientation, size of the openings and siting are used. The selective mode relies on the building fabric to filter out harsh external environmental conditions.

Finally the regenerative mode uses applied power to achieve optimum internal environmental conditions. This mode of environmental control is more energy intensive and due to advancement in technology, it is becoming the most common mode of environmental control, despite its energy consumption consequences.

The buildings in the study area exhibit environmental management systems ranging from the conservation mode to the regenerative mode. Older buildings exhibit the conservation mode of environmental management systems and rely chiefly on siting, size and orientation of openings and massive structure to achieve the required internal environmental conditions.

The selective mode is observed in form of the choice of the materials in the building fabric. Careful combination of glazed areas, walls and use of sun shading are the notable attributes of this mode of environmental control. This is the most prevalent form of environmental management in the study area. Some buildings in the study area have the regenerative mode of environmental control which includes extensive air conditioning and lighting systems. This mode of environmental control is generally the result of clients' preferences and special requirements.

2.3.00 Energy Use Determinants in Buildings

Earlier, it was observed that the objective of a building system is to provide the optimum internal environmental conditions to aid human activity. To achieve the objective, the building system must contain a sub-system which Mavers refers to as the services subsystem. He suggests that the aim of the services sub-system is to create and maintain a desired level of physical environment[10].

The service system will include ventilation and air conditioning sub-systems, lighting systems, acoustic systems, vertical transportation systems, and drainage and water systems. The study concentrates on the ventilation and air conditioning sub-systems, lighting sub-system, and vertical transportation system due to their comparative high levels of energy use.

2.3.10 Ventilation and Air Conditioning Systems

The aims of both the ventilation and air conditioning sub-systems are to provide the appropriate thermal comfort levels in the building. The mode of application of each sub-system is however different.

Givoni observes that ventilation serves three distinct functions in the building, it maintains the quality of air by increasing air movement and reducing the level of carbon dioxide, it provides the necessary thermal comfort levels by increasing heat loss from the body and finally, it serves to cool the structure of the building when indoor temperature is above the outdoor temperature[11].

Air conditioning on the other hand is used to provide thermal comfort by simultaneously controlling the temperature, humidity, air movement and cleanness of the air[12]. These are achieved by use of mechanical and electronic systems.

Givoni defines thermal comfort as the absence of irritation and discomfort due to heat or cold. The acceptable levels of heat or cold are subjective. The comfort zone will rely on a set of conditions. These conditions depend on the building fabric, physiological characteristics of the occupants and climatic factors. The conditions will interact to produce a given level of thermal comfort.

Ventilation and air conditioning systems significantly increase energy consumption levels in the building. Studies have shown that 30% of the energy consumed in offices in warm climates is used in air conditioning[13]. In the study area, air conditioning systems for the entire building are restricted to a few buildings. However localised air conditioning units are prevalent. Mechanical ventilation is used in basements and supermarkets. The use of portable fans for air circulation is used in offices. The choice of air conditioning in office buildings is chiefly to reduce traffic noise and dust. Pollution has also accelerated the trend toward air conditioning systems.

Air conditioning will play a more dominant role in future buildings due to increased pollution, office automation, and the rise in the required internal environmental standards. Reduction of energy used for air conditioning will require the designer to reduce the dependency on air conditioning in internal environmental management by paying attention to passive methods of environmental control. The designer can achieve reduction of energy used in air conditioning by careful combination of fenestration, shading, expected ventilation rates, orientation and location.

2.3.20 Lighting

Another important consumer of electrical energy in commercial building is the lighting system. It consumes approximately 40% of electrical energy, slightly more than the air conditioning system[14]. Lighting will contribute to heat generation in the room giving rise to the cooling loads on air conditioning systems.

The reduction of lighting loads will play a major role in reducing energy consumption in the building. Usage factors must also be considered since occupancy hours will determine energy consumption levels. Lighting in the building can be provided using natural lighting or artificial lighting systems. Different combinations of both systems have varying energy use implications. Where the building design incorporates extensive use of natural lighting then energy consumption levels will be lower as opposed to a situation where artificial lighting is used. This however is not generally the case since there is a possibility of the building occupants using artificial lighting even where natural lighting is available and adequate.

The use of natural lighting in building as a method of reducing energy consumption has been suggested by several writers. Dick asserts that greater application of ambient energy sources in buildings would reduce energy use. He argues that where buildings are of shallow plan, naturally lit and ventilated, energy consumption levels will be low[15]. Owens has also decried the design philosophy that windows are not intended to provide daylight for task lighting but rather as the psychological link of occupants with the exterior space which also provides quality to the interior. This philosophy would result in deep plan offices that require artificial lighting and ventilation. These recommendations for having shallow plan offices to ensure natural lighting have been used in a significant number of buildings in the study area, however, there are several limitations due to planning regulations, siting and economic consideration.

Designing for daylighting is based on the ratio of the required amount of indoor to outdoor illumination . This is expressed as the daylight factor. The daylight factor concept is valid under overcast sky conditions only. Daylight factor will be determined by three components. The sky component externally, reflected component and internally reflected component. The sky component will depend on sky conditions, window size and position relative to a point where the daylight factor is being computed, thickness of window frames, quality of glass and other external obstruction. The external reflected components depend on the quality of external surfaces. Finally, the internal component will depend on the size of room, ratio of window area to wall area, and their surface characteristics.

Burberry argues that daylight consideration in the building will determine the depth, shape and spacing of buildings[16]. Where daylighting is to be applied then a narrow building will be suitable. Spacing between facades of buildings should be such that enough daylight can enter the buildings.

Daylighting has its own problems and these should be solved during the design process. If a building is extensively glazed to maximise daylighting the problems of glare and overheating must be solved. The design must take into account daylighting from an overcast sky and direct rays from the sun. Koenisberger suggests that in the tropics adequate daylighting should be improved even if louvres and other forms of shading are used for thermal reasons. He also emphasises that glare should be reduced from the visual field by avoiding the use of excessively bright surfaces[17].

By using artificial lighting most problems of daylighting can be solved. Artificial lighting can be used to supplement daylighting in the Permanent Supplementary Artificial Lighting of Interiors (PSALI) system. The PSALI system is used to supplement daylighting by maintaining daylight levels in the interior when daylight levels fall[18]. The use of PSALI system will possibly result from the reduction of window areas, in order to limit the amount of glare, noise and heating getting into the room. Some rear parts of the room will experience lower daylight factor hence the need to use PSALI to increase illuminance to the rear part of the room.

Permanent Artificial Lighting (PAL) systems can be used when it is not possible to provide lighting for example in laboratories and theatres. It is the only form of lighting at night. These systems will require greater inputs in terms of energy and capital costs. All the buildings considered in this study do not have a PSAL system. Hence the lighting system is not responsive to changes in daylight levels in the office spaces. The artificial lighting is used permanently even when daylighting is adequate. This leads to increased levels of energy use for lighting in buildings.

2.3.30 Vertical Transportation

Movement in building can be vertical or horizontal. Vertical movement is more prevalent in high rise buildings. It is achieved through the use of lift, conveyor systems, staircases and ramps. The lift system provided must provide adequate transportation capacity for the building.

Lift systems use electrical energy for their operation. To minimise energy use and maximise lift efficiency careful design of lifts is important. Saleh asserts that the design of vertical transportation in the building takes into account factors like cost, building restriction, type of building and expected occupancy[19]. These factors should be known since the installed capacity of a lift system cannot be easily changed.

In designing a lift system, the different traffic patterns must be taken into account. Traffic patterns have been identified as the morning up-peak, evening down-peak and the random inter-floor traffic. The design is normally based on the morning up-peak traffic when people are arriving into the building. The assumption is that if the lift system can handle the morning up-peak then it can handle all the other traffic patterns. This view is however discounted by Green et al when they suggest that the design of a lift system using morning up-peak traffic is not adequate since lifts make more stops during the day than in the morning[20]. Use of morning up-peak might provide a lift system that cannot handle random inter-floor traffic resulting to longer waiting times.

Lift design is a probabilistic process since most parameters considered are dynamic parameters, like highest floor visited, total transfer time of passengers and the number of stops made by the lift. It is however assumed that a lift system is efficient if it is capable of handling 75% of the population above first floor during any thirty minute period[21].

The lift system designed for a building is influenced by the type of building. The design parameters which determine the configuration of the building have impact on the size and capacity of the lift system designed and installed. Thus floor areas determine occupancy density which influences the capacity of the lift system, larger lift systems will lead to higher levels of energy consumption in the building. The same case applies for building height and the building form generally. This implies that conscious control of these parameters can result to an optimum size of a lift system which results in optimum use of energy in the building. It is also notable that the choice of the lift system is limited to what manufacturers have to offer. In most cases the choice of a lift system is based on a set of parameters provided by the manufacturer. The designers control of the design of the lift system is thus very limited.

2.3.40 Acoustics

The design for aural comfort has energy use consequences in the building. Where a designer uses good acoustics as a design objective then his decision will have an impact on internal environmental conditions. This view is supported by Lords et al when he observes that designing for aural comfort has influence on building form[22]. He further argues that architectural style will alternatively influence building acoustics since designers are rarely guided by technical criteria but by architectural concept when designing. The resulting design solution will have varying environmental performance[23].

In office buildings the design for aural comfort is of paramount importance since the buildings are situated in an urban setting, in most cases with street and other noise sources adjacent the building.

For external noise sources various design solutions can be applied and these have an impact on energy use in the building. For example use of double glazing and non-openable windows require mechanical methods of internal environmental control which result in higher energy use. Internal noise control will also have its energy consequences. Use of closed plan offices to ensure privacy and lower noise levels will influence lighting and ventilation requirements.

2.4.00 Impact of Design Parameters on Energy Use in Buildings

Reference has been made to energy conscious design as a way of influencing energy use patterns in the building. It is important to discuss the design process and its impact on energy use in buildings. It is only through design that energy use by air conditioning, lighting and vertical transportation can be controlled.

Design can be defined as an activity that is purposeful. It is a goal oriented search for a physical solution to a perceived and more or less understood problem[24]. The purpose of design in architecture is to provide shelter for human needs within various constraints. Design will start with people, land, human needs and activities as constraints. These can be summarised as human needs, resources constraints building system constraints and environmental constraints. The design solution must provide a balance between these constraints. Thus the design process can be viewed as an optimisation process.

Design proceeds through a series of iterative steps. It is guided by goals, objectives and constraints. Generally three stages in the design process have been identified.

These are analysis, synthesis and appraisal[25]. These steps are inseparable and can occur in any sequence, but proceed through time with increasing concreteness and detail (Figure 2.1).

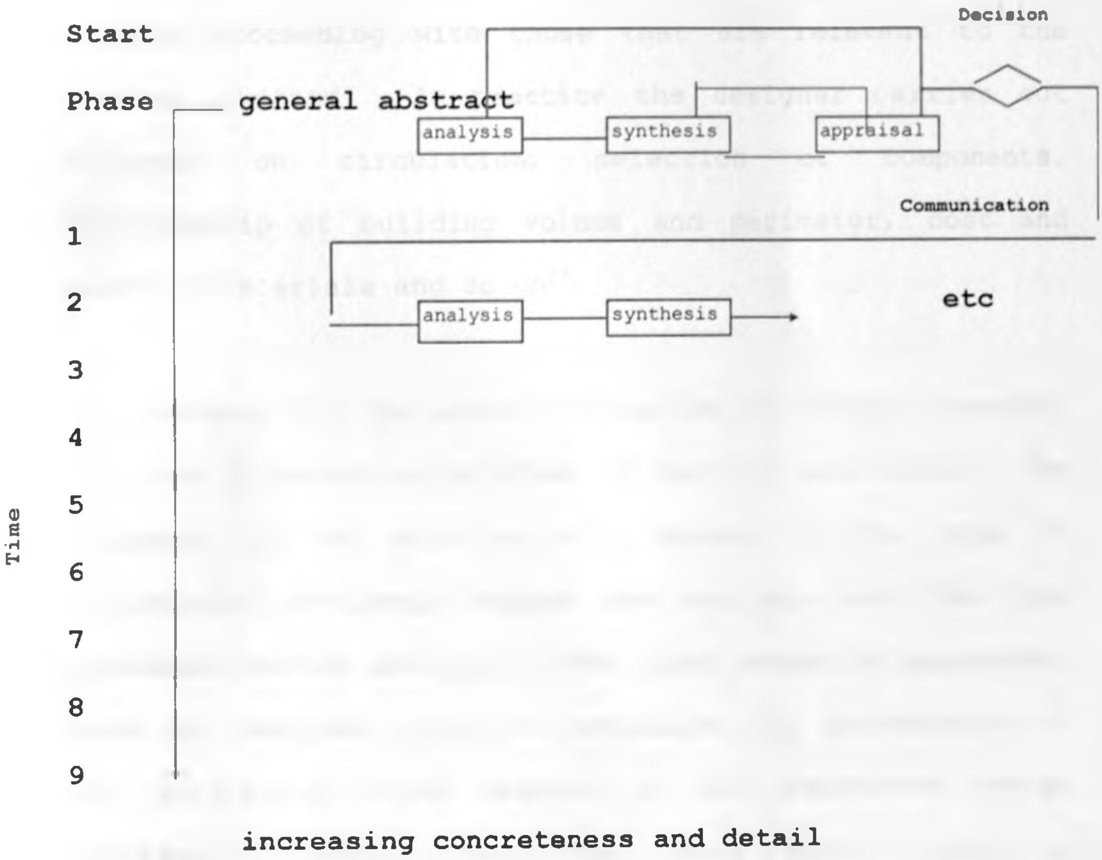


Figure 2.1. Model of the design process

Source: Markus p117.

The analysis stage of the design process tends towards understanding the problem. Markus suggests that at this stage the designer should obtain all the relevant information and establish relationships between constraints, objectives and criteria[26]. The designer will use his imagination to relate all the aspects of the problem proceeding with those that are relevant to the problem at hand. In practice the designer carries out analysis on circulation, selection of components, relationship of building volume and perimeter, cost and cladding materials and so on[27].

In synthesis all the above information is brought together to form a tentative solution or set of solutions. The adequacy of the solution will depend on the type of information available before the analysis and the type generated during analysis. The final stage is appraisal, here the designer tries to establish the performance of the solution(s) with respect to the perceived design problems. Markus identifies three basic steps in appraisal, these are representation where the solution is modelled; measurement where the performance of the model is obtained in terms of cost, environmental conditions, flexibility and space utilization among others. The final step is evaluation, whereby the measured results are evaluated. After appraisal the designer can redesign, or re-examine the analysis. As the process continues more information is generated and the design process approaches the solution.

An energy conscious design process will require the designer to react to energy as a resource constraint. The subsequent solution will be energy efficient without compromising the required internal environmental standards. The concept of energy conscious design has been emphasised by many writers. These writers have identified a number of design parameters which must be considered if an energy conscious design has to be evolved.

Energy conscious design can thus be produced by paying attention to various design parameters. Meffert et al suggest that energy saving design in the tropical areas can be achieved by paying attention to the orientation of the building, building shape and insulation of the walls and the roofs[28].

This view is supported by Kusuda when he suggests that design parameters such as orientation, height of the building, occupancy, air conditioned areas and lighting have an impact on energy use patterns of buildings[29].

The idea of using a set of design parameters to design energy saving buildings has also been discussed by Bouchlaghem et al. Bouchlaghem identifies two groups of design parameters that affect the thermal performance of a building. These are the parameters related to climate and those that are related to the building. The climatic based design parameters cannot be easily controlled but building design parameters can be controlled at the design stage. He argues that the thermal response which in turn influences energy consumption in the building will be influenced by climate together with design parameters like:- general layout and siting, thermal physical properties of the building materials, location of windows and their sizes, shading of windows and envelope; insulation; surface treatment of the enclosing envelope and weight and surface areas of the partitions[30].

It is observed that energy consumption in any single building is due to the interaction of a large set of parameters. This study separates these parameters into four groups, climate based parameters, parameters due to siting occupancy parameters and the building design parameters. The first three groups cannot be influenced by the designer. Climate is a variable, so are the parameters that are associated with it. Parameters due to site conditions cannot be controlled since designers rarely have a choice of sites. The occupancy patterns and composition will vary throughout the life of the project. This study concentrates on building design parameters since they are under the direct control of the designers. It can be summarised that the following building design parameters have significant impact on energy use in the building. These are the parameters associated with the building form, orientation, fenestration and thermal physical properties of the materials among others[31]. The parameters considered for detailed study are floor areas, perimeter/floor area ratio, glazed area, heights of buildings, shading, orientation and perimeter.

Each of the above design parameter will play an important role in the energy consumption patterns of the building. The parameters will interact among each other and with other extraneous factors to generate the net consumption patterns, this study aims at evaluating the extent of this relationship.

2.4.10 Building Shape

The shape of a building is an important determinant of energy consumption of the building. A given shape of the building will define the ratio of volume to surface area which provides the rate at which the building heats up or cools down[32]. The shape of the building generates the volume of the building, thus it has a direct impact on the lighting and ventilation requirements. In a large deep plan building there is greater need for both artificial lighting and ventilation which would require greater use of energy to maintain. A shallow building would ensure good daylighting standards. Low rise buildings could incorporate courtyards whereas taller buildings could use atria for lighting and ventilation.

Shape is defined in quantitative terms by use of perimeter/floor area ratio. Complex shapes have a higher perimeter/floor area ratio. A simple building shape, for example a circle or a square, would generate a perimeter floor area ratio close to 1

The more complex the shape of the building the larger the surface area. This implies that heat transmission into or out of the building will be higher. The building will be hotter during the day and colder at night depending on the orientation and the surface areas of the wall. It can be deduced that during daytime when there is peak occupancy in the building mechanical means of cooling must be employed to counter the effect of heat transfer into the building.

The shape of the building will also determine the extent of the envelope and hence its thermal penetration properties. Bouchlaghem propose that the use of a ratio to quantify the area of the fabric i.e plan ratio length/width of the building. Other design parameters specified are storey height and orientation[33]. This study uses perimeter/floor area ratio as an indicator of shape. This is a more realistic approximation of the shape of the building since most buildings are not necessarily regular. The floor area and building height are other parameters associated with shape.

2.4.20 Orientation

This refers to the disposition of the building relative to the ground and the north pole. Orientation can have a major impact on energy consumption. The orientation of the building determines how the building envelope will interact with climate factors like solar radiation, wind, rain, etc. To reduce heat absorption from solar radiation, Meffert et al suggest that the long axis of the building should be aligned on an East - West axis whereby the wall areas facing East and West which receive the largest amount of radiation is minimized[34]. To minimise further entry of solar radiation the glazing should be minimised in these areas.

The same view is expressed by Kebathi when he suggests that energy saving buildings in Nairobi are those that have their longer axes facing East-West with few or no windows on the East-West ends and shading in the North-South sides. This design would maximise free daylight and minimise cooling loads.

The impact of orientation on energy use in a building will be influenced by site characteristics. The neighbourhood, composed of vegetation or tall buildings can influence the amount of solar radiation and wind entering the building.

Orientation in this study is measured as the deviation of the longest axis of the building from the North expressed as a ratio of 360°. It is however important to note that in the already planned areas the general disposition of the building is set.

2.4.30 Fenestration

Fenestration refers to the arrangement and size of windows in a building[35]. Windows are provided in the building to provide daylight, ventilation and visual link between the occupants and the outside. In modern building where the use of mechanical and electrical systems provide ventilation and lighting, windows are used to provide the visual link only. This approach gives a building that is energy-use intensive, since mechanical ventilation and artificial lighting must be used.

The orientation and size of windows in a building has an impact on internal environmental conditions of the building. If there is extensive fenestration in the elevations of the building receiving high intensities of solar radiation, it will result to internal solar heat gain.

Lim et al[36] and Meffert, et al[37] caution that although large glazed areas would improve the daylight factor in the building, it would also be a source of glare and heat gain, especially in the tropics. This is because glass is a poor insulator. Fenestration in the tropics should be kept to the minimum required to provide adequate ventilation. This implies that the designer must use other design elements like shading if he or she chooses to use extensive glazed areas. Shading is a passive and thus cheaper method of controlling the amount of solar heat gain in the building compared to mechanical cooling and air conditioning. Shading is more useful where there are site restrictions on the orientation of the building especially in already built areas.

Studies by Arison et al have shown that the reduction of glazed area would result to lower peak air conditioning load by more than 30%. The reduction in air conditioning requirement will reduce energy used to operate the air conditioning and ventilation systems in the building. It should be noted that adequate balance should be maintained between the extent of glazing required for lighting and ventilation. This would reduce the possibility of using air conditioning for internal environmental control.

Glazed area is one of the design parameters being analysed in this study.

2.4.40 Thermal Physical Properties of Materials

The choice of materials to be used in the building fabric has an impact on the performance of the building fabric as a filter between harsh external environment and the required internal environment. Bouchlaghem et al, argues that the ability of a material to transmit heat will influence the thermal comfort levels in the building[38].

The thermal transmission characteristics of the building element will influence the amount of heat transfer into or out of the building at any given time. Building with wall and roof with high thermal penetration coefficients will have high heat transmission into the building. To dissipate the heat then mechanical means might be applied.

The thermal transmission characteristics of building fabric materials will be influenced by the thickness of materials and surface characteristics. Materials which are light coloured will dissipate the heat through reflection. The thermal physical properties and their influence on energy use patterns are not treated in this study. The main reason being that all the buildings forming the study area had very similar materials specifications for the building fabric. At the same time it is observed that the only variation in the composition of the fabric in the area of the facade occupied by glazing. This has been measured elsewhere as one of the variables.

2.5.00 Building Energy Use Models

Attempts to analyse the energy flow between buildings and the environment have led to the development of different building energy models. Lyberg et al identified two general types of building energy models and classified them as static and dynamic models[39]. The fundamental difference is that the static model assumes constant conditions whereas dynamic models accept varying conditions over time. These models are set to determine the interaction between the building fabric, building mass, external environmental conditions and the resulting energy use to maintain the internal environment. The models are more suited in the temperate climates where the external environment components varies significantly over the year.

In the tropics variation in the main climatic elements is relatively small over the greater part of the year. However, the climatic component should not be discounted.

2.6.00 Energy Consumption and Energy Costs

Energy consumption of any building will ultimately result to an energy bill which is expressed as a cost to the consumer. Though the quantity of energy consumed might remain fairly constant over the years, energy cost will vary throughout the life of the building. Energy cost will be influenced by tariff regulations, inflationary factors and taxation among other factors.

Energy cost for any building will be highly significant if viewed as a life cycle cost of the building. Stone[51] argues that over the life of a building running costs are usually greater than initial construction costs. The running cost will include maintenance and fuel costs. These account for over 55 - 60% of cost over the life of the office building in temperate climates. Stone further argues that the running cost of a building will be influenced by decisions made at the design stage[40]. It is at this stage when the designer chooses the site, building structure, fabric and the types of environmental control systems provided. Thus the energy costs for any building can be influenced by the design. It is important to adopt an energy conscious approach from the outset if an energy saving building is to be designed.

2.7.00 Summary

It has been observed that there is need to adopt an energy conscious design process if the resulting building designs have to be energy saving. To achieve this, there must be unity of approach during the design of the fabric and service systems in the building. The interaction of the building fabric and service systems should be carefully studied with due respect being paid to external environmental conditions.

Design parameters which play an important role in determining the energy consumption patterns of building have been identified. These include floor areas, perimeter/floor area ratio orientation, building heights, glazed area, shading and thermal physical properties of materials used in walls and roofs of the building. The designer should pay attention to these parameters while noting their energy consumption implication in the building.

The next chapter will examine how the energy use patterns of the buildings in the study area can be attributed to the design parameters mentioned above. Data will be analysed and presented to measure the extent of the relationship between the design parameters and energy consumption.

REFERENCES

[1] Christopher E., ***Energy Consumption in Building in Denmark and the Possibilities of Energy Conservation***, Built Environment ed. R.G Courtney, BRE, Construction Press, 1976, p016.

[2] Dubin, F.S. and Chalmers, G.L, ***Energy Conservation Standards for Design, Construction and Operation***. McGraw Hill, New york 1978, p19.

[3] Burberry, Peter, ***Ambient Energy - Criteria for Building Design***, in Ambient Energy and Building Design ed. J.E Randall, Construction Press, Lancaster, England, 1978, p143-162.

[4] Bunham, Reyner ***The Architecture of a well Tempered Environment***, Architectural Press, London, 1969, p13.

[5] Gupta, T. N. and Chandrah, Prakash ***Energy Efficient Building Design***. A paper presented at the 9th CIB Congress on Energy Technology and Conservation, Vol. 3(a) CIB, Stockholm 1983, p317.

[6] Ibid p317

[7] Forwood, Bruce S ***Environment Design and Building Services*** in 'Computer Applications in Architectural' ed John S. Gero, Applied Science Publishers Ltd. London 1977. p95.

[8] Banham, Op Cit p267.

[9] Knowles, Ralph L. ***Energy and Form 'Ecological Approach to Urban Growth'***, MIT Press, London, 1974, p1-2.

[10] Mavers W. Thomas, ***Building Services Design - A Systematic approach to Decsion Making***, RIBA Publication Ltd. 1971. p7.

[11] Givoni, B, ***Man, Climate and Architecture***, Elsevier Publishing Company Limited, London 1969, p230.

[12] Thornley, L. Deryck ***The Case for Air Conditioning - Keynote Discourse*** in 'Air Conditioning System Design for Building' ed. AFC Sheratt, Mc Graw-Hill Book Company (UK) Limited, London 1983, p1.

[13] Givoni, Op. Cit, p47

[14] Cooperation for Development in Africa (CDA), ***Designing and Implementing National Energy Conservation Programs*** ' A Seminar held at Nairobi Vol.1, May 1984, Chpt 5.

[15] Dick, James, ***Ambient Energy in the Context of Buildings*** in 'Ambient Energy and Building Design' ed J. E. Randall, Construction Press Ltd. Lancaster, England 1978, p10.

[16] Ibid, p190.

[17] Koenigsberger Op, Cit p144.

[18] Ibid p145.

[19] Saleh, M. Ridenam, ***Vertical Transportation in Tall Buildings*** form the proceedings of seminar on 'Tall Building in an Urban Context' ed Sad, Assaf, et al held on Nov, 24-28 1986, Dhara, Saudi Arabia, 1986 p189.

[20] Green, M.F. and Smith, B.S. ***Survey and Analysis of Lift Performance*** in an Office Building in ***Built Environment Vol.12***, 1977, p65.

[21] Ibid.

[22] Larod, Peter, et al ***The Architecture of Sound, Designing Places of Assembly***, Architectural Press, London, 1986, p24.

[23] Ibid.

[24] Markus ed, et al, ***Building Performance***, Applied Science Publishers, New York 1972, p13.

[25] Ibid p22.

[26] Ibid p34.

[27] Broad bent, Geoffrey, ***Design in Architecture - Design and the Human Sciences***, David Fulton Publishers, London, 1988, p330.

[28] Meffert, E.F. and Asante, Y. ***The Impact of Energy Conservation Measures on architectural Design in Hot Humid Tropical Areas***, A paper presented in a seminar on the @Interaction Between Physics and architecture in Environment - Conscious Design' held at Miramare, Trieste, 21-25 September 1977, p4.

[29] Kusuda, Shell, J.E and Didion D.A, ***Energy Conservation in Office Buildings*** in Energy Conservation in the Built Environment ed. R. Courtney, BRE, Construction Press, Lancaster, 1967, p135.

[30] Bouchlaghem, N.M et al ***Numerical optimaization Applied to the Thermal Design of Buildings. In Building and Environment Vol.25, No.2*** ed. C.B. Wilson, Pergamon Press, Oxford 1990, p117.

[31] Ibid, p118.

[32] Design in Hot Climates.

[33] Bouchlaghem, p118.

[34] Kebathi, S. ***Urban Design and Energy Conservation for Naiorobi.*** Unpublished thesis, University of California Barkeley 1978, p90.

[35] Sidney, I, L. ed., ***Chamber English Dictionary***. W & R Chambers Ltd. and Cambridge University Press, Cambridge 1988, p524.

[36] Lim, B. P. et al, ***Environmental Energy Factors in the Design of Building Fenestration***. Applied Science Publishers Ltd. London 1979. p45.

[37] Meffert, et al p6.

[38] Bouchlaghem, N.M. et al, p118.

[39] Lyberg, M.D. ***Source Book for Energy Auditors Vol. 1***. International Energy Agency, Swedish Council of Building Research, Stockholm, 1987, p40.

[40] Stone, P.A ***Buiding Design Evaluation*** E & F. N. Spon Ltd, London, 1980, p15.

CHAPTER THREE

DATA ANALYSIS AND PRESENTATION

3.1.00 Introduction

The last two chapters have discussed conceptually, the factors that affect energy consumption in buildings in general and office buildings in particular.

In this chapter empirical evidence is provided following data collection and field measurement undertaken on 26 buildings in the Nairobi's Central Business District. The sample contained 14 private owned and managed buildings and 12 government owned and managed buildings.

The results are analysed using correlation and multiple regression statistical analysis that provides information on the energy consumption model formulated in the introductory chapter. The principle aim of this chapter is to determine the extent to which energy consumption in office buildings is influenced by various design parameters through statistical data analysis.

3.2.00 Data Collection

The data collection process was done using a questionnaire (see appendix), which was directed to building managers/caretakers, owners and the Kenya Power and Lighting Company. The questionnaire was used on a random sample of 40 buildings out of a population of 128 buildings.

The population of office buildings consisted of buildings that are more than 6 storeys high. The basis of this exception was that buildings with less than 6 storeys do not have the same level of services with buildings having more storeys. These services would include lift installation and plumbing installations among others. It was also realised that the planning and zoning regulations no longer allow buildings of less than 6 storeys in the Central Business District.

3.2.10 Sources of Data

Data was available from a variety of sources, which included: -

(a) Architectural and engineering drawings obtained from the Nairobi City Commission and the Lands Department of the Ministry of Lands and Housing.

(b) Electricity bills obtained from the Kenya Power and Lighting Company.

(c) General observation from a walk-through survey into the buildings.

(d) Interviews using a questionnaire with the property managers, caretakers and owners of the buildings.

Among the 40 questionnaires issued, only 26 were completely filled showing a response rate of 65%. The main problem attributing to this was lack of detailed architectural drawings and information from the Kenya Power and Lighting Co. Ltd.

3.3.00 Measurement of Variables

During the data collection process all the variables both independent and dependent were measured. The dependent variable is the mean annual energy consumption while the independent variables are floor area, glazed area, height, orientation, perimeter and shading.

In the field measurement the variables were measured as follows.

3.3.10 Floor Area (X_1)

The floor area is measured in square metres. This was measured over the walls and represented the total area of the floors in the buildings including basements. Any extended areas, for example the verandas, not covered by the building fabric i.e. the roof or the walls are not included.

3.3.20 Perimeter/floor area ratio (X_2)

Shape was measured as a ratio of perimeter to the floor area of the building. The average perimeter was measured by computing the sum of perimeters of all the floors of the buildings and then dividing by the number of floors. This is done to take into account the varying perimeters due to shape of the buildings.

3.3.30 Glazing Area (X_3)

Glazing area was measured in square meters. This represented the total window area and glazed door area in the building. The area covered by the window frame was included as part of the glazing area.

3.3.40 Total height (X_4)

The height of the building was measured from the lowest basement floor level to the ceiling level of the highest storey. It was measured in metres.

3.3.50 Shading (X_5)

Shading refers to the existence of sun breakers or shading glass or both in the building.

It was measured using a dummy variable where,

1 - represented existence of some form of shading

0 - represented lack of any form of shading.

3.3.60 Orientation (X_6)

Orientation represents the direction of the longest side of the building from the north. This was measured as a ratio of the angle of the longest side of the building from the north to 360°.

3.3.70 Perimeter (X_7)

The perimeter of a building represent the circumference of the building. Perimeter was computed for each of the floors and the average perimeter computed by dividing the sum of all the floors perimeter with the total number of floors.

3.3.80 Mean Annual Energy Consumption (E)

This is the dependent variable in the study. This was derived from the monthly electricity bills from 1988 to 1990 expressed as annual average. It is measured in KWH/yrM^2.

3.4.00 Data Input Matrix

Finally the above variables were measured in a sample of 26 buildings, 14 private owned and 12 government owned. The data was then tabulated as below in table 3.1 to form the data input matrix.

BUILDING	X1	X2	X3	X4	X5	X6	X7	E
KILIMO	11,880.00	0.02	2,197.60	31.00	1.00	0.84	183.18	17,619.00
KILIMO	9,119.06	0.01	1,968.88	34.00	1.00	0.08	124.80	23,957.00
AFYA	27,401.00	0.01	1,028.98	87.00	1.00	0.75	364.00	80,041.00
NYAYO	7,518.70	0.03	1,166.05	36.00	1.00	0.31	201.30	22,753.00
TRANSCOM	13,436.00	0.01	4,240.20	36.00	1.00	0.44	110.40	61,944.40
NSSF	10,806.00	0.02	3,912.40	40.00	1.00	0.55	196.60	15,885.00
JOGOO	7,029.00	0.02	872.78	29.00	1.00	1.00	122.80	10,628.00
SHERIA	6,977.20	0.02	858.74	20.00	1.00	0.55	171.80	12,584.00
OLD TRESURY	9,036.29	0.02	771.20	32.00	1.00	0.25	153.20	8,306.00
MOQ H/Q	8,449.90	0.02	1,896.43	42.00	1.00	0.31	138.36	33,005.00
HUGHES	8,695.94	0.09	2,427.82	32.00	0.00	0.33	758.00	21,214.00
UNION	5,035.64	0.03	1,786.44	42.00	1.00	0.34	138.51	8,374.00
JUBILEE	6,324.00	0.06	1,601.70	22.00	0.00	0.07	356.00	24,206.00
ICEA	18,206.00	0.01	5,669.40	62.00	1.00	0.24	136.70	96,826.00
REINSURANCE PLAZA	10,614.65	0.05	5,499.13	60.00	1.00	0.33	528.10	159,826.00
SONALUX	2,547.00	0.13	628.09	32.00	1.00	0.89	324.00	10,328.00
KENYA BANKERS HSE	3,498.46	0.04	271.16	26.00	0.00	0.43	124.10	14,354.00
MAENDELEO	7,016.37	0.03	812.32	31.00	1.00	0.16	207.68	13,922.00
FOURWAY	3,523.00	0.07	2,112.81	43.00	1.00	0.44	253.29	13,212.00
NORWICH	9,564.00	0.05	2,112.81	43.00	1.00	0.82	467.50	2,007.00
COMMONWEALTH	1,626.00	0.16	2,112.81	43.00	1.00	0.44	253.29	2,021.00
NATIONAL BANK	14,880.00	0.02	4,591.82	71.00	1.00	0.83	253.29	19,219.00
KCS	3,967.00	0.03	312.72	52.00	1.00	0.35	133.00	20,486.00
DIAMOND TRUST	4,903.00	0.07	275.30	29.00	1.00	0.32	323.68	11,600.75
ELECTRICITY	14,255.00	0.21	2,038.20	49.00	1.00	0.07	295.00	106,448.00
KICC	35,183.70	0.01	3,766.32	107.00	1.00	0.33	267.11	98,058.19

X 1	Floor area (M^2)
X 2	Perimeter floor area ratio
X 3	Glazed area (M^2)
X 4	Height of buildings (M)
X 5	Shading
X 6	Orientation
X 7	Perimeter (M)
E	Mean annual energy use (KWH/Year)

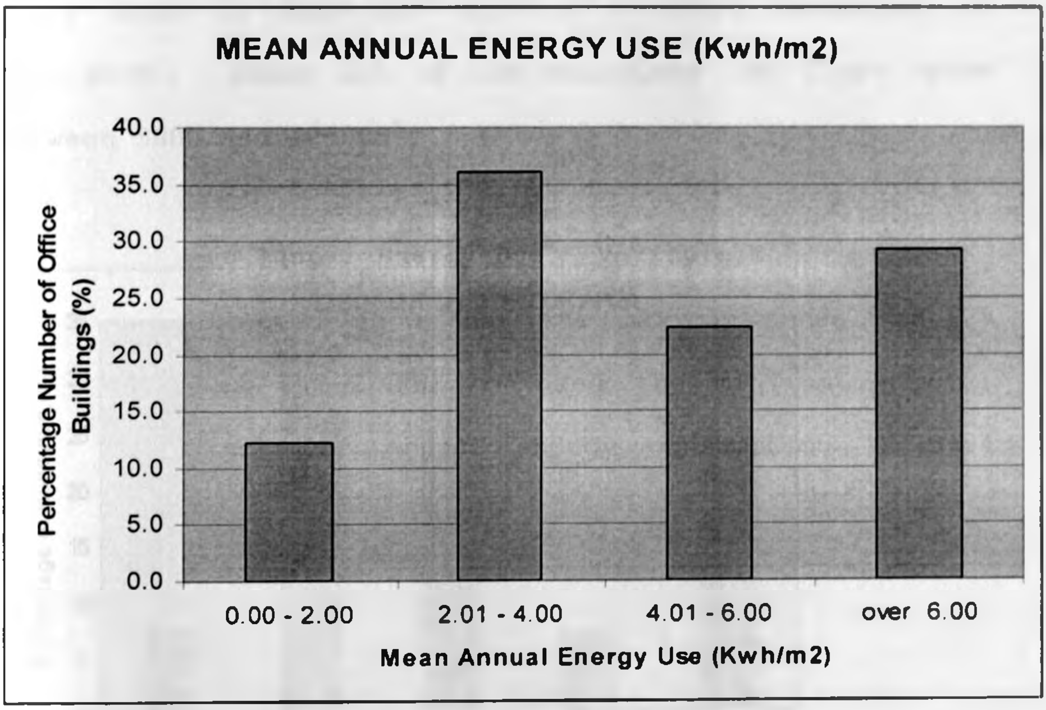
Table 3.1 Data input matrix

Source : Field Survey 1991

3.5.00 Descriptive Analysis

3.5.10 Mean Annual Energy Use - Variable E

The data collected show that the maximum annual energy consumption is 74.67 KWH/yrM^2 and the minimum is 0.21 KWH/yrM^2. The mean annual energy consumption is 3.24 KWH/yrM^2.



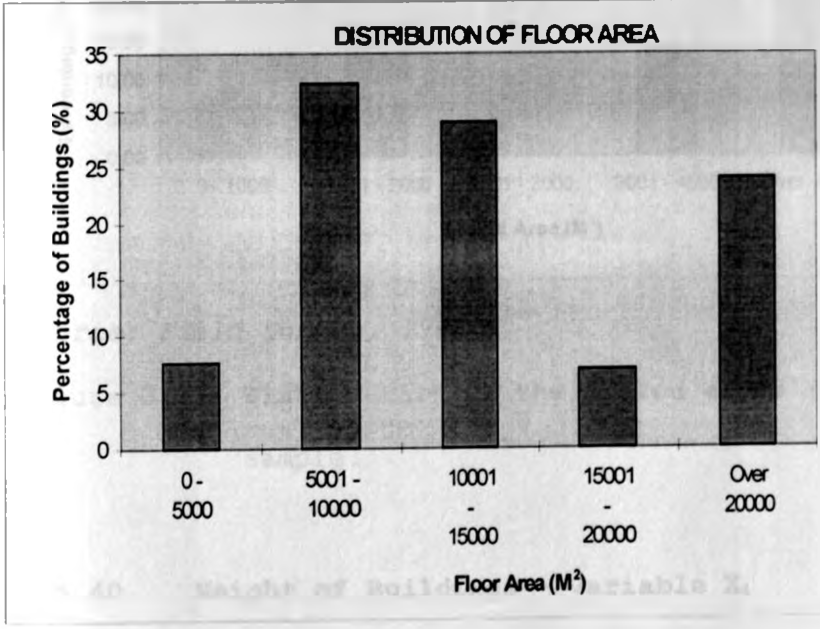
Source: Field Survey, 1991

Figure 3.1: Distribution of the mean annual energy use.

About 38% of the buildings in the sample have mean annual energy use of between 0 and 2.0 KWH/yrM^2 and 15% of the building had mean annual energy use of 5.01 KWH/yrM^2 and above, see figure 3.1.

3.5.20 Floor Area (M^2) - Variable X_1

The floor area was distributed (see figure 3.2) with a maximum of 35183.70M^2 and a minimum of 1425M^2. The mean floor area is 9564.02M^2 with a standard deviation of 7648.683M^2. About 50% of the buildings had floor areas between 5000 and 10000M^2.

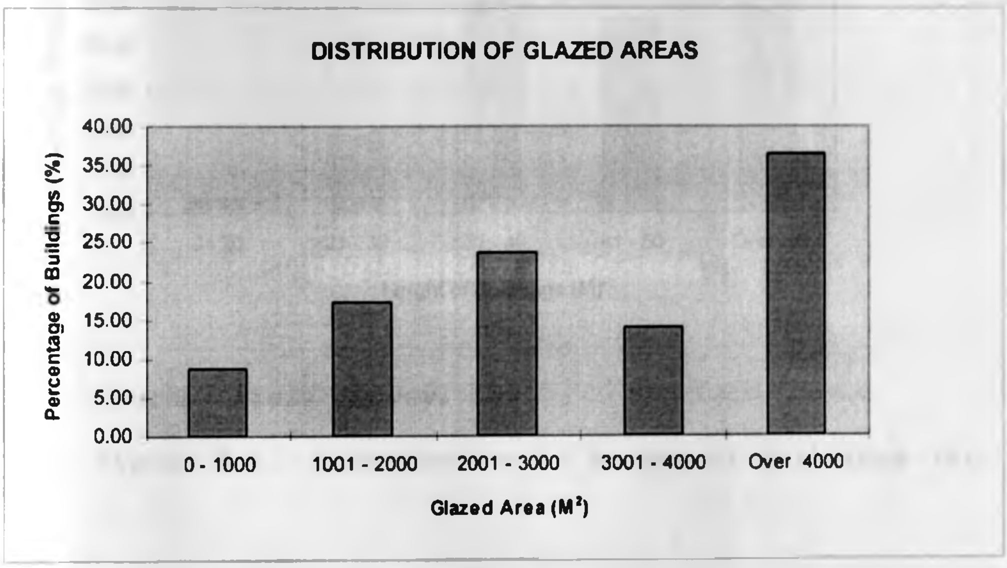


Source: Field Survey, 1991

Figure 3.2: Distribution of the floor areas (x_1) in the sample

3.5.30 Glazed areas - Variable X_3

The distribution of glazed areas in the sample had a maximum of $5669.4M^2$ and a minimum of $271.16M^2$. The mean glazed area is $2112.773M^2$ with a standard deviation of $1577.252M^2$, see figure 3.3.

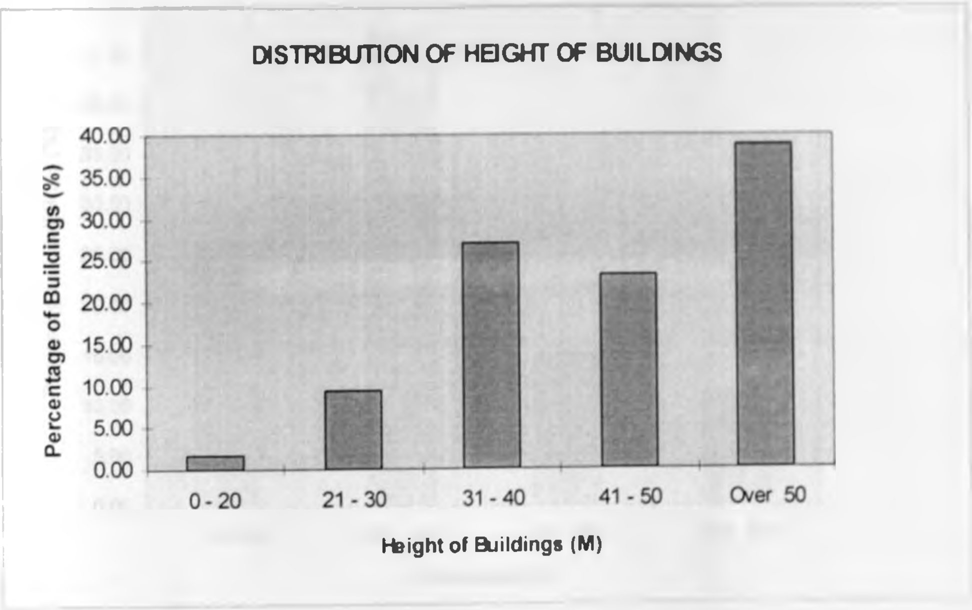


Source: Field Survey, 1991

Figure 3.3: Distribution of the glazed areas (x_3) in the sample.

3.5.40 Height of Buildings - Variable X_4

The internal heights of the buildings are distributed (see figure 3.4) with a maximum of 107.00 meters. The minimum height is 20.00 meters. The mean height of the buildings in the sample is 43.5 meters.

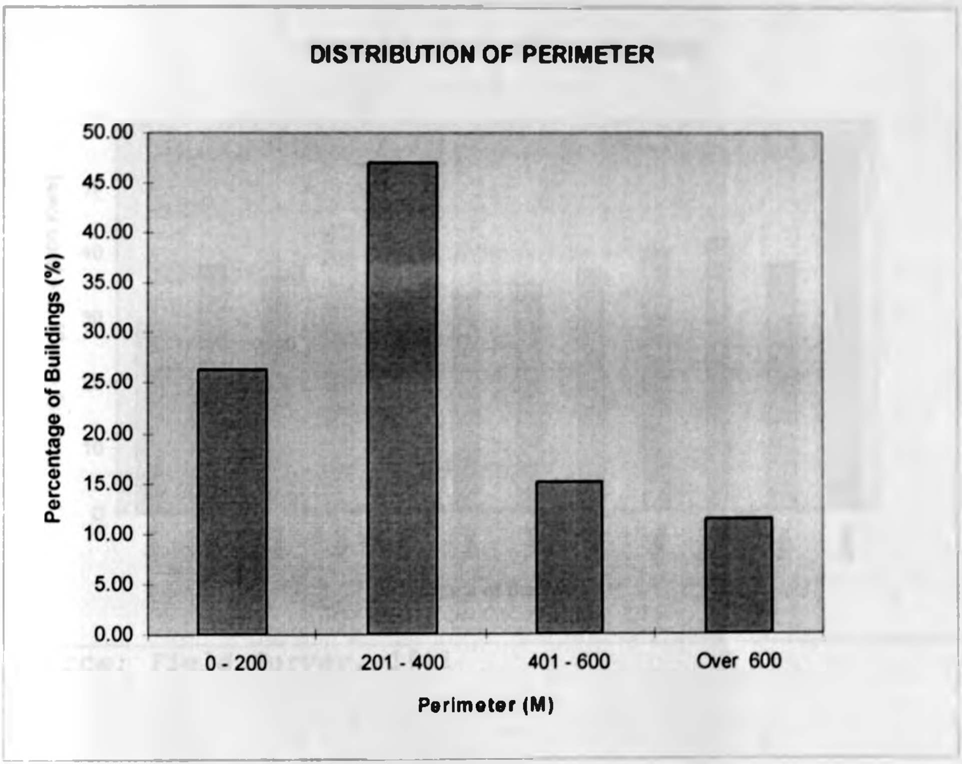


Source: Field Survey, 1991

Figure 3.4. Distribution of height of buildings (x_4)

3.5.50 **Perimeter - Variable X_7**

The maximum perimeter is 758.00 meters and minimum perimeter is 110.40. The mean perimeter is 253.296 meters. (See figure 3.5)

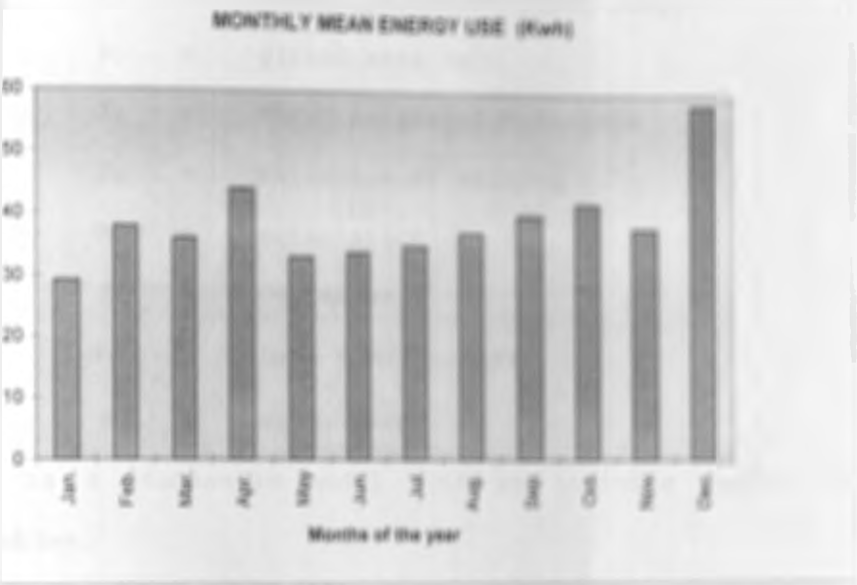


Source: Field Survey, 1991

Figure 3.5: Distribution of perimeter (x_7) in the sample

3.5.60 Distribution of Energy Demand Over the Year

When the distribution of energy demanded over, the year was considered. It was found the highest energy consumption was the months of April and December and the lowest consumption was in the months of January and May.



ce: Field Survey, 1991

re 3.6: Distribution of energy demand over the year

00 Energy Consumption Model

The model of this study was based on the hypothesis energy consumption in office buildings is influenced he various design parameters.

Thus

$X_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \ldots \beta_nX_n + e$

Where E = mean annual energy consumption (KWH/yr)

X_0 = constant term

X_1 = floor area (m^2)

X_2 = shape (perimeter/floor area)

X_3 = glazed area (m^2)

X_4 = total height of buildings

X_5 = existence of shading

X_6 = orientation

X_7 = perimeter

$\beta_1 \ldots\ldots \beta_7$ Beta Coefficients

e = error term

This is a stochastic model with an infinite number of variables.

Assumptions

The above model is based on the following assumptions.

(i) The population is normal

(ii) The variables are not significantly interacting with each other.

With regard to the data collected and the study model formulated, data is analysed statistically using the correlation and regression procedures of the SPSS. The theoretical framework is outlined as follows:

3.6.10 Correlation

This is a measure of linear association between two variables. The strength of association is quantified using a summary index. The commonly used measure is the Pearson correlation coefficient denoted r and defined as

$$r = \frac{\sum_{i-1}^{n} (X_i - X)\ (Y_i - Y)}{(N - 1)\ S_x\ S_y}$$

Where N - the number of cases

X, Y - means for each variable.

S_x and S_y are the standard deviation of the two variables.

The largest possible value is r=1. It shows a strong relationship and the smallest is r=0 and shows lack of linear relationship between the variables. The coefficient of correlation r is positive when the line has a positive slope and negative when it has a negative slope.

The correlation coefficients are computed for all the dependent and independent variables in the above model to measure the strength of relationship between the design variables (independent) and the mean annual energy use (dependent variable).

3.6.20 Regression

Linear regression is a method of approximating a statistical function by a simple linear equation. The study model is essentially a regression model seeking to approximate a statistical function between the dependent variable (E) and the independent variables X_1 to X_7.

Essentially the procedure is to fit the best line through a set of points. This line should minimise the sum of the squared vertical distances from the observed data points on the line.

The line is expressed as

$$Y_i = \beta_o + \beta_i X_i + e_i.$$

Where Y_i - dependent variable

X_i - independent variable

β_0 - intercept on the Y axis

β_1 - slope of the line. It reflects the extent that a change in X is translated to a change in Y

e_i - the effect of other factors

The function represents a simple stochastic model of the relationship between the dependent variable, mean annual energy consumption (E) and each of the dependent variables (X_1 to X_7). Several statistical characteristics and measurements of this model are computed. These include the intercept (β_0, slope of the line (β_1), the coefficient of determination (R^2), the standard error of estimates, t-statistics and analysis of variance (ANOVA). The implications of these statistical characteristics and measurements are summarised as follows.

(a) Coefficient of determination

This is the measure of the goodness of fit for the model and is denoted by R^2. The coefficient of determination is defined as:

$$R^2 = \frac{\text{regression sum of squares}}{\text{total sum of squares}}$$

Thus $1 < R^2 < 0$, the higher the R^2 the higher the correlation and the better the observed points are represented by a straight line. The square root of the R^2 is the unadjusted coefficient of correlation. R is negative or positive depending on the slope of the line. Low values of R^2 indicate that the observed points fall closely to the regression line. This might be due to the curvature of the relationship that is poorly approximated by the straight line. It is also due to random impact of unspecified variables[1]. The coefficient of determination is used in the analysis to measure the degree of association between the dependent (E) and the independent variables.

The coefficient of determination is adjusted to take into account the size of the sample.

(b) Standard **errors**

The following standard errors are computed and analysed. These are summarised as follows:-

(i) Standard error of estimate

ii) Standard error of the slope

(iii) Standard error of the intercept

(i) The Standard Error of Estimate

The standard error of estimate is required to establish a confidence interval of the deviation between the observed and the estimated value of the dependent variable.

(ii) The Standard Error of β_i

The standard error of β_i is the standard error of the slope. It establishes the confidence interval of the distribution of slope within the sample. The variation is caused by various unspecified causes. The 95% confidence interval is computed for the respective slopes.

The standard error of β_i is also a significance test for the linear regression. The student t-test is used to test the null hypothesis that there is no correlation between the two variables and $\beta_i=0$ thus the observed value is a chance accident[2].

(iii) Standard Error of β_0

The standard error of β_0 is the standard error of the slope it is not of great importance in the study though it would show the relative movement of the regression line after introduction of more variables in the computation.

(c) Analysis of Variance (ANOVA)

This is used in the analysis as a significance test to show that the variables are related or not. The F-ratio is computed where

$$F = \frac{\text{regression variance}}{\text{residual variance}}$$

The calculated F-ratio is compared with the theoretical F-ratio at a given confidence level. If $F_{\text{calculated}} > F_{\text{theoretical}}$ then there is significant correlation between the dependent and the independent variable.

The F-ratio compares the regression variance i.e. the variation due to the independent variable and the residual variance i.e. the variation caused by chance variation.

Correlation Analysis of the Model

The partial correlation between all the variables in the model was computed. The resulting correlation matrix is illustrated as follows. (See Table 3.2)

	E	X_1	X_2	X_3	X_4	X_5	X_6	X_7
E	1.000							
X_1	0.4866	1.000						
X_2	0.0527	-0.5181	1.000					
X_3	0.6100	0.4560	-0.1642	1.000				
X_4	0.6058	0.8023	-0.1466	0.4795	1.000			
X_5	0.1381	0.1633	-0.1010	0.1586	0.3100	1.000		
X_6	0.2700	0.1244	-0.1369	-0.0455	0.0650	0.2327	1.000	
X_7	0.2273	0.0649	0.3749	0.1548	0.1209	-0.3904	0.0256	1.000

Table 3.2. Correlation Matrix

The correlation matrix, Table 3.2 shows the strength of relationship between the dependent variable (E) and the independent variables X_1 to X_7. It is important to discuss each partial correlation.

3.6.31 Floor Area X_1

The correlation coefficient is 0.4866 showing a positive relationship between energy consumption and floor area. The correlation coefficient is significant at 95% confidence level.

3.6.32 Perimeter/Floor Area Ratio X_2

The correlation coefficient for the two variables is 0.0527 showing a weak but positive relationship between the variables E and X_2. It is also probable that the relationship is curvilinear. This relationship will be explored further using regression analysis.

3.6.33 Total Window Area X_3

The correlation coefficient between mean annual energy consumption and total window area is r=0.6100. This shows that there is a positive relationship between the two variables. The correlation coefficient was significant at a 95% confidence level. This shows that the chance of getting a correlation coefficient of 0.6100 given that there is no relationship is low. The relationship is therefore linear with less probability of chance variation.

3.6.34 Total Height X_4

The correlation coefficient between mean annual energy consumption (E) and total height of buildings in the sample r=0.6058. This shows that there is a positive relationship between the two variables.

The correlation coefficient is significant at 95%. This implies that the chance of getting no relationship given a correlation coefficient of 0.6058 is less than 0.005. It is highly probable that a relationship exists.

3.6.35 Existence of Shading X_5

The correlation coefficient for the two variables r=0.1381. This illustrates a weaker positive relationship between the two variables. The relationship is not significant at 95% of confidence level. It is likely that there is curvilinear relationship or a high likelihood of chance variation due to inadequate measurement of the parameter.

3.6.36 Orientation X_6

The correlation coefficient between the two variables is r=0.2700 showing a weak positive relationship between mean energy consumption and orientation. The relationship is probably curvilinear hence linear approximation is inadequate. The likelihood of chance variation also exists.

3.6.37 Perimeter X_7

The correlation coefficient is 0.2273 showing a positive relationship between the two variables. The relationship is probably curvilinear or there is a possibility of chance variation. This is explored further in regression analysis.

3.6.40 Regression Analysis of the Model

The energy consumption function is represented as

$$E = \beta_o + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \beta_6 X_6 + \beta_7 X_7 + e_i$$

To estimate the influence of the independent variables on energy consumption, regression analysis described earlier is used. The procedure adopted in the development of the model is to perform regression analysis between the dependent variable and each of the seven independent variables.

Then the second stage is multiple regression analysis to determine the effect of all the variables acting together. A stepwise regression analysis is used in this case. The results are shown in the computer print out (see appendix 4). The summary of the resultant analysis is described below.

3.6.41 Floor Area X_1

The scatter plot between E and X_1 is shown in fig. 3.7.

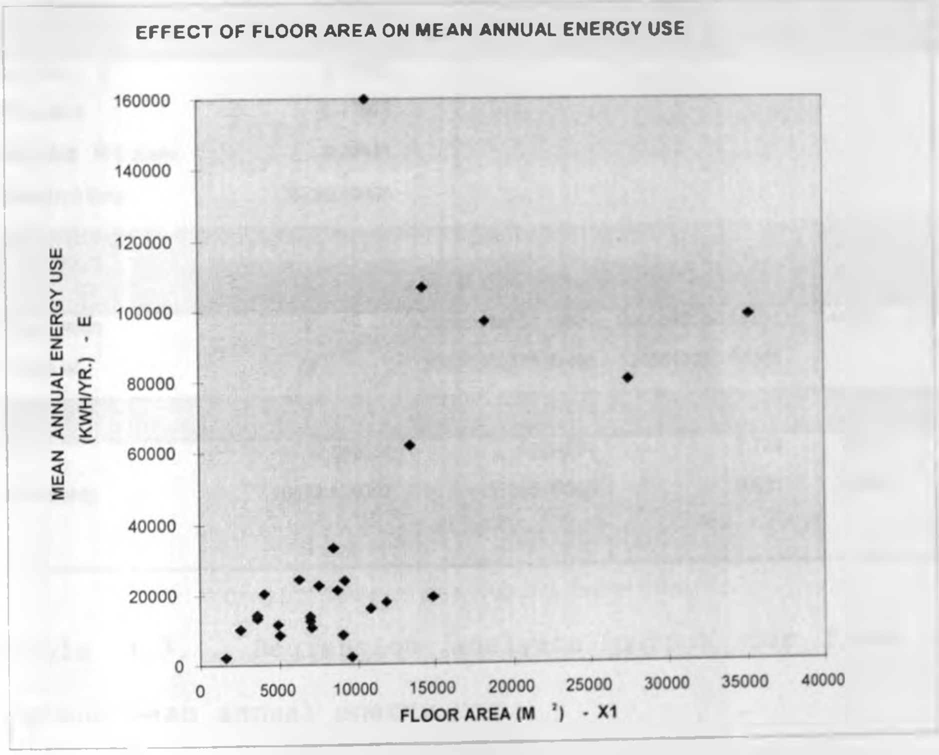
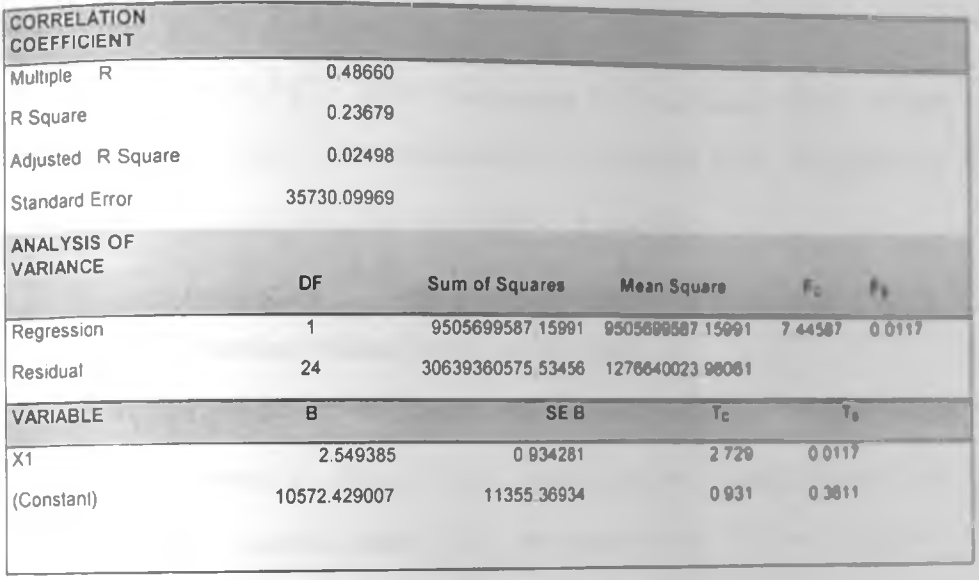


Figure 3.7. Scatter plot of floor area on mean annual energy use

Regression analysis on the two variables with E as the dependent variables reveals that the best line of fit has a slope (β_i) of 2.54938 and an intercept(β_o) of 10572.4290 thus the equation of line can be expressed as

$$E = 10572.429 + 2.54938 X_1$$

(11355.369) (0.93428)



CORRELATION COEFFICIENT					
Multiple R	0.48660				
R Square	0.23679				
Adjusted R Square	0.02498				
Standard Error	35730.09969				
ANALYSIS OF VARIANCE	**DF**	**Sum of Squares**	**Mean Square**	**F_c**	**F_s**
Regression	1	9505699587.15991	9505699587.15991	7.44587	0.0117
Residual	24	30639360575.53456	1276640023.98061		
VARIABLE	**B**	**SE B**	**T_c**	**T_s**	
X1	2.549385	0.934281	2.729	0.0117	
(Constant)	10572.429007	11355.36934	0.931	0.3811	

Table 3.3. Regression analysis output for floor area versus mean annual energy use.

Table 3.3 shows that the coefficient of determination is $R^2 = 0.23678$, showing a positive relationship between the two variables. The standard error of the slope of (β_1) is 0.93428 at 95% confidence level and standard error of intercept (β_o) is 11355.369 at 95% confidence level. The hypothesis test is done to determine whether the relationship exists. The hypothesis in this case is that there is no relationship between the two variables and the slope $\beta_i = 0$. It was revealed that $t_{calculated} = 2.729$ and $t_{significant} = 0.017$. Thus $t_{calculated} > t_{significant}$ showing that the slope exists, hence there is a relationship.

The ANOVA test reveal that $F_{calculated} = 7.44587$ and the $F_{significant} = 0.0117$ thus $F_{calculated} > F_{significant}$, this shows that $R^2 > 0$, thus the independent variable has explanatory characteristics for the dependent variable.

3.6.42 Perimeter/Floor Area ratio (X_2)

Regression analysis between the dependent and independent variable reveals that the correlation coefficient is 0.05270 and coefficient of determination $R^2 = 0.00278$. Both coefficients were relatively low.

CORRELATION COEFFICIENT					
Multiple R	0.05270				
R Square	0.00278				
Adjusted R Square	-0.03877				
Standard Error	40841.96189				
ANALYSIS OF VARIANCE					
	DF	Sum of Squares	Mean Square	F_C	F_S
Regression	1	111479744.28334	111479744.28334		
Residual	24	40033580418.41114	1568065850.76713		
VARIABLE IN THE EQUATION	B	SE B	BETA	T_C	T_S
X2	42843.806172	165728.2940	0.052697	0.259	0.7982
(Constant)	32978.763630	11071.69224		2.979	0.0065

Table 3.4. Regression analysis output of perimeter floor area ratio versus mean annual energy use.

The regression line has an intercept of 32978.7636 and a slope of 42843.8062 see table 3.4. The standard errors of β_o and β_i were 11071.692 and 165728.30 respectively. The regression line is estimated as

$$E = \underset{(11071.692)}{32978.7636} + \underset{(165728.30)}{42843.8062}\, X_2$$

The $t_{calculated} = 0.259$ and the $t_{significant} = 0.798$ thus $t_{computed} < t_{significant}$ which shows that there might be no linear relationship between the two variables, further examination of the scatter plot figure 3.8 confirms this.

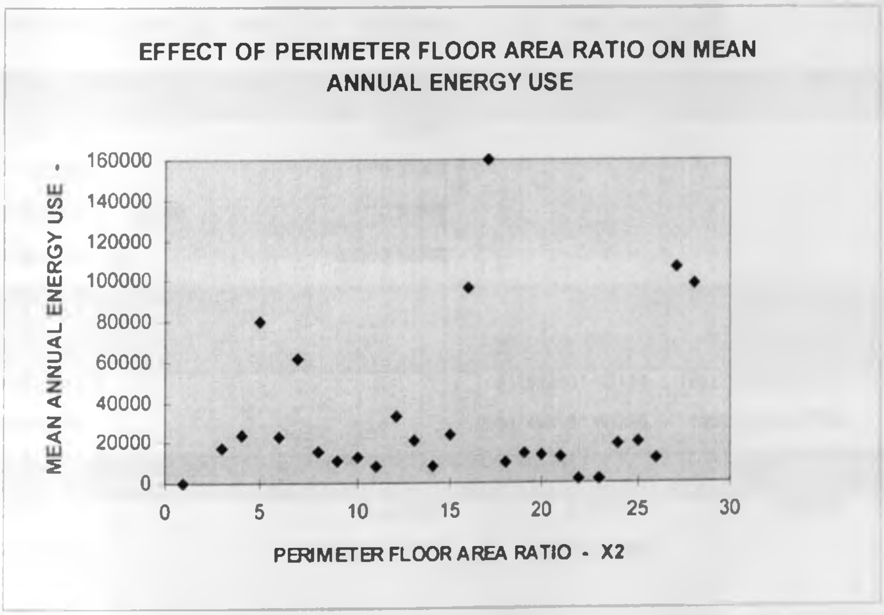


Figure 3.8. Scatter plot of perimeter floor area ratio on mean annual energy use.

The ANOVA-test is done to determine the variability between the two variables thus $F_{calculated} = 0.6683$ and

$F_{significant}$ = 0.7982 $F_{calculated} < F_{significant}$. The hypothesis $R^2 = 0$ is accepted hence there is probably no linear relationship between the two variables. The large size of the standard error of the slope, reveal the possibility of a curvilinear relationship between the two variables.

3.6.43 Glazed Area X_3

The correlation coefficient between the two variables is r=0.60999 and the coefficient of determination R^2 = 0.37209 see table 3.5. This reveals that a positive linear relationship exists between the two variables.

CORRELATION COEFFICIENT					
Multiple R	0.60999				
R Square	0.37209				
Adjusted R Square	0.34593				
Standard Error	32408.52393				
ANALYSIS OF VARIANCE					
	DF	**Sum of Squares**	**Mean Square**	**F_C**	**F_s**
Regression	1	14937562001.63111	14937562001.63111	14.22202	0.0009
Residual	24	25207498161.06336	1050312423.37764		
VARIABLE IN THE EQUATION	**B**	**SE B**	**BETA**	**T_C**	**T_s**
X3	15.497807	4.109506	-0.609992	3.771	0.0009
(Constant)	2210.845722	10760.31665		0.205	0.8389

Table 3.5. Regression analysis output of glazed area versus mean annual energy use.

The slope is 15.49781 and the intercept is 2210.84572. The standard errors of intercept and slope are 10760.316 and 4.10951 respectively thus the regression equation is

$$E = 2210.84572 + 15.49781\ X_3$$
$$(10760.316) \qquad (4.10951)$$

The $t_{calculated}$ = 3.771 and the $t_{significant}$ = 0.0009 thus $t_{calculated} > t_{significant}$ showing that there is a significant linear relationship between the two variables. This is quite clear from the scatter plot in figure 3.9.

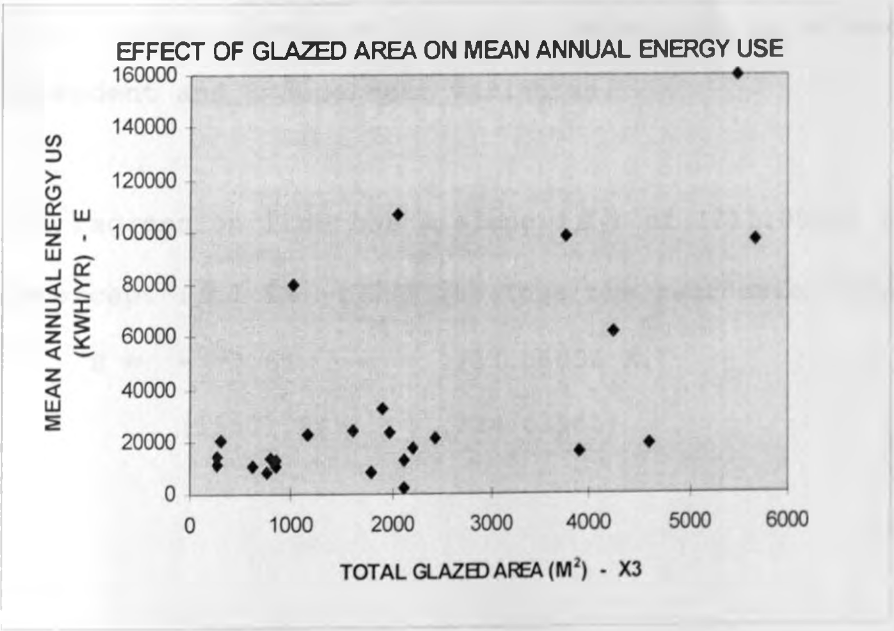


Figure 3.9. Scatter plot of Glazed area on mean annual energy use.

The ANOVA-test show that the $F_{calculated}$ =14.22202 and the $F_{significant}$ =0.009. This again confirms that $R^2 > 0$ is accepted, thus there is a relationship between the two variables. The standard error of estimate of the slope is reasonably small discounting any significant effect of chance variation.

3.6.44 Height of Building X_4

The correlation coefficient is r=0.60585 and coefficient of determination R^2=0.36705 see regression output table 3.6. This shows a positive relationship between the dependent and independent variables.

The regression line has a slope (β_i) of 1211.08006 and the intercept (β_o) is -17773.765 thus the regression line is

$$E = -773.65 + 1211.08006\, X_4$$

$$(15507.649) \quad (324.62961)$$

CORRELATION COEFFICIENT					
Multiple R	0.60585				
R Square	0.36705				
Adjusted R Square	0.34068				
Standard Error	32536.28840				
ANALYSIS OF VARIANCE					
	DF	**Sum of Squares**	**Mean Square**	**F_C**	**F_s**
Regression	1	14735295068.52484	14735295068.52484	13.91776	0.001
Residual	24	25409765094.16962	1058740212.25707		
VARIABLE IN THE EQUATION	**B**	**SE B**	**BETA**	**T_C**	**T_s**
X4	1211.080065	324.629618	-0.605848	3.731	0.0010
(Constant)	.-17773.76513	15507.64895		-1.146	0.2630

Table 3.6. Regression analysis output for height versus mean annual energy use.

The standard errors of estimates of intercept and slope are 15507.649 and 324.6296 respectively.

The $t_{calculated}$ = 3.731 and the $t_{significant}$ = 0.0010 thus $t_{calculated} > t_{significant}$. The hypothesis that slope=0 is rejected proving that a relationship exists between the two variables as shown in figure 3.10 below.

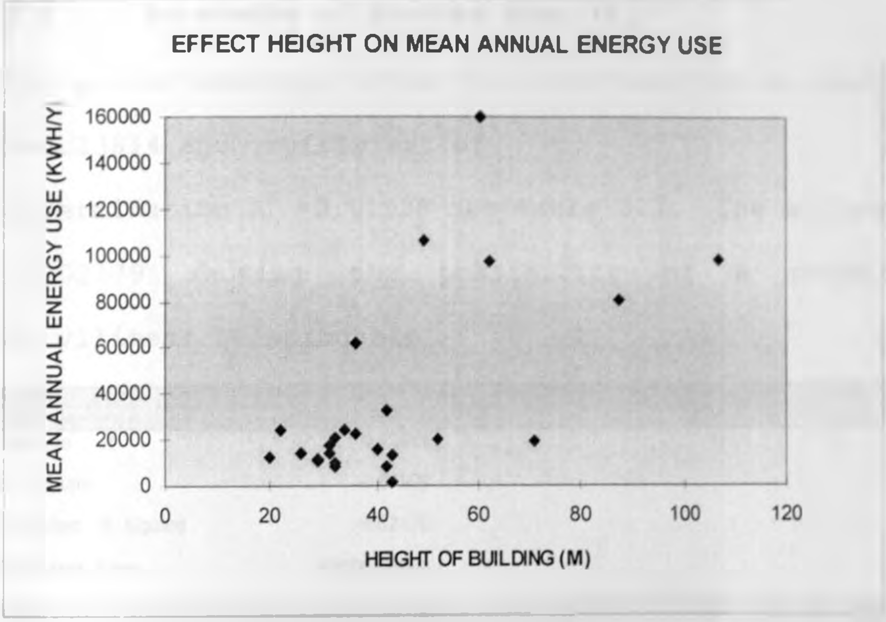


Figure 3.10. Scatter plot of height of building on mean annual energy use.

A further ANOVA test reveal that the $F_{calculated} = 13.91776$ and the $F_{significant} = 0.0010$ thus $F_{calculated} > F_{significant}$ the hypothesis that $R^2 > 0$ is accepted. This proofs existence of a linear relationship between the dependent and the independent variable.

3.6.45 Existence of Shading Area (X_5)

Regression analysis shows that the correlation coefficient r=0.13814 and coefficient of determination R^2 =0.01908 see table 3.7. The adjusted R^2 = -0.02179 showing the possibility of a negative or curvilinear relationship.

CORRELATION COEFFICIENT					
Multiple R	0.13814				
R Square	0.01908				
Adjusted R Square	-0.02179				
Standard Error	40506.66000				
ANALYSIS OF VARIANCE					
	DF	**Sum of Squares**	**Mean Square**	**F_C**	**F_s**
Regression	1	766112061.50170	766112061.50170	13.91776	0.0010
Residual	24	39378948101.19277	1640789504.21637		
VARIABLE IN TH EQUATION	**B**	**SE B**	**BETA**	**T_C**	**T_s**
X5	16990.582899	24865.00571	0.138143	0.683	0.5010
(Constant)	19924.666667	23386.53105		0.852	0.4027

Table 3.7. Regression analysis output of shading versus mean annual energy use.

The regression analysis shows that the slope = 16990.5829 and the intercept = 19924.6667. Thus the regression equation is

$$E = 19924.6667 + 16990.5829\, X_5$$
$$(23386.531) \quad (24856.006)$$

The $t_{calculated} = 0.683$ $t_{significant} = 0.5010$ thus $t_{calculated} > t_{significant}$. The hypothesis that there is no slope is rejected. Thus a relationship existed between the two variables.

The ANOVA test for the hypothesis that $R^2 = 0$ shows that $F_{calculated} = 0.46692$ and $F_{significant} = 0.5010$ thus $F_{calculated} < F_{significant}$. The hypothesis that $R^2 = 0$ is accepted, indicating that there is no linear relationship between the two variables. The relationship is probably curvilinear or there is a greater possibility of chance variation. This is illustrated by the large standard errors of the slope.

3.6.46 Orientation (X_6)

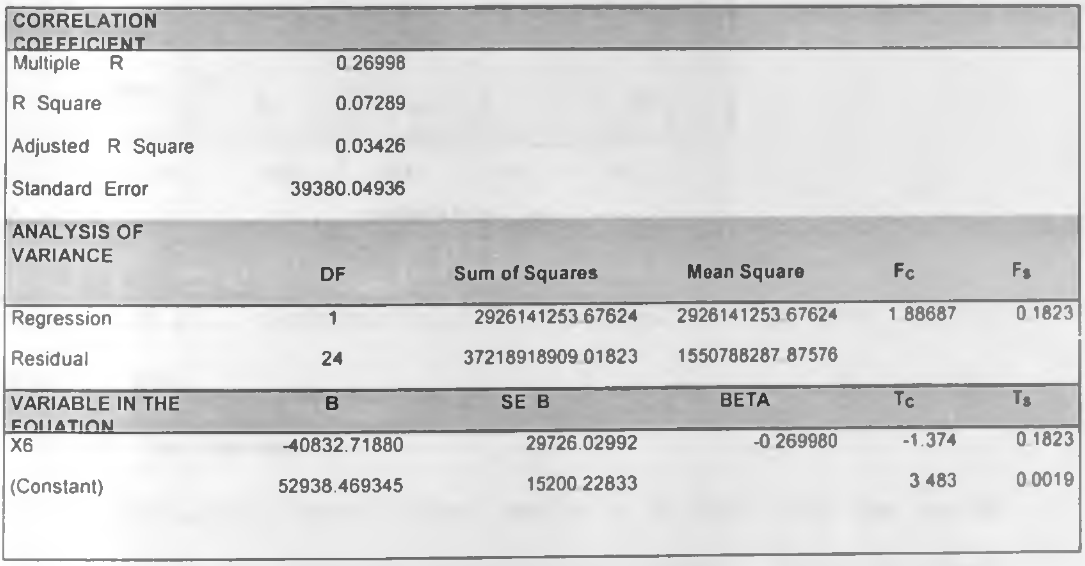
The regression analysis output Table 6 shows that the correlation coefficient r=0.26998 and coefficient of determination $R^2=0.07289$. The negative r implies a negative linear relationship between orientation and the mean annual energy consumption.

The slope was -40832.719 and the intercept = 52938.4693. The regression equation was

$$E = 52938.4693 - 40832.719\ X_6$$
$$(15200.229) \qquad (29726.029)$$

The $t_{calculated} = -1.374$ and $t_{significant} = 0.1823$ thus $t_{calculated} < t_{significant}$ showing the possibility of negative slope.

The ANOVA test showed that $F_{calculated} = 0.1823$ thus $F_{calculated} > F_{significant}$, the hypothesis $R^2 = 0$ is rejected confirming a negative relationship between orientation and mean annual energy consumption.



CORRELATION COEFFICIENT					
Multiple R	0.26998				
R Square	0.07289				
Adjusted R Square	0.03426				
Standard Error	39380.04936				
ANALYSIS OF VARIANCE	**DF**	**Sum of Squares**	**Mean Square**	**F_c**	**F_s**
Regression	1	2926141253.67624	2926141253.67624	1.88687	0.1823
Residual	24	37218918909.01823	1550788287.87576		
VARIABLE IN THE EQUATION	**B**	**SE B**	**BETA**	**T_c**	**T_s**
X6	-40832.71880	29726.02992	-0.269980	-1.374	0.1823
(Constant)	52938.469345	15200.22833		3.483	0.0019

Table 3.8. Regression analysis output of orientation versus mean annual energy use.

The high standard error of estimate for the slope implies that the relationship is possibly curvilinear or a high possibility of chance variation exists. This is quite clear from the scatter plot in figure 3.11.

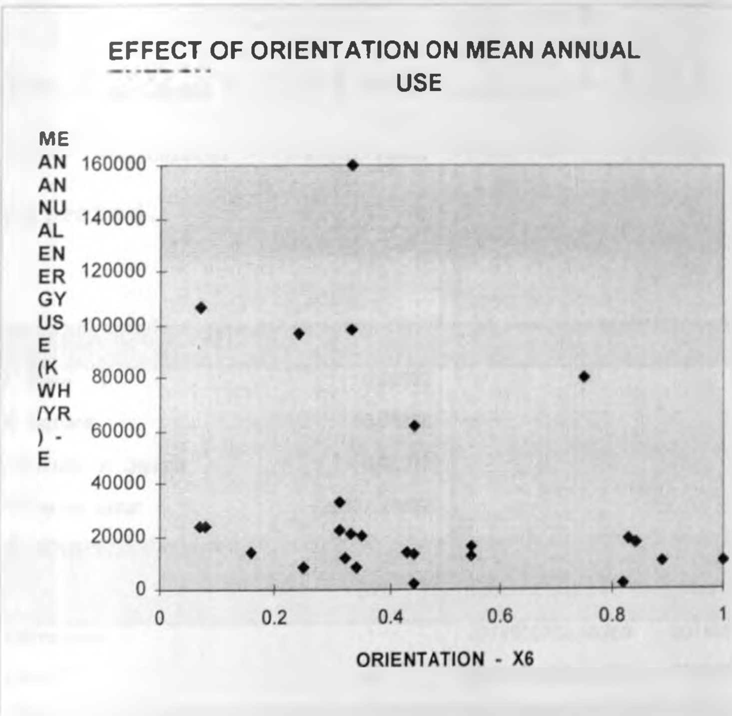


Figure 3.11. Scatter plot of orientation on mean annual energy use.

3.6.47 Perimeter X_7

The correlation coefficient was r = 0.2273 and the below coefficient of determination $R^2 = 0.05168$. This is shown in Table 3.9.

The slope is 60.56886 and the intercept is 19612.8917 thus the regression equation.

$$E = 19612.8917 + 60.56886\, X_7$$
$$(15523.403) \quad (52.96208)$$

The $t_{calculated} = 1.144$ and $t_{significant} = 0.2641$ thus $t_{calculated} > t_{significant}$ thus the hypothesis slope = 0 is rejected.

CORRELATION COEFFICIENT					
Multiple R	0.22733				
R Square	0.05168				
Adjusted R Square	0.01217				
Standard Error	39827.96832				
ANALYSIS OF VARIANCE					
	DF	**Sum of Squares**	**Mean Square**	**F_C**	**F_s**
Regression	1	2074650709.46269	2074650709.46269	1.30788	0.2641
Residual	24	38070409453.23178	1586267060.55132		
VARIABLE IN THE EQUATION	**B**	**SE B**	**BETA**	**T_C**	**T_s**
X7	60.568860	52.96208	0.227330	1.144	0.2641
(Constant)	19612.891749	15523.40356		1.263	0.2186

Table 3.12. Regression analysis output of perimeter versus mean annual energy use.

The ANOVA test reveal that $F_{calculated} = 1.30788$ and $F_{significant} = 0.2641$, thus $F_{calculated} > F_{significant}$. The hypothesis $R^2 = 0$

is rejected confirming that a positive relationship exists between energy consumption and perimeter of the building. The standard error of estimate of the slope (β_i) is significantly large showing a high possibility of chance variation. The scatter plot between perimeter and mean energy use is shown in figure 3.12 below.

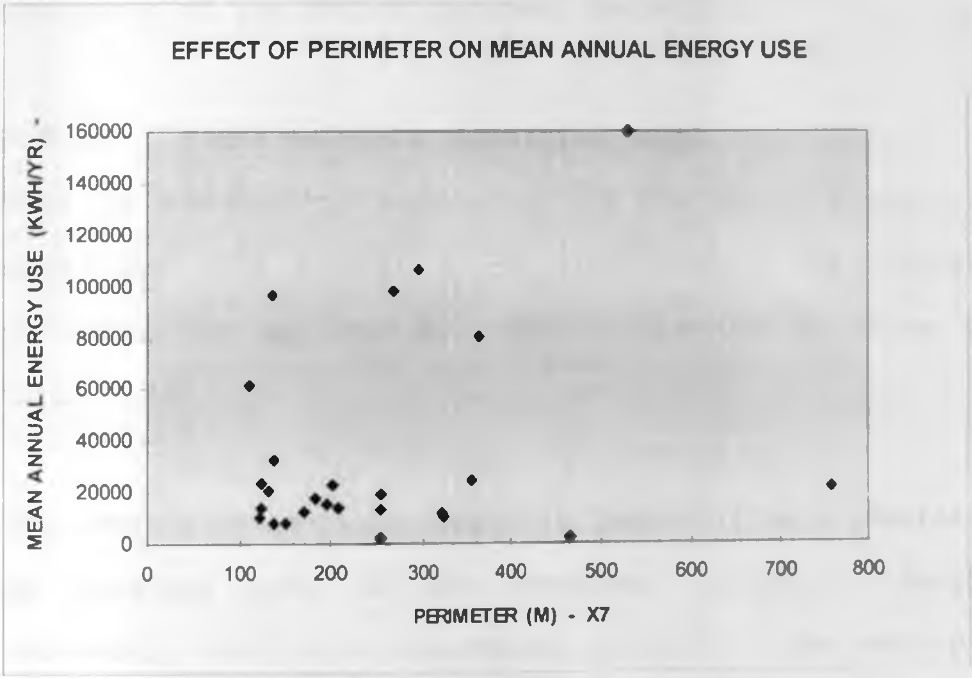


Figure 3.12. Scatter plot of perimeter on mean annual energy use.

3.6.50 Multiple Regression Analysis of the Model

The final regression model is used to illustrate the effect of all design parameters (independent variable) on the mean annual energy use (dependent variable). This is achieved, first by regression of all the variables to determine their partial regression coefficients. This is done using the list wise regression procedure of the SPSS-PC program. Table 3.10 secondly to determine the relative importance of each design parameter in explaining mean annual energy use in buildings, the stepwise regression procedure of the SPSS-PC program, Table 3.11.

3.6.51 First multiple regression model

This is achieved by regressing all the design parameters with the mean annual energy use, using the "enter" procedure of the SPSS-PC. The output was as shown in Table 3.10.

The regression analysis output in Table 3.10 was generated by entering each of the dependent variables (design parameter) into the computation process. The multiple coefficient of determination (R^2) is 0.80500. The ANOVA test reveal that $F_{calculated} = 4.73421$ and $F_{significant} = 0.0036$, thus $F_{calculated} > F_{significant}$. This shows that the relationship is significant at 95% confidence level. Thus the design parameters explain about 80.5% of the variation in mean annual energy use.

The estimate regression model equation is

$$E = -20825.69891 + 2.160722X_1 + 141641.98840X_2 + 9.143719X_3 + 194.532386X_4 + 12059.521303X_5 - 41440.34346X_6 + 28.135611X_7 + e.$$

The design parameters X_2, X_5, X_6 i.e. perimeter/floor area ratio, shading and orientation respectively have the largest standard errors. See table 3.10 below.

CORRELATION COEFFICIENT					
Multiple R	0.80500				
R Square	0.64802				
Adjusted R Square	0.51114				
Standard Error	28018.05458				
ANALYSIS OF VARIANCE					
	DP	**Sum of Squares**	**Mean Square**	**F_c**	**F_s**
Regression	7	26014856444.42364	3716408063.48909	4.73421	0.0036
Residual	18	14130204887.99597	785011382.66644		
VARIABLE IN THE EQUATION	**B**	**SE B**	**BETA**	**T_c**	**T_s**
X7	28.135611	48.360396	0.105597	0.582	0.5679
X6	-41440.34346	22633.51748	-0.273877	-0.1 831	0.0837
X1	2.160722	1.462177	0.405228	1.478	0.1568
X3	9.143719	4.205077	0.359897	2.174	0.0433
X2	141641.98840	136563.7258	0.176678	1.037	0.3134
X5	12059.521303	21647.22853	0.098051	0.557	0.5843
X4	194.532386	555.874491	0.097422	0.350	0.7304
(Constant)	-20825.69891	24034.41244		.0 866	0.3976

Table 3.10. Multiple regression analysis output of the design parameters versus mean annual energy use

3.6.52 Stepwise Multiple Regression Model

In the stepwise regression procedure the first variable considered for entry in to the equation is the one with the highest negative or positive correlation coefficient with the dependent variable. The F-test for the hypothesis is that the coefficient (slope) of the entered variable is calculated and compared to an established criterion for inclusion into the equation. If it succeeds it is included.

The second variable is selected on the basis of the highest partial correlation. After the second variable is included the first variable is examined to see whether it satisfies the removal criterion. It is removed if it satisfies. This process continued until no variables meet the inclusion and removal criteria.

The stepwise regression is used in analysing the variables in the model. The results are shown in table 3.11. The probability of F-test entered PIN is set at default (0.05). Thus a variable is included only when the probability associated with F-test is less than or equal to 0.05. The removal criterion maximum probability of F to removal (POUT) is set at 0.10, which means that variables with less than 0.10 are removed.

The first variable entered in the stepwise process is X_1 that represents the glazed area. Then the correlation coefficient is $r = 0.60999$, the coefficient of determination $R^2 = 0.37209$. This is shown in table 11. The ANOVA test reveals that $F_{calculated} = 14.22202$ and $F_{significant} = 0.0009$. Thus $F_{calculated} > F_{significant}$ which proves the hypothesis $R^2 = 0$ false, thus we reject the hypothesis that there is no significant positive relationship between window area and energy is reflected.

The second variable entered is X_4 that represents height of the building. The partial correlation coefficient increases to 0.70681. The ANOVA test reveals that $F_{calculated} = 11.48086$ and the $F_{significant} = 0.0003$. The hypothesis $R^2 = 0$ is rejected. The R^2 of change in these cases can be computed

$$R^2_{x2} - R^2_{x1} = 0.49958 - 0.37209 = 0.12747$$

The null hypothesis that $R_{2change} = 0$ can be tested using

$$F_{change} = \frac{R^2_{change} - (N-P-1)}{q(1-R^2_{change})}$$

Where N = number of cases in the equation

P = number of independent variables

q = number of variables entered at this stage

Thus $F_{change} = \dfrac{0.12747\,(26-8-1)}{2(1-0.12747)} = \dfrac{0.12747(17)}{2(0.98363)} = 1.10152$

From the tables $F_{0.05}$, 2,17 = 3.59 thus $F_{0.05} > F_{change}$, thus hypothesis $R^2_{change} = 0$ is accepted.

CORRELATION COEFFICIENT					
Multiple R	0.71791				
R Square	0.51539				
Adjusted R Square	0.47325				
Standard Error	29083.49580				
ANALYSIS OF VARIANCE	**DF**	**Sum of Squares**	**Mean Square**	**F_c**	**F_s**
Regression	2	20690517591.28650	10345258795.6433	12.23061	0.0002
Residual	23	19454543741.13311	845849727.87535		
VARIABLES IN THE EQUATION	**B**	**SE B**	**BETA**	**T_c**	**T_s**
X1	2.274401	0.872101	0.426548	2.608	0.0157
X3	10.503689	4.155396	0.413425	2.558	0.0188
(Constant)	-0.1011.84378	10750.38887		-0.941	0.3567
VARIABLES NOT IN THE EQUATION	**BETA IN**	**PARTIAL**	**MIN TOLERANCE**	**T_c**	**T_s**
X2	0.266715	0.36811	0.731949	1.838	0.0796
X4	0.177513	0.137752	0.291826	0.652	0.5209
X5	-0.009019	-012676	0.773525	-0.059	0.9531
X6	-0.265434	-380218	0.784050	-1.928	0.0668
X7	0.130224	0.184789	0.774175	0.882	0.3874

Table 3.11. Stepwise multiple regression analysis of design parameters mean energy use

REFERENCES

[1] Suits, Daniel B. ***Statistics***. An Introduction to Quantitative Economic Research (Rand Mc Nally and Co., Chicago, 1963) p171

[2] Ibid, p179

CHAPTER FOUR

CONCLUSIONS AND RECOMMENDATIONS

4.1.00 Introduction

This is the final Chapter of this study. It consists of the conclusions and recommendations. The conclusions summarise and interpret the results obtained from the analysis of the data and the theoretical framework established earlier.

The recommendations are based on the conclusions and any other information acquired in the course of the study.

4.2.00 Impact of design parameters on energy use in office buildings

This study is aimed at evaluating the impact of design parameters on energy use patterns of office buildings in a tropical climatic setting. The study has highlighted design parameters like floor area, height of buildings, glazed areas, perimeter/floor area ratio, shading, orientation and perimeter as having significant impact on energy use patterns in office buildings. Data has been collected from a total of 26 buildings in Nairobi's Central Business District. Statistical analysis has been performed to measure any statistical relationship between energy use and the design parameters. The results of the statistical analysis form the basis of conclusions on the impact of each design parameter on energy use patterns in office buildings. The implications of all the design parameters acting together are determined using a multi-regression model. This combines all the design parameters and analyse them to establish how much the design parameters can explain energy use patterns in office buildings.

Let us now examine the conclusions and implication of each design parameter on energy use in office buildings.

4.2.10 Floor Area (m^2) Variable X_1

The floor area is an important characteristic of a building. It defines the size and extent of the building. The design of any building will start with assigning the spatial extent of each activity in terms of floor areas. Thus from the outset, floor area is an important determinant of design characteristics of any building.

The role of floor area in determining energy use patterns in office buildings has been developed in the theoretical framework. It is quite clear that energy determinants such as lighting, air conditioning, ventilation and lift system are related to the floor areas. Lighting required will be determined by the area to be lit. Lighting intensity is expressed in terms of electrical, energy per unit floor area (W/m^2). Volume of air to be air-conditioned is also determined by floor area and storey height. Lift design is based on number of people per unit floor area, which in turn is based on the floor area.

In the analysis it is noted that the office buildings in the sample have a minimum floor area of $1425.50m^2$ and maximum floor area of $35183.70m^2$ with a standard deviation of $7648.68m^2$. The correlation coefficient between mean annual energy use (E) and floor area (X_1), $r = 0.4866$. The correlation coefficient is significant at 95% confidence level. This shows a strong positive relationship between mean energy use and floor area.

Regression analysis between the two variables show that a linear relationship exists and is expressed as

$$E = 10572.43 + 2.54938X_1$$

$$(11355.34)\,(0.93428)$$

The coefficient determination $R^2 = 0.23678$. This implies that 23.6% of total observed variance in Mean annual energy use (E) is linearly associated with variation in floor areas (X_1).

Both the Student t test and ANOVA test reveal that the independent variable (X_1) has explanatory characteristics of the dependent variable (E).

The low coefficient of determination i.e. $R^2 = 0.23678$ is possibly due to the fact that there is poor approximation of the linear relationship between the E and X_1. It implies that the random impact of other variables influence the relationship. The probable reason for this is the use of gross floor area in the analysis. The gross floor area includes the areas covered by the walls and the extent of walling in each building is highly variable introducing some degree of error. However, it can be concluded that floor area has significant impact on energy use in office buildings.

4.2.20 Perimeter/Floor Area Ratio - Variable X_2

This variable is computed from the floor area and the perimeter. Perimeter/floor area ratio is used as a determinant of shape in the study. It has been shown that buildings with complex shapes have higher perimeter/floor area ratio.

The theoretical framework has pointed to the fact that complex shapes will exhibit greater wall areas. The energy use consequences of this are that greater parts of the building fabric are exposed to external environmental conditions. These conditions include solar insolation, heat and humidity among others. These conditions will in turn influence lighting requirements, air conditioning and ventilation rates. These services have direct bearing in energy use.

Correlation analysis between the mean annual energy use (E) and perimeter floor ratio (X_2) shows the correlation coefficient r =0.0527. This reveals a weak but positive relationship between perimeter/floor area ratio and mean energy use.

Regression analysis shows that the coefficient of determination $R^2 = 0.00278$, implying that perimeter/floor area ratio determine only 0.278% of the total variation. The t-test further reveals that the relationship is not significant at 95% confidence level. The same case applies to the ANOVA test.

It is possible that the relationship between the two variables is not linear. The relatively small $F_{calculated}$ points out the fact that the relationship is possibly curvilinear. A further examination of the scatter plot reveals a curve like relationship. The adjusted R^2 = -0.03277 showing a negative curvilinear relationship. The results discount the fact that complex shapes with higher perimeter floor area ratio use more energy. The most plausible explanation is that most buildings with high perimeter floor area ratio incorporated a courtyard, which would encourage the use of natural lighting and ventilation thus resulting to low energy consumption.

4.2.30 Glazed Area (m^2) - Variable X_3

Glazed area represents the windows and door area of the building covered by glass in the external building fabric. The glazed areas admit natural lighting and are used for ventilation. At the same time glass admits significant solar insolation into the building. The glazed areas present conflicting energy use consequences. The admission of natural lighting would cut down on the use of artificial lighting, which is more energy intensive. However glazed areas admit solar insolation that causes internal heating in the building. The glass will not allow the heat to escape out of the building. This means that the heat has to be removed through air conditioning.

Correlation analysis between the mean energy use (E) and glazed area (X_3) gives a correlation coefficient r = 0.60999. This shows a strong positive relationship between the variables with significance at 95% confidence level.

Regression analysis shows that the coefficient of determination, $R^2 = 0.37209$. The regression equation is

$$E = 2210.84572 + 15.49781X_3$$
$$(10760.316) \quad (4.10951)$$

Thus 37.209% of total observed variation in mean annual energy use is linearly associated with variation in glazed area (X_3).

Both the student t-test and ANOVA test confirm the existence of strong explanatory characteristics between glazed area X_3 and mean annual energy use (E).

The coefficient of determination (R^2) is low, possibly due to the random impact of unspecified variables. The probable unspecified variables are partly due to measurement errors of the glazed areas which was done inclusive of the frame, orientation factors, lack of differentiation between open able and non-open able glazed areas and the type of glazing. It is however conclusive that the extent of glazed areas in office buildings has significant impact on their energy use patterns.

4.2.40 Height of building - Variable X_4

Earlier in the theoretical framework it was noted that height of building is an important determinant of energy use in buildings. The reasons put forward are that taller buildings will require more services in terms of lighting, air conditioning, ventilation and lift systems.

Artificial lighting systems will be utilised since greater reliance on natural lighting will lead to internal heating. Most taller buildings extensively use shading glass that result to the need for artificial lighting. At the same time greater areas of the building fabric are exposed to solar insolation. These lead to higher cooling loads on air conditioning systems resulting to increased use of energy.

The correlation analysis reveals that the correlation coefficient (r) between mean energy use and height of building is r = 0.6058. This is significant at 95% confidence level.

Regression analysis shows that the coefficient of determination $R^2 = 0.36705$. The regression equation is

$$\begin{array}{ccccc} E & = & -773.65 & + & 1211.08006X_4 \\ & & (15507.649) & & (324.62961) \end{array}$$

It shows that 36.705% of variation in mean energy use is explained by variation in height of buildings.

The negative intercept would imply that buildings of some height do not use energy. This is, however not the case, but it is due to the fact that buildings lower than a certain height (i.e. 6 floors) were not considered in the study.

Both the student-t and ANOVA test are significant at 95% confidence level confirming a possible explanatory relationship between the height and mean annual energy use. The low coefficient of determination suggest to the possible effect of unspecified random variable. These include other design parameters and unspecified factors like efficiency of lift systems and variation of the relative storey heights in the sample. It is also important to realise that the choice of environmental control and other service systems is not based on height of the building alone. Many other factors must be taken into account. The analysis however confirms that taller buildings will use more energy for internal environmental control.

4.2.50 Existence of shading - Variable X_5

This is generally a dichotomous variable, which simply measures the existence or lack of shading in the buildings.

The correlation coefficient $r = 0.13814$ showing a possible linear relationship between the two variables. The correlation coefficient is however not significant at 95% confidence level.

The regression analysis shows a coefficient of determination of $R^2 = 0.01908$. The regression equation is

$$E = 19924.6667 + 16990.5829X_5$$

$$(23386.531) \quad (248506.006)$$

The student t-test is significant at 95% confidence level. The ANOVA test is however not significant at 95% confidence level. This shows the possibility that there is no correlation between the two variables. The large standard errors prove the high possibility of chance variation between the two variables.

The possible conclusion on this aspect is that other unspecified variables play a greater role in explaining energy use in buildings. It might also relate to the inadequacy of the method of measuring shading in the study. The employment of ordinal (dummy variable) measurement cannot possibly measure effectively the efficiency of shading which is an important aspect when comparing shading and energy use. The other possible explanation is that shading is generally not efficient in the majority of the cases it is used.

The variable would require re-examination, possibly with a more efficient method of measurement, which would take care of the shading efficiency.

4.2.60 Orientation - Variable X_6

Orientation has been earlier defined as the general disposition of the building to the ground relative to the North Pole.

The impact of orientation on energy use in buildings is highly influenced by the sun path relative to the buildings fenestration and fabric. It has been hypothesised that in tropical climates like in Nairobi buildings should have the longest axis on the East/West direction and the shortest on the North/South direction.

This would minimise the area affected by solar insolation thus reducing heating and the resulting cooling loads. The East West sides would receive almost all the insolation. Its ingress can however be reducing the use of sun shading and shading glass.

Orientation in the study was determined by measuring the direction of the longest side from North and expressing it as a ratio of 360°.

The correlation coefficient $r = -0.26998$. This shows, a negative linear relationship between orientation and mean annual energy use.

The coefficient of determination

$R^2 = 0.07289$. The regression line equation is

$$E = 52938.4693 - 40832.719X6$$

$$(15200.229) \qquad (29726.029)$$

Both the student t-test and the ANOVA test are significant at 95% confidence level. However $R^2 = 0.07289$ this implies that 7.289% of the total observed variation in the mean annual energy use is linearly associated with orientation. The low value of R^2 points out to the possibility of having a curvilinear relationship. There is a possibility that the impact of other unspecified variables is significant. This is illustrated by the large standard errors of estimates.

The negative relationship between the orientation and mean energy use has important implication. It is important to note that the North South direction has value of 1. This value decreases as the orientation moves away from the North South direction.

The implications are that when the longest side is facing the North the orientation is 1 and energy use is at the lowest, possibly due to low cooling loads. However, when the longest side is facing the East West direction the value of orientation tends to zero, but then energy use is at the highest due to the increased cooling loads. This confirms the hypothesis set forth by Meffert and Kebathi in the theoretical framework.

The effect of other variables like neighbourhood and vegetation reduces the possible effect of orientation on mean annual energy use.

4.2.70 Perimeter - Variable X_7

The perimeter of a building determines the extent of the building envelope. The perimeter will determine the area of the building fabric on which various environmental factors are incident upon. The most important environmental factor is solar insolation and other external thermal conditions. The transmission of heat to and from a building will be influenced by the extent and thermal transmission characteristics of the fabric.

The correlation coefficient $r = 0.22733$. This illustrates a positive linear relationship between energy use and perimeter. The regression analysis reveal the coefficient of determination $R^2 = 0.05168$.

The regression line equation is

$$E = 19612.8917 + 60.56886X7$$
$$(15523.403) \qquad (52.96208)$$

The student t-test and ANOVA test are significant at 95% confidence level. These confirm a positive linear relationship between the two variables. It is observed that only 5.16% of the total variation of the mean annual energy use is attributed to variations in the perimeter. This confirms the possibility that the relationship is not necessarily linear but curvilinear and the linear relationship is a poor approximation. Some of these include the thermal characteristics and extent of the fabric. The ever-changing external environmental factors also influence the energy use patterns of the buildings. It is however noted that perimeter has significant impact on energy use in office buildings.

4.2.80 Multiple Regression Model

The principle objective of this study is to identify the relationship between energy use and design parameters. The relationship between each design parameter and energy use has been discussed. It is important however to relate all these parameters together and measure their relationship with mean annual energy use. This is necessary since all parameters act together and the parameters must be considered, together in the formulation of an energy conscious design.

A multiple regression procedure analyses of the model revealed the resulting equation is as follows.

$$E = 3457.03 + 0.0686X_1 + 1104.12X_2 + 1.12X_3 - 57.16X_4 - 1098.47X_5 + 38.79X_6 + 0.0152X_7$$

The ANOVA tests show that the relationship is significant at 95% confidence level where $F_{calculated} > F_{0.05\ 18,7}$. See Table 3.10.

The multiple coefficient of determination $R^2 = 0.28265$. The examination of the Beta (ß) coefficient shows the variables that explains energy use are:- orientation (X_6), Floor area (X_1), Height of building (X_4), glazed area (X_3) perimeter/Floor area ratio (X_2), perimeter (X_7) and shading (X_5) respectively.

All the variables explain over 28.265% of the variation in energy use. The other unspecified variables explain the remaining proportion. These variables are not covered in the study. They include climate and occupancy related variables.

The conclusion derived from the model is that the designer during the design stage will have control of about 28.265% of energy use patterns of the building. This percentage would however increase as more information on how buildings use energy is acquired.

4.3.00 Recommendations

The development of energy conscious building designs so as to reduce energy consumption in new buildings has been the prime objective of this study. It is realised that to make this feasible, it is important to study the effects of various design parameters on energy use in buildings. This would provide a tentative basis on which recommendations on energy conscious design process can be made.

4.3.10 Design parameters and Energy Conscious Design

The study concludes that the most important design parameters influencing energy use in buildings are orientation (X_6), floor area (X_1), height of buildings (X_4), glazed area (X_3), perimeter (X_7), perimeter/floor area ratio and shading (X_5) respectively. It would however be inadequate to consider each variable alone since in any single building, all the variables are prevalent and interact with each other.

First, the study confirms that buildings with longest axis in East West alignment use less energy. This should be emphasised during design to achieve a low energy consuming building. In cases where this is not possible then the designer should employ smaller windows i.e. less glazed areas and more shading to reduce ingress of solar insolation. This should lower be balanced with the day lighting requirements.

Secondly in high-rise office buildings, the percentage of solar insolation incident on the walls and windows is relatively higher since in most cases the neighbouring buildings do not overshadow other buildings. It is important to reduce the extent of glazing. The use of reflective glazing is not a solution since the heat will be transmitted into the local microclimate and into the buildings. The emphasis should be on low-lying buildings with courtyards and atria for lighting and ventilation. These, while reducing the solar insolation incident on them, they would provide adequate delighting and natural ventilation.

Thirdly, though the designer is seriously constrained as far as floor area is concerned. It is recommended that even if the designers cannot control the floor area they should avoid deep plan buildings, which would significantly rely on artificial lighting and ventilation. Buildings with extensive floor areas should adopt other principles of passive design to ensure energy efficient buildings.

Fourth, the designers should carefully control the shape of the building, complex shapes result to higher energy use levels. Complex shapes are however useful where natural lighting and ventilation is being maximised.
Fifth, it is important to pay attention to the efficiency of shading to be used in buildings. This is important to avoid cases where shading is only effective for shorter periods in the year. The shading elements should also be able to dissipate heat away from the building.

Finally to reduce energy consumption in buildings there is need to adopt energy conscious design principles from inception. Winch, et al suggest that a co-ordinated design concept whereby the design of the building fabric, the functions of various spaces, required environmental conditions and external environmental factors should be incorporated to produce energy saving design[1]. This suggestion if adopted in the study area, would require that the anticipated energy performance standards be incorporated in the brief together with other design requirements.

To achieve energy conscious design there should be general awareness on the need to conserve energy use in the built environment. The Government should lead on this by providing detailed energy use policies that should set energy use standards. These would provide energy use yardsticks to the clients and the designers, thus promoting energy conscious design.

4.3.20 Research

This study is generally evaluative, more detailed, specific and scientifically based research is required in the following areas: -

- Thermal properties of common materials used in the building fabric.
- Climatic and energy use in buildings.
- Occupancy behaviour and energy use in buildings.

Research in the above areas would hopefully provide the designers with more tools to use in creating energy conscious design.

BIBLIOGRAPHY

Agency for International Development (AID). Energy Assistance Policy Paper, (- - 1981).

Anson, M. et al, Office Building Cost as a Function of Building Envelope Design in Architectural Science Review, Melbourne, 1973.

Asante, Yaw and Meffert, E.F., The Impact of Energy Conservation Measures on Architectural Design in Hot, Humid Tropical Areas. Unpublished Paper Presented at the 'Conference on the Interactive between Physics and Architecture in Environment Conscious Design, Mira mare - Trieste, Switzerland 1987.

Banham, Reyner The Architecture of a Well Tempered Environment, Architectural Press, London, 1969.

Broadbent, Geoffery, Design in Architecture - Design and the Human Sciences, David Fulton Publishers, London, 1988.

Bouchlaghem, N.M. et al Numerical Optimization Applied to the Thermal Design of Buildings in Building and Environment Vol.25, No.2 ed. C.B. Wilson, Pergamon Press, Oxford 1990.

Building Research Establishment, Energy Conservation A "Study of Energy Consumption in Buildings and Possible Means of Saving Energy in Housing" BRE CP56/75 (Watford, United Kingdom, 1975).

Burberry, Peter, Environment and Services BT Bastford Limited, London 1970.

Burberry, Peter, Ambient Energy - Criteria for Building Design In Ambient Energy and Building Design ed. J.E Randall, Construction Press Ltd, Lancaster, England, 1978.

Central Bureau of Statistics, Statistical Abstract 1989 (Government Printer, Nairobi, 1989).

Central Bureau of Statistics, Statistics Abstract 1988 (Nairobi Government Printer, 1988).

Christopher E, Energy Consumption in Building in Denmark and Possibilities of Energy Conservation in the Built Environment ed. R.G Courtney, BRE, Construction , Lancher, 1976.

Cooperation for Development in Africa (CDA), Designing and Implementing National Energy Conservation Programs (A seminar held at Nairobi Vol.1 May 1984).

Dick, James, Ambient Energy in the Context of Buildings in `Ambient Energy and Building Design' ed J.E. Randall, Construction Press Ltd. Lancaster, England 1978.

Forwood, Bruce S. Environment Design and Building Services in 'Computer Applications in Architectural' ed John S. Gero, Applied Science Publishers Ltd. London 1977.

Givoni, B. Man, Climate and Architecture, Elsevier Publishing Company Limited, London 1969.

Green, M.F. and Smith, B.S. Survey and Analysis of Lift Performance in an Office Building in Built Environment Vol.12, 1977.

Gupta, T.N. and Chandrah, Prakash Energy Efficient Building Design. A Paper Presented at the 9th CIB Congress on Energy Technology and Conservation, Vol.3(a) CIB, Stockholm 1983.

Kebathi, Stanley., Urban Design and Energy Conservation for Nairobi, (Berkeley, University of California 1978).

Kenya Development Plan 1989-1993 (Government Printer, Nairobi, 1989).

Knowles, Ralph L. Energy and Form 'Ecological Approach to Urban Growth, MIT Press, London, 1974.

Koenisberger, O.H., et al Manual of Tropical Housing and Building Part one: Climate Design, Longman, New York, 1973.

Kusuda, Snell, J.E. and Didion D.A Energy Conservation in

Office Buildings in Energy Conservation in the Built Environment ed. R. Courtney, BRE, Construction Press, Lancaster, 1967.

Lord, Peter, et al The Architectural of Sound, Designing Places of Assembly, Architectural Press, London, 1986.

Leach S.J. and Desson R.A., Energy Consumption in Buildings in UK and Possibilities of Energy Conservation in Energy Conservation in Built Environment ed. Roger G. Courtney Construction Press, London 1986.

Lim, B.P. et al, Environmental Energy Factors in the Design of Building Fenestration. Applied Science Publishers Ltd London 1979.

Markus ed, et al, Building Performance, Applied Science Publishers, New York 1972.

Mavers W. Thomas, Building Services Design - A Systematic Approach to Decision Making, RIBA Publication Ltd, 1971.

Meffert, E.F. and Asante, Y. The Impact of Energy Conservation Measures on Architectural Design in Hot Humid Tropical Areas, A paper presented in a seminar on the 'Interaction Between Physics and Architecture in Environment-Conscious Design' held at Mira mare, Trieste, 21-25 September 1977.

Ministry of Energy and Regional Development, Kenya National Energy Policy (Nairobi, Energy Development International, 1983), Passim.

Owens P.G.I, Energy Conservation and Office Lighting in Energy Conservation in the Built Environment ed. R. Courtney, BRE Construction Press, Lancaster, 1976.

Saitoti, George, Minister for Finance Nation Newspaper 3rd October 1990, Nairobi, 1990).

Saleh, M. Ridenam, Vertical Transportation in Tall Buildings from the proceedings of seminar on 'Tall Building in an Urban Context' ed. Sad, Assaf, et al held on Nov, 24-28 1986, Dhara, Saudi Arabia, 1986.

Schipper, Lee and Mbeche, Oyuko, Energy Demand and Conservation in Kenya, Beiger Institute of Energy and Human Ecology (Berkeley, California, 1979)

Sidney, I, L. ed., Chambers English Dictionary. W & R Chambers Ltd and Cambridge University Press, Cambridge 1988.

Stone, P.A. Building Design Evaluation E & F.N. Spon Ltd, London, 1980.

SPSS - Statistical Package for Social Sciences.

Thornley, L. Deryck The Case for Air Conditioning - Keynote Discourse in 'Air Conditioning System Design for Building' ed. AFC Sheratt, McGraw-Hill Book Company (UK) Limited, London 1983.

Winch, G.R. and Burt, W. Environmental Design Strategy in Energy Conservation in the Built Environment ed. J. Courtney, CIB, London.

World Commission on Energy and Development, WCED Our Common Future (Oxford, WCED, 19xx). p168.

APPENDIX I

AN INVESTIGATION INTO THE IMPACT OF DESIGN PARAMETERS ON ENERGY COSTS OF OFFICE BUILDINGS IN NAIROBI

QUESTIONNAIRE

Interviewer ....

Respondent ....

Date ....

A. General Information

Please fill in the following data:-

1. Name of the building ....
2. Location of the building ....
3. Age of the building ....
4. The number of tenants in the building ....
5. Who owns the building? ....

Government	Yes/No
Parastatal	Yes/No
Private	Yes/No

6. Who manages the building?

Government	Yes/No
Parastatal	Yes/No
Private	Yes/No

7. What is the name of the managing firm? ....

8.What is the gross floor are of the building .... m^2

9.What is the rentable floor area? .... m^2

B Design Parameters of the Building

Please fill in the following data about the building:

1.Average perimeter of the building ....

2.Number of storeys ....

3.Average storey height ....

4.Total height of the building above ground level ...

5.Total floor area ....

6.Plot ratio ....

7.Orientation of the longest side of the building from north......................... degrees.

C Windows and Doors in the Building

1.What area has the following type of glazing in the building?

(a)Clear glass single glazing .... m^2

(b)Double glazing .... m^2

(c)Reflective glazing .... m^2

(d)Tinted glass .... m^2

Others (specify) .... m^2

2.Total window area .... m^2

3.Openable window area .... m^2

4.Non openable area .... m^2

5.What wall area is occupied by glazing in the following exposures?

(a)North: Type of glazing ....

Area ....

(b)South: Type of glazing ....

Area ....

(c)East: Type of glazing..................

Area ....

(d)West: Type of glazing..................

Area ....

6.Does the building have any sun breaks? ....

7.If yes, are they of the following types (Tick where applicable)

(a)Vertical

(b)Horizontal

(c)Crate

(d)Shading glass

Others (specify) ....

8.Which side does the building have sun breaks? (Tick where applicable)

(a)North

(b)South

(c)East

(d)West

9.What material is used for external doors? ....

[1] Banham, Op Cit p267.