AN APPLICATION OF LIFE CYCLE COSTING TECHNIQUE TO THE CONSTRUCTION INDUSTRY IN KENYA

WITH PARTICULAR REFERENCE TO ROOF COVERING MATERIALS.

A CASE STUDY OF NAIROBI - RAILWAYS BUILDINGS.

BY

SYLVESTER MUNGUTI MASU

B.A. (Build. Econ) Hons; M.A.A.K.(Q.S.); A.C.I. Arb.

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DECLARATION

I, SYLVESTER MUNGUTI MASU, hereby declare that this thesis is my original work and has not been presented for a degree in any other University.

DECLARATION OF THE SUPERVISORS

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

George K. Kingoriah

DR. G.K. KING'ORIAH

Syagga

DR. P.M. SYAGGA

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ABSTRACT

There is evidence that large numbers of buildings do not achieve the level of performance intended by designers and the client. In many cases short-comings appear as defects of either design, materials or workmanship or a combination of these proportions the relative of which are difficult to determine. Some instances are spectacular and involve large expenditures on remedial work or in the very extreme cases the domolition of recently completed buildings. Amongst the building elements with greatest short-comings are the roofs. Roofs are the most exposed to the severe environment and apparently contribute betweeen $12\frac{1}{3}$ and 16% of the total initial cost of construction. Any designer dealing with buildings would be failing in his function as an adviser if he did not understand the problems involved in maintenance and running costs of buildings and apply this knowledge at the design stage.

The user costs plus the initial costs constitute the total building costs. The initial costs are those which arise directly out of the erection of the building and management of its contract, and cost of construction itself, including the cost of raising capital and any other expenditure necessary to change the state of having an empty site to one of having a site with a building on. Comparatively capital cost is often the major component for decision making. Many organizations concentrate on this to the exclusion of most other facets, prefering to consider asset lives in terms of capital cost related to profitability and payback. Yet it may be the smallest component of cost. For many purposes this results into many inadequate decisions regarding productive assets, but it may well mean the purchase of an asset with a worse performance over its whole life.

On the other hand are, user costs, which include maintenance

repairs, redecoration, operating costs such as routine cleaning and care-taking and in addition such alterations, adaptions, or conversions as may be necessary and the payment of rates and insurances. The essential of costs-in-use is to provide a rationale for choice in circumstances where these alternatives differ not only in their initial costs but also in their subsequent running costs. The use of lifecycle costs enables the various technical and operations options to be compared and trade offs measured in common terms.

The need for the study arose because there is little known about the influence of design on subsequent costs of maintaining buildings. This gap of knowledge means that designers have failed in their duties, for they cannot provide appropriate life cycle costs of the alternative design of roof components with a view to minimizing the total costs of the component.

The role of life cycle costing is to design out maintenance, which is obviously a matter of compromise, since neither the designer nor the manufacturer will be influenced by solely maintenance considerations when planning and producing new building roofing components or materials.

The study hopes to create an awareness within both the public and private sectors in the industry for the use of life cycle costing technique in order to minimize total costs of buildings or their components.

The literature reviewed include the construction process in the construction industry outlining all the various stages right from inception to the completion of the project including maintenance defects and liability period. The concept of total building costs, components of life cycle costing, life spans of the various

roof covering materials are discussed in the literature review section.

Chapter three reviews the various cost models and life cycle cost methodologies with a view to identifying a suitable cost model for use in this study. In this section cost models are discussed, and a cost model has been modified, and identified as suitable and used in this study.

Chapter four deals with building design and construction in Nairobi laying special emphasis on the influence of climate on design, and the effects of weathering on the various roof covering materials.

Chapter five deals with data analysis and discussion on the data. It is shown that asphalt has shorter life span in the study area than the expected lifespan. Roofing felts and asbestos are not significantly affected by change of climatic conditions at 95% confidence level. Galvanized corrugated iron sheets have a longer lifespan in the study area than their expected lifespans according to the results, and finally mangalore tiles show a singificantly shorter lifespans in the study area than in their expected lifespans as identified in the literature review.

The study shows that the total life cycle costs of the various components differ significantly, and therefore caution should be taken when choosing design alternatives. These have been tested bearing in mind the sensitivity analysis of discount rates at both 3% and 6% respectively, as explained in the text of this thesis.

It is recommended that data banks be established by every department or body that deals with the construction of buildings at various towns, municipalities and cities in Kenya. It is worth recommending that more work be carried out in other towns and especially Mombasa Municipality where climatic conditions are more

severe than in Nairobi which possibly would change some of the findings of this study. The study has mainly explored the importance of life cycle costing for roof covering materials, thus laying a basis for future researches on the other building elements.

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CHAPTER I

INTRODUCTION

The Problem and its Setting

There is evidence that large numbers of buildings do not achieve the level of performance intended by the designers and by the client.[1] In many cases shortcomings appear as defects of either design, materials or workmanship or a combination of these proportions the relative of which are difficult to determine. Some instances are spectacular and involve large expenditures on remedial work or in the very extreme cases the demolition of recently completed buildings. Amongst the building elements that have greatest shortcomings are the roofs.

It is believed that there are larger total costs of roof covering components of most buildings than it could possibly have been. In a recent survey it was found that roofs alone accounted for 19.79% of the annual fabric maintenance costs whereas decorations accounted for 25.02%, plumbing 29.88%, electrical works accounted for 4.03%; walls and floors accounted for 4.15%, and miscelleneous accounted for 4.68%.[2]

This shows that roofs are the third most expensive element in the building fabric maintenance according to the study.

Roofs turn out to be expensive during maintenance because of a number of reasons. Namely, the degree of inaccessibility, safety requirements on the part of the operatives, establishment cost in repair work, the nature and type of roof covering materials and the methods deployed during maintenance.

Accessibility to the roof becomes more difficult with increasing height of the building; hence making it necessary to employ hoists to transport materials for repair to the required areas of the roof. This makes minor repairs more uneconomical by increasing the cost of the roof repair. Operatives working on roofs require a high degree of safety precautions as compared to operatives on other elements of the buildings. Thus insurance policies are taken to cater for those operatives working on roofs due to the higher degree of risks involved. For instance, an operative repairing tiled roofs might risk falling down when he walks on tiles whose battens are rotten; or even slide off the roof in case of very steep pitches.

Establishment costs in repair works are normally higher especially where the use of hoists are essential in lifting up materials for repair works. These costs are higher than the initial cost of construction of the roof in case of the whole roof replacement. The contractor pays higher insurance if he were to undertake the whole roof replacement due to the likely consequential damage to other parts of the building.

The nature and the type of roof has a contribution to make towards maintenance costs of the roof. For instance, tiled pitched roofs require cleaning to remove rubbish and biological growth (moss) on them. When executing this exercise most tiles break under weight from the operatives necessitating the need to replace them when they only required cleaning.

In the case of asbestos and galvanized iron sheets, a crack or even rust rotten parts in any one sheet calls for replacement of the whole sheet, and not patching. Also in the case of flat roofs the point at which water enters the building through the roof is not in most cases the direct point for patching because the problem might have emanated from the edges where the skirting might have been cracked or damaged. This means that the whole roof covering has to be ripped off and redone anew. Patching is not good maintenance practice because it is very difficult to trace the cause of roof leakages in flat roofs.

It is also generally observed that there is a high frequency of roof leakage repairs carried out on most buildings, as evidenced by cases of roof repairs in public buildings such as hospitals, etc.

There is lack of information on life spans of different roof covering materials, depending on environmental situation which would make it possible for comparative studies to be carried out with a view to minimizing total costs of a roof component in the whole economic life of the building in question.

It has been found that building maintenance is of great significance to the economy not only because of the expenditure involved, but also because it is important to ensure that the nations stock of buildings, both as a factor of production and of accommodation, is used as effectively as possible.[3] Therefore to neglect maintenance is to neglect an investment which carries a considerable capital debt, and if serious deterioration is permitted future generations would be faced with a major capital burden. Of all the major components of the building the roof is the most exposed to environmental impact and as such requires more maintenance work and most probably does not last the life of the building. A good roof which is well maintained should last the life of the building and it is false economy to save money on the roof during construction, because if it ever requires replacement, it will cause serious dislocation of production and other activities within the building.[4] A leaking roof a part from causing considerable inconvenience to users, can lead to accelerated deterioration of other parts of the building such as ceilings, floors and walls, and can cause serious damage to decorations and electrical installations. Considerable loss of time and disruption of activities can stem from the failure of building components or alterations made necessary by poor design. Education for the designer in the appreciation of maintenance requirements and costs-in-use techniques could be most fruitful.

Designers could contribute significantly to a reduction in maintenance costs if they asked themselves the following questions when designing each component or part of the building. Namely, how can it be reached? How can it be cleaned? How long will it last? and how can it be replaced?[5] Design teams too frequently neglect consideration of maintenance aspects and there is a great need to reduce the gulf between design and maintenance. Occupiers of new buildings should ideally be provided with maintenance manuals listing the materials and equipment used in buildings together with precise details of maintenance required for most efficient and economic use.[6]

Economics examines the process by which scarce resources or factors of production, such as land, labour and capital are allocated amongst the various competing claims on their use. Because maintenance involves the use of resources, it follows that decisions have to be made to the level and the nature of maintenance expenditure.[7] The interdependence and interrelationship of initial and user costs are of prime importance when planning maintenance expenditure. The relationship of one to other is often in inverse proportions. A reduction in future maintenance costs may often be obtained by increasing initial costs; similarily economics of initial costs may follow from the acceptance of an increased level of maintenance costs.

Wright has shown how decisions as to the ratio of initial costs to future (planned) maintenance costs are influenced by time preferences and commercial judgement.[8] Speculative development with the objective of sale will generally show more regard to economics in initial costs than in user costs, although recognizing that too high a level of user costs will jeopardise the opportunity for sale; purchasers will however show concern for user costs.

The provision of buildings with low maintenance costs will assist in reducing the demand for scarce building resources, since such buildings often possess higher user and even environmental benefits, when viewed against the visual cost to society of deteriorating buildings.

Surveyors, maintenance managers and other interested parties need to identify the items generating the highest maintenance costs, and to be constantly questioning the suitability of not only materials and components in meeting their functional requirements but also of the method by which they were assembled.[9]

According to parliamentary question number 1004 of 1985, the house wondered whether the government was aware of the serious roof leakages in Nyamira district hosptial in Kisii.[10] This reveals the significance of maintenance to the built environment. In another article which appeared in the Daily Nation indicated that the government will no longer approve designs for flat roofed buildigns in the country, and that a circular had been sent to all practising Architects, Building Inspectors and all Architects in the civil service.[11] The Permanent Secretary to the Ministry of Works, Housing and Physical Planning was reacting to claims by the Deputy Central Provincial Commissioner about leaks in the provincial headquarters. The Permanent Secretary is reported to have said that virtually all provincial headquarters with flat roofs were leaking. He further instructed the provincial administration to be on the lookout and discourage erection of flat roofed buildings. He cited the flat roofed Kenya Institute of Mass Communication buildings as leaking terribly and taking a huge toll of expensive machinery. He further said there was a possibility of the government making it a policy that there will be no erection of a flat-roofed building in the country.

According to departmental circular number 02/81 prepared by the Ministry of Works, Housing and Physical Planning - cost planning unit, the roof as an element contributes 16% of the total initial cost of construction of standard type houses, 16% of the total cost of standard type servant quarters and $12\frac{1}{3}\%$ of the standard type three-storey Ministry of Works flats.[12] From the above information it is clear that the percentage cost contribution by the roofing element decreased with the number of storeys in a particular type building. The type bungalows show a higher percentage of the initial cost contribution compared to the three-storey type flats. Hence the percentage cost of the roof decreases with the increasing number of storeys, showing an inverse relationship. On the other hand the percentage cost contribution of the other building elements increase with the number of storeys and therefore have a direct relationship.[13]

From a general observation in the city of Nairobi a lot of maintenance work has been carried out on roofs of most buildings. For instance repair works were carried out on St. Andrews University flats on 21st March 1985; St. Pauls University Chapel offices and flats in February 1985, and the Marshalls building along Koinange Street between January and February 1985.

A simplistic view of the cost of the building would be to consider the cost of construction with no allowance for costs which occur in the future. A comprehensive view will include operating costs such as energy, and maintenance. Such costs are known as costs-in-use. These are present and future costs over the entire life cycle of the building. Hence life cycle cost approach which takes into account the time-scale of the building by which the user or client is affected, which may not often be the full expected life of the building.

Stone defined costs-in-use as 'the total real cost (of buildings) to the community.'[14] Although the concept of costs-in-use was initially within the concept of social costs, its relevance to the more limited concern of the building owner was immediately apparent. The building owner was responsible for construction and for most of the maintenance and running costs. The financial burden of a building may in different circumstances fall on a number of people.

Sometimes the occupier is not the owner, sometimes building owner who contracts to erect the building may sell it, or let it, or he may only be an agent. For instance, if a religious body arranges to build a school, part of the initial cost may be provided by that body, part by an overseas donor, part by the local authority, and when it is in use, the running and maintaining the building is born by the occupiers and possibly the local authority as per their divided responsibilities. On the other hand an International body like United States Agency of International Development, for instance may give the Kenya Government a grant in form of built facilities like agricultural laboratories together with personnel for a period of say five years. During their period of stay they are responsible for maintenance and running costs of the built facilities. Once they leave these facilities are handed over to the Kenya government and this adds to the stock of buildings in the public sector. This additional stock of buildings will require to be maintained and kept to acceptable standards for use. The government will now bear the costs of running and maintaining these buildings although it may not have planned for this or may not even be aware of the existing expenditure required. In most cases and especially in developing countries funds for maintenance are not readily available.

It is not uncommon to find buildings which have deteriorated simply because the owner or occupier is unable to cope up with the increasing costs of maintenance, and therefore precautions would have been taken to provide better buildings.

According to Benroy any designer dealing with buildings would be failing in his function as an advisor if he did not understand the problems involved in maintenance and running costs of buildings and apply this knowledge at the design stage.[15] He further advocates that design is essentially evolved by the marrying of various materials, whereas maintenance is of necessity, indirectly considered at all stages and therefore it is only by increasing the importance of this subject in educational establishments or by gaining rapid experience that the relationship between design and maintenance can be properly established.

The user costs plus the initial costs constitute the total building costs or component costs.[16] The initial costs are those which arise directly out of the erection of the building and management of its contract, and the cost of construction itself, including the cost of raising capital and any other expenditure necessary to change the state of having an empty site to one of having a site with a building on it. Hence the developers equation.[17]

$$\text{G.D.V.} = C_s + S_{si} + C_b + C_{bi} + P$$

where G.D.V. is Gross Development Value.

C_s is Cost of Site.
C_{si} is Cost of Site Finance.
C_b is Cost of building including fees, legal and agency.
C_{bi} is Cost of building finance and
P is profit expected by the developer which is often expressed as a percentage.

Comparatively capital cost is often the major component for decision making. Many organizations concentrate on this to the exclusion of most other facets, preferring to consider asset lives in terms of capital cost related to profitability and pay back.[18] Yet it may be the smallest component of cost. For many purposes this results into many inadequate decisions regarding productive assets; and it may well mean the purchase of an asset with a worse performance over its whole life. On the other hand, the user costs, which include maintenance repairs, redecoration, operating costs of any plant and installation and other running costs such as routine cleaning and care-taking, and in addition such alterations, adaptions, or conversions as may be necessary and the payment of rates and insurances. The essential role of costs-in-use is to provide a rationale for choice in circumstances where these alternatives differ not only in their initial costs, but also in their subsequent running costs.[19]

Significance of the Study

The use of life cycle costs enables the various technical and operational options to be compared and trade offs measured in common terms.[20] This enables patently uneconomic possibilities to be eliminated whether between different building components or within one range.

The reason why the study was undertaken is because little is known about the influence of design on total costs of buildings. This gap of knowledge means that designers have failed in their duties, for they cannot provide an appropriate life cycle cost of the alternative designs of roof components with a view to minimizing the overall total costs of the component. Thus the construction industry in Kenya is providing less than optimal value for money solutions to its clients who bear and sponsor the burden of subsequent expenditures. This suggests that there is information problem and data feedback in construction management. Academic research has shown that

> "... experience is personal: it spreads in shared tasks, and travels with a person quite well, but it passes on hardly at all on paper or by consultants visitations."[21]

"... it passes on hardly at all on paper ..." these eight words summarise the information problem in engineering management and data feedback. The same can be said of the construction industry not only in Kenya but also to the rest of the world.

There is evidence that there is a need for minimizing the total costs of buildings within their economic life spans, because of the lack of appreciation of the maintenance funding in most organizations or clients.

> There is rarely an obvious end-product in building maintenance, and the effect of neglected industrial buildings, for instance, will seldom be as serious for the owner as the disruption caused by a breakdown in production following neglect of plant maintenance.[22]

For this reason building maintenance is often considered as one of the first items for budget cuts when retrenchment becomes necessary. Consequently it can be said that even where maintenance policies do exist, the funds allocated to maintenance are in most cases allocated to other uses. Few organizations regard building maintenance as the preservation of the value of the asset as a functioning property. Thus bedgeting for the total upkeep of the property is rarely conducted in full knowledge of all relevant facts.[23]

Barden points out that the role of life cycle costing is to design out maintenance, which is obviously a matter of compromise, since neither the designer nor the manufacturer will be influenced by solely maintenance considerations when planning and producing new building roofing materials.[24] This can reduce the repercussions from that tendency of investing capital in new works only and paying insufficient or no regard to replacement policy.[25] Delayed expenditure in these areas means higher future costs, owing to increased prices and possibly higher operating costs. Larger items of machinery are generally financed out of capital whereas items like roof renewals or replacement of building services are often treated unsatisfactorily as write-off or revenue expenditures.[26] To overcome these difficulties, Jarman advocates financial authorizations for new assets to include the capital cost of the project, depreciation and running costs so that it can be considered as a whole from initial conception.[27]

The study hopes to create an awareness within the public and the private sectors for the use of life cycle costing technique in order to minimize total costs of buildings or their components. This is felt essential because economic resources are always scarce and the little there is should be allocated to the most needy aspects of the economy.

According to Cullen, if on average the maintenance expenditure on a component or building element is equivalent to 5% of its construction cost, it is considered as a marginal figure, and there should be no worry about the running costs of buildings. But if an amount equivalent to 25% of the elements/components construction costs will be spent on its maintenance and getting on to two-thirds of its construction cost then the running costs gain significance provided that the long term view is taken into consideration.[28]

The benefits to the economy or the individual users if the results of the study about roofs are known would be:

(i) To provide appropriate information to the design teams with respect to the competing alternatives in roof design, and the choice of roof covering materials.

(ii) To provide a replacement strategy to maintenance surveyors with regard to material/component life spans, and enabling the use of a roof element maintenance manual.

(iii) To provide a basis for decision making in the early design stages for optimal value for the money solutions to clients who bear and sponsor construction works and

(iv) To provide buildings with low maintenance costs which will assist in reducing demand for scarce building resources, since such buildings often possess higher use and even environmental benefits, when viewed against the visual cost to society of deteriorating buildings.

The Study Hypothesis

The reason why roof covering components do not achieve the level of performance intended by designers, is because designers only consider initial costs without due regard to user costs. This approach precludes the user costs which include maintenance, repairs, redecoration, operating costs of any plant and installation and other running costs such as routine cleaning and care taking, and in addition such alterations or conversions and the payment of rates and insurances.

For the purpose of life cycle costing user costs depend on the life cycles of components and elements under given climatic conditions. It is based on the frequency of failures of the component or element in question relative to the economic life of the building. The roof being one of the major components of a building is the most exposed to environmental impact and as such requires more maintenance work and most probably does not last the life of the building. Most elements of the building are designed to last the economic life of the building. For instance, substructure, reinforced concrete frame, floors, structural roofs and walls. Windows, doors, electrical installations and plumbing works do require maintenance but not so frequently. Finishes and roof coverings do require maintenance mainly due to environmental exposure on the part of the roof and excessive use on the part of the internal finishings. The capital outlay on the roof forms $12\frac{1}{3}$ - 16% of the buildings construction cost and therefore is substantial to warrant its study.

The Study Assumptions

It is a basic assumption of this study that proper use of life cycle costing techniques would lead to appropriate choice of roof covering components.

Any replacements carried out is through the normal wear and tear and that the maintenance policies of the particular users do exist given the expected lives of components.

It is also assumed that roof construction is per specification and building regulations as contained in the Kenya Building Code. Designers are interested in the aesthetic function of the built environment and that the clients are interested in the cheapest costs which they can comfortably afford. It is also assumed that designers do not carry out a comparative cost study between alternative design solutions so as to come up with the most optimum real cost analysis of the roofing element, and therefore subsequently giving the client the worth for his money. It is the prerogative of the design to determine future costs of the roofing element by careful comparative studies on different roof covering materials available to the design and maintain the basic requirements of the roofing element. It is also assumed that engineers have used life cycle costing techniques, but Architects have not used life cycle costing techniques successfully to analyse building costs. Building Economists or Quantity Surveyors who are concerned with buildings have not come nearer to their engineering counterparts and the use of engineering models of life cycle cost analysis. The study recognizes that one way of carrying out life cycle cost analysis is through the examination of initial costs of components, their replacement period, and their present cost values incurred as a result of having the component in its present use.

The Objectives of the Study

The primary objectives of the study is to analyse the total costs of roof covering components over its life span and in relation to the economic life of the building on which it is laid. Specifically the study will attempt to:

(i) Analyse the total costs of using each of the five roof covering materials, namely roofing felts, galvanized corrugated iron sheets, clay tiles (mangalore), asbestos and asphalt over the economic life of the buildings they are laid on.

(ii) Analyse the frequency of failure or replacement of the roof covering material in question.

(iii) Relate all costs of the material used to the economic life of the building taking into account different rates of return on capital employed (sensitivity).

(iv) Compare the total costs of the five different roof covering materials and attempt to give an optimal value for money solutions to development options.

(v) Indicate the patterns of the replacement cycles of these materials under the case studies climatic conditions.

After the above tasks are completed conclusions will be drawn and recommendations made that would be useful for feedback to the future of buildings in an attempt to design out roof maintenance and achieving optimal value for money for users.

The Scope of the Study

The study will be specifically confined to the costs of the various roof covering materials in use in Kenya today. These are bituminous roofing felts, asphalt, asbestos, galvanized corrugated iron sheets, and clay mangalore tiles.

Thatching materials are not taken into consideration because they are used in temporary buildings and they are not commonly used in the study area; except in the rural areas. The study will not look at the life cycle cost of the whole building, because a building is a composition of many and different components with differing life spans, whose life cycle cost analysis can be carried out separately relative to the economic life of the building in question. The focus of the study is on the total life cycle cost of roof coverings incurred as a result of the design decisions made at the various design stages, and throughout maintenance period. The study will find its use at the early design stages where decisions are made on material specification, cost targets for each particular element and the overall cost of the building project.

The case study to support the reserch was originally intended to be carried out on the Kenya Railway Corporation's buildings in Nairobi, Ministry of Works, Housing and Physical Planning and Nairobi City Commission. Kenya Railways Corporation could have been chosen as the sole research area for homogeneity of management but it was not possible to get the information covering all the five roofing materials under study. The problem of different managerial and financial or even maintenance policies is taken care-of by the fact that, all information is obtained from the same organization.

The period of analysis should be at least twenty years, because a period less than this may not have the necessary information required for life cycle costing. This makes the chosen area of study suitable for the research because the majority of the buildings surveyed are more than twenty years old, and it is within this period when possible replacement have been carried out. The study is confined within Nairobi Province where the effect of environmental impact is relatively uniform throughout the seasons of the year.

The Research Methodology

The exercise of data collection involved a survey of maintenace records from Building Registers which gave the summary of the defect in question and the overall cost of repairing that defect. The date on which the repair and costing were done was indicated in the building registers. The defect reporting date is not available from the maintenance registers, and therefore maintenance work instruction sheets were extracted from the works instruction property files where they were separately kept; and where they were not separated, the general maintenance files right from the erection dates of the buildings chosen from the registers, going as far back as the year 1900. The reporting delay time was not taken into consideration because the people who report the defects are not qualified inspectors and as such it would be too difficult to ascertain the time lapse between the time when the defect would have been noticed by a qualified inspector and the time when the occupier would report the defect to the maintenance department.

An attempt was made to get construction costs for the various roof covering components from some of the oldest professional quantity surveying firms in Nairobi. The remaining information was obtained from library sources such as books, journals, hand books, thesis, dissertations and manufacturers catalogues.

The Data Population

The total population of building with roof leakages as per the records of Kenya Railways Maintenance Building Registers were 450 buildings. Of these only 188 had files whose records were scrutinized and taken down in order of dates in which the defects had appeared and repaired. This information was obtained from the work order sheets which were prepared by the maintenance officers. 47 buildings have been identified to have galvanized corrugated iron sheets, 5 with asbestos roof covering, 15 with roofing felts, and 121 with mangalore tiled roof. From Norfolk towers 4 No. blocks had been identified to have asphalt roofing covering and the maintenance records were available for examination. From the Ministry of Works industrial area depot 254 buildings had been identified to have roof leakage problems, however their maintenance records could not be traced. There were only three buildings whose information was available from the whole lot. From City Commission three estates were identified as a source of the required information, however the maintenance records were not available for two reasons. First the commission keep their records for a maximum period of ten years and 15 years for classified documents. After these periods these documents are destroyed by selling them to waste paper recyclers under supervision for the unclassified documents, and burnt under strict supervision for the classified documents. Secondly the Commissions Architectural and Engineering Department burned on the 26th January 1986, thus destroying all the possible records which one could have perused through to get any reasonable information for the study. The only information of some importance obtained from the City Commission's Building Maintenance Department are the construction dates for Ziwani, Outering and Pumwani Estates.

Treatment of the Data.

The raw data would be used to find the average life spans.

$$\bar{X}, \mu = \frac{\sum_{i=1}^{n} X_i}{N}$$

where $\bar{X}, \mu$ is the population average or mean.

X_i is the raw score.

Standard deviation would also be calculated for the raw scores.

$$\hat{s}; \sigma = \sqrt{\frac{\Sigma(X_i-\mu)^2}{N - 1}}$$

To test the hypothesis and the significance level, chi-square and analysis of variance would be used.

Chi-square, Analysis of variance and coefficient of variation would be used in the testing of the results; and comparison.

$$cv = \frac{\hat{s}}{\bar{X}} \times 100\%;$$

where cv = coefficient of variation.

$\hat{s}$ = standard deviation.

$\bar{X}$ = calculated mean.

$$X^2 = \sum \frac{(f_o - f_t)^2}{f_t},$$

where f_o = observed frequency

f_t = theoretical (or expected frequency).

The test of significance is taken to be 0.05 alpha level. Thus the results will be accepted at 95% confidence level.

The results of information and data collected will be presented in written texts with data matrix tables, graphs, charts and equations where necessary. The costs were expressed in percentages of Kenya shillings per square metre of the component to be analysed.

Definition of Important Terms

The need to define terms in a study of this nature arises firstly because terms have a special meaning in different fields or under special circumstances. A building component is a constituent part of a building element. For instance the roof covering is part of the element roof, and therefore it cannot be called an element on its own. A group of components form a building element. This is a working definition for purposes of the study.

On the other hand a building element has received different definitions from different authors. It has been defined as "a major component common to most buildings which usefully fulfills the same funtions irrespective of its construction and specification.[29] Another author defines it as that part of a building which always performs the same functions irrespective of building type.[30] The last definition is from Seeley which defines it as 'a component or part of a building that fulfills a specific function(s) irrespective of its design, specification, or construction such as walls, floors, and roofs.[31] Many cost plans and cost cnalysis are prepared on elemental basis. It is this last definition which is used in this study. Building materials are the substances from which components are made, for instance cement, sand, aggregates, clay, timber, iron ore etc. The other terms which are going to be used frequently in the study are value analysis, costs-in-use, life cycle costing, terotechnology, value engineering, value management, economic life of a building and maintenance.

The term value analysis has been defined as the study of the relationship, of design, function and cost of any product, material or service with the object of reducing its cost through modification of design or specifications, manufacture by efficient processes, change in source of supply (external or internal) or possible elimination or incorporation into a related item.[32] Value addresses itself to minimizing both initial and future running costs of an item. It is applied as a tool and a planning procedure in engineering and industrial design. Lislie points out that the concept of value is like the concept of sin, because it varies. There are four type of values, namely, the use value, esteem value, exchange value and cost value.[33] However many times cost and use values are confused. For instance if somebody goes to a material stockist shop and picks an item from the shelves, and asks the shopkeepers "what is the value of this? They think for a while and come up with a figure based on labour, material and direct burden. As a result they say so many shillings or cents. Actually their answer is based on what it would cost to make the particular item in question. Whereas the value would be considered as the lowest price for reliably accomplishing a task or a service. In other words, we are trying to obtain functionality and so our thinking should be functionally oriented. Thus value analysis presents itself as a system of techniques or a common sense method of thinking which addresses itself to detecting unnecessary costs and providing the techniques or tools to be used to remove unnecessary costs.

The term costs-in-use was devised by P.A. Stone at the Building Research Establishment in 1950s and has been defined as "an essential tool for analysis by the designer who is considering alternative design solutions to his brief, embracing as they do, important implications not only for costs of construction but also for future maintenance and running expenses.[34]

The term life cycle costing was devised by the Logistics Management Institute of the United States of America, which defined it as follows:-

> It is the total cost of ownership of a system during its functional life. It embraces all costs associated with feasibility studies research, development, design and production, and all support, training and operating costs generated by the operation of the equipment.[35]

The term is both applicable in engineering as well as the construction industry. There is no way one is going to talk about life cycle costing techniques without touching on the role of terotechnology. Terotechnology is a concept which helps to bridge the gap between design and maintenance and is concerned with all the processes by which considerations of building performance are applied to design and construction. These processes comprise dialogue between providers and users of buildings and other bodies in the technical press etc. also organized feedback within the organization or within a particular project group. This includes the modification of existing codes, specifications, guides, and other reference documents used to define the standard of construction, education and training of practitioners at all levels and stages. The definition of terotechnology appears in the revised British Standards Institute glossary of maintenance terms in terotechnology B.S. 3811 1974. However the Building terotechnology group have revised this definition as far as the application to construction industry is concerned to read:-

> a combination of management, financial engineering and other practices applied to physical assets in persuit of economic life cycle costs. In the construction sense this practice is concerned with design and specification for reliability and maintainability of buildings and structures including their associated, plant, machinery, and equipment with their installation, commissioning, maintenance, modification and replacement, and with the feedback of information on design performance and cost.[36]

Briefly this could be defined as "resource management," "costs of ownership", "cradle to grave management," "physical asset management" or "long-life-care."[37] However at this point it should not be assumed that the words terotechnology and maintenance are synonymous. Maintenance is being regarded as the axle on which rotates the wheel of life cycle costing. It is logical to regard maintenance as the central feature of terotechnology because it occupies the midway between design and disposal.

Terotechnology only serves to emphasize that maintenance should be eliminated whenever this can be justified, and if not possible it can be minimized. B.S. 3811 defines maintenance as "work undertaken in order to keep or restore every facility, that is every part of a site, building and its contents, to an acceptable standard." The processes envisaged are keeping, work carried out in anticipation to failure and restoring work which is carried out after failure.

The former is usually referred to as prevetative maintenance and the latter as corrective maintenance. There is also the concept of an acceptable standard. This may be understood as an acceptability to the person paying for the work, to the person receiving the benefit or to some outside body with responsibility for enforcing minimum standards.

The term "value management" is defined as an engineering management discipline that focusses attention on basic function in a particular design or construction process; emphasizes meeting the basic function at the lowest life cycle cost without reduction in quality and acceptable aesthetics; encourages evaluation of new systems and materials through innovative design.[38] On the other hand it has also been defined as the systematic application of recognized techniques which identify the function of a product or service establish a monetary value for that function and improve the necessary function reliably at the lowest overall cost.[39]

These two definitions illustrate the interchangeability of the terms value engineering and value management and additionally emphasize that life cycle costing is inseperable from value methodology. The last term "economic life" has been defined as "the period over which the occupation of a particular building is considered to be the least cost alternative for meeting a particular objective."[40] The moment another alternative building which is cheaper becomes available, the building will strictly speaking, have reached the end of its economic life, although its use may continue for other reasons. Social and legal obsolescence occurs when human pressures render a building unacceptable due to changes in expectations and standards; these are comfort, appearance and safety which is often reinforced by legislation.

FOOTNOTES

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CHAPTER II

REVIEW OF RELATED LITERATURE

The Construction Process in the Construction Industry

The modern construction industry is descended in a direct line from mediaeval builders of cathedrals, castles and towns, which where; they still survive exercise a strong influence on todays built environment, and also influence our reactions to modern buildings.[1] Such survivals are probably the oldest examples of a co-ordinated industrial activity employing many specialists under a central direction. Most of the early building trades continue to play a part in modern building but the number of different specialisms has increased and the sophistication of techniques used has grown so that the building is now one of great complexity. A brief outline of the construction process from the first decision to build to the time when the performance of the building is fully evaluated, a period spanning many years will show the importance of making special provision for the transfer of information and data between different specialisms and different phases, so as to harmonize the need to agree on construction policies which offer the best hope of giving value for the building industry. The construction process involves the brief, inception and feasibility study; sketch plans (outline proposals and scheme design), working drawings (detailed design, production information, bill of quantities and tender action), and site operations (construction, commissioning, maintenance and feedback).[2] Although feedback is described as the last stage in the Architectural design process, it should actually run through between each of the stages of the design in the same manner a spoke holds the hub of a wheel.[3] The flow chart in figure 2.1 illustrates the stages or operations on site and the final evaluation of buildings in use so that the upward loops describe the role of the feedback.[4]

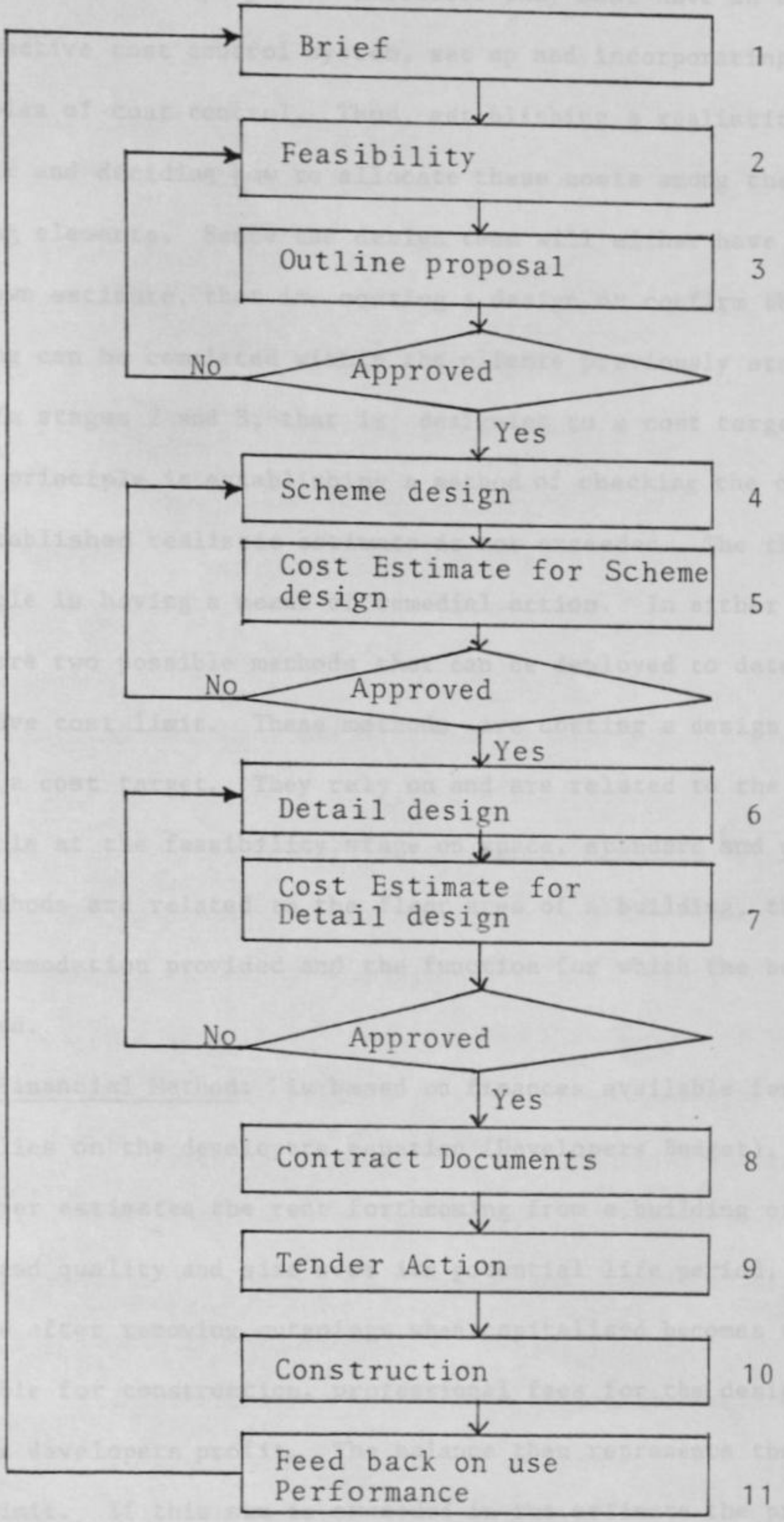

Figure 2.1: CYCLIC NATURE OF DESIGN PROCESS (Based on RIBA Plan of Work).

Stages 4, 5, 6 and 7 are the most crucial in determining the overall cost of the project. Therefore they must have an established and effective cost control system, set up and incorporating the three principles of cost control. Thus, establishing a realistic first estimate and deciding how to allocate these costs among the various building elements. Hence the design team will either have to calculate their own estimate, that is, costing a design or confirm that the building can be completed within the clients previously stated cost limit in stages 2 and 3, that is designing to a cost target. The second principle is establishing a method of checking the costs so that the established realistic estimate is not exceeded. The third principle is having a means of remedial action. In either situations there are two possible methods that can be deployed to determine an effective cost limit. These methods are costing a design and designing to a cost target. They rely on and are related to the information available at the feasibility stage on <u>space</u>, <u>standard</u> and <u>use.</u> Thus the methods are related to the floor area of a building, the standard of accommodation provided and the function for which the building is intended.

<u>Financial Method</u>: is based on finances available for building and relies on the developers equation (Developers Budget). Thus a developer estimates the rent forthcoming from a building of a given value and quality and size over its potential life period, and the balance after removing outgoings when capitalised becomes the sum available for construction, professional fees for the design team, and the developers profit. The balance then represents the absolute cost limit. If this sum is exceeded in the estimate the project may well not be persued. In capitalising the balance, the developer finds from annuity tables how much he would have to invest

at an acceptable rate of interest to obtain an annuity equal in value to his expected yearly balance of rental over the expected life of the building. This technique is often the province of valuation surveyors whose expertise opinion would be sought for. The developers equation is as follows:-

Gross Development = site cost + site cost
Value (GDV) Finance + Building Finance
+ Building Cost Finance
+ Professional fees
+ Legal Agency and
Advertising costs
+ Developers Profit.

Interpolation Method:

The costs of other buildings of the same type are studied bearing in mind the space and standard provided by these buildings. The total cost for each building is expressed in a similar form and in a common unit, such as cost per square metre. The total cost of the building is the cost/m^2 multiplied by the total floor space in square metres. From these range of costs an appropriate choice of cost limit can be made, bearing in mind and making adjustments for differences in space, standards and use. Any major changes required are thus made at this point. This method has been extensively used by the design team and still is in the process of refinement.

Life cycle costing techniques should be applied in stages 6 and 7; where principle two (there must be a method of checking) and principle three (there must be a means of remedial action) are incorporated into the cost control system. This is the most crucial stage in the construction process. It is during this stage that detailed designs are prepared for each element; then the designs are cost checked by the Quantity Surveyors. If the cost element design is within the element cost target, then consultants confirm to the client that the element design is suitable for production drawings. Should the cost element design exceed the cost target, then the element design should be changed so that it is within the cost target. On the other hand, should the cost element design be unrealistic, then the cost targets should be adjusted throughout the cost plan, thereby releasing funds for the elements in trouble. Thereafter a final elemental cost check is carried out, after which the design is confirmed as suitable for production drawings.

This is the stage on which the results of this study would be of paramount importance, and it is essential that future costs should be given consideration. Being the most crucial stage in the design process real and effective cost planning should be taken into consideration which encompass both initial and future costs of an alement or design component. It is the lack of appreciation of future costs which makes most cost planning of many projects inadequate. The term cost-in-use is used to describe this technique, but a more apt term is the 'total cost'. More recently the term life-cycle costing has gained popularity to embrace the total cost of an asset over its operating life.[5] Using these techniques which both have the same objective in mind, all costs in erecting, maintaining and using the building are converted to a single sum, which is the annual cost or present value of costs over the life of the building. They are employed as a design tool for the comparison of different designs, materials and constructional techniques. Hence they provide a valuable guide to the designer in securing value for money for the employer, and may also be used by property managers or developers to compare costs against the net value accrueing from future rents less outgoings.

Most design decisions affect running costs as well as first costs, and what appears to be a cheaper building in the long term may be far more expensive than one with higher initial costs. Running costs often amount to about two-thirds of the annual equivalent first costs for residential buildings, and for industrial buildings can be as much as one-and-a-half times the equivalent.[6] The proportions vary widely from one class of building to another.

There are problems in assessing the lives of components and materials, discounting rates, inflationary rates, effect of taxation, changing statutory and occupancy requirements and other factors. Nevertheless it is better for the design team to make these comparisons rather than ignore future costs. If small differences result then too much regard would not be paid to them, but where significant differences arise, then they warrant careful consideration at the design stage.

The Concept of Total Building Costs

The initial cost of constructing a building attracts our attention as being the largest expenditure made at any one time. This of course is a simplification. The initial cost is in fact spread over a period of months and in the case of large projects it takes place over a number of years. From the building owners point of view it may represent cash outflows and inflows if the construction costs are being financed by a long term security loan, the cashflows may be spread over years. What distinguishes initial costs fundamentally from other costs is that the amount of obligation is known before the building starts its long life, and that this obligation is greater than any other associated with the building.[7] User costs is a convenient expression to refer to all costs other than initial costs (otherwise known as costs-in-use). The initial costs plus user costs together constitute the total building costs.

Life cycle costing involves the examination of initial capital costs and future operating costs of a complete building or parts of a building over a selected period of time, in order to determine the most effective design option.[8] The technique converts all the costs in erecting, maintaining and using the building to a single sum which is the annual costs or present value of all costs over the life of the building. The components of life cycle costing are planning, analysis, and life cycle cost management.[9]

Life cycle cost planning is the process by which the decisions taken during design process are supported and improved. The technique involves the prediction of overall eventual operating costs, the ability to select the most attractive alternative on the basis of future costs as well as capital costs. The technique of life cycle cost planning equates very closely to everyday decision making of practising Architects. Life cycle cost analysis is the collection of data on running costs and performance of existing buildings or their elements. Information on the building type, location, the structural system of the building, any drawings available, nature of the information that exists on running costs, a record of the maintenance policy that has been adapted in the past and the period during which the building has been occupied. The date at which various costs were met is recorded so that the effect of the change in money value over the years may be allowed. Life cycle cost analysis is an essential part of the technique and philosophy of life cycle costing.[10]

Life cycle cost management follows on from life cycle cost analysis, which involves the examination of data from the past. This relates to the means by which costs being incurred now and in the future may be controlled, and the making of recommendations on how the building should be utilized and operated more efficiently. It includes the establishment of appropriate maintenance policy and the provision of data for use by the accountants such as lives of different elements.[11]

Bathurst[12] emphasized the use of total cost concept in elemental cost planning such that initial capital costs, repairs and replacements and fuels and cleaning costs are expressed as annual charges of the building costs. However the information used in this analysis is based on assumptions to demonstrate how the method can be used by designers. Bathurst has not looked at life cycle costs of the various building components or elements as the roof.

Harvey[13] wrote an article on the technique of life-cycle costing together with a terotechnology approach, and demonstrated how such an approach could provide a major decision making and profit improving in manufacturing industries. However he acknowledges that, the technique is fairly used widely within military investments, although some major industrial enterprises are already applying life cycle costing or are researching into its possible application. The article is theoretically based, and does not have supporting case studies to demonstrate the effectiveness of his ideas. Nevertheless this study does not concern itself with the theoretization of the life cycle costing as a technique, but on both the application and determinination of lifespans of the roof covering materials in question, and within the defined area of study.

Alastair Law[14] observed that an examination of the distribution of total costs throughout the useful life of a building demonstrates the justification for applying life cycle cost analysis. What is even more dramatic, however, is the fact that, if one considers the total cost of ownership as being all the costs associated with the useful life of the building, that part associated with the design represents by far the smallest proportion. At the same time, it is the designer who, by his skill as a planner and his ability technically, can make the greatest impact on future life costs. He has observed that the technique is most common in the selection of energy sources and systems.

In his opinion a valid life cycle cost analysis should include function, time frame, quantities, quality level, level of service, economic conditions, market conditions and operating conditions. According to Alastair the capital cost or first cost contributes to approximately one-third of the total life cost of a building. However he emphasized on the use of the technique without carrying out a cost comparison study to demonstrate how design solutions could be arrived at.

Smith published a paper of a case study which was carried out in Essex, U.K.[15] In Essex the annual accounts of the Essex County Council showed that, out of the gross revenue expenditure 14% was accounted for by premises related running costs and interest charges. The council having recognized the need to extend its budgetary control over future costs of capital programmes, the council amended its standing order in 1981 to read:

> Before entering into a contract for the execution of any capital work which is estimated to exceed £5,000 sterling pounds in value, a chief officer shall provide the county council an estimate of the annual running costs and staffing requirements arising from taking the work into use.[16]

The effect of the amendment of its standing orders in real terms meant an increment of the value of projects generated using financial appraisals from £3.9 million sterling pounds in 1982/3 to £12.3 million sterling pounds in 1984/5. The increase in Essex, capital building programme may not be simply attributed to the use of life-cycle-costing showing that increased capital will be offset by future revenue premises related savings. According to the paper, many of the councils projects over 30 or 40 years do show that capital cost will be offset by revenue savings, but there are also many where the capital expenditures do not produce the lowest Life-cyle cost but is nevertheless seen as being good value for money. In a bid to replace old timber temporary classrooms with permanent buildings, the council found that continued maintenance of old timber classrooms was not good value for money, when many aesthetic and organizational disadvantages for schools are taken into account. The council carried out an example of the application of life-cycle costing to a scheme for replacing a junior and infant school, built in 1960s in South Essex. This had developed a number of defects which would require substantial maintenance expenditure over ten years. Four alternatives were considered. The first option was to carry out all necessary major repairs to both school buildings to bring them upto a maintainable standard. The second option was to carry out major repairs to the junior school building, extend the junior school, demolish the infants building and sell part of the site. The third option was as option number two, but retaining the infants building with extensions and demolishing the junior school, or the fourth option of building a new primary school, demolishing the two existing buildings and sell part of the site.

From the results of the life-cycle cost estimates carried out on the two existing schools, the county council chose option 4, which not only provided the lowest life-cycle costs, but also provided the community with a new school built to modern standards of internal planning and design as well as releasing the most valuable part of the site for house-building. However this study did not give life-cycle costs for the roofing covering component of buildings with different construction materials.

According to another study [17] carried out at Strathcycle University (U.K.) it was found that costs-in-use of some existing industrial buildings could be reduced by design, often at no overall capital cost. The study provides both design guidance and methodology for use in refurbishment and new buildings. The study concentrated on the five chosen buildings which were typical factories representing a range of building forms, for instance terraces and semi-detached, office areas, materials and structure, past alterations, ages, lengths of lease, company types, production processes and levels of technology. The results of the study showed that one of most costly elements was the roof in the first group of buildings, and this element required no replacements or unnecessary maintenance expenditures if the buildings were designed according to their guidelines. The roof covering component appeared in the five chosen buildings to have been one element design could have taken precautions to avoid future maintenance and running costs. However the results of this study were not very accurate because of the problems of getting the actual costs-in-use, and therefore their estimates were based on assumed frequencies of failure of the various building components which were considered in this study.

Flanagan[18] believes that although information exists about the expendiency of using life cycle costing methods, it is not put across to the client convincingly enough. He supports his arguement by citing the works of David Hoar who is a directing surveyor of Nottinghamshire County Council. Hoar observed that people are not always aware of how much their buildings would cost; and that under used buildings are phenomenally expensive. Hoar cites the example of a study into the running costs of two schools in Nottinghamshire. One school is a modern 1980s building; the other was built in 1890s. The resulting cost ratio for the two schools is 1:3.5, which means that the older school is 3.5 times more expensive to run compared to the modern school. Clearly the older school is very uneconomical, although before the study took place, the authority had no idea on this. Although roof covering is one of the many building components the study was primarily concerned with the life-cycle costing of the two schools with respect to gross maintenance and therefore did not single out the roof covering as a separate component thereby focusing attention onto it.

A study of the maintenance costs of 50 primary schools and ten secondary schools carried out at Bristol Polytechnic[19] showed that the maintenance policy of the county played a great part in the order of maintenance expenditure. Because of the maintenance policy of the county on flat roofs, 60% of the flat roofs had already been replaced by 1982. The study showed that roofing had the largest expenditure because the county's policy required the identification of flat roofs which were thought to have reached the end of their useful lives. It was found that, flat-roofing repairs usually started to appear as major recurring items between the eighth and twelfth years of its life. Heating systems were a large element in recurring repairs with boiler renewals starting to occur mainly in the 16 to 22-year life. Floor finishes almost invariably incurred costs which fell within the definition of minor costs, although a larger number of jobs were recorded.

Roy Swanston[20] said that a life cycle costing approach offers potential cost savings when applied to the existing building stock. Indeed this is probably one of the most important areas of application of life cycle cost techniques in building. The basic point is that while initial costs are clear and visible at an early stage, longer term costs can far outweigh initial capital costs and should have a much stronger influence on decisions with respect to buildings and building elements than currently. This is illustrated by life cycle cost commitment for a small primary school,[21] where running costs, which were incurred either annually or at periodic intervals and were compared with the capital costs which were incurred at the construction stage. Capital costs accounted for 42.5%, fuel 10.3%, cleaning and caretaking 28.3%, rates and sewerage 7%, routine services 3% and replacement and maintenance 8.9%. It is clear that capital costs accounted for well under-half of the total cost commitment, being only 2.3% greater than combined cleaning and caretaking, replacement and maintenance and routine servicing costs.

A further study [22], showed that the life cycle cost commitment for a new flooring system installed in an engineering facility were as follows: Initial capital cost which included carpet and floor screed accounted for 39.5%, maintenance (cleaning) 41.1%, and replacement accounted for 19.4%. Again it can be shown that concentration on initial costs can give a very imperfect view of the actual costs. However these two studies do not say anything about the lives of the components which were understudy and therefore have very little contribution on the failure frequencies of the components such as roof covering components.

Thabit[23] carried out a comparative study between gas turbines and electric motor used for main drives in the oil and gas industry. The work presented a study into life cycle costing concept, assessing its applicability to project appraisal in the developing world, and advising on the profitability of its use in the oil and gas industries. It also undertook to design a plan aimed at introducing the life cycle costing technique to the industrial management procedures. A decade of the use of life cycle costing techniques was analysed and an up-todate state of the art summarised. This was further supported by a questionnaire raised to monitor the progress of two previously published cases of life cycle cost applications. An actual case study was detailed to demonstrate the interaction between physical and financial factors. The study looked into the main power requirement through a prime mover selection exercise; concluding that energy is the main cost driver of the life cycle. This led to a construction of a new 8-stage life cycle cost methodology for the oilfield system, associated with functional analysis, cost breakdown structure, and cost parameters checklist. Present day practices were tested on the case study indicating how and where life cycle costing technique can be applied most profitably. In addition areas of improvement on the approach adopted by the case study were identified for re-appraisal. Full potential of the life cycle cost application was not realized due to the critical unavailability of cost data and information available to the researcher at the time of investigation. In attempting to reduce the effects of such limitation, a 4-step programme was recommended to create a favourable environment prior to the use of life cycle costing technique.

The Determinants of the Actual Life Span

Actual life span of a structure will vary with the circumstances and does not necessarily relate to the physical lifespan of the structure; nor to the period over which the capital has been borrowed. Building lifespans came to an end very rarely due to the building collapsing, but usually due to obsolescence of some sort. This may be:

(i) Physical
(ii) Functional
(iii) Economic
(iv) Social and
(v) Legal

Obsolescence in very broad terms is a loss in value for reasons other than the physical deterioration. The test of obsolescence is whether or not local demand is sufficiently strong to warrant the cost of reconstruction of a property, if it were to be destroyed and then rebuilt with the same design and quality of construction. If the market conditions do not warrant such rebuilding, the property is subejct to some form of value-reducing obsolescence.[24]

Physical life is almost never a deciding factor. It is possible to save almost any building, regardless of condition, if the reasons for doing so are good enough, and the money is available. Functional obsolescence affects the life of the building when the building ceases to be used for the purpose for which it was intended. This may be generally due to changes in demand derived from the goods or services produced through the use of that particular building. This is closely linked to its economic life. Economic obsolescence occurs when the building is considered to be the least cost alternative for meeting a particular objective. As soon as another alternative building which is cheaper becomes available, the building will, strictly speaking, have reached the end of its economic life, although its use may continue for other reasons.[25] Social and legal obsolescence occur when human pressures render a building unacceptable due to changes in expectations and standards. These concern comfort, appearance, and safety which is often reinforced by legislation. There can be no rules about which factors will eventually determine the actual life span. It must be a matter of trying to predict how these different aspects of lifespan, and obsolescence will act together to determine the point at which the building will be demolished, sold or radically altered.[26]

The length of time over which capital is borrowed is not a suitable basis for forecasting lifespan, neither is the life calculated for depreciation against taxation. Lifespan concerns the life of the building and the life of its component parts. When calculating the life cycle costs of a part of a building the life to be used is not the life of the part but the life of the building it is in. That is, the cost of replacing the part however many times is necessary, must be included. Economic life of a building is the most commonly used lifespan in development studies, because it relates to the objectives of life cycle costing in that, in this period the building commands a capital value (price) greater than the capital value of the cleared site. Capital value decreases due to the fact that buildings are subject to wear and tear in use, and that better standards of accommodation are expected; so that an older building will not include modern conveniences, and it will not be built of newer materials.

Life Spans of Roof Covering Materials

The choice of roof covering material as related to the economic life of the building is vital, because it would be false economics for any designer to make savings on the roof when considering initial costs of construction.[27] If the roof ever requires replacement it will cause serious dislocation of production and other activities within the building and the consequential costs would be enormous if all are quantified in monetary terms.

Lifespans of roofing components depend on the degree of exposure to the atmospehre. Exposure is influenced by rainfall, direction of prevailing winds, microclimate, atmospheric pollution, and aspect and height of the building. Durability of building materials is also influenced by frostation, crystallization of salts, sunlight, biological agencies, abrasion and impact, and chemical action and corrosion. In addition to considering the physical and chemical properties of building materials, the designer should ensure that wherever practical, the materials to be used must take full advantage of their natural and structural potentialities. Where materials are unlikely to last the life of the building attention should be directed to convenience of their replacement. Actual performance of roof covering materials can be determined under various climatic conditions on buildings on which they are fixed.

Holmes[28] carried out a study on the maintenance costs of heavy type flat roofs with asphalt covering and of pitched roofs. The essence of his exercise was to determine which type of roof was cheaper to construct and maintain. He found that flat roofs were very expensive both to build and maintain. However his major concern was not roof life cycle costing, but overall maintenance costs of the roofs.

According to Bathurst[29] lifespans of roofing materials have been established in United Kingdom, and a comparison could be used between different roof materials during design process. He contends that felt roofs have a life of 20 years, without planned maintenance, otherwise the application of bitumen treatment every 5 years would extend its life by another 10 years to 30 years. Hence, this latter approach is likely to have a better value for money once the economic life of the building extends the 40 year period. Studies at the Building Research Station[30] have shown that built-up felt roofs can last and remain serviceable for a period of 20 years or more with little need for maintenance or repairs. Asbestos normal minimum life is 40 years when the material becomes brittle and starts cracking with the slightest impact or even wind sunction.[31] Galvanized corrugated iron sheets are affected by atmospheric pollutants which form protective surface layers, primarily carbonates. Metal sheets may perish and become pitted in industrial atmospheres. Galvanized corrugated iron sheets should last 40 years unless they are primarily attacked by sulphuric acids, which is especially harsh. The rate of decay depends on the local concentration of atmospheric pollutants.[32]

The life of clay tiles is dependent on a number of factors including physical properties of constituent materials, and the method of manufacture, climatic conditions, degree of pollution and the method of fixing. Machine made poorer quality tiles have a restricted life of 40 years on account of their laminar structure which is susceptible to freezing conditions.[33] Clay tiles deteriorate fast as a result of the growth of Algae.

Porous tiles which are lightly fired may have a relatively high content of soluble salts adversely affecting their durability, by causing disintegration of nibs.[34] These tiles are manufactured in sizes ranging from 340mm - 400mm long x 200mm - 340mm wide x 9mm - 15mm thick.[35] When large number of tiles are defective it is generally more satisfactory to strip and renew rather than to carry out extensive patching.[36] Better quality clay tiles are said to last for 59 years.[37]

Built-up felt is the cheapest, less durable (15-20 years) and often the least expertly laid roof covering as opposed to asphalt.[38] Felts belong to a different age to metals and asphalt, relying on glueing sheets together with bitumen to form an impervious layer. The bitumen outer coating of bitumen roofing felt, if exposed to weather, is gradually attacked by solar radiation. This deterioration can be suspended if the utmost layer of felt, which is normally laid in three layers, has a surfacing of mineral aggregate, preferably white, partially embedded in a coat of bitumen dressing compound. Unfortunately, the mineral aggregate or stone chippings may in time puncture the felt and also obscure the source of leaks. Water vapour trapped during construction or due to condensation, causes bubling and in time cracks. An investigation by the Building Research Establishment showed that splitting accounted for 50% of all bitumen felt roof failures resulting from the inability of bitumen felt to withstand more than a slight amount of stretching without splitting or tearing apart.[39] This defect may be remedied by patching with a strip of felt reinforced with hessian bedded in bitumen. The next common cause of failure results from differential movement at skirtings to parapets and at other peripheral weatherings. Some times blisters develop between layers of felt as a result of insufficient pressure being applied when rolling a layer of felt in hot bitumen bonding compound or the entrapping of moisture between two layers of felt. They do not often lead to leakage and no remedial action is usually necessary.[40] Upstands and skirtings should be integral with the surface felt and be formed by turning up the second and top layers against abutments to a minimum height of 150mm. The felt should be turned up over an angle fillet at the base of the upstand to prevent the felt cracking at the bend or becoming damaged due to lack of support. The angle fillet should be securely fixed to the roof to prevent distortion. Skirtings and upstands should be masked by a metal or semi-rigid asbestos/bitumen sheet flashing.[41]

Small holes in bitumen felt roofing can be sealed with a patch of felt bedded in bitumen. More extensive repairs may make necessary the removal of an entire sheet of felt by heating and softening a lapped joint and bedding a new layer of felt. Where general deterioration of felt has occured without fructure, a top dressing of hot bitumen and stone chippings may suffice. A survey of maintenance work on hospital buildings showed that felt roofs were replaced on average at 16 year intervals, while asphat lasted 28 years.[42] Maintenance costs were also high accounting for 45 percent of the total hosptial roof area but accounted for 70 percent of the total maintenance and replacement costs of all roofs.[43]

Two layers of asphalt are always necessary on flat roofs, with a finished thickness of 20 mm and joints staggered with a minimum lap of 150mm between layers. A well made layer can last up to 60 years.[44] Where a roof is likely to take considerable traffic the asphalt is best finished with asbestos cement or concrete tiles, preferably with solar reflective properties. The asphalt should not be heated over 215° or it may become brittle on setting. An isolating membrane should be provided immediately beneath the asphalt to create a slip-plane to absorb differential movement; a suitable material being bitumen felt type 4A(i) to BS747. Concrete upstands should be keyed and primed with a suitable solution such as Bostik 1255 or Elastopruf to take asphalt skirtings in two coats 13mm thick and at least 150mm high with top edge tucked into chase, 25mm x 25mm, pointed and masked with a flashing.[45]

A survey of 130 mastic covered flat roofs,[46] showed a 28 percent failure rate, resulting from either splitting and cracking of the asphalt due to movement of the substrate and the absence of an isolating membrane or peripheral cracking due to differential movement between roof deck and a non-integral parapet wall to which an asphalt skirting was fixed without any provision for movement. Slight hollows in a roof result in ponding and this may cause crazing of the asphalt but is unlikely to lead to water penetration. Cracked and blistered areas should be heated, cut out and made good with new asphalt without delay.[47] The new asphalt should be carefully bonded to the old by stepping the existing asphalt. Oxidation occurs when asphalt is exposed to light and heat, water soluble products are formed, slow hardening occurs and cracks may form following a rapid decrease of temperature.[48] There are five "states" through which an asphalt roof passes as it deteriorates; namely:

(1) No visible defects.

(2) No leaking but slightly worn and wrinkled.

(3) Some leaks due to blistering and slight cracks and crazing.

(4) Broken blisters, extensive cracking and leaking.

(5) Asphalt broken up, perished and offkey.[49]

In practice the deterioration processes are not uniform and at any point in time different parts of an asphalt roof will be in different states. In order to specify the condition of a roof it is generally necessary to measure or estimate the percentage in each of these states.

Problems have arisen through the application of white paint to the asphalt to reduce absorption of solar heat. The shrinkage of the relatively tough paint film is sufficient to pull the asphalt with it and cause cracking of the asphalt with consequent loss of water tightness.[50] Dampness in ceilings below asphalt roofs may result from interstitial condensation rather than moisture penetration.

Conclusion

In reviewing the literature for this study it became clear that there is a need to consider the total costs of alternative designs that include both initial as well as future costs. It may be necessary therefore to relate total cost to both initial and future costs, which include running costs and replacement costs. The technique is favoured, mainly for two reasons.

First, it is always better to have an objective as well as a subjective view point. It is therefore preferable to provide some calculation wherever this is possible. Secondly, costs included for some expenditure in the distant future will be of a lesser magnitude after discounting, and therefore their effect on the calculation is of much less importance. However this technique has some drawbacks in its practical application. The major difficulties associated with the use of this technique in practice are as follows:

(i) The difficulty of accurately assessing the maintenance and running costs of different materials, processes and systems. There is great scarcity of reliable historical cost data and predicting the lifes of materials and components is often fraught with dangers. In these circumstances the quantity surveyor may be compelled to rely on his own knowledge of the material or component, or possibly on the manufacturers data in the case of relatively new products. Even the lives of commonly used materials like paint show surprising variations and are influenced by a whole range of factors, such as type of paint, number of coats, degree of exposure and atmospheric conditions. Owners and occupiers of procedures also vary considerably.

(ii) There are three types of payments: initial, annual and periodic, and all these have to be related to a common basis for comparison purposes. This calls for knowledge of discounted flow-techniques incorporating the use of valuation formulae.

(iii) Tax has a bearing on maintenance costs and needs consideration, as it can reduce the impact of maintenance costs. Taxation rates and allowances are subject to considerable variation over the life of the building.

(iv) The selection of a suitable interest rates for calculation involving periods of upto sixty years is extremely difficult. When carrying out costs-in-use calculations, it is necessary to discount future sums of expenditure, or income. In order to do these calculations, appropriate interest rates need to be selected. Although different rates could be chosen, for simplicity and without a loss of accuracy, a single rate is used for the full time of the building. It is not possible to predict with any degree of certainty interest rates that might prevail in five years time, let alone the much longer periods of time into the future that are required in these calculations.

(v) Inflationary tendencies may not affect all costs in a uniform manner, thus distorting significantly the results of costs-in-use calculations, particularly as maintenance work has a higher labour component than new work.

(vi) Where projects are to be sold as an investment on completion, the building client may show little interest in securing savings in maintenance and running costs.

(vii) Where the initial funds available to the building client are severely restricted, or his interest in the project is of unique short term duration, it is of little consequence to him to be told that he can save large sums in the future by spending more on the initial construction.

(viii) Future costs can be affected by changes of taste, and fashion, changing statutory requirements for buildings and the replacement of worn out components by superior updated items.

The next chapter discusses cost models and life cycle cost methodologies, with a view to identifying a suitable working cost model for use in life cycle costing during the design of the roofing element. It is hoped that the cost model developed would be useful even in the design of the other building elements.

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CHAPTER III

COST MODELS AND LIFE CYCLE COST METHODOLOGIES

The most familiar form of life-cycle costing technique is the accounting model.[1] Some of these models compute "in-use" expenditures as a function of the systems reliability and maintenability characteristics. They are normally made up of many equations or sub models, each representing a component of the total cost of resources required to operate the system. The use of cost models suffers from the lack of accurate in put data. Historical data form the main source of supply, but their compatibility to future situation is always suspected.

Life cycle cost models treat cost estimates as the "most likely" predictions of what the actual costs will be many years in the future. A new approach to deal with this uncertainty is defined by non-symetric (probability confidence levels or limits) range round this "most likely" cost estimate which uses a number of probability density functions as deployed in equipment replacement strategies or replacement decisions. Some of these probability density functions which could be used to predict future cost estimates are: Hyper-exponential, Negative exponential, Normal and Weibull distributions.

Hyper-exponential: When equipment has failure times which may be very short or very long the distribution is frequently expressible by the hyper exponential distribution. Electronic computers have been found to fail according to this distribution.[2] For Hyper-exponential distribution the 'short' times occur more frequently (often) than in the Negative exponential distribution, and similarily the 'Long' times to failure occur more frequently than in the Negative exponential case. The density function for the hyper-exponential distribution is:

$$f(t) = 2\sigma^2 \lambda \exp[-2\sigma\lambda t] + 2\sigma\lambda(1-\sigma)^2 \ \exp.[-2(1-\sigma)\lambda\ t]$$

for $t \geq 0$ and $0 < \sigma \leq 0.5$ where λ is the mean arrival rate of breakdowns and σ is a parameter for the hyper-exponential distribution (σ

should not be confused with the standard deviation as in the Normal Distribution).

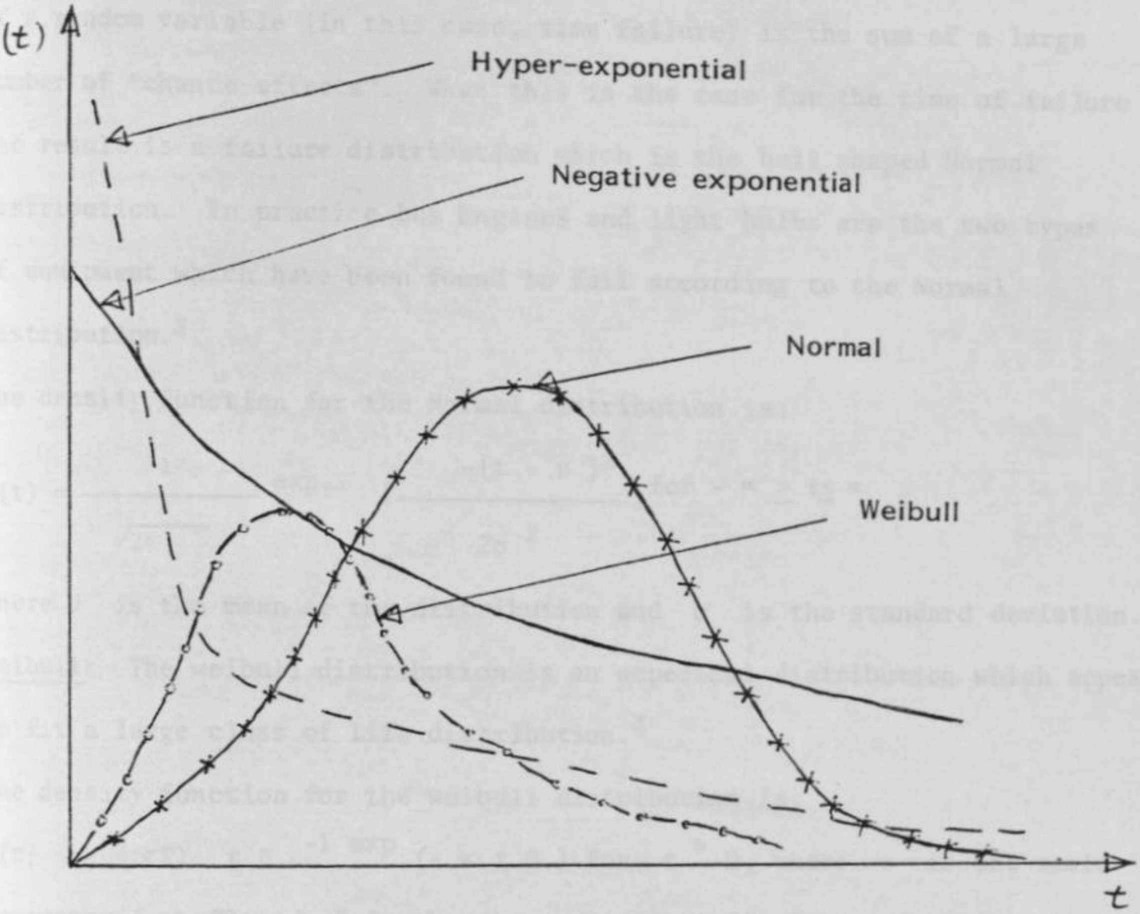

Figure 3-1 Various Probability functions.
(Source: Operations Research "in maintenance"
pp. 20-42. Manchester University Press)

Negative exponential: The negative exponential distribution is one which arises in practice where failure of equipment can be caused by failure of any one of a number of components which comprise the equipment. These component failures may be caused by sudden excessive loading etc. and this failure distribution is found to be typcial for electronic equipment. The density function for the Negative exponential distribution is:

$f(t) = \lambda \exp.[- \lambda t]$ for $t \geq 0$, where $1/\lambda$ is the mean of the distribution.

Normal: The theoretical justification for the Normal distribution is the central limit therorem. This theorem applies when the measurement of a random variable (in this case, time failure) is the sum of a large number of "chance effects". When this is the case for the time of failure the result is a failure distribution which is the bell shaped Normal distribution. In practice Bus Engines and light bulbs are the two types of equipment which have been found to fail according to the Normal distribution.[3]

The density function for the Normal distribution is:

$$f(t) = \frac{1}{\sqrt{2\pi}} \text{ exp. } \left\{\frac{-(t - \mu)^2}{2\sigma^2}\right\} \text{for } -\alpha \geq t \leq \alpha$$

where μ is the mean of the distribution and σ is the standard deviation.

Weibull: The weibull distribution is an emperical distribution which appears to fit a large class of life distribution.[4]

The density function for the weibull distribution is:

$f(t) = (\alpha\beta)\ t\ \beta^{-1}\ \exp\ (-\alpha\ t\ \beta)$ for $t \geq 0$, where α is the scale parameter ($\alpha > 0$) and β is the shape parameter ($\beta > 0$).

By alteration of the parameter the weibull distribution approximates to the form of the Hyper-exponential, Negative exponential and Normal distributions. This is illustrated in figure 3 - 2. However this distritions are not suitable for use with the cost model because meantime before failures of components were not ascertainable from the records as it would have been the case with Engineering equipment so as to come up with a statistical replacement strategy.

COST MODELS

A model by definition is any representation of an actual phenomenon such as an actual system or process. The actual phenomenon is represented by model in order to explain it; to predict it, and to control it. Sometimes the actual system is called the "real-world system" to emphasize the distinction between it and the model system that represents it. Modelling - the art of model building is an integral

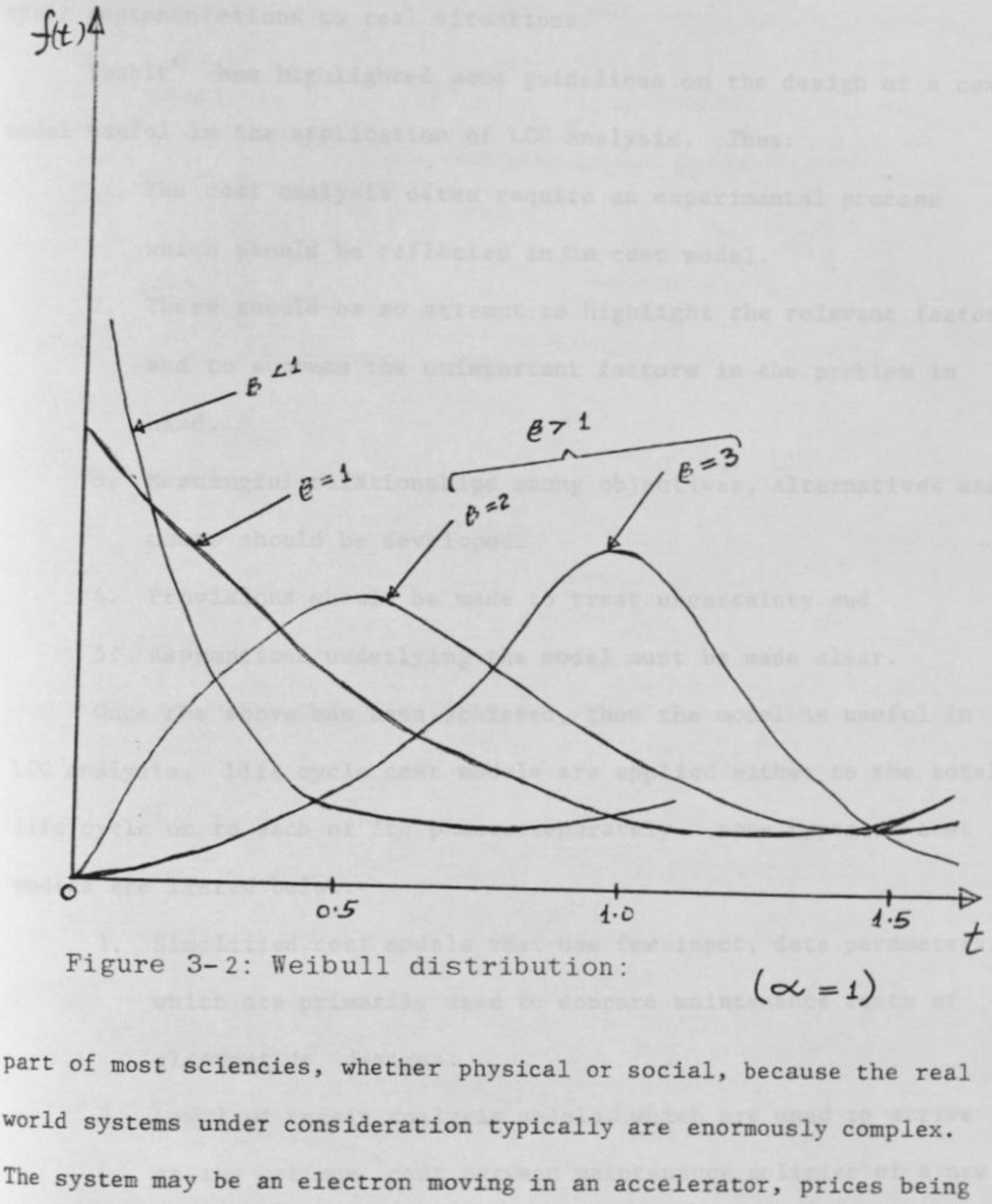

Figure 3-2: Weibull distribution: $(\alpha = 1)$

part of most sciencies, whether physical or social, because the real world systems under consideration typically are enormously complex. The system may be an electron moving in an accelerator, prices being set in various markets, or the determination of total costs of an equipment.[5] In these and many other cases the real-world phenomenon are so complicated that they can be treated only by means of a simplified representation, that is via a model. Any model represents between reality and manageability. It must be reasonable and realistic for the purposes of analysis in that it yields certain insights or conclusions not obtainable from direct observations of the real world system.

Models in general are based on assumptions in order to match their representations to real situations.

Thabit[6] has highlighted some guidelines on the design of a cost model useful in the application of LCC analysis. Thus:

1. The cost analysis often require an experimental process which should be reflected in the cost model.
2. There should be an attempt to highlight the relevant factors and to supress the unimportant factors in the problem in hand.
3. Meaningful relationships among objectives, alternatives and costs should be developed.
4. Provisions should be made to treat uncertainty and
5. Assumptions underlying the model must be made clear.

Once the above has been achieved, then the model is useful in LCC analysis. Life cycle cost models are applied either to the total life cycle or to each of its phases separately. some types of cost models are listed below.

1. Simplified cost models that use few input, data parameters, which are primarily used to compare maintenance costs of alternative designs.
2. Level of repair analysis models, which are used to arrive at the optimum cost between maintenance policies of a new system.
3. Reliability models which are used to quantify the reliability cost relationships for trade-off decisions,
4. Others include, manpower requirements comparisons, inventory management control etc.

Thabit has used the following cost model when carrying out a comparison study between gas turbines and electronic motors as used for main drives in the oil and gas industry.

$$Lcc = \sum_{j=o}^{k-1} P-j(1+i)^{i} + U_{1}^{o}\frac{(1+i)^{n} - 1}{i(1+i)^{n}} + R\,\frac{(1+i)^{n} - (1-n_{i})}{i^{2}(1+i)^{n}} - SV(1+i)^{-n}$$

(initial Investment) + (Uniform annual in-use costs)

+ (Unform changing in-use costs)

\- Salvage Value

where P = Project initial costs

U_1^o = Constant operating costs

R = Annual charge of operating costs

SV = salvage value

k = Investment cost spread, years

n = Useful life, years

i = Cost of captial

This model is suitable for energy modelling and many engineering investments where there is use of series present worth cash flows and Gradient present worth cash flows. The series present worth factor is the conversion factor for converting a series of uniform annual payments made for a number of years at a certain rate of return to a single present sum which would be payable at thebeginning to cover all the annual payments within the specific period. The gradient uniform series arises as a result of having out-of-pocket costs for maintenance and operation of a piece of equipment increasing each year by some constant amount. The present worth of the gradient uniform series can be computed to present value single sum, which is equivalent to the annuities paid yearly.

Barden[7] identifies two methods for use in computing plant life cycle costs. The first method computes total life-cycle costs using the Nett present value approach at a time period T. Thus:

$$NPV_T = C + \sum_{L=1}^{T}\left(\frac{0 + M}{(1 + r)^{L}}\right) + \sum_{Y=1}^{T}\left(\frac{D}{(1+r)^{y}}\right)$$

where NPV_T = Nett prevent value at time T.

C = Initial investment costs.

L = Life of the component.

O = Operating costs over the years.

M = Maintenance costs over the years.

r = required rate of return.

y = expected years of incidence of machine down time.

D = Downtime/outage cost during the years.

The second method[8] is a further refinement of the computation of life cycle costs for plant equipment. The formular or cost model is as follows:

$$C_2 = C_i + \{\frac{O_1 + M_1 + D_1}{(1 + r)}\} + \{\frac{O_2 + M_2 + D_2}{(1 + r)^2}\} + \{\frac{O_n + M_n + D_n}{(1 + r)^n}\}$$

where r = discount rate chosen which allows for a given rate of return on capital invested.

C_i = Initial capital cost.

O_1 = Operating cost during the first year etc...O_2...O_n

M_1 = Maintenance cost during the first year etc...M_2...M_n

D_1 = Down time/outage cost during the first year etc...D_2... D_3...D_n

C_2 = Total life cycle costs.

As it can be drawn from the models, their application per se is suitable for engineering equipments only. For these cost models to be used in the cosntruction industry and especially in the light of roof covering materials, they need to be modified such that some parameters are dropped out of the models. The method which is closer to the one the author would use in this study is the second model by Barden. This model would be modified to exclude operating costs and down time outage costs during the years, for the second expression in the author's model, and then the replacement costs would be added to this model to take account of replacements made within the particular life of the building in question.

Conceptual and Working Model

The cost model tobe used would involve the use of continuous discounting since money does not grow in stages, but in a gradual continuity over the period under consideration.

The cost model would take the following form:

Implicitly

$Lcc = f(C, M, R)$

where C is capital costs,

M is maintenance or operating costs and

R is replacement costs.

All these costs are discounted to the base year of construction.

Explicitly the relationship takes the form:

$$Lcc = C_o + \sum_{l=i}^{k} Me^{-rn} + \sum_{i=1}^{k} Re^{-rn}$$

where,

Lcc = Total life cycle costs per square metre.

C_o = Initial costs per square metre.

M = Maintenance costs at various periods within the life of the building to be discounted per square meter.

R = Replacement costs to be discounted per square metre.

e = Natural logarithm or Niaperian, which is defined as the limit by the quantity $(1 + \frac{1}{k})^k$ as k increases indefinitely.

It is shown that e = 2.718284+.[9] This is sometimes called Eulers Constant. This Eulers constant is used in continuous compounding where interest is assumed to be computed and added to the principal amount at every moment throughout the year. The results obtained using continuous compounding are very close to the results obtained using monthly compounding with a nominal rate r.

r = Nominal interest rate per year and

n = the number of years.

k = the period or a particular time when maintenance expenditure is incurred over the whole life of the material in question.

Although continuous compounding is rarely used in actual loan transactions, it is evident that sums are not spent at the end of the year but at varying points within the year. Thus the growth of these sums of money will have different periods on which compounding can be computed. Most transactions use discrete compounding which indicates that money grows in stages when invested in a bank. But the growth is continuous, assuming a gradual growth over the period in consideration, and it is only reasonable to use continuous compounding in investment decisions.

The following serves to illustrate the working of the cost model as it would be used for analysing the data.

$$Lcc = C_o + [M_1 e^{-r \times 1} + M_2 e^{-r \times 2} \ldots + M_k e^{-r \times k}] + [R_1 e^{-r \times 1} + R_2 e^{-r \times 2} \ldots + R_L 2^{-r \times L}].$$

The discount rate is governed by the return available on the best alternative rather than by the cost of funds on the market as far as public works are concerned. In reality, however, because of great difficulty of expressing social benefits in financial terms it seems to be general practice to discount at the current treasury rate.[10] More complex problems arise in the non-public sector owing to the existence of taxation regulations and alternative sources of captial.

When proposing a value for discount rate, three factors should be considered. These are;

(i) The real discount rate.

(ii) The money discount rate.

(iii) The inflation rate.

Inflation rate has the effect of increasing cash flows when converted into current monetary terms. Inflation effect is not uniform overtime or the various cost components such as materials and labour. Inflation rate and interest rate are interdependent and jointly inflate the discount rate. In treating the effect of inflation upon the discount rate the use of "Real" or "Inflation free" return is appropriate. Hence a method of converting a real discount rate into equivalent money rate can be expressed in the following form:[11]

$$i = (1 + h)\,(1 + r) - 1$$

where $$\underset{\text{Money discount rate}}{(1 + i)} = \underset{\text{Inflation rate}}{(1 + h)} + \underset{\text{Real discount rate.}}{(1 + r)}$$

r = real discount rate

i = money discount rate

h = inflation rate

The choice of discount rate and inflation have a powerful effect on the result of L_{cc} calculations. To simplify such calculations the use of a single parameter is proposed.[12]

$$L_{cc} = \sum_{k=1}^{n} C_k V^k$$

where n = life of project

C_k = estimated yearly cost, at year k

$$V = \frac{1 + j_k}{1 + i_k}$$

where i_k = interest rate at year k

j_k = inflation rate at year k

It is argued that inflation could be taken into account where it is difficult to accept the argument that inflated costs are automatically offset by increased incomes.[13] However it would seem inevitable that inflation will continue so that it may be felt, that a life cycle cost evaluation over a period of analysis of a number of years should include an allowance for the effects of inflation. Nevertheless this is both difficult and largely unnecessary.[14] This is because there can be no way any body can predict what the rates of inflation will be in the future. This is because inflation of future costs will be broadly matched by inflation of the money that is available at the time they fall due, to meet them. Consequently with respect to life-cycle costs evaluation no allowance should be made for inflation.[15]

Wilson points out that there are three ways of assessing the interest rate to be used.[16] These are:

(i) The social time preference rate, which is a positive rate of interest which expresses the value persons place on having assets now, rather than at some time in the future and adopting the kind of life tables used by insurance companies, social time preference rate could be as low as 2%.

(ii) The rate of interest at which the government rents and borrows, and is roughly the risk free rate of interest possibly about 8% to 10%.

(iii) The opportunity cost rate of interest. This is the rate of interest which could operate if the project evaluated were not carried out, and so freed the capital for alternative opportunity, possibly in the range of 9% to 14%.

Building clients must either borrow money to finance the project or sacrifice an alternative use of their money. A realistic rate of interest is therefore either the market rate for money borrowed on the security of the building or the average return which the building client can secure for money invested in his own business.

The discount rate to be used for this study would be 6% which is the current central bank interest rate on current stocks as at December 1985. There would be no allowance for inflation in this study for its effects would be compensating on expenditures incurred on maintenance.

Sensitivity Analysis

Sensitivity analysis is important in life cycle cost technique because of the uncertainty in prediction of life cycle costs, and the involvement of estimation and assumptions. Its purpose is to identify the extent to which a particular result is dependent upon any assumptions or estimation that has been made in arriving at it. If the findings of analysis are to be allowed to influence a decision, the sensitivity of that finding to changes in any of the variables should be tested. This would be applicable to the discount rates, since one discount rate may show significant results whereas another discount rate when used on the same information would show the results as being insignificant.

The study proposes to use 3% and 6% discount rates to test for sensitivity of the rates of return. The 3% rate of interest is the Post Office Savings Bank rate which was obtained from the Central Bank of Kenya Annual Financial Reports. This rate dates back in 1967 which is the earliest recorded information as far as the Central Bank Annual Financial Reports are concerned. The method of equating capital costs to discounted maintenance cost has a number of drawbacks. The use of discounting principle renders the present worth of reducible maintenance costs small in relation to capital cost which is taken at its face value. The maintenance and repair costs become negligible especially as the building exceeds 20 years, or as the discount rate increases. The following table serves to illustrate the effects of interest rates and discounting periods on the present values of periodic maintenance expenditures, of say K.Shs. 100.

Discount Rate	PV of Ksh. 100 at end of period in years.						
	10	20	30	40	50	60	100
5%	60.65	36.79	22.31	13.53	8.21	4.98	0.67
10%	36.79	13.53	4.98	1.83	0.67	0.25	0.00
15%	22.31	4.98	1.11	0.25	0.06	0.00	0.00
20%	13.53	1.83	0.25	0.03	0.00	0.00	0.00
25%	8.21	0.67	0.06	0.00	0.00	0.00	0.00

Table 3-1: PVs in Ksh. for various periods at varying rates.

Source: Own Theoretical Computation. Using continous present value method involving **e** (Eulers constant).

An alternative to showing relative magnitude of discounted expenditure to initial costs is to compare annual equivalent costs of the initial capital and running costs. Thus using appropriate mortgage lending rate, of say 16%, it is possible to calculate how much needs to be repaid every year to recover the capital over the estimated life of the building. The amount of repayment called annuity, is then compared with the estimated annual maintenance cost. However this method will not be appropriate in the sense that it is not possible to express future costs as a percentage of the initial costs so that comparison can be made between differing design alternatives. Even so the method will be unable to compare buildings or components with differing ages. Therefore the most suitable method for use in this study would be the present value method for discounting future costs, simply because the information concerns a variety of buildings.

FOOTNOTES

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CHAPTER IV

BUILDING DESIGN AND CONSTRUCTION IN NAIROBI

Introduction

This study is centred in the City of Nairobi. Nairobi is the largest urban area in Kenya, with a population of approximately one million inhabitants. It is the centre of government business, as well as the headquarters of most companies and government organizations. Consequently, it is the centre of all communications in the country with the exception of Marine Navigation. Most of the industries are located here, particularly in the city's industrial area. The city is located at 36° 49' East of Greenwich Meridian (approximately 500 kilometres west of the Indian Ocean) and 1° 15' south of the equator (approximately 140 kilometres south of the equator)[1]. The city covers an area of 681 square kilometres. It is approximately 1661 metres (5450 ft) above sea level.[2]

Nairobi was established around the year 1899. At the end of the century the railway was being constructed between Mombasa and Uganda. Situated at a point where the central highlands of Kenya merge into the Athi plains Nairobi had an abundant supply of crystal clear water from the highlands. It was therefore selected as an ideal resting place and storage depot after the long construction and haulage from Mombasa through dry arid areas. Because of the danger from mosquito and wild animals, the first exploration caravan camps were established on higher ground in the area now known as Fort Smith (Lower Kabete). After some time the importance of being closer to the water supply overcome other considerations and the first settlers moved down to the area now occupied by the city centre. At that time less than 90 years ago Nairobi must have had a "frontier town" appearance and the beautiful city it has become today is to some extent a monument to the tremendous energy, drive and resolution of its early pioneers. On the 16th April 1900 it was made a township and by 8th October 1928 the township committee was raised to the status of a Municipal Council. It attained the status of a city on 30th March 1950.

Building Development in Nairobi

The current additional annual stock of buildings in the whole country since 1975 to 1983 by main towns shows that Nairobi has the largest stock of buildings as shown by the table 4-1.[3]

Table 4-1: Current Additional Stock of Buildings in Kenya.

ANALYSIS OF BUILDING COST EXPENDITURES BY TOWNS IN KENYA %										
Towns	1975	1976	1977	1978	1979	1980	1981	1982	1983	Average %
NAIROBI	70.91	71.59	64.87	70.14	80.14	67.50	67.29	63.68	61.53	68.63
MOMBASA	18.65	14.21	17.58	19.26	13.44	22.85	19.77	24.43	25.39	19.51
OTHER MAIN TOWNS	10.44	14.20	17.55	10.60	6.42	9.65	12.94	11.89	13.09	11.86

Source: Central Bureau of Statistics.

Other main towns include Kisumu, Nakuru, Eldoret, Kitale, Thika, Nyeri, Kakamega, Embu and Meru.

On the average 68.63% of the built environment expenditure have been used in Nairobi for the last 9 years. The lowest expenditure being in 1983 of 61.53% and the highest being in 1979 of 80.14%. Therefore Nairobi was chosen for this study due to the large volume of assets in this one particular city. The percentages shown in the table comprise the annual stock of new residential buildings; non-residential buildings and extensions both residential and non-residential. Residential buildings include housing estates of both bungalows, maisonettes and flats. Non-residential buildings comprise offices, shops, godowns, stores, factories and social buildings such as churches and social halls.

Factors affecting building Design and Construction in Nairobi.

In its simplest sense a building means any structure movable or fixed of whatsoever kind, or any part thereof; and includes drainage work and excavation.[4] The factors affecting design and construction in Nairobi are soils, climate, social economic factors, level of technology, and availability of building resources. Of these climate requires special attention because it has direct weathering effects on the roof covering materials.

Sites can vary widely in quality as well as in size. The quality of the land itself, its load bearing capacity, slope and drainage will affect the costs of construction through the foundations, site preparation and the provision of siteworks, such as roads hard-standing and drainage. If the soil load bearing capacity is poor it calls for expensive foundations such as the use of columns and column bases; raft foundation or even piles. These affects the design and construction costs of the substructures. Greater depths may be necessary so as to reach a firm base with firm and high load bearing capacity. Foundation costs are usually low, except in cases where basements are required either to comply with the byelaws or by user requirements. The existence of rock on the site poses a problem to having low costs. In such cases the construction of basements becomes expensive because the rock has to be removed through the use of expensive techniques. Sloping sites also pose problems; especially in strip foundations, because these foundations must be stepped to reduce most of the unnecessary excavations.

Buildings are the result of the interaction between man and nature, where man creates a building form that suits his cultural needs. The form is however modified by the environment comprising physical climate, landscape or building materials. Often the Architect is not supplied with equivalent climatic knowledge despite the fact that a building which is considered economically feasible and socially acceptable must meet human comfort requirements, which are determined in part by climatic circumstances. One possible reason of this information lacking is because developers are not aware of the extent of climatic influence on building forms; and also because climatic data may not be readily available when required.

Building forms that minimize the areas of roofs, together with the east and west walls are advantageous in Nairobi as they limit solar heat gains. Multi-storey buildings, dwellings and flats excepting their top floors have considerable advantage of receiving no direct solar heating from above with an exception of their first floors. Single storey buildings with elongated East-West axis so that the proportion of East-West walls to North-South walls is reduced, have an advantage in reducing solar heat gains and according to reasonable human comfort. Major openings should be located in the North and South walls, because it is these walls that are subject to the least solar heating. Also, Roof overhangs and verandahs provide more effective shade to openings in North and South walls than to openings in walls of other orientations.

Since rainfall is high in Nairobi, a pitched roof will probably be used. However the choice of a roof shape is significant because aesthetic considerations must be met, besides satisfying the climatic as well as constructional requirements. Mono-pitched and double pitch or gable roofs are the easiest to construct. However the gable walls are difficult to protect from both rain and sun. This is why hipped roofs which have an everhang over all the sides of the walls came to be necessary. These roofs are more expensive and difficult to construct than the gable roofs. Flat roofs have no advantage at all in tropical climates because of the intense solar radiation during the day and the problems of drainage during heavy storms. They are expensive and even more difficult to construct to waterproof.

However most multi-storeyed office blocks in Nairobi have flat roofs. The most possible reason for this is that archtiects belief there is no need of having a pitched roof on top of a flat roof slab because those are unnecessary costs to the developer and especially when future upward extensions are anticipated.

It is also a possible believe that a hipped roof on top of a multi-storey building is unsightly and most probably may not comform with the trend of finishings in Nairobi. Designers argue that a flat roof may be used for other purposes other than serving as a protective measure against rain penetration and solar radiation. They could be used as drying yards, basking grounds or even supports for watertanks and other installations.

Social economic factors also influence design and construction of buildings in Nairobi. Churches have special ways of design. They have high pitched roofs and high storey heights, and possibly internal balconies in the form of mezzanine floors. Others do have even special designed high towers for installation of Bells. A good example of this would be the Holy Family Cathedral in Nairobi. Like wise social halls have special designs which must be fancy because of the fact that the building should stand out clearly above the others to act as a psychological social focus. Due to the different ethnical groups which existed during the colonial days, the kind and quality of buildings in most residential areas are designed to suit the racial communities living in particular areas of the city. For instance the so called high class residential areas were meant and designed for Europeans, while the so called low class residential areas were for Africans. It is rather difficult to find a high class residential building in a low class residential area simply because the planning regulations in the city did not allow for this. There is still a hangover of these colonial rules. Commercial buildings such as godowns, factories, stores (warehouses) and even offices have their own design and construction styles befitting each particular user requirements.

The level of building technology and availability of building materials will affect the design and construction of buildings. Less expensive materials will be used for construction to save money in the construction. The developer and his professional advisers do not go for expensive and sophisticated construction techniques which may actually be required for some forms of constructions because usually the funds are always limited. This way they tend to use cheaper methods of construction, especially when they are shortsighted about future costs entailed in the use of specific and cheap materials design and construction technology.

Ventillation even becomes more difficult in deep rooms because open windows ceases to be satisfactory. The effect of building spaces deeper than can be lit and ventillated naturally is to raise the capital and running costs of buildings. Noise is also another environmental factor particularly in cities like Nairobi. In city centres tolerable noise levels can only be achieved by using sealed double glazing which necessitates the use of forced ventillation, and possibly air conditioning.

Planning regulations affect the costs of construction and operating of buildings. The current planning regulations in this country encourage the deep office buildings of a tower on a pondium form or generally high rise buildings. The building types have large areas lit and ventillated artificially. This increases the costs of buildings in such away that developers are only interested in the initial costs only. They tend to disregard the operating costs of their development in the future. In this way the design and construction methods ignore life cycle costs of the built environment.

The Climatic Zones of Kenya

The study area is primarily chosen because of the availability of the research information required for the study, the uniformity in climate within the area, and the uniformly distributed micro-urban type of climate. That being the case, it is logical to look at the climatic conditions and zones within Kenya, and identify the zone where the study is focussed.

A wide range of climatic conditions are experienced in Kenya. The design characteristics that buildings must have if they are to afford their occupants with favourable environmental conditions vary accordingly throughout the country. The country has six broad climatic zones.[5] The existing climatic divisions of Kenya relate to vegetation cover, or the needs of agriculture rather than to human comfort and the need of building design. Consequently, a new climatic zone map that relates to the latter has been developed.[6] The six climatic zones are, coastal zone, semi-desert, savanah, lake highland and upper highland zones, as shown in figure 4-1. The study area is in the highland climatic zone with respect to building design and construction considerations.

Climatic Conditions within the Highland Zone.[7]

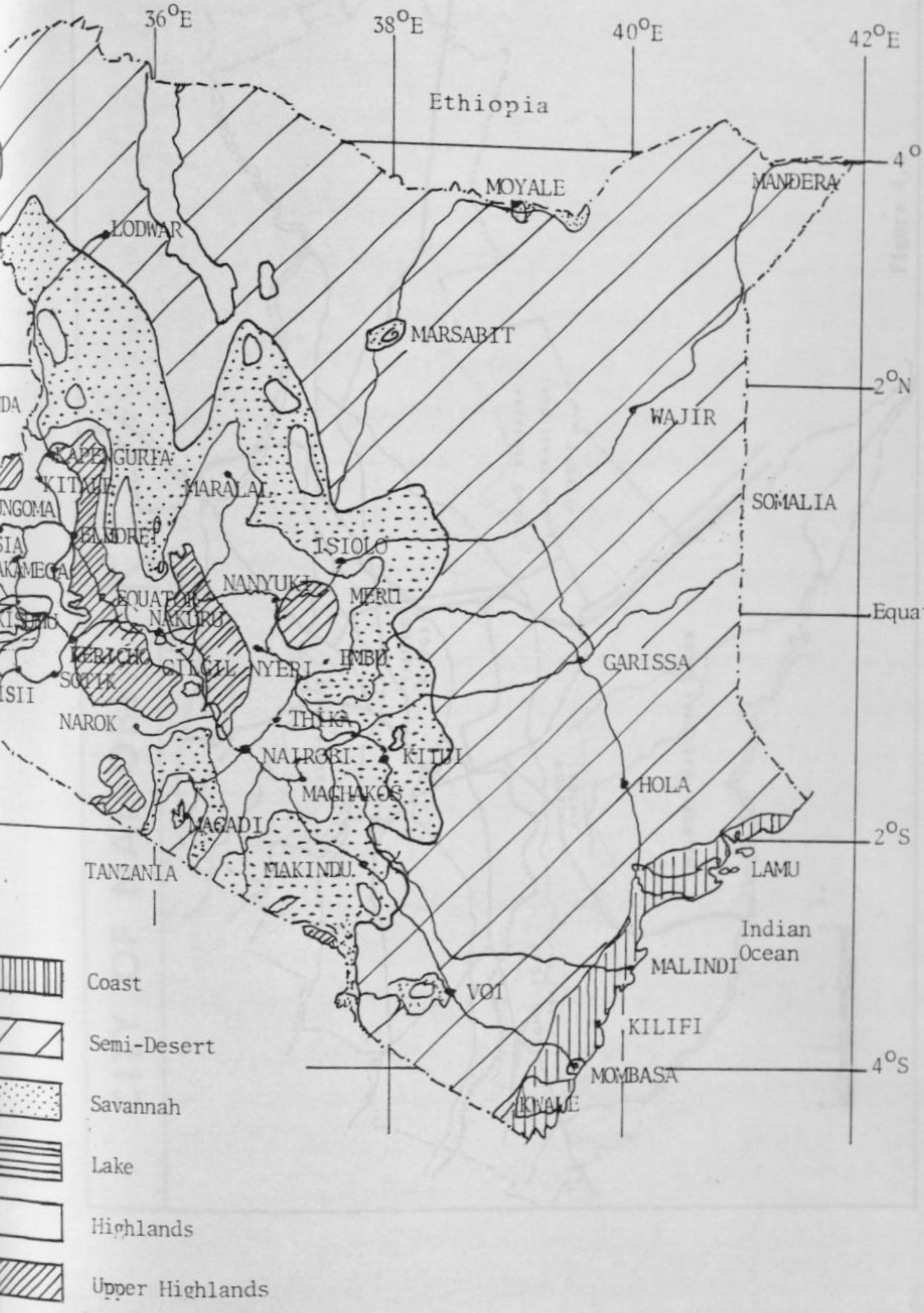
This zone lies between 1,250 and 2,000 metres altitude, consists basically of the Western Highlands lying to the West of Rift Valley, the elevated Rift Valley and the Eastern Highlands that lie on the eastern flanks of the Rift Valley. They also include the Taita Hills

Mount Marsabit and a few other outlying hills, but exclude a small area of dry savanah that lies between 1,250 and 1,500 metres. The zone is by far the most populated, urbanized and extensively cultivated. Though mostly well wooded vegetation here is green, it is luxuriant during rainy seasons, but may wither and turn brown during long dry spells. The latter is particularly true of the plains of the elevated Rift Valley. The highland zone has a pleasant climate, where extremes of temperatures rarely occur.

Annual mean maximum temperatures range from 23.4° C at Kabete to 25.6° C at Nakuru while the mean minimum range from 8.2° C at Nakuru to 13.6° C at Nairobi. Temperatures in the Eastern Highlands tend to be slightly higher than at similar altitudes in the Western Highlands, which are also wetter.[8] Air temperatures are, determined by altitudes. They fall (on average) 0.6°C for every 100 metre rise in altitude, though the modifying effects of local topography have local moderating effects. Mean diurnal temperature ranges are wide varying from 10.8° C at Kabete to 17.4° C at Nakuru, the widest ranges being experienced in the elevated Rift Valley, where skies are clearer, and humidities are lower than elsewhere in the highlands zone.

The mean annual relative humidities at 1500 hours vary from 46% at Nakuru to 53% at Kericho while at 0600 hours they vary from 86% at Kabete to 94% at Nakuru. High relative humidities are rare during the day, but are the norm at night. Heavy dews are often experienced.

On clear days the intensity of solar radiation, especially the ultra-violet components, and the intensity of outgoing long wave radiation are considerably greater in the highlands than at lower altitudes, as the atmospheric layer, through which both types of radiation are transmitted, is thinner. The duration of sunshine and the level of both incoming and outgoing radiation is however much reduced by cloud, the amount of could tending to increase with altitude. In the Kenya



CLIMATIC ZONES: KENYA

Figure 4-1.

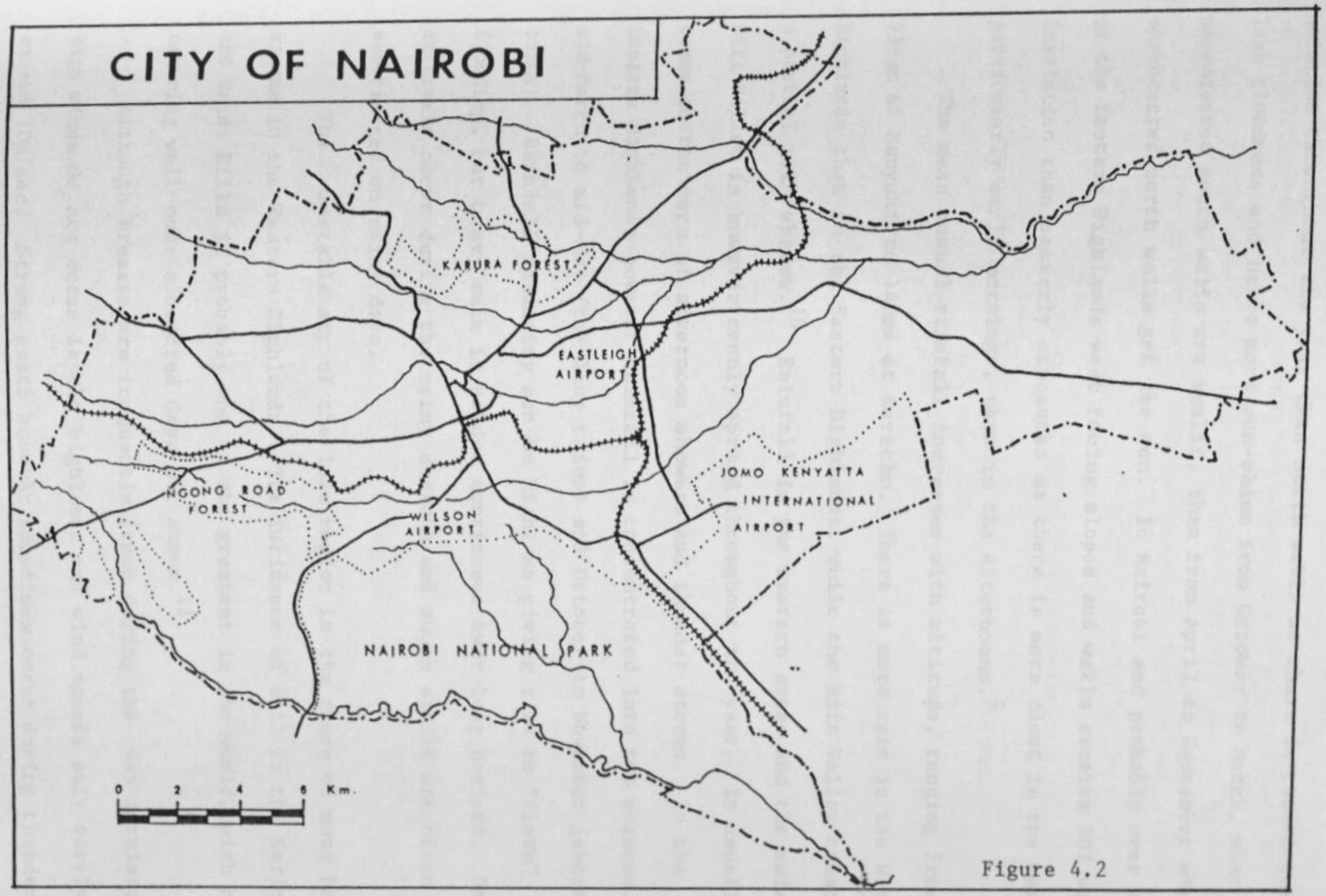


Figure 4.2

Source: G.K. Kingoriah

Highlands which bestride the equator south walls receive greater insolation throughout the year than north walls as there is considerably less cloudness and hence more sun-shine from October to March, when unprotected south walls are sunlit, than from April to September when unprotected north walls get the sun. In Nairobi and probably over most of the Eastern Highlands west facing slopes and walls receive 30% more insolation than easterly exposures as there is more cloud in the mornings, particularly early mornings, than in the afternoons.[9]

The mean annual rainfall increases with altitude, ranging from 739mm at Nanyuki to 140mm at Kericho. There is more rain in the Western Highlands than in the Eastern Highlands, while the Rift Valley creates a partial rain shadow.[10] Rainfall in the western areas and the raised Rift Valley is however evenly spread throughout the year. It usually comes in the form of afternoon showers and thunder storms. In the Eastern Highlands however rainfall is concentrated into two seasons, mid-March to mid-May (the long rains) and October to November (short rains). Rainfall intensity can be high, so giving rise to "flash" flooding, but heavy rain is seldom continuous over long periods. Dry intervals occur during the rainy seasons and sunny spells are often experienced on rainy days.

The unstable air of the lake region is the cause of many hail storms in the Western Highlands. The incidence of hail in the Kericho and Nandi Hills is probably one of the greatest in the world, with hail occuring well over a hundred days per annum.[11]

Although breezes are frequently fresh during the day persistent high winds do not occur in the highlands and wind speeds only rarely exceed 10m/sec. Strong gusts however sometimes occur during thunder storms that are common in the Western Highlands. In the Eastern Highlands winds are variable and light during transitional months between the North-east and South-east Monsoons when the rainfall is greatest. The rather weak general winds associated with the Equatorial tropics may be almost modified almost to the point of reversal by the zones often dramatic topography.[12] At night on calm nights a layer of cold air will usually form over the ground surface. This layer of air is still except over sloping ground, where the downward flow of cool air may create Katabatic winds that can be quite strong as in parts of the Rift Valley.[13]

Factors Affecting Durability of Roof Covering Materials.

The factors affecting durability of roof covering materials are air temperatures, sunshine and radiation, humidity and rainfall and winds.

Air Temperatures: In climates where the diurnal temperature range is wide and where the heat flow through the building fabric of houses is reversed twice a day, thermal insulation is much less effective than thermal capacity as a means of thermal control. Thermal insulation is nonetheless of great importance in protecting the house interiors from the impact of solar radiation on light-weight walls and roofs.

The thermal conductivity of a material, which determines the rate at which heat is conducted through a material, is measured as the rate of heat flow through unit area of unit thickness of the material; when there is a unit temperature difference between the two sides (unit of measurement-watts/^{o}C metres). The resistivity of a material is the reciprocal of its conductivity and is hence measured in M.^{o}C/W. The lower the conductivity the higher the resistivity, the better the insulation value of a material is. Although there is no direct relationship between the resistivity and the density of a material, dense materials tend to have a low resistivity and a low insulation value while light weight materials, which are likely to be more porous and thus contain more air tend to have a high resistivity and a high insulation value. The densities, and resistivities of some of the materials commonly used in Kenya are given in figure 4-3.[14] Thermal movements in materials have deteriorating effects in that it is a major agent of mechanical weathering on exposed surfaces such as roofs and external walls. Physical changes such as caused by temperature, and/or pressure in or around the materials cause forces to be created. Examples of physical changes commonly encountered are: expansion or contraction of metals and other materials on being heated or cooled; expansion or contraction of many porous materials like clay, stone, cement, and especially timber on absorbing moisture or giving off moisture; expansion of adjoining materials as the result of chemical action or physical change; water freezing, thawing or turning into vapour and melting of asphalt, lead and thermoplastics.[15]

Figure 4-3: Densities and Resistivities of Some Common Roofing Materials.

MATERIALS	DENSITY (Kg/M^3)	RESISTIVITY (M^oC/W)
Galvanised iron sheets	7,850	0.02
Asbestos cement sheets	1,600	2.50
Clay tiles	1,900	1.40
Bitumen felt	1,200 (Upper side)	4.5×10^3
Asphalt	2,240	0.82

Sunshine and Radiation: When considering the impact of thermal radiation on the design of buildings it is helpful to divide radiation into five component parts.[16]

1. Direct short-wave radiation from the sun.
2. Diffuse short-wave radiation from the sky vault;
3. Short-wave radiation reflected from the surrounding terrain.
4. Long-wave radiation from the heated ground nearby objects;
5. Effective outgoing long-wave radiation from building to sky.

Diffuse solar radiation is that which reaches the earth's surface from the sky vault after being scattered by suspended dust or air molecules in the atmosphere. The relative quantity of diffused radiation, which is uniformly distributed over the sky vault, increases as the altitude of the sun decreases; cloud and atmospheric dust up to a certain degree increase this component. The quantity of reflected solar radiation reaching walls can be significant particularly when the terrain surrounding buildings is reflective and is fully exposed to the sun.

The cooling effect of out-going long-wave radiation is an important factor particularly in desert type climates. The effective outgoing radiation to a cloudless sky is roughly in inverse proportion to the relative humidity. When the sky is heavily clouded, however, the effective outgoing radiation is reduced to a very low level as the earth's radiation is almost fully absorbed at the base of the cloud. The quantity of direct solar radiation received on the earth's surface is dependent upon atmospheric conditions, for instance the amount of the cloud, dust and haze and the thickness of the atmosphere, that the sun's rays must traverse, and not directly on the prevailing air temperature. The effect of solar radiation is to increase the temperature of sun lit surfaces, thereby accelerating the rate at which heat will flow into the body of the material. Radiation on external surfaces of walls and roofs can raise their temperatures well above that of the ambient air; a dark coloured sheet roof, for instance might reach temperatures up to 30°C above the maximum air temperature.[17] This heat is conducted to the inner faces of walls and to the roofs which then become heat radiators. The rise in the mean radiant temperature of the internal surfaces will in turn raise the indoor air temperatures. However it is the radiation from hot internal surfaces, especially roofs, rather than the resulting increase in air temperatures that is potentially the greater source of discomfort in hot climates.

Glazed openings are largely transparent to solar radiation. The solar energy that passes through glazed openings is obsorbed by sunlit internal surfaces, which in turn become heat radiators. The heat they emit, however is of low temperature or long-wave radiation which cannot be transmitted back to the outdoor environment through the glass, because glass is opaque to energy emitted from low temperature sources: This is commonly known as the "green-house" effect. Sunshine penetrating shaded openings can significantly raise both indoor air and surface temperatures.

Solar heat gains on different surfaces: The solar radiation intensities at Nairobi (latitude 1° south) for selective months on horizontal, and north, south east and west facing vertical surfaces are given in figure 4-3. From the figure 4-4 horizontal surfaces receive the greatest quantities of radiation followed by east and west walls with north and south walls receiving the lowest intensities. The relative magnititude of solar heat gains on different vertical orientations over the year for Nairobi are shown in figure 4-5. Greater solar heat gains are experienced on west than east elevations, as there is more cloud in Nairobi during the morning i.e. when the sun is in the east, than during the afternoon, and on south than north elevations, as there is greater cloudness during the months when the sun is north of the Equator (April to September) than during the months when the sun is south of the Equator.

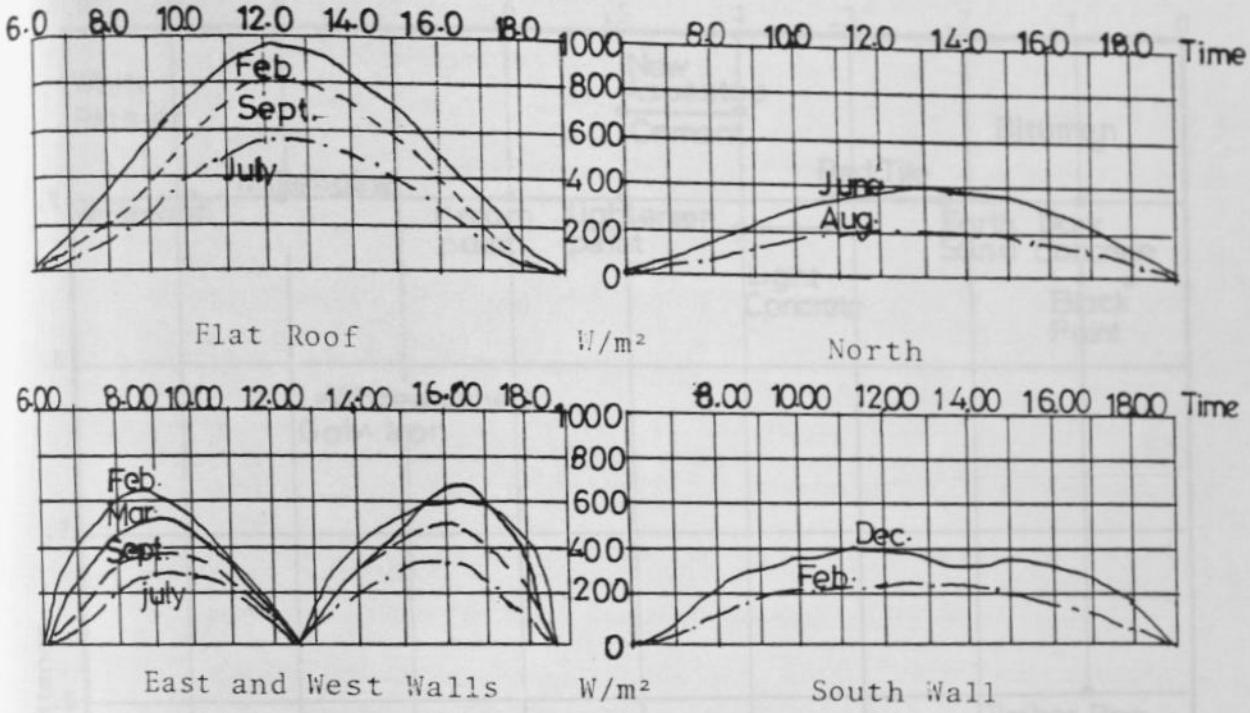


Figure 4.4 : Solar Radiation Intensities on different surfaces at Nairobi

Source: S.V. Szokolay: Design of Buildings for Equatorial Highland climates. M.Arch. Thesis. University of Liverpool, 1968.

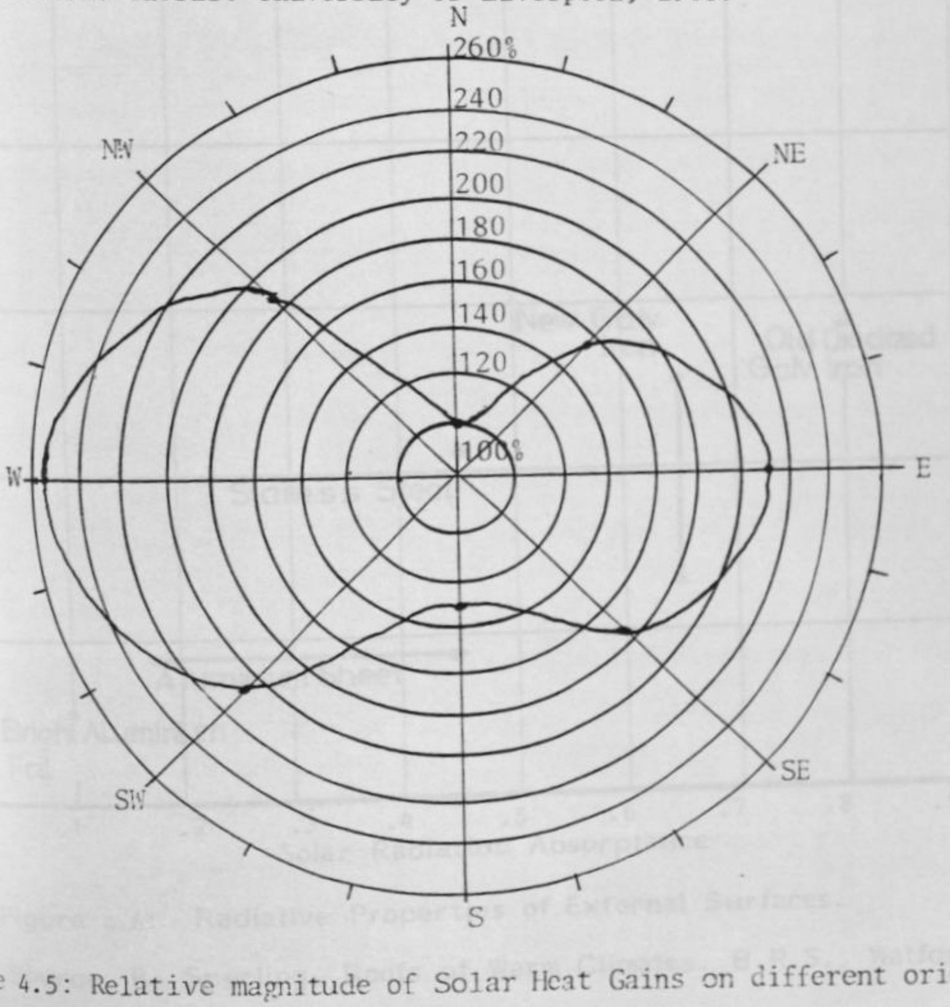


Figure 4.5: Relative magnitude of Solar Heat Gains on different orientations at Nairobi.

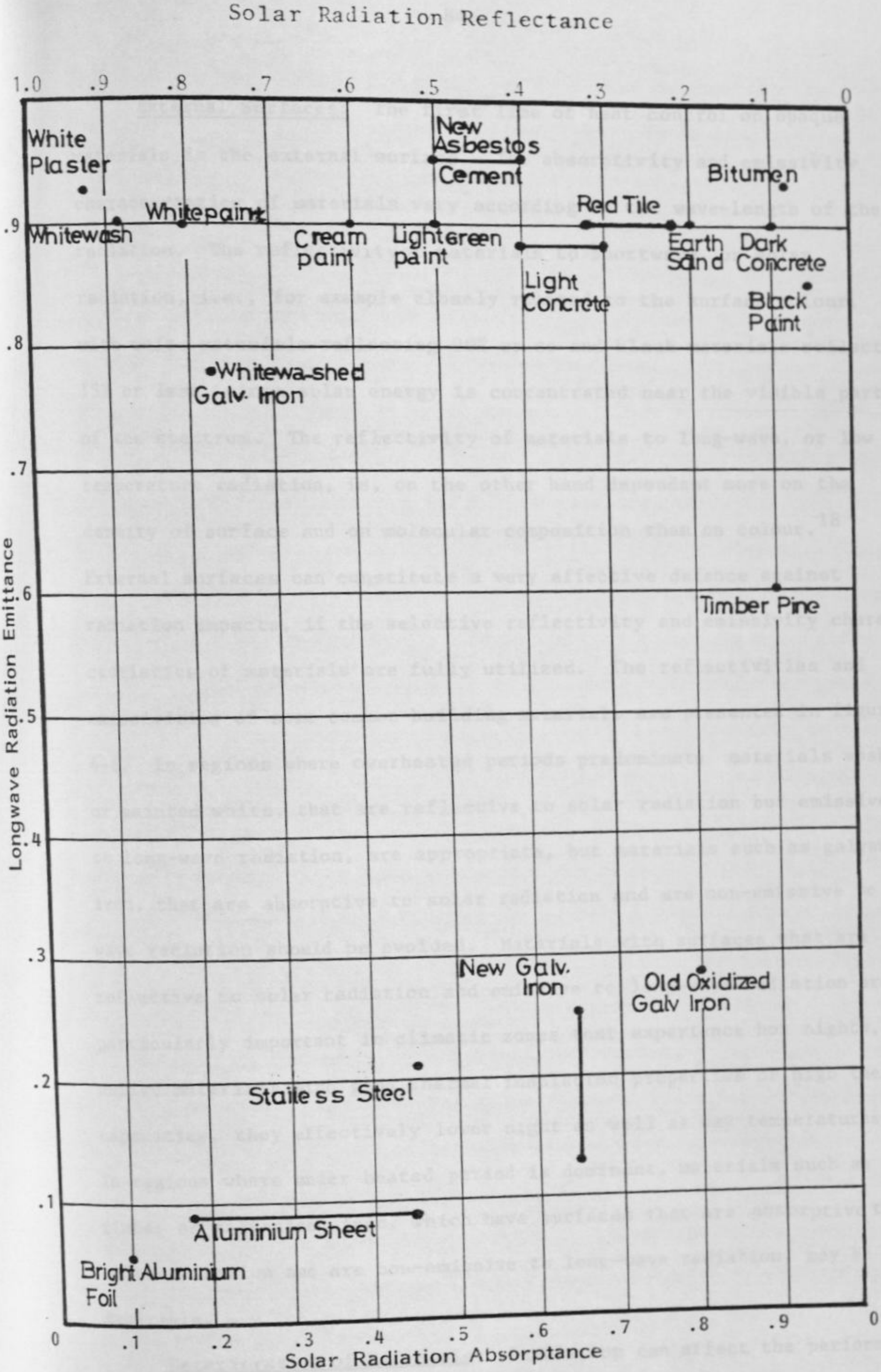


Figure 4.6: Radiative Properties of External Surfaces.

Source: R. Sperling, Roofs of Warm Climates. B.R.S., Watford.

External Surfaces: The first line of heat control on opaque materials is the external surface. The absorptivity and emissivity characteristics of materials vary according to the wave-length of the radiation. The reflectivityof materials to shortwave, or solar radiation, i.e., for example closely related to the surface colour, with white materials reflecting 90% or so and black materials reflecting 15% or less, since solar energy is concentrated near the visible part of the spectrum. The reflectivity of materials to long-wave, or low temperature radiation, is, on the other hand dependent more on the density of surface and on molecular composition than on colour.[18] External surfaces can constitute a very effective defence against radiation impacts, if the selective reflectivity and emissivity characteristics of materials are fully utilized. The reflectivities and emissivities of some common building materials are presented in figure 4-6. In regions where overheated periods predominate materials washed or painted white, that are reflective to solar radiation but emissive to long-wave radiation, are appropriate, but materials such as galvanized iron, that are absorptive to solar radiation and are non-emissive to long-wave radiation should be avoided. Materials with surfaces that are reflective to solar radiation and emissive to long-wave radiation are particularly important in climatic zones that experience hot nights, as unlike materials with good thermal insulation properties or high thermal capacities, they effectively lower night as well as day temperatures. In regions where under heated period is dominant, materials such as timber or galvanized iron, which have surfaces that are absorptive to solar radiation and are non-emissive to long-wave radiation, may be desirable.

Deterioration of Materials: Insolation can affect the performance of building materials by causing large changes in their temperatures, leading to correspondingly large thermal expansions, followed by equally large contractions during the night, or by sudden contractions following the advent of rain. Such thermal movement can lead to cracking and disintegration of rigid walls and roofs, though this should not be serious in small domestic structures. The ultra-violet content of solar radiation, which is proportionately greater at low latitudes, causes chemical deterioration in some materials, for instance bituminous materials, and causes fading of coloured products. Paints deteriorate more rapidly when exposed to solar radiation since it tends to destroy polymerization and causes loss of plasticity which cause cracking and flaking.[19] The deteriorating effects of solar radiation can be reduced by the application of reflective surfaces and by solar shading.

Thermal Movement: Most metals are subject to considerable dimensional change when exposed to solar heating. A common manifestation of this is the creaking of corrugated iron roofing, when relative movement occurs between components or when stress is relieved suddenly at the fixings. Disturbing roof creaking noises could largely be eliminated if the sheets were fixed slightly by means of screws, with washers inserted through oversized holes drilled through the sheets. This solution is probably however too sophisticated and expensive for consdieration in construction and if improperly done could result in leaking roofs.

Humidity and Rainfall: The relative humidity of air is defined as the ratio of the vapour pressure to the saturation vapour pressure at the same temperature. As the temperature of air rises its relative humidity decreases since the capacity of air to absorb water vapour increases with temperature. Therefore maximum relative humidities can be expected when temperatures are at their lowest during the cool of the night, and the minimum when temepratures are at their highest during the heat of the day.

High humidities, particularly when combined with high temperatures, often result in the growth of surface moulds on certain materials.

Concrete and other cement products, for instance cement mortar rendering, concrete tiles, asbestos cement sheets and clay tiles, are particularly susceptible to intense slackening of exposed surfaces as a result of algal growth. The biological decay of timber and other organic materials is greatly encouraged by hot, humid conditions. Cement that is packed in sacks is liable to hydrate prematurely if it is stored in a damp humid place. The chief way in which plants may assist in chemical weathering is to maintain damp conditions on the surface of building materials, although they may also "exude" acids. Mechanical weathering can be influenced to some degree by the root systems of plants. Roots do have extra ordinary penetrating and expanding powers, thus being able to break open or widen existing cracks and crevices. Such opening up then allows access for water and air, and subsequent chemical weathering. Asphalt as a building material does have some nutrients for certain types of plants especially the gum trees. They flourish very well on asphalted flat roofs, as has been a practical case with the roof top, of Mechanical Engineering Block of the University of Nairobi. Although these plansts/trees may not grow to great heights given the subbase is reinforced concrete work, they do have weakening and deterioration effects on the roof covering.

High humidities quicken the corrosion of metals, in particular galvanized iron sheets and related evaporation from wet surfaces. Corrosion of galvanized iron roofs is most pronounced at the laps, where evaporation is slow, and on the underside of roof overhangs, which are subject to thorough wetting as a result of condensation, but which are not periodically washed free of corrosive salts by rain. Nairobi has high relative humidities at night, and low relative humidities during the day except in rainy days. Hence heavy dews are often experienced.

Warped timber in both joinery work and furniture is a common sight in Kenya. Though this is usually the result of the use of the poorly seasoned timber, warping can also result from moisture movement in seasoned but unprotected timber. As asbestos cement roof sheets are both brittle and liable to moisture movement, they should be loosely fixed, by means of screws inserted through oversized holes, so as to prevent the build-up of stress within the sheets that could result from moisture movement in firmly fixed sheets. Savings in the quality of asbestos roof fittings, particularly washers are liable to lead to not easily repairable leaks at the fixing points and are therefore liable to prove a false economy.

Rain is the media through which atmospheric pollution plays an important part in the chemical attack of a variety of materials. Thus gases such as carbon dioxide, and sulphur oxides form acids when they disolve in rainwater in the atmosphere, therefore forming chemicals that attack most building materials and particularly metals. The extent to which water is allowed to penetrate past the exposed surfaces of materials will depend on the sbsorption/evaproation performance of the materials. The time element, that is the period during which dampness may persist is of primary importance. This allows the distinction between the porous and the non-porous materials or impervious materials. Porous materials do allow the absorption and evaporation of water, although quantities involved in each type of materials are subject to wide variations. Impervious in this context do not absorp water. Thus control of rain water penetration in porous materials is necessary. The incidence of hail over parts of the Western Highlands of Kenya and most other parts of the country is as great as anywhere else in the world. Hailstorms might be of sufficient severity to cause cracking of brittle roofing materials such as tiles or asbestos cement sheets.

Winds: The pressures induced by wind on a roof are strongly influenced by its form. Steeply pitched roofs for instance experience positive wind pressures on their windward sides, while flat roofs or low pitched roofs are subject only to suction.. As uplift forces generated by suction are much more critical, regarding lightweight roofs, than positive wind pressures, particular attention must be paid to adequate roof ties in construction. Also attention must be paid to roof overhangs which may simulteneously be subjected to suction from above and positive pressure from below. Winds scour surfaces of building materials used on vertical planes of a building. Such scouring effects are greatly increased when rainwater contains abrasive material usually derived from polluted atmospheres. There is also another aspect of wind occuring during rain particularly applicable to roofs (sloping or flat) and related to the fact that water may be driven uphill by wind into joints and over upstands, and the fact that wind exerts pressure.[20] The pressure exerted by wind is capable of supporting a column of water, the height of which is dependent on wind speed. The relationship between wind speeds of from 5 to 30 m/s and the height of a water column which can be supported at various speeds is given in the comparative chart in figure 4-7. From the values given in this chart it is possible to calculate the size of lap or upstand necessary during rain accompanied by a particular rain speed. If for example the design condition is taken to be 20 m/s then the laps in the pitched roof or the upstand joints in a flat roof would have to be of sufficient size to avoid a head of water of 26 mm to cause leakage. In other words a head of water of more than 26 mm would have to be capable of moving upwards before leakage occurred.

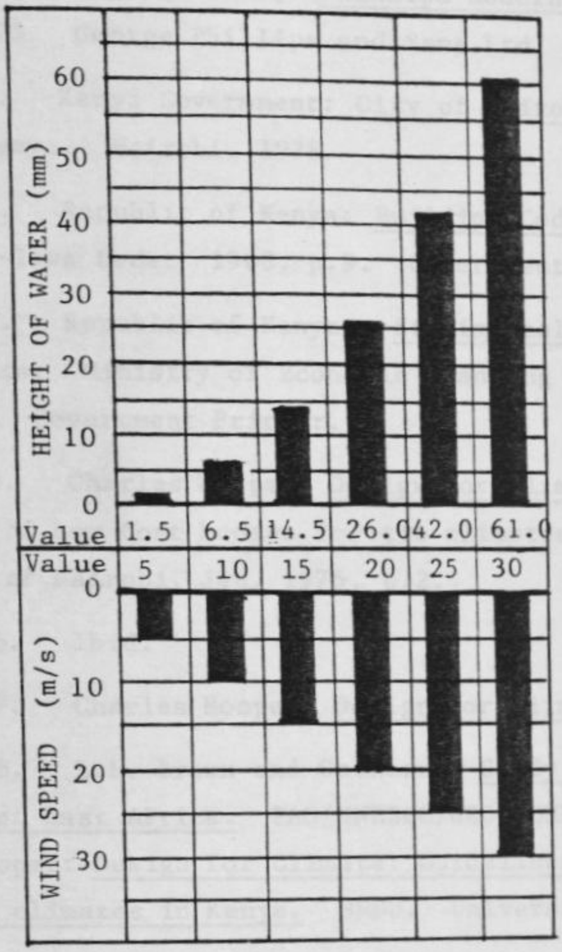


Figure 4.7

Relation between wind-speed and height of a water column which can be supported.

(Reference: 'Principles of Modern Building', Vol.II, p.103, HMSO, 1961).

FOOTNOTES

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CHAPTER V

EVALUATION OF LIFESPANS AND LIFECYCLE COSTS.

Nature of the Data Generally.

The survey comprises five buildings with asphalt roof covering materials, seventeen buildings with roofing felts, five buildings with asbestos sheeting, fourty seven buildings with galvanized corrugated iron sheets gauge 24, and one hundred and nineteen buildings with mangalore roofing tiles, which were analysed and the results appropriately documented. These were all what were available from all the records in Kenya Railways Maintenance Department.

The data was obtained from building registers which gave the summary of the defect in question and the overall cost of repairing the defect. The date on which the repair and the costing was done were indicated in the building registers. The defect reporting date is not available from the building registers, and therefore maintenance work instruction sheets were extracted from the works instruction property files where they were separately kept. The data obtained from the building registers were the serial number of the property, the construction cost of the building, the type of roof covering, floor areas, erection dates, the economic life of the building, and the building type by functional use.

The costs of maintenance; that is operating costs; replacements costs; the frequency of replacements and repairs, and the details of the buildups of these costs were obtained from works instruction property files. The roof areas were calculated from drawings for each type of building type identified from the property files.

Where the cost break downs were not available from the works instruction files, the following percentages were applied to the construction costs for the roof covering itself.[1]

(1) 16% for single storey buildings with both g.c.i. and asbestos roof coverings to arrive at the total cost of the element, and a further 42% and 40% to arrive at the total roof covering cost respectively.

(2) 18% for three-storey buildings covered with roofing felts and managalore tiles to arrive at the total cost of the element, and a further 47% and 51% to arrive at the total roof covering cost respectively.

(3) 11% for two-storey buildings to arrive at the elements total cost, and then the respective percentage for each type of roof covering.

(4) 49% of the total cost of the element in case of roofs covered with asphalt.[2]

The resulting total cost of the roof covering, were then divided by the roof surface area to obtain the cost per metre squared. This cost per metre squared obtained then formed the initial costs as indicated in the cost model. The operating and replacement, costs obtained from the works instruction property files were also expressed in cost per metre squared of the total roof surface area. These subsequent costs were then discounted to present values using the cost model developed for this study. Then both the running and replacements costs were discounted at 3% and 6% respectively and summed up together with the initial costs to arrive at the total costs per square metre over the life of the building. Thus the life cycle cost of the roof covering component. The subsequent costs were then expressed as a percentage of the initial costs as documented in Appendix B. The working model:

$$LCC = C_o + (M_1 e^{-rx2} + M_2 e^{-rx2} \ldots + M_k^{-rxk}) + (R_1 e^{-rx1} + R_2 e^{-rx2} \ldots R_n^{-rxn})$$

summarises all the above algebraically.

Expressing the components, in prcentage form with respect to initial costs, we have

(i) $C_o/C_o \times 100\%$ is 100% which forms the base year cost as it appears in Appendix B.

(ii) $\dfrac{(M_1e^{-r \times 1} + M_2e^{-r \times 2} + \ldots\ldots + M_ke^{-r \times k})}{C_o} \times 100\%$ becomes

the percentage of running costs over initial costs in Appendix B; at the discount rates of 3% and 6% respectively.

(iii) $\dfrac{(R_1e^{-r \times 1} + R_2e^{-r \times 2} + \ldots\ldots R_ke^{-r \times n})}{C_o} \times 100\%$ becomes

the percentage of replacement costs over initial costs as in Appendix B, at the discount rates of 3% and 6% respectively.

(iv) Finally the values obtained from (ii) and (iii) above are summed up to become the percentage of total future, costs over initial costs as in Appendix B; at 3% and 6% discount rates respectively.

The values of the discount rate 'r' are 3% and 6% to test for sensitivity analysis.

Lifespans

The first sub-problem to be discussed relates to the actual lifespans of the roof covering materials within the study area. From table 5-1, it can be observed that the mean lifespan of asphalt is 5.6 years as opposed to 28 years as expected and identified from the literature review in chapter II. This means that it has a shorter life in the study area than what is expected. This is probably attributed to the effects of short wave solar radiation within the study area.

Table 5-1:

Mean Lifespans and Economic Lives, Population standard deviations and coefficient of variation for five roof covering materials.

Materials	$\hat{s}$	$\bar{x}$	μ	Coefficient of Variation $cv = \hat{s}/\bar{x}$
Asphalt	0.894	5.60	28	15.964%
Roofing Felt	6.220	21.33	20	29.161%
Asbestos	16.423	40.20	40	40.853%
Galvanized Corrugated Iron sheets Gauge 24	9.80	50.28	40	19.491%
Mangalore Tiles	11.42	43.57	59	26.211%

$\hat{s}$ = Population standard deviation

$\bar{x}$ = Population mean from the data collected

μ = Expected mean lifespan as identified in the literature review. (In Britain and elsewhere)

cv = Coefficient of variation.

Source: Own Field Survey, 1985.

The short wave solar radiation is possibly more than in Great Britain where the expected lifespan of the material is 28 years. Asphalt has a standard deviation of 0.894 from the population mean, which when expressed as a percentage of its mean gives a coefficient of variation of 15.964%. This means that the variation between the observations from the mean are relatively uniform as compared to the other roof covering materials. The second material is roofing felt with a mean lifespan of 21.33 years as opposed to the expected mean of 20 years. This compares favourably with the observed lifespan and the reasons for this could perhaps be attributable to good workmanship and provision of the right falls to drain water away from the roof or even constant removal of any fallen rubbish on roof tops so as to prevent water collecting into pools. However studies have shown that the lifespan can be increased by 10 more years if bitumen surfacing is applied on top of the roofing felts every five years.[3]

Asbestos has a lifespan of approximately 40 years which compares favourably with the expected lifespan. However the reasons for this could not be clearly adduced from the data in the study area, but it could be argued that short wave solar radiational effects do not have a bigger role to play on the weathering effects of asbestos roof sheeting.

Galvanized iron sheets gauge 24 shows a mean lifespan of 50.28 years far more than the expected lifespan of 40 years. This is contrary to what was expected by virtue of being in tropics where weathering effects are expected to be more than the temperate or cool areas. However as a matter of policy, Kenya Railways Maintenance Department paints these roof surfaces every ten years to prevent them from decaying by rusting.

Mangalore tiles have a mean lifespan of 43.57 years as opposed to the expected lifespan of 59 years. The reasons adduced to this shorter lifespan, would be solar radiational effects, combined with other agents of weathering, such as algae growth on the tiles, and atmospheric pollution resulting to corrosion by carbonic acids from the atmosphere.

Generally the study area has smaller variations in the mean annual temperatures which is 3° centigrade as opposed to variations in Great Britain which 13° centigrade.[4] In Great Britain temperatures as low as 0° Centigrade are recorded on the lower side, and temperatures as high as 20° centigrade are recorded on the upper side.[5]

From table 5-1, the coefficients of variation gives a relative measure of comparison between the five roof covering materials with respect to their popuations. Asphalt shows the lowest variation from its mean, followed by galvanized corrugated iron sheets, then mangalore tiles, roofing felts and finally asbestos sheets.

Table 5-2 shows the pattern of replacement cycles of the respective roof covering materials. Asphalt shows the highest frequency of replacements, followed by roofing felts, with respect to the average economic lives of the buildings, they are laid on, as shown in Appendix A. The other three materials have a frequency of 1, and the economic life of the building is reached, which calls for demolition of the structure in question. Consequently, one wonders why a building covered with galvanized corrugated iron sheets should have an economic life of 56 years and not 75 years. The reason for this is, that galvanized corrugated iron sheets tend to be associated with temporary buildings or lower classes of residential buildings by most people because of the colonial legacy it was accorded by the whites. Kenya Railways being one of the earliest corporations in Kenya is no exception from this kind of arguement, because the galvanized corrugated iron sheeting were used for the African quarters, whereas tiles were used to cover the houses of their masters.

Table 5-2:

Pattern of Replacement Material Cycles with respect to Economic Life of the Buildings.

Materials	Frequency of Replacement	Economic Life of the Buildings (mean)$\bar{x}_{EL}$
Asphalt	13	75 years
Roofing Felt	2	60 years
Asbestos	1	57 years
Galvanized corrugated iron sheets Gauge 24	1	56 years
Mangalore Tiles	1	60 years

$\bar{x}_{EL}$ = Mean Economic Life of the Buildings from Appendix A.

Source: Own Field Survey, 1985.

Testing for Significance of the results at 95% confidence level by using the x^2 Distribution (chi-square Distribution) about the observed mean lifespans of the five different roof covering materials and the expected lifespans for these materials.

The chi-square distribution when used on population data is meant to test whether or not two variables are independent.[6] Tests of independence constitute a method for deciding whether the hypothesis of independence between different variables is tenable. The x^2 test furnish a conclusion on whether a set of observed frequencies or means differs so greatly from a set of theoretical (expected) frequencies or means that the hypothesis under which the theoretical expectations were derived should be rejected.[7] To do this, a probability distribution is used, namely the x^2 Distribution. The chi-square distribution is a theoretical probability distribution that under the proper conditions may be used as the population or sampling distribution of x^2. It is described by a single parameter, namely the number of degrees of freedom - which is the single parameter that determines the shape of its curve, which is n-1 (because for a fixed value of $\bar{x}$, there are only (n-1) "free choices" for the values of the n observations used to calculate $\bar{x}$ and $\hat{s}$). The procedure for establishing the number of degrees of freedom[8] is

(Number of rows - 1) x (Number of columns - 1)

(r - 1) x (c - 1)

where r is the number of rows and c is the number of columns. The fundamental reason for deploying this method is to compare what is observed with what is expected and find out whether the observed and expected variables are independent.

Table 5-3:

Chi-square calculations for Mean Lifespans for Roof covering materials.

Roof covering Materials	Observed Mean f_o	Theoretical (Expected) Mean f_e	$f_o - f_e$	$(f_o - f_e)^2$	$\frac{(f_o - f_e)^2}{f_e}$
Asphalt	5.60	28	-22.40	501.76	17.920
Roofing Felt	21.33	20	1.33	1.7689	0.0880
Asbestos	40.20	40	0.20	0.04	0.001
Galvanized Corrugated Iron sheets	50.28	40	10.28	105.678	2.642
Mangalore Tiles	42.90	59	-16.10	259.21	4.393
Total					25.0440

$$\chi^2 = \sum_{i=1}^{k} \frac{(f_o - f_e)^2}{f_e} = \underline{\underline{25.044}}$$

Source: Own Field Survey, 1985.

Table 5-3 shows the calculations of the computed χ^2 value used for testing the hypothesis.

(i) The problem is to test at an α level of 0.05 if there is significant difference between the mean observed lifespans of the five different roof covering materials and the theoretical (expected) mean lifespans for the same materials. We are testing the Null Hypothesis that the observed mean lifespans and the expected mean lifespans are independent.

H_o: The two variables are independent.

(ii) The Null Hypothesis states that there is significant difference between the observed and expected mean lifespans.

H_a: The two variables are not independent, but dependent.

(iii) Using the χ^2 distribution and an alpha level of 0.05, with 4 degrees of freedom a value of 9.488 for single tailed critical levels is obtained. This is denoted by

$\chi^2_{0.05} = 9.488$

Criterion: The Null Hypothesis is rejected if χ^2 computed is greater than the critical value $\chi^2_{0.05} = 9.488$.

Consequently the alternative hypothesis is accepted.

(iv) Using the data from table 5-3, the computed value of χ^2 is 25.044.

(v) Since $\chi^2_c = 25.044$ is greater than $\chi^2_{0.05} = 9.488$ which is the critical value, the Null hypothesis is rejected and the alternative hypothesis is accepted. Thus the results are significant at 95% confidence level, and the variables are dependent.

The means that there is difference between the observed observations and the expected observations. However this does not tell us why the two groups are different because χ^2 is simply an invitation for closer investigation. Since there is no data collected for the expected mean, then possibly analysis of variance could not be used to tell us why the two populations are different. Since the results show dependence of the two groups or variables, then one can only conclude that the observed and expected mean lifespans are the subject of temperature changes and therefore solar radiation effects contributes to the differences in the lifespans. This leads to the conclusion that weathering effects determine the lifespans in the study area, and the areas for the expected mean lifespans.

Life Cycle Costs

The second sub-problem in the discussion relates to the component/material life cycle costs, of the various roof covering materials, within the study area. One way factor analysis of variance is used to test at an alpha level of 0.05 if there is significant difference between the various means as contained in the analysis tables. This method of analysis is chosen because it compares means of more than two populations.[9] This kind of analysis is useful in many areas of decision analysis.

Table 5-4 is a contigency table which sets the first step in the analysis of variance. Table 5-5 shows the calculations for percentage variations in total life cycle costs and the lifespan for the roof covering materials at 3% discount rate.

The test for the problem is then carried out as follows:

Table 5-4:

A CONTINGENCY TABLE

Variation between total Life Cycle Costs and Lifespan for roof covering materials.

At 3%.

Roofing covering Materials	Life cycle total costs over initial costs %	Mean life span of Materials	Total X_i
Asphalt	317.62	5.60	
Roofing Felt	216.061	21.33	
Asbestos	198.012	40.20	
Galvanized Corrugated Iron sheets	354.15	50.28	
Mangalore Tiles	23.412	42.90	
Total $T._j$	1109.255	160.31	T..=1269.565
$\bar{X}._j$	$\bar{X}._1$ =221.851	$\bar{X}._2$=32.062	$\bar{\bar{X}}$=126.9565

$$\bar{\bar{X}} = \frac{\sum_{i=n}^{n} \sum_{j=j}^{k} X_{ij}}{m} = \frac{T..}{M}$$; M = Total number of observations

Table 5-5.

ONE-Factor ANOVA Table for percentage variations in total Life Cycle Costs and Lifespan for Roof covering materials.

At 3%.

Source of variation	Degrees of freedom (df)	Sum of squares	Mean Square	F computed value
Explained variation by roof covering materials (between columns)	$(c-1)=2-1=1$	SST = $r\sum_{i=i}^{k}(\bar{X}_{.j}-\bar{\bar{X}})^2$ 90049.661	MST = $\frac{SST}{(c-1)}$ = 90049.661	$F_c = \frac{MST}{MSE}$ $=\frac{90,049.661}{8,498.198}$ = 10.596
Error, or unexplained variation (within columns)	$c(r-1)$ $2(5-1)=8$	SSE $\sum_{i=1}^{n}\sum_{j=1}^{k}(X_{ij}-\bar{X}_{j})^2$ 67,985.584	MSE = $\frac{SSE}{c(r-1)}$ = 8498.198	

$$SST = 5[(221.851 - 126.957)^2 + (32.062 - 126.957)^2] = \underline{\underline{90049.661}}$$

$$MST = 90049.661 \div 1 = \underline{\underline{90049.661}}$$

$$SSE = \sum_{i=1}^{n}\sum_{j=1}^{k}(X_{ij}-\bar{X}_{j}.)^2; \quad SSE = 8498.198 = \frac{67,985.584}{c(r-1)8}$$

$$= [(317.62 - 221.851)^2 + (198.012 - 221.851)^2 + (216.061 - 221.851)^2 + (354.15 - 221.851)^2 + (23.412 - 221.851)^2 + (5.60 - 32.062)^2 + (21.33 - 32.062)^2 + (40.20 - 32.062)^2 + (50.28 - 32.062)^2 + (42.90 - 32.062)^2 + (160.31 - 32.062)^2] = \underline{\underline{67,985.584}}.$$

(i) The problem is to test at an α level of 0.05 if there is significant difference in the average total life cycle costs of the five different roof covering materials. We are testing the Null Hypothesis that the mean life cycle total costs are identical at 3% discount rate.

$$H_o: \mu_1 = \mu_2 = U_3 = \mu_4 = \mu_5$$

(ii) The alternative Hypothesis states that there is a difference between the means.

$\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

(iii) Using the F-distribution and an alpha level of 0.05, with the following degrees of freedom,

$$\text{d.f.} = [(c - 1); c(r - 1)] = [1; 8]$$
$$(2 - 1); 2(5 - 1)$$

a value of 5.3177 for single tailed critical levels is obtained.

Criterion: Reject H_o (accept H_a) if $F_c > 5.3177$;

do not reject H_o if $F_c \leq 5.3177$.

(iv) Using the data from table 5-5 $F_c = \frac{MST}{MSE} = 10.596$

(v) Since F_c (10.596) > F_α (5.3177); we reject H_o and accept H_a; and conclude there is a significant difference in the average total life cycle costs.

At an α level of 0.01;

$P_r[F_c \geq 11.261] = 0.01$ F-Distribution

Since F_c (10.596) < F_α (11.26), accept the H_o and reject the H_a. There is no significant difference in the average total life cycle costs. The results from the analysis suggests that the mean lifespans of the materials have nothing to do with mean future total costs, and therefore the life of the material has no influence on the mean total costs of the component over the economic life of the building on which they are laid on. The results have been found to be statistically significant at 3% discount rates and at 95% confidence level. Consequently at 99% confidence level the results have shown to be statistically insiginifcant. Thus reversing the decision already made at 95% confidence level.

Table 5-6 is another contigency table which sets the first steps in analysis of variance for sensitivity analysis tests by using a different discount rate. That is 6% to find out whether the decision made by using 3% discount rate is affected. Table 5-7 shows the calculations for percentage variations in total life cycle costs and the material lifespans at 6% discount rate.

Table 5-6:

CONTINGENCY TABLE

Variation between total Life Cycle Costs and Lifespan of roof covering materials.

At 6% for sensitivity.

Roof covering Materials	Life Cycle Total Costs over Initial Costs %	Mean Lifespan of Materials	Total X_i
Asphalt	262.82	5.60	
Roofing Felt	103.096	21.33	
Asbestos	90.428	40.20	
Galvanized Corrugated Iron sheets	113.938	50.28	
Mangalore	11.938	42.90	
Total $T._j$	$T._j$ = 581.318	$T._j$ = 160.31	T.. = 741.628
$\bar{X}_i.$	$\bar{X}._1$ = 116.264	$\bar{X}.2$ = 32.062	$\bar{\bar{X}}$ = 74.163

Source: Own Field Survey, 1985.

Table 5-7:

ONE Factor ANOVA Table for percentage variations in total Life Cycle Costs and Lifespan for roof covering materials.

At 6% for sensitivity

Source of Variation	Degrees of freedom (df)	Sum of Squares	Mean Square	F_c
Explained variation by roof covering materials (between columns)	$(c - 1) = 1$	SST = $r \sum_{i=1}^{k} (\bar{X}_{\bullet j} - \bar{\bar{X}})^2$ 17,724.942	MST = $\frac{SST}{(c-1)}$ = 17,724.942	$F_c = \frac{MST}{MSE}$ $= \frac{17724.942}{4318.111}$ $= 4.105$
Error, or unexplained variation (within columns)	$c(r - 1) = 8$	SSE = $\sum_{i=1}^{n} \sum_{j=1}^{k} (X_{ij} - \bar{X}_j)^2$ 34544.889	MSE = $\frac{SSE}{c(r-1)}$ = 4318.111	

$$SST = 5[(116.264 - 74.163)^2 + (32.062 - 74.163)^2] = \underline{\underline{17,724.942}}$$

$$MST = \underline{\underline{17,724.942}}$$

$$SSE = [(262.82 - 116.264)^2 + (103.096 - 116.264)^2 + (90.428 - 116.264)^2 + (113.036 - 116.264)^2 + (11.938 - 116.264)^2 + (5.60 - 32.062)^2 + (21.33 - 32.062)^2 + (40.20 - 32.062)^2 + (50.28 - 32.062)^2 + (42.90 - 32.062)^2] = \underline{\underline{34544.889}}$$

$$MSE = 34544.889 \div 8 = \underline{\underline{4318.111}}$$

$$F_{\alpha\,0.05\,(1,\,8)} = P_R[F \geq 5.32] = 0.05$$

The test for the problem is then carried out as follows:

(i) The problem is to test at an α level of 0.05 if there is significant difference in the average total life cycle costs of five different roof covering materials. We are testing the Null

Hypothesis that the mean life cycle total costs are identical at 6% in order to test sensitivity of the two discount rates.

$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$

(ii) The alternative Hypothesis states that there is a difference between the means.

$\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

(iii) Using the F-Distribution and an alpha level of 0.05 with the following degrees of freedom.

$$\text{d.f.} = [(c - 1); c(r - 1)] = [1:8]$$

$$(2 - 1); 2(5 - 1)$$

a value of 5.3177 for single tailed critical levels is obtained. Criterion. Reject H_o (accept H_a) if $F_c > 5.3177$; and accept the H_o if $F_c \leq 5.3177$

(iv) Using the data from table 5-7 $F_c = \frac{MST}{MSE} = 4.105$

(v) Since F_c (4.105) < F_α (5.3177); H_o is accepted and H_a rejected, and concluded that there is no significant difference in the average total life cycle costs.

This suggests that the results obtained by testing the hypothesis with costs discounted at 3% are reversed, and any decisions taken should be reversed when the costs are discounted at 6%. This test of sensitivity analysis of the two discount rates shows that the results are significant at 3% and not significant at 6%. The material lifespans have an influence on the mean total costs of the components in the economic life of the building. This could be interpreted to mean that costs increase as a result of the roof covering materials chosen in the design stages, and this should be controlled at these stages.

Table 5-8 is a contigency table which sets out the first steps in an analysis of variance for comparing maintenance costs with the lifespans for the five roof covering materials, and total future costs whose costs are discounted at 3%. Table 5 - 9 gives the calculations ready for testing the results at 95% confidence level.

Table 5-8: CONTIGENCY TABLE

Variation in maintenance costs with the life of the component and total Life Cycle Costs of components over initial costs. At 3%.

Roof covering Materials	Running costs over initial costs %	Total future costs over initial costs %	Total X_i
Asphalt	130.07	317.62	
Roofing Felt	33.24	216.061	
Asbestos	23.52	198.012	
Galvanized Corrugated Iron sheets	270.234	354.15	
Mangalore Tiles	15.81	23.412	
Total $T_{\cdot j}$	472.874	1109.255	$T_{\cdot\cdot}$=1582.129
$\bar{X}_{i\cdot}$	$\bar{X}_{\cdot 1}$=94.575	$\bar{X}_{\cdot 2}$=221.851	$\bar{\bar{X}}$=158.213

Source: Own Field Survey, 1985.

Table 5-9:

ONE-Factor ANOVA Table for percentage variations in maintenance costs over the life of the component and total life cycle costs of components over initial costs.

At 3%

Source of Variation	Degrees of freedom (df)	Sum of Squares	Mean Square	F_c
Explained Variation by Roof covering Materials (between columns)	$(c - 1)$ $(2 - 1)=1$	SST = $r\sum_{j=1}^{k} (\bar{X}_{.j}-\bar{\bar{X}})^2$ 40,497.951	MST = $\frac{SST}{(c-1)}=$ 40,497.951	$F_c = \frac{MST}{MSE}$ $\frac{40{,}497.951}{14{,}223{,}161}$
Error, or Unexplained Variation (within columns)	$c(r - 1)$ $2(5 - 1)=8$	SSE = $\sum_{i=1}^{n} \cdot \sum_{j=1}^{k} (X_{ij}-\bar{X}_j)^2$ = 113,785.285	MSE = $\frac{SSE}{c(r-1)}=$ =14,223.161	= 2.847

$$SST = 5[(94.57 - 158.213)^2 + (221{\cdot}851 - 158.213)^2] = 40{,}497.951$$

$$MST = \underline{\underline{40{,}497.951}}$$

$$SSE = [(130.07 - 94.575)^2 + (33.24 - 94.575)^2 + (23.52 - 94.575)^2 +$$
$$(270.234 - 94.575)^2 + (15.81 - 94.575)^2 + (317.62 - 221.851)^2$$
$$+(216.961 - 221.851)^2 + (198.012 - 221.851)^2 +$$
$$(354.15 - 221.851)^2 + (23.412 - 221.851)^3] = \underline{\underline{113{,}785.285}}$$

$$MSE = 113{,}785.285 \div 8 = \underline{\underline{14{,}223.161}}$$

The test for the problem is then carried out as follows:-

(i) The problem is to test at an α level of 0.05 if there is significant difference in maintenance costs over the life of the component and its total future life cycle costs over its initial costs. We are testing the Null Hypothesis that the average running costs of the five roofing materials are identical at 3% discount rate.

$H_o: \mu_1 = \mu_2 = \mu_3 = U_4 = U_5$

(ii) The alternative Hypothesis states that there is a difference between the average running costs

$\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5$

(iii) Using the F-Distribution and an alpha level of 0.05 with the following degrees of freedom;

$$\text{d.f.} = [(c - 1); c(r - 1)] = [1:8]$$
$$(2 - 1); 2(5 - 1)$$

a value of 5.3177 for single tailed critical levels is obtained

Criterion: Reject H_o (accept H_a) if $F_c > 5.3177$; and accept H_o if $F_c \leq 5.3177$.

(iv) Using the data from table 5-9 $F_c = \frac{MST}{MSE} = 2.847$

(v) Since F_c (2.847) < F_α (5.3177); accept H_o and reject H_a conclude that there is no significant difference in the average running costs. This means that the average running costs within the five roof covering materials do not varry from one component or material to another and therefore this could not be used as criterion for any decision affecting choice in the design stages.

Table 5-10 is a contingency table for testing the sensitivity of the discount rates for the comparison of running costs and total future costs at 6%. Table 5-11 shows the calculations for computing the F-Statistic for the tests.

Table 5-10: CONTIGENCY TABLE

Variation in maintenance costs with the life of the component and total Life Cycle Costs of components over initial costs.

At 6% for sensitivity.

Roof covering Materials	Running costs over initial costs %	Total future costs over initial costs %	Total X_i
Asphalt	104.83	262.82	
Roofing Felt	17.121	103.096	
Asbestos	5.113	90.428	
Galvanized Corrugated Iron sheets	90.144	113.036	
Mangalore Tiles	8.731	11.938	
Total $T._j$	271.939	581.318	$T..=853.257$
$\bar{X}_i.$	$\bar{X}._1=54.388$	$\bar{X}._2=116.264$	$\bar{\bar{X}} = 85.326$

Source: Own Field Survey, 1985.

Table 5-11:

ONE-Factor ANOVA Table for percentage variation in maintenance costs with the life of the component and total Life Cycle Costs of components over initial costs.

At 6% for sensitivity.

Source of Variation	Degrees of freedom (df)	Sum of Squares	Mean Square	F_c computed
Explained Variation by Roof covering Materials (between columns)	$(c - 1)$ $(2 - 1) = 1$	SST = $r \sum_{j=i}^{k} (X_{.j} - \bar{\bar{X}})^2$ $=9{,}571.598$	MST = $\frac{SST}{(c-1)} =$ $=9{,}571.598$	$F_c = \frac{MST}{MSE}$ $= \frac{9{,}571.598}{4{,}891.508}$ $= \underline{\underline{1.957}}$
Error, or Unexplained Variation (within columns)	$c(r - 1)$ $2(5-1) = 8$	SSE = $\sum_{i=1}^{n} \sum_{j=1}^{k} (X_{ij} - \bar{X}_j)^2$ $=39{,}132.065$	MSE = $\frac{SSE}{c(r-1)} =$ $=4{,}891.508$	

$$SST = 5[(54.388 - 85.326)^2 + (116.264 - 85.326)^2] = \underline{\underline{9{,}571.598}}$$

$$MST = \underline{\underline{9{,}571.598}}$$

$$\begin{aligned} SSE = [&(104.83 - 54.388)^2 + (17.121 - 54.388)^2 \\ &+(51.113 - 54.388)^2 + (90.144 - 54.388)^2 \\ &+(8.731 - 54.388)^2 + (262.82 - 116.264)^2 \\ &+(103.096 - 116.264)^2 + (90.428 - 116.264)^2 \\ &+(113.036 - 116.264)^2 + (11.938 - 116.264)^2] = \underline{\underline{39{,}132.062}} \end{aligned}$$

$$MSE = 39{,}132.065 \div 8 = \underline{\underline{4{,}891.508}}$$

The test for the problem is then carried out as follows:-

(i) The problem is to test at an α level of 0.05 if there is significant difference in maintenance costs over the life of the component and its total future life cycle costs over the initial costs. We are testing the Null Hypothesis that the average running costs of the five roofing materials are identical at 6%

discount rate in order to test <u>sensitivity</u> of the two different discount rates.

$H_o: \mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5.$

(ii) The alternative Hypothesis states that there is a difference between the average running costs.

$\mu_1 \neq \mu_2 \neq \mu_3 \neq \mu_4 \neq \mu_5.$

(iii) Using the F-Distribution and an alpha level of 0.05 with the following degrees of freedom,

d.f. = $[(c - 1); c(r - 1)] = [1:8]$

$(2 - 1); 2(5 - 1)$

a value of 5.3177 for single tailed critical levels is obtained.

Criterion: Reject H_o (accept H_a) if $F_c > 5.3177$; and accept

H_o if $F_c \leq 5.3177$.

(iv) Using the data from table 5-11 $F_c = \frac{MST}{MSE} = 1.957$

(v) Since F_c (1.957) < F_α (5.3177); accept H_o and reject H_a.

Conclude that there is no significant difference in the average running costs. This means that the results obtained by using the 3% discount rates are not different from those obtained by using 6% discount rate. Thus the results are not significant at both 3% and 6% discount rates as used for sensitivity analysis.

FOOTNOTES

1. Republic of Kenya. Ministry of Works, Housing and Physical Planning. Cost Planning Unit. Quantities Branch.

2. Ibid.

3. Peter E. Bathurst et al. Bauilding Cost Control Techniques and Economics. Heinman Publishers Ltd. London, pp.65-57.

4. Fullard, Harold, Phillips East African Modern Atlas. Seventy-second edition, 1975. George Phillip and Sons Ltd. London, p.vi.

5. Ibid.

6. Lawrence L. Lapin: Statistics for Modern Business Decisions. Third Edition. Harcourt Brace Javanovich. Inc. New York, p. 525.

7. Morris Hamburg. Statistical Analysis for Decision Making. Third edition. Harcourt Brace Javanovich. Inc. New York, p.303.

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9. Lapin. Statistics for Modern Business Decisions. p.525.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

(i) Lifespans

Generally considering the five different roof covering materials it has been shown that asphalt is the most unsuitable roof covering material whose life is on average 5.6 years in the study area. In some instances the life is likely to be less than 5 years depending on the workmanship and climatic conditions as the case of areas such as Mombasa Municipality due to severe solar radiational effects. When considering variation between the observations from the mean lifespan, asphalt shows a relatively uniform variation as compared to the other roof covering materials, although with a worse performance in terms of replacement cycles. The next material on merit of variation between the observations and the calculated mean is galvanized iron sheets with 19.491% coefficient of variation, followed by mangalore tiles and roofing felt with 26.211% and 29.161% respectively. The roof covering material with the highest variation between the observations and the computed mean is asbestos. It has 40.853% coefficient of variation between the observations and the computed mean lifespan.

The hypothesis [illegible]ing χ^2 and a confidence level of 95% showed that, observed mean lifespans and the theoretical or mean lifespans were dependent. Thus the results were significant at 95% confidence level, and the conclusion drawn from the results suggests that both the observed and expected lifespans are influenced by temperature changes and therefore solar radiational effects contributes to the differences in lifespans.

Asphalt has an observed mean lifespan of 5.6 years as opposed to the expected lifespan of 28 years as identified elsewhere. This means that the effects of climate in the study area plays an important role in the deterioration of the materials, and therefore reduces its lifespan.

The next roof covering material in discussion was the roofing felts which has an observed mean lifespan of 21.33 years as opposed to 20 years as identified in the chapter of literature review. This compares favourably with the expected or theoretical mean lifespan. However from general observations in places such as Mombasa Municipality lives which are less than mean lifespan have been experienced due to severe environment. It is also true that in Nairobi roofing felts may have lifespans between 13 years and 14 years as is the case of Outering and Pumwani Estates which are owned by the City Commission. This information was obtained from the City Commissions maintenance of Buildings Section which falls under the City Engineers Department. Although no recorded cost information were available, this type of information were available, and even field observations confirmed the state of affairs as recorded in the files. This shows that lifespans may differ due to different policies of maintenance and organizational management strategies in different organizations. From a discussion with the Chief Ma Officer of Kenya Posts and Telecommunications Corporation it was found that roofing felts do last between 3-5 years, and the reasons attributed to this were poor workmanship and intensive solar radiation. unfortunately this had been identified as one of the possible study area, but due to lack of data bank on maintenance costs, construction dates, renewal lifes etc. it fell out of favour.

The third roof covering material discussed was asbestos sheeting. The study showed that the lifespan does not vary significantly from the expected lifespan and therefore it could only be argued that the climatical effects does not play a very important role in the deterioration effects of asbestos roof sheeting.

The fourth material under consideration was the galvanized corrugated iron sheets gauge 24 , which showed that the mean lifespan in the study was higher than the expected lifespan. This was attributed to the low annual temperature ranges (3^o centigrade as opposed to 13^o centigrade) in the study area against high annual ranges of temperatures in the temperate climates, ranging from 0^o centigrade to 20^o centigrade in the extremes. It was also observed that maintenance policies which have a painting cycle of ten years are possibly one reason as to why the life is more than mean lifespan as was expected. However due to high humidity in the study area their lifespans were expected to have decreased with increasing humidity. It can be argued that mechanical weathering due to temperature changes in the temperate regions is more pronounced than possibly in the study area.

The fifth and the last roof covering material discussed in the study is clay mangalore tiles. The results show that the mean lifespan is smaller than what was expectedas identified in the literature review. As far as the Kenya Railways Buildings are concerned mangalore tiles form the bulk of the roof covering materials for residential houses. The roof covering material is locally available, and is manufactured by Clay Works Company Limited. However as explained in the literature review most clays deteriorate with moisture obsorption due to algal growth, which leads to a process called biological weathering. It was also observed that, from discussions held between the researcher and the artisans who carry out maintenance works in Kenya Railways Buildings, the life of the roof tiles do not last for more than two years after the roof tiles have been cleaned to clear off algal growth and dead tree leaves. This possibly shortens the life of the tiles due to imposed loads from the weight of the artisans.

From the results of the data analysis the frequency of failure of the roof covering materials show that asphalt has the highest failure frequency of 13 with regard to the building economic life. Roofing felt shows a frequency of 2, and the rest of the other materials show a frequency of 1. This is an achievement of one of the study objectives.

In the whole Kenya Railways Buildings Department under the District Civil Engineer have kept their records properly especially with regard to the dates of erection, demolition times, maintenance costs over the periods under which they are economically useful. However, roof surface areas are not indicated in their buidling registers. Any researcher interested in this aspect has to measure them on the sites. The oldest building found in the registers was built in the year 1899, when Nairobi started as a Railway Station. This shows how consistent their registers are, showing even those buildings which were later acquired from the government; and those which were demolished, and the reasons why such decisions were taken to demolish or acquire them.

(iii) Life Cycle Costs.

From the cost evaluation the mean life cycle total costs were compared for the five roof covering materials with respect to their lifespans. It was observed that asphalt, roofing felts and galvanized corrugated iron sheets were very expensive over their lifespans and the economic lives of the buildings on which they are laid on respectively. Mangalore tiles showed the least cost, whereas asbestos were the second least expensive over their lifespans and economic lives of the buildings they are laid on. The results obtained in testing for significant difference in the average total life cycle costs of the five roof covering materials were tested using 3% and 6% discount rates. The results were found to be significant using 3% discount rate at 95%

confidence level, and not significant using 6% discount rate for the same level of confidence. However at 99% confidence level using 3% discount rate the results were found not to be significant. Nevertheless the sensitivity analysis shows that different discount rates show different results in life cycle cost analysis. The second analysis was based on variation of maintenance costs over the lifespan of the component, and then compared with its total life cycle costs. Galvanized corrugated iron sheets shows a high maintenance over its lifespan, and this explains why its lifespan is increased when compared to temperate regions. The next most expensive were asphalt, roofing felt, asbestos and mangalore tiles respectively, all using 3% discount rates. Asphalt is the most expensive using 6% discount rates because of the short lifespan of 5.6 years. The ANOVA test showed that the results are not significant using both 3% and 6% discount rates at 95% confidence level. This means that there is no sensitivity in the discount rates, and therefore the findings remain unaltered. Generally this shows that maintenance costs are within the same limits when compared to their total life cycle costs within the economic life of the buildings.

All the five objectives of the study have been achieved through the analysis of the data collected and analysed from the study area. The first objective of analysing the total costs for each of the fiv roof covering materials was achieved and the results are as tabul in Appendix B. The second objective which relates to the frequency of failure or replacement has been achieved through the analysis in table 5-2 in chapter V; where asphalt shows the highest frequency followed by roofing felts, and the rest shows a uniform frequency of 1. Objectives three and four have been achieved through the analysis shown in appendix B, and the analysis from the life-cycle costs table in the previous chapter. The fifth objective was achieved through the previous chapter.

The results of the study show that asphalt is the most unsuitable roof covering material with respect to buildings which have high economic lives in the study area. Roofing felts turns out to be the second most uneconomcial due to its frequency of failure in the study area with regard to the economic life of the building on which they are laid on. Asbestos, galvanized corrugated iron sheets and mangalore tiles are favourable in the study area, because of having a frequency of replacement of 1, over the entire economic life of the building. However mangalore tiles are used on high class residential buildings, whereas galvanized corrugated iron sheets and asbestos are used mostly on commercial sheds or buildings and possibly in low class residential areas. Thus when the designer is considering to make a choice between these five roof covering materials, his decisions would also be influenced by the suitability of the material to the class of building in question. Roofing felts and asphalt are commonly used in flat roofed buildings which could be either offices, flats or any other form of high rise buildings. From the study mangalore tiles are the least cost alternative which would be chosen for by a designer with respect to future costs. The next cheap alternative is asbestos, followed by galvanized iron sheets, then roofing felts and finally asphalt.

Recommendations

The study recommends the following recommendations based on the preceding conclusions.

1. Data banks be established by every department or body that deals with the construction of buildings at various towns, municipalities and cities in Kenya. This will alleviate scarcity of reliable maintenance data which can be used in cost planning to help in designing out maintenance costs

during the design stages.

2. The Kenya National Archives could be used as the storage in cases of organizations where storage of data banks becomes a major problem.
3. Organizations concerned with buildings should deploy the necessary qualified manpower to tackle the problems related to maintenance of buildings, who should be able to brief the designers and advise on costs-in-use decisions for various types of roof covering materials.
4. It is worth recommending that more work be carried out in other towns and especially more so in Mombasa Municipality where the climatic conditions are more severe than in Nairobi.
5. The industry and especially the designers should be made aware of the total costs of building components over their lifespans and the economic lives of the buildings they are laid on, so as to give an optimal value for money solutions to their clients.

At the beginning of this research, it was stated that the roof was one of the elements of the building and as such the findings on the roof does not bear on the other elements. Therefore it is advisable for future researchers to attempt to carry out some work on these other building elements so as to establish how cost planning of costs, can incorporate costs-in-use for the overall building. At the same time frequencies of replacement or failures would be established for better design decision making.

Finally the study has mainly laid a basis for future researches on the other building elements.

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FORMAT OF RAW DATA. LIFESPANS

ASPHALT

	Lifespan
X_1	6
X_2	6
X_3	6
X_4	6
X_5	4

$\Sigma X_i = 28 \quad \bar{X} = 5.6$ years

$\hat{S} = 0.894$

$\mu = 28$

Economic Life 75 years

ROOFING FELTS

	Lifespan	Economic Life
X_1	16	75
X_2	19	75
X_3	26.84	50
X_4	25.08	50
X_5	26.84	50
X_6	26.84	50
X_7	25.06	50
X_8	15	50
X_9	28	75
X_{10}	25	50
X_{11}	25	50
X_{12}	25	75
X_{13}	20.56	75
X_{14}	12.39	75
X_{15}	8	60
X_{16}	25	60
X_{17}	13	50
	$\Sigma X_i = 362.61$	$\Sigma X_i = 1020$
	$\overline{X} = 21.33$	$\overline{X} = 60$ years

$\mu = 20$

$\hat{S} = 6.220$

ASBESTOS

	Lifespan	Economic Life
X_1	53	60
X_2	24	50
X_3	29	75
X_4	33	40
X_5	62	60
	$\Sigma \chi_i =$ 201	$\Sigma \chi_i =$ 285
	$\bar{\chi}_i =$ 40.20	$\bar{\chi}_{EL} = 57$

$\hat{S} = 16.423$

$\mu = 40$ years

CORRUGATED GALVANIZED IRON SHEETS

GAUGE 24

	Lifespans	Economic Life
X_1	60.23	90
X_2	54.50	90
X_3	56	60
X_4	54	60
X_5	56	60
X_6	49	60
X_7	45	60
X_8	54	60
X_9	54	60
X_{10}	40	60
X_{11}	42	60
X_{12}	48	60
X_{13}	44	60
X_{14}	40	60
X_{15}	40	60
X_{16}	44	60
X_{17}	43	60
X_{18}	43	60
X_{19}	54	60
X_{20}	48	60
X_{21}	44	40
X_{22}	41	40
X_{23}	50	60
X_{24}	38	60

	Lifespans	Economic Life
X_{25}	47	50
X_{26}	50	50
X_{27}	52	50
X_{28}	69	50
X_{29}	68	50
X_{30}	50	50
X_{31}	50	50
X_{32}	50	50
X_{33}	72	50
X_{34}	50	50
X_{35}	59	50
X_{36}	60	50
X_{37}	63	50
X_{38}	49	50
X_{39}	42	50
X_{40}	47	50
X_{41}	42	50
X_{42}	48.5	50
X_{43}	47	50
X_{44}	43	40
X_{45}	34	40
X_{46}	86	60
X_{47}	43	60
$\Sigma X_i =$	2363.23	2610
$\overline{X} =$	50.28 years	55.53 years

$\hat{S} = 9.800$

$\mu = 40$ years

MANGALORE ROOFING TILES

	Lifespan	Economic life
X_1	32	50
X_2	26	50
X_3	31	60
X_4	54	60
X_5	59	60
X_6	52	60
X_7	53	60
X_8	49	60
X_9	51	60
X_{10}	50	60
X_{11}	50	60
X_{12}	51	60
X_{13}	51	60
X_{14}	56	60
X_{15}	55	60
X_{16}	54	60
X_{17}	52	60
X_{18}	54	60
X_{19}	50	60
X_{20}	50	60
X_{21}	50	60
X_{22}	55	60
X_{23}	51	60
X_{24}	54	60

	Lifespan	Economic Life
X_{26}	50	60
X_{27}	49	60
X_{28}	47	60
X_{29}	51	60
X_{30}	42	60
X_{31}	49	60
X_{32}	49	60
X_{33}	46	60
X_{34}	49	60
X_{35}	45.5	60
X_{36}	47	60
X_{37}	48	60
X_{38}	51	60
X_{39}	45	60
X_{40}	46	60
X_{41}	48	60
X_{42}	51	60
X_{43}	50	60
X_{44}	81	60
X_{45}	61	60
X_{46}	72	60
X_{47}	79	60
X_{48}	53	60
X_{49}	47	60
X_{50}	46	60
X_{51}	46	60
X_{52}	50	60
X_{53}	73	60

	Lifespan	Economic Life
X_{54}	51	60
X_{55}	52	60
X_{56}	51	60
X_{57}	49	60
X_{58}	50	60
X_{59}	50	60
X_{60}	46	60
X_{61}	38	50
X_{62}	36	60
X_{63}	35	60
X_{64}	35	60
X_{65}	33	60
X_{66}	34	50
X_{67}	34	50
X_{68}	34	50
X_{69}	35	50
X_{70}	25	50
X_{71}	30	50
X_{72}	34	50
X_{73}	32	50
X_{74}	34	50
X_{75}	33	60
X_{76}	31	60
X_{77}	32	60
X_{78}	31	60
X_{79}	34	60
X_{80}	26	60
X_{81}	30	60
X_{82}	31	50

	Lifespan	Economic Life
X_{83}	31	50
X_{84}	31	50
X_{85}	29	60
X_{86}	33	60
X_{87}	34	60
X_{88}	32	60
X_{89}	32	60
X_{90}	33	60
X_{91}	30	60
X_{92}	33	60
X_{93}	33	60
X_{94}	30	75
X_{95}	30	75
X_{96}	29	75
X_{97}	31	75
X_{98}	47	75
X_{99}	29	75
X_{100}	29	50
X_{101}	24	60
X_{102}	54	60
X_{103}	69	60
X_{104}	41	60
X_{105}	47	60
X_{106}	31	60
X_{107}	45	60
X_{108}	46	60
X_{109}	43	60
X_{110}	54	60
X_{111}	50	60
X_{112}	49	60

	Lifespan	Economic Life
X_{113}	35	60
X_{114}	32	60
X_{115}	45	60
X_{116}	34	60
X_{117}	47	60
X_{118}	49	60
X_{119}	36	50

ΣX_i = 5184.5 7060

$\overline{X}$ = 43.57 $\overline{X}_{EL}$ = 59.33 years

$\hat{S}$ = 11.422

μ = 59 years

FORMAT OF LIFE CYCLE COST DATA.

ASPHALT

LIFE CYCLE COSTS

$$C_o + \sum_{i=1}^{k} M e^{-rn} + \sum_{i=1}^{k} R e^{-rn}$$

Initial costs	Percentage of running costs over initial costs		Percentate of replacement costs over initial costs		Percentage of total future costs over initial costs	
%	3%	6%	3%	6%	3%	6%
100	142.58	119.10	152.80	123.85	337.485	277.667
100	142.58	119.10	152.80	123.85	337.485	277.66
100	142.58	119.10	152.80	123.85	337.485	277.66
100	142.58	119.10	152.80	123.85	337.485	277.66
100	80.03	47.75	158.12	105.68	238.15	203.43
500%	650.35	524.15	769.32	601.08	1588.09	1314.10
100%	130.07	104.83	153.864	120.216	317.62	262.82

ROOFING FELT

LIFE CYCLE COSTS

$$C_o + \sum_{i=1}^{k} M e^{-rn} + \sum_{i=1}^{k} R e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_1	100	1.90	0.90	196.31	80.64	198.21	81.54
X_2	100	2.19	1.25	301.79	138.33	303.92	139.58
X_3	100	0.22	0.123	335.48	149.96	335.70	150.08
X_4	100	nil	nil	417.46	189.77	417.46	189.77
X_5	100	nil	nil	417.46	189.77	417.46	189.77
X_6	100	nil	nil	336.70	146.89	335.70	146.89
X_7	100	0.16	0.08	369.90	174.66	370.06	174.74
X_8	100	0.44	0.36	133.39	85.06	133.83	85.42
X_9	100	32.79	13.61	nil	nil	32.79	13.61
X_{10}	100	nil	nil	249.07	120.97	249.07	120.07
X_{11}	100	118.48	57.53	nil	nil	118.48	57.53
X_{12}	100	61.0	30.34	nil	nil	61.00	30.34
X_{13}	100	72.53	36.34	nil	nil	72.53	36.54
X_{14}	100	4.12	2.67	147.20	96.71	151.32	99.38
X_{15}	100	76.90	55.95	nil	nil	76.90	55.95
X_{16}	100	28.13	6.3	nil	nil	28.13	6.30
X_{17}	100	nil	nil	370.48	175.12	370.48	175.12
ΣX_i =	1700	398.86	205.453	3274.24	1547.88	3673.04	1752.63
(N)		12	12	11	11	17	17
$\bar{X}$	100%	33.24	17.121	297.658	140.716	216.061	103.096

ASBESTOS SHEETS

LIFE CYCLE COSTS

$$C_o + \sum_{i=1}^{k} M\, e^{-rn} + \sum_{i=1}^{k} R\, e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_1	100	12.40	2.47	Nil	Nil	12.40	2.47
X_2	100	Nil	Nil	669.77	328.98	669.77	328.98
X_3	100	Nil	Nil	249.74	107.82	249.74	107.82
X_4	100	5	3.5	Nil	Nil	5.0	3.50
X_5	100	53.15	9.37	Nil	Nil	53.15	9.37
ΣX_i =	500	70.55	15.34	919.51	436.80	990.06	452.14
(N)		3	3	2	2	5	5
$\bar{X}$	100%	23.52	5.113	459.755	218.40	198.012	90.428

GALVANIZED IRON SHEETS GAUGE 24

LIFE CYCLE COSTS

$$C_o + \sum_{i=1}^{k} M e^{-rn} + \sum_{i=1}^{k} R e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_1	100	127.70	42.69	122.48	70.48	250.18	62.86
X_2	100	78.84	32.50	28.25	5.06	107.09	37.56
X_3	100	214.26	85.61	-	-	214.26	85.61
X_4	100	214.56	85.16	-	-	214.56	85.16
X_5	100	214.56	85.16	-	-	214.56	85.16
X_6	100	214.56	85.16	-	-	214.56	85.16
X_7	100	214.56	85.16	-	-	214.56	85.16
X_8	100	214.56	85.16	-	-	214.56	85.16
X_9	100	214.56	85.16	-	-	214.56	85.16
X_{10}	100	214.56	85.16	-	-	214.56	85.16
X_{11}	100	144.29	56.90	-	-	144.29	56.90
X_{12}	100	214.56	85.16	-	-	214.56	85.16
X_{13}	100	213.00	83.93	-	-	213.00	83.93
X_{14}	100	215.02	85.26	-	-	215.02	85.26
X_{15}	100	212.75	83.93	37.82	20.52	250.56	104.45
X_{16}	100	214.56	85.16	-	-	214.56	85.16
X_{17}	100	213.00	83.93	-	-	213.00	83.93
X_{18}	100	238.15	89.07	114.82	32.36	352.97	121.43
X_{19}	100	182.33	71.57	-	-	182.33	71.57
X_{20}	100	909.996	88.82	651.38	172.59	916.59	261.41
X_{21}	100	763.52	93.03	568.55	156.28	769.21	249.31
X_{22}	100	130.89	44.65	273.52	81.36	404.42	126.01
X_{23}	100	214.56	85.16	-	-	214.56	85.16
X_{24}	100	124.49	42.46	203.39	65.26	327.89	107.72

$$C_o + \sum_{i=1}^{k} M e^{-rn} + \sum_{i=1}^{k} R e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_{25}	100	135.45	61.36	-	-	135.45	61.36
X_{26}	"	281.61	110.96	-	-	281.61	110.96
X_{27}	"	281.61	110.96	-	-	281.61	110.96
X_{28}	"	486.57	137.21	-	-	486.57	137.21
X_{29}	"	357.48	101.50	-	-	357.48	101.50
X_{30}	"	364.38	104.31	-	-	364.38	104.31
X_{31}	"	311.48	88.42	-	-	311.48	88.42
X_{32}	"	288.97	71.70	-	-	288.77	71.70
X_{33}	"	290.93	72.51	-	-	290.93	72.51
X_{34}	"	343.08	115.09	-	-	343.08	115.09
X_{35}	"	288.87	115.05	60.84	10.51	403.92	125.56
X_{36}	"	352.26	118.28	-	-	352.26	118.28
X_{37}	"	253.75	96.67	-	-	253.75	96.67
X_{38}	"	390.40	117.91	-	-	390.40	117.91
X_{39}	"	253.75	96.67	-	-	253.75	96.67
X_{40}	"	253.75	96.67	-	-	253.75	96.67
X_{41}	"	183.39	69.86	-	-	183.39	69.39
X_{42}	"	183.39	69.86	-	-	183.39	69.39
X_{43}	"	236.02	93.07	-	-	236.02	93.07
X_{44}	"	342.63	186.13	755.10	213.13	1097.73	399.26
X_{45}	"	249.97	195.77	860.85	183.75	1110.82	379.52
X_{46}	"	412.57	98.69	1487.41	115.36	1899.97	214.05
X_{47}	"	177.80	72.18	-	-	177.80	72.18
ΣX_i	4700	12700.966	4236.78	5164.41	1076.35	16644.84	5312.69
$\bar{X}$	100%	270.2339	90.1443	430.3675	89.696	354.15	113.036
N		47	47	12	12	47	47

MANGALORE TILES

LIFE CYCLE COSTS

$$C_o + \sum_{i=1}^{k} M\ e\text{-}rn + \sum_{i=1}^{k} R\ e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_1	100	12.64	9	-	-	12.64	9
X_2	"	-	-	553.36	253.65	553.36	253.65
X_3	"	10	5	-	-	10	5
X_4	"	15	7	-	-	15	7
X_5	"	22.84	7.39	-	-	22.84	7.39
X_6	"	17.05	6.8	-	-	17.05	6.80
X_7	"	4.98	2.38	-	-	4.98	2.38
X_8	"	11.50	4.22	-	-	11.50	4.22
X_9	"	9.27	3.50	-	-	9.27	3.50
X_{10}	"	19.024	7.97	-	-	19.024	7.97
X_{11}	"	6.43	5.80	-	-	6.43	5.80
X_{12}	"	85.69	20.48	-	-	85.69	20.48
X_{13}	"	35.76	17.58	-	-	35.76	17.58
X_{14}	"	58.45	13.74	-	-	58.45	13.74
X_{15}	"	12.50	6.20	-	-	12.50	6.20
X_{16}	"	15.48	13.83	-	-	15.48	13.83
X_{17}	"	11,28	10.48	-	-	11.28	10.48
X_{18}	"	12.43	4.85	-	-	12.43	4.85
X_{19}	"	14.66	12.09	-	-	14.66	12.09
X_{20}	"	14.91	12.40	-	-	14.91	12.40
X_{21}	"	18.62	15.32	-	-	18.62	15.32
X_{22}	"	15.50	13.52	-	-	15.50	13.52
X_{23}	"	33.07	33.75	-	-	33.07	33.75
X_{24}	"	20.44	19.96	-	-	20.44	19.96
X_{25}	"	16.27	15.81	-	-	16.27	15.81
X_{26}	"	16.54	7.53	-	-	16.54	7.53
X_{27}	"	22.56	17.38	-	-	22.56	17.38
X_{28}	"	18.91	18.52	-	-	18.91	18.52
X_{29}	"	12.46	11.92	-	-	12.46	11.92

$$C_o + \sum_{i=1}^{k} M e^{-rn} + \sum_{i=1}^{k} M e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_{30}	100	13.79	12.25	-	-	13.79	12.25
X_{31}	"	16.77	8.22	-	-	16.77	8.22
X_{32}	"	10.00	2.12	-	-	10.00	2.12
X_{33}	"	12.05	5.48	-	-	12.05	5.48
X_{34}	"	13.31	12.98	-	-	13.31	12.98
X_{35}	"	35.07	28.85	-	-	35.07	28.85
X_{36}	"	12.05	5.48	-	-	12.05	5.48
X_{37}	"	13.70	12.74	-	-	13.70	12.74
X_{38}	"	12.05	5.48	-	-	12.05	5.48
X_{39}	"	26.30	25.84	-	-	26.30	25.84
X_{40}	"	11.71	11.23	-	-	11.71	11.23
X_{41}	"	24.21	23.34	-	-	24.21	23.34
X_{42}	"	42.50	38.18	-	-	42.50	38.18
X_{43}	"	15.08	6.84	-	-	15.08	6.84
X_{44}	"	15.08	6.84	-	-	15.08	6.84
X_{45}	"	17.87	8.96	-	-	17.87	8.96
X_{46}	"	-	-	103.00	61.00	103.00	61.00
X_{47}	"	15.84	6.79	-	-	15.84	6.79
X_{48}	"	20.20	16.31	-	-	20.20	16.31
X_{49}	"	6.04	3.45	-	-	6.04	3.45
X_{50}	"	17.83	12.17	-	-	17.83	12.17
X_{51}	"	23.22	12.16	-	-	23.22	12.16
X_{52}	"	49.85	25.14	-	-	49.85	25.14
X_{53}	"	7.80	6.13	-	-	7.80	6.13
X_{54}	"	3.00	1.83	-	-	3.00	1.83
X_{55}	"	4.44	2.84	-	-	4.44	2.84
X_{56}	"	3.96	2.10	-	-	3.96	2.10
X_{57}	"	-	-	147.35	37.05	147.35	37.05
X_{58}	"	5.84	3.45	-	-	5.84	3.45
X_{59}	"	3.8	1.32	-	-	3.80	1.32
X_{60}	"	11.10	9.08	-	-	11.10	9.08
X_{61}	"	24.11	9.23	-	-	24.11	9.23
X_{62}	"	12.20	10.78	-	-	12.20	10.78

$$C_o \quad + \quad \sum_{i=1}^{k} M\, e^{-rn} + \sum_{i=1}^{k} R\, e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_{63}	100	14.50	11.68	-	-	14.50	11.68
X_{64}	"	6.47	2.53	-	-	6.47	2.53
X_{65}	"	-	-	164.18	64.79	164.18	64.79
X_{66}	"	35.75	14.10	-	-	35.75	14.10
X_{67}	"	3.60	1.40	-	-	3.60	1.40
X_{68}	"	2.88	1.07	-	-	2.88	1.07
X_{69}	"	2.88	1.07	-	-	2.88	1.07
X_{70}	"	6.22	2.41	-	-	6.22	2.41
X_{71}	"	2.98	1.14	-	-	2.98	1.14
X_{72}	"	3.14	1.23	-	-	3.14	1.23
X_{73}	"	6.22	2.46	-	-	6.22	2.46
X_{74}	"	7.20	1.75	-	-	7.20	1.75
X_{75}	"	16.97	7.11	-	-	16.97	7.11
X_{76}	"	16.28	6.82	-	-	16.73	6.82
X_{77}	"	3.11	2.3	-	-	3.11	2.30
X_{78}	"	13.64	2.697	-	-	13.64	2.697
X_{79}	"	4.00	0.50	-	-	4.00	0.50
X_{80}	"	13.67	3.65	-	-	13.67	3.65
X_{81}	"	15.00	7.84	-	-	15.00	7.84
X_{82}	"	14.70	7.50	-	-	14.70	7.50
X_{83}	"	10.05	5.35	-	-	10.05	5.35
X_{84}	"	10.05	5.34	-	-	10.05	5.34
X_{85}	"	10.05	5.34	-	-	10.05	5.34
X_{86}	"	18.90	10.24	-	-	18.90	10.24
X_{87}	"	18.90	10.24	-	-	18.90	10.24
X_{88}	"	25.23	12.00	-	-	25.23	12.00
X_{89}	"	10.05	5.34	-	-	10.05	5.34
X_{90}	"	12.68	5.98	-	-	12.68	5.98
X_{91}	"	14.06	6.47	-	-	14.06	6.47
X_{92}	"	13.94	7.03	-	-	13.94	7.03
X_{93}	"	7.84	3.60	-	-	7.84	3.60
X_{94}	"	10.24	6.24	-	-	10.24	6.24
X_{95}	"	11.18	5.92	-	-	11.18	5.92
X_{96}	"	13.67	3.85	-	-	13.67	3.85

$$C_o \quad + \quad \sum_{i=1}^{k} M\,e^{-rn} + \quad \sum_{i=1}^{k} R\,e^{-rn}$$

	Initial costs	Percentage of running costs over initial costs		Percentage of replacement costs over initial costs		Percentage of total future costs over initial costs	
	%	3%	6%	3%	6%	3%	6%
X_{97}	100	13.24	5.71	-	-	13.24	5.71
X_{98}	"	9.87	4.34	-	-	9.87	4.34
X_{99}	"	11.08	4.86	-	-	11.08	4.86
X_{100}	"	25.18	12.04	-	-	25.18	12.04
X_{101}	"	6.34	2.38	-	-	6.34	2.38
X_{102}	"	7.63	3.49	-	-	7.63	3.49
X_{103}	"	9.07	4.43	-	-	9.07	4.43
X_{104}	"	14.78	8.98	-	-	14.87	8.98
X_{105}	"	10.13	5.24	-	-	10.13	5.24
X_{106}	"	13.96	6.02	-	-	13.96	6.02
X_{107}	"	6.39	2.34	-	-	6.39	2.34
X_{108}	"	13.67	3.65	-	-	13.67	3.65
X_{109}	"	13.67	3.65	-	-	13.67	3.65
X_{110}	"	6.18	1.59	-	-	6.18	1.59
X_{111}	"	13.67	3.65	-	-	13.67	3.65
X_{112}	"	10.17	4.69	-	-	10.17	4.69
X_{113}	"	87.65	40.27	-	-	87.65	40.27
X_{114}	"	63.29	34.81	-	-	63.29	34.81
X_{115}	"	2.74	1.06	-	-	2.74	1.06
X_{116}	"	6.98	2.44	-	-	6.98	2.44
X_{117}	"	13.64	7.33	-	-	13.64	7.33
X_{118}	"	11.99	4.61	-	-	11.99	4.61
X_{119}	"	5.72	2.27	-	-	5.72	2.27
ΣX_i	11900	1818.124	1004.077	967.89	104.123	2786.014	1420.567
$\bar{X}$	100	15.81	8.731104	241.973	416.49	23.412	11.9375
N	119	115	115	4	4	119	119

APPENDIX C

MATERIAL LIFE AND COST DATA SURVEY:-

1. PROPERTY SERIAL NO.:-

2.A. BRIEF DESCRIPTION OF THE BUILDING I.E. FLOOR AREA, ROOF COVERING MATERIALS:-

B. ROOF SURFACE AREA M^2

3. LOCATION:-

4. TYPE OF USE:- COMMERCIAL, WORKSHOPS, RESIDENTIAL.

5. DATE OF ERECTION: CONSTRUCTION COST:

6. ECONOMIC LIFE:-

7. (a) INDICATE WHETHER BILLS OF QUANTITIES WERE USED AT THE TIME OF CONSTRUCTION:-

(b) IF THERE ARE NO BILLS OF QUANTITIES THEN ARE THERE DRAWINGS AVAILABLE?

8. ROOF COVERING MATERIALS:-

(a) Asphalt (Thickness)
(b) Bituminous Felts
(c) G.C.I. and gauge
(d) Asbestos
(e) Tiles (clay/concrete)

9. STATE HOW MANY TIMES YOU HAVE UNDERTAKEN

(i) RUNNING PREVENTATIVE MAINTENANCE ON THAT PARTICULAR ROOF COVERING MATERIAL.

TYPE OF REMEDY

I DATE COST

II DATE COST

III DATE COST

IV DATE COST

V DATE COST

(ii) MAJOR REPLACEMENTS:

REASON FOR REPLACEMENT

I DATE COST

II DATE COST

III DATE COST

IV DATE COST

V DATE COST

9. (iii) UNIFORM PERIODIC MAINTENANCE:

SPECIFY:

I	DATE	COST
II	DATE	COST
III	DATE	COST
IV	DATE	COST
V	DATE	COST

10. OVERALL MAINTENANCE COST OVER TIME UP TO NOW, FOR THE WHOLE BUILDING AND NOT THE PARTICULAR ROOF COMPONENT

I	<u>DATE</u>	<u>COST</u>
II	<u>DATE</u>	<u>COST</u>
III	<u>DATE</u>	<u>COST</u>
IV	<u>DATE</u>	<u>COST</u>
V	<u>DATE</u>	<u>COST</u>

etc.

APPENDIX D

East African Railways Corporation

BUILDING REGISTER

Serial No. ____________

SITUATION	Local No.	DRG. Nos.	Life ______ Year ______ R.V. ______ per UNIT
DESCRIPTION		ACCOMMODATION	

Construction		Class
Walls		
Floor		
Trusses		Depth of Founds below Ground Level
Roof		
Ceiling		

PAINTING AREAS Sq. Ft.

	Main Building	Outquarters
Oil Paint Internal		
„ „ External		
Water Paint Internal		
„ „ External		

MAIN BUILDING

Original Building and Subsequent Additions and Partial Renewals	Year of Completion	Estimate Number	Cost £	Area sq. ft.	Mean Height ft.	Cubic Contents c. ft.	Equivalent Cubic Feet		
							Remainder	Roof	Floor
Original Building									

OUTQUARTERS

ORIGINAL BUILDING				ADDITIONS AND RENEWALS						
Building	No.	Construction	Size ft.	Building	No.	Construction	Size ft.	Est. No.	Year	Cost £
Kitchens										
Living Rooms										
Bath Rooms										
Store Rooms										
Latrines										
Garages										

MAINTENANCE

Date	Estimate No.	Particulars	Cost Sh.

INTERNAL ALTERATIONS AND ADDITIONAL FITTINGS

Date	Estimate No.	Particulars	Cost £	