Control of Energy in Offices in Nairobi

A Study of Fenestration in a Tropical Highland Climate

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Abstract

Heavily glazed office buildings in the Kenyan Capital City Nairobi, common in recent times does not augur well for a micro and macro architectural environment. This has a consequent negative impact on energy use in office spaces.

By use of computer simulations, traditional tools and literature review glazing use in office fenestration is analysed and its implications for architectural design investigated.

The results indicate a direct relationship between the variable parameters of glazing type and size, glazed opening orientation, shading devices and control of energy loads within the office spaces and the objective of human comfort in the office spaces.

In conclusion it is recommended that optimum levels of glazing size and type as well as suitable glazing orientations for architectural use in office buildings in Nairobi.

Introduction

In a tropical context like Kenya, architects are often confronted with briefs requiring utilization of contemporary materials in large buildings like offices. This often means attempting to import and implant products tested elsewhere but whose local environmental performance has hardly been proven.

Nairobi is one such city whose cosmopolitan nature and future orientation finds itself in such an ambivalent position. Thus aspiration for use of contemporary building materials like glass often may conflict with environmental considerations of human comfort at the micro level in the spaces created and as well as the urban macro climate.

The paper discusses the climatic parametric constants witnessed in Kenya in general and in Nairobi in particular. It focuses on glass utilisation in Nairobi office buildings. By use of computer simulations we attempt to assess the criteria for glazing choice and utilization in the said office buildings.

A prime object of this study is to appraise simulation results and compare to traditional tools of climatic design previously employed by others. The appropriateness of these tools is briefly discussed.

Geography & Climate

Kenya is situated to the East of the African continent with a coastline to the Indian Ocean. On land, Somalia, Ethiopia and Sudan to the North, Uganda to the West and Tanzania to the South border her.

The country lies astride the Equator between latitude 5.6 °N to 5 °S and longitudes 33 - 42 °E. She covers an area of about 582,000 km^2. The Great Rift Valley that splits the country from North to South is the most prominent feature of Kenya's topography. The other topographical features include Mt. Kenya (5,200m) located in the central part and whose name the country borrows and Mt. Elgon (4,300M) to the western border with Uganda. (see fig.1.1)

Fig. 1.1 Map of Kenya

Other important natural features include inland lakes like Lake Victoria to the west, which have localised effects on climate.

At global scale, Kenya's climate is mainly influenced by the East African Monsoons. These Monsoons, or Trade

Winds, result from the changes in pressure systems and their associated wind flow patterns following the seasonal shift of the sun's position.

During the Northern summer, the south easterly winds bring into East-Africa a lot of moisture due to their maritime track over the Indian Ocean. While in southern summer, the continental dry north easterly winds invade the region.

Due to the above differences in seasonal characteristics of the Monsoons, Kenya's rainfall is generally bi-modal. The two main rainy seasons locally referred as the 'long' and the 'short' rains. The rainfall is mainly convective arising from the Inter-Tropical Convergence Zone.

The long-rains usually occur between March-May, while the short rains occur October - December, in between these wet spells there some sunny and dry spells. The warmest spells occur in December to March peaking in February while the coolest months are June and July. (see fig.1.2)

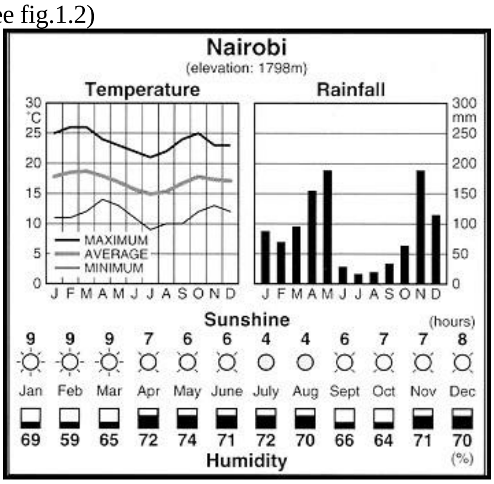


Fig.1.2 Nairobi Climate Chart

As hinted above the differences in climate regimes in Kenya are characterised by high spatial variability in rainfall amounts, which are highly influenced by micro-scale features such as lakes and mountains.

These features are concentrated in an area about one third of the country to the south where most arable land is found. This area stretches between the South - Easterly coastal city of Mombasa up to the central highlands where Nairobi is situated then to the Western and North - Western parts of the country. Most of the population occupies rural and urban settlements in this zone. Most foreign exchange earning cash crop farming and other agricultural activities are performed here.

As per the 1989 census, Kenya has a population of 25million people. The growth rate of 3.5% is the highest on the planet. The population growth rate for the urban settlements is even greater at up to 7%.

The capital, Nairobi is the primary urban settlement with a population of about 3 million. Other major towns include Mombasa, Kisumu, Nakuru, and Eldoret with inhabitants ranging from 200,000 to 1 million.

Nairobi Architecture and Environment

One can trace the origin of Nairobi as we know it today to 1896. This was the time of British colonisation of Kenya. Then and now, it was considered of good climate hence its choice as a railway depot during the construction of the Uganda Railway line linking the Indian Ocean port of Mombasa and the neighbouring Uganda territory.

In its century long history, Nairobi has witnessed various architectural interventions.

The name Nairobi is derived from the Maasai word for a watering point. It was in fact used as a water source for livestock and human nourishment in the pre-colonisation age. One cannot fail to notice that from the outset Nairobi was conceived as an environmentally friendly place. In fact it is probably for this very reason that the builders of the Railway decided to pitch camp here.

In the pre-colonial era, we can but postulate that the Masaai traditional hut was the main architectural feature. This domed shelter was built from mud and wattle for the walls as well as the roof. Architecturally it was a simple structure with minimal openings for lighting and ventilation. Further it must have been of a temporary nature given the lifestyle of the nomadic Maasai people.

In terms of thermal comfort, it was well insulated against heat during the days. If one were to subject the structure to hazards of weather like rain, it would singularly fail. (Fig.1.3)

This is mainly because the rains experienced in Nairobi would definitely denude the mud roofed unit to a shell. It is possible that during its occupation as a Maasai settlement, the rains witnessed currently were not possible then. But then we do not have documented information of those. One should also add that, present day Maasai inhabit a drier patch of Savannah south of Nairobi where the hut is still largely used. Here it is more suited given the hotter and more arid climes.

Fig. 1.3 Maasai Dwelling

In more ways than the above hut discussed, we can also look at the neighbouring Kikuyu shelter (Appendix C) as a precursor to the present day office building. This is so because they are the current dominant tribe around the city and save the historical anecdote above it is a city in the heartland of the Kikuyu. A closer look at their shelter depicts more environmentally sensitive qualities.

Grass thatched roofs with large overhangs dominate the Kikuyu house. (Appendix D). The thick grass thatch acts as an insulator for direct overhead tropical sun while the same acts well for draining the rains in this area. However the poor quality lighting internally reduces the functionality of the house for a modern day Nairobi resident. The durability of the structure was probably not a significant negative factor in the prevailing societal context. It is noteworthy the popularly used house typology nowadays exploits the more permanent tin roofs, corrugated galvanised iron sheets, concrete and clay tiles. It also adopts an orthogonal form in response to new household artefacts, rectilinear materials and other functional changes among others.

The brief glimpse of the traditional structures brings us to the issue of functionality. In the traditional setting most human activity involving a building were largely domestic. In fact some domestic activities like cooking were possible outside. Bigger functions like of government and ceremony were performed outdoors, possibly under the shade of a natural feature like a huge tree or a grove, then commonly found. In Kenya in particular scanty information, if any can be found for traditional non-residential architecture.

The advent of the colonialism and the consequent urbanisation has led to multiples of modern functions. We posit that in many ways this has rendered traditional built-forms of less substance and relevance in the their pure state. It is possible and probably desirable that transformations and modifications be made to adapt to the contemporary functionality.

In our subject of environmental consciousness there are qualities and approaches of the structure that we may borrow and adapt in the modern city. However, this is not a core issue in this paper.

A brief glimpse of colonial office building architecture in Nairobi does not unfortunately seem to point to its sensitivity to environmental concerns. Instead one witnesses a preoccupation with style prevalent in the west then. (see Fig.1.4)

Fig.1.4 Gill House

This was further reinforced by adoption of Building Regulations and Codes from London. Little or no consideration was given to the local climate and conditions. As mentioned above revisions of these codes have been slow.

Conscious energy considerations became more significant in the late 1960s and1970s. Whereas this roughly coincides with political independence, it was more to do with the then modern aesthetic of regionalism rather than deliberate political affirmative action. This must have been further fuelled by the rise in the price of petroleum during the energy crisis in the early 1970s. The architecture of Nairobi's Central Business District shows traces of this in the extensive use of sun breaking devices. (Fig.1.5)

Despite this, the landmark 28-storey Kenyatta International Conference Centre (KICC) building, until less than a decade ago the tallest structure in the city, ignored an energy conscious form. The circular glazed tower has undifferentiated elevations exposing the western and the south-western facades to high levels of direct solar radiation. The use of mechanical systems in this building has yet to be documented but the appliances commonly litter the facades. (see fig.1.6)

Fig.1.5 Shading Devices in Nairobi

Fig.1.6 KICC House

Fig. 1.7 Afya House

A sensitive form to energy concerns is witnessed in architectural resultant of the Richard Hughes ICEA office block on Kenyatta Avenue. Its form attempts to respond to sun movements. The lift core provides shading to a glazed façade as result of the orientation and non-orthogonal form.

The 1990s have witnessed an obsession for glass as curtain walling and in windowpanes to most facades. This seems set to continue unabated if recent examples like Afya House on Tom Mboya Street (fig1.7) are anything to go by. Given that aesthetics is more of a subjective matter than objective we can offer no convincing arguments to dissuade clientele and professionals from opting for it. However we do have a say regarding objective issues as environmental comfort.

Before we focus on this issue, we wish to briefly address aspects of urban climate and comfort in Nairobi. As stated in the introduction, the city has witnessed rapid population increase the last three decades. This has had reciprocal effect in built-form as can be seen from expanding city boundaries and building densities in all city zones. Through revision of planning density requirements, minimum plot sizes have been made lesser and lesser in the said period. Thus for in instance the upscale Karen residential zone has changed from minimum acreage of 2.5acres to down to 0.5acres in some parts. This has had an implication of increased building and infrastructure density.

For the environment this has meant an increase in solar absorptive and reflective materials used in modern buildings and road infrastructure. This in turn re-radiate this absorbed radiation as heat; warming the city. Hooper (1975)(ref.1) in his primer for climatic design for Kenya places Nairobi in the Highland climatic zone. In this "exceptionally agreeable" climate he recommends:

- 15-25% openings in North and South walls
- Use of glazed openings to shutters
- Placement of windows in North and South walls but NE, SE and E wall openings acceptable, among others. He also appreciates that though comfort levels are hardly exceeded, solar heating can cause discomfort necessitating ventilation.

Hooper's was biased towards residential design where privacy and security requirements hardly demand more percentage openings anyway. Where office design is concerned we need to redefine our parametric constants. This is so because in most standard offices, the Glass to Wall Area Ratio (GWAR) is higher. Placement of windows in the North and south walls is desirable but if the percentage glazing is high we may need to be wary of the "green house" effect whereby higher temperatures are achieved in the space in the event of direct solar radiation.

As stated, in addition to the influence on the micro climate, glass also impacts the external macro climate in the urban spaces surrounding.

Building Materials and Environment

Kenya has a variety of building materials available in the market. These can be broadly classified in three categories based on nature, origin, context and use.

First the ***traditional materials*** based on local exploitation of the environment. Here we place materials of organic nature like timber and grass. We also have earth as a traditional building material. A typical traditional dwelling often is built of mud and wattle walling and a grass thatched roof. (fig.1.8). (Appendix D)

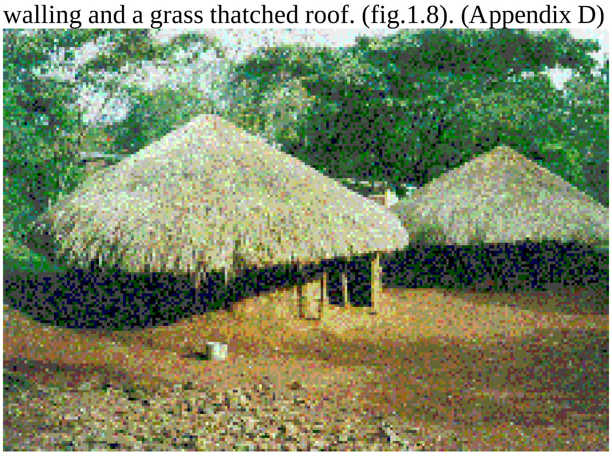


Fig.1.8 Traditional Shelter

Traditional materials possess physical qualities, which promote good insulation when hot outside ensuring a cool interior. Their application beyond the traditional setting is hampered by the consequences of their loss to the habitat. The increased human population densities further aggravate the habitat, which means their replacement through normal ecological circles may not be sustainable. There is thus a general propensity to turn to materials from without for building.

Contemporary materials include cement, metals and glass. Since Kenya lacks most of the local primary material resources for the production of the said products, their import content is high. This in turn has macro-economic implications including depletion of often scarce foreign exchange, high capital investment denying local labour and skills development, among others. It should be stressed that some key products like cement are locally produced but require heavy capital imports as energy and machinery.

Surprisingly clay products are not extensively used in most parts of Kenya despite their better performance thermally and capacity for recycling in the construction industry. It is only in western Kenya that this material has some popularity at local level and from cottage industries.

Fig.1.9 Clay Products.

A popularly used material for walling in modern buildings is Nairobi Stone; a limestone locally sourced through quarrying. Environmental consequences of this quarrying process have not been fully investigated but its negative effects are commonly accepted.

What is of consequence in the context of this paper is their often environmental inappropriateness in the use of contemporary materials. This is often manifest in a multiple of ways including misdirected use and/or in the wrong context

As a bridge between the traditional materials and contemporary alternatives, research has been done in ***Appropriate Materials*** at the University of Nairobi's Housing and Building Research Institute (HABRI). Focus has been on walling and roofing materials. These combine locally available materials with imported types.

For instance Stabilised Soil Blocks (SSB) use the easily available soil stabilised with the dearer cement for walling blocks. This way the durable properties of cement are combined with better thermal qualities of earth.

Another example is the use of Fibre Cement Roofing (FCR) tiles. Here a cement and sand mixture is reinforced with locally available sisal fibres for these tiles. The insulating qualities of the organic sisal are thus put to good use for thermal comfort in the interiors. Significant also is that these are manufactured locally with labour intensive methods and hopefully cost effectively.

Despite these efforts these materials have not had any recognition in local Building Codes until recently.

Problem

In buildings implemented in the recent past, we observe minimal consideration of orientation. Thus we witness undifferentiated treatment of the elevation disregarding the critical south-western and western sun penetration.

Use of glass is as said considered classy. This exposes the client and designer to a huge danger of blind aping of this popular fashion. This is likely because in one building the glass used could actually be solar glass i.e. reflecting an/or heat absorbing glass while the copy may ignore this for the price of the popular aesthetics concrete elements is common in older buildings. As stated this is loosing popularity for aesthetic reasons yet they constitute a possible vocabulary in solar control.

Use of glass can result in overheating problems and the lead to mechanical cooling. This is so because glass is opaque to long wave radiation and ‘traps’ heat in the space. One should thus avoid too much use of glass or use solar protective glass or shading devices.

It is the goal of this study to demonstrate the effectiveness of these special glazing.

Optimum sizes of glazed fenestration need to be considered if we are achieve efficient window size openings for offices. The popular trend is keeping as much non-structural part of an external wall as glazed as possible. The energy consequences cannot be overstated. We posit that openings over and above basic functional requirements is superfluous and should be controlled if anything for environmental and energy considerations.

Limiting internal energy sources from within the office space can curb energy consumption. With computerisation of office operations, we actually are compounding human comfort conditions in our own micro environment.

The problem statement is that contemporary office architecture in Nairobi lays little emphasis on environmental comfort particularly in respect of building orientation, percentage of glazed opening, type of glazing, sun shading devices and the internal energy load within the functional spaces.

Hypothesis

We posit glazing can be employed in fenestration of office buildings in Nairobi in an environmentally accommodating manner. Through research we can achieve an architecturally inspiring result with glass without compromising the environment. This can achieved this cost effectively by use of passive energy control tools. Computer modelling can optimise designs for architectural glass use in Nairobi office buildings.

Methodology

We use mainly computer simulations for this study. The program DEREOB (Dynamic Energy Response Of Buildings)-LTH is our main tool. This is a software developed at the University of Texas and improved by the Department of Building Science at Lund University. Details of the operation are found in program Manuals (Ref. 2)

Inputs include:

- Building Geometry
- Materials
- Time and Location of Project
- Internal Load
- Air Infiltration levels
- Climate File, Outputs included:
- Perspective drawing of building
- Text files for resultant temperatures, energy loads, Solar Factors, geometric factors, wall properties, luminance factors,
- Comfort contour images

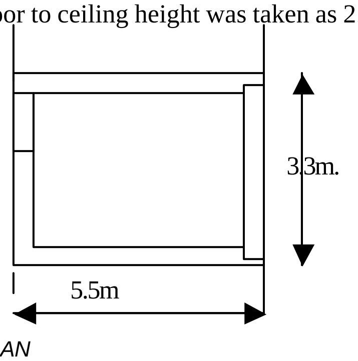
Baseline Case

A hypothetical but typical office space in a 15 storey structure was adopted as our building model. The space measured 5.5 m. by 3.3m.

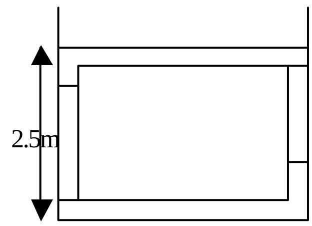
Only one wall on the narrow side assumed glazed. This external wall made of 200mm. stone blocks and 12mm. plaster on the interior. Opposite this was an adiabatic wall made of 50mm. stramit partition boards with a 45mm. timber flush door. The other walls were of the same construction but with no doors.

To achieve the adiabatic condition we assumed a lagging of 500mm. thick mineral wool and ½ the ordinary thickness of the walling material.

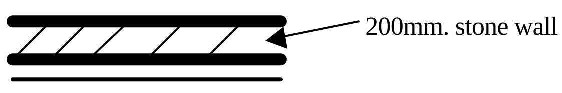
For the floors we used a 200mm reinforced concrete slab finished with cement sand render on the ceiling side and wood parquet as floor finish. Similarly, we used ½ their thickness and 500mm. mineral wool lagging. The floor to ceiling height was taken as 2.5m.

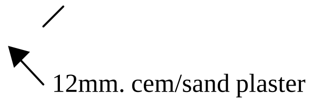


PLAN

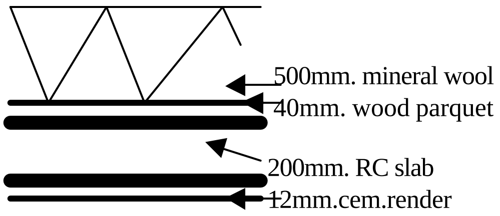


SECTION

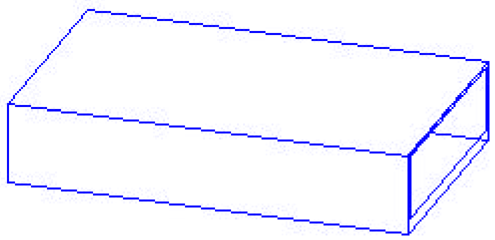




EXTERNAL WALL



FLOOR



3-D view of model office

The parametric study comprises of the following variable parameters:

- Glazing size (Glazing to Wall Area Ratio, GWAR)
- Glazing type
- Building orientation
- Air infiltration in the day and night
- Shading type
- Internal energy loads

The parameters are studied mainly separately i.e. holding the others constant and assessing the singular impact on internal comfort and energy loads.
Appendix D summarises the cases.
The systematic procedure was as follows:

Case1:
GWAR
By varying percentage glazed openings we assessed the worst performer in high indoor temperatures.

- 75%, 60%, 30%, 15%

Worst performing case identified and forms the basis for the next case.

Case 2:
Orientation
Eight Main Compass Directions were investigated. The worst performer was identified. We compared the comfort conditions during the hot and cold conditions in February and July respectively.

- N, NW, W, SW, S, SE, E, NE

Case3:
Glass Type
Using the worst orientation and the worst GWAR we varied glass types.

- Clear Glass
- Absorptive glass
- Reflective Glass
- Double Clear Glass
- Double Glass-outer reflective
- Double Glass-outer absorptive

Case4:
Glass Shading Screens
Using the worst orientation and the worst GWAR we different types of Glazed Screens.

- Clear Glass Screen
- Absorptive Glass Screen
- Reflective Glass Screen

Case5:
Internal Energy Loads
Using the worst orientation and the worst GWAR we varied internal energy loads to respond to different types of office activities and occupation.

- 150W- low activity office with few equipment, normal lights, one occupant
- 330W- in addition to above some equipment or one more person, normal lights
- 660W- high activity, more equipment, more lights, computer, 3-4 occupants

Case6:
Energy loads from Active Energy Sources
We tried to assess the energy requirements in the event of failure to achieve comfort conditions in the worst cases for different types of glazing conditions

- Load with single clear glass
- Load with double clear glazing
- Load with double-outer reflecting glass
- Load with double-outer absorbing glass

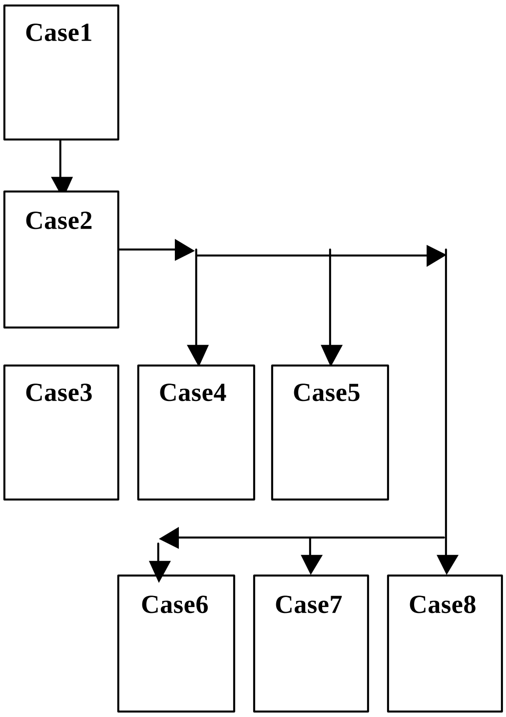
Case7:
General Energy Loads from active Sources for the extreme periods in the year

- February energy Loads
- July Energy Loads

Case8:
Energy Loads with controlled Air Infiltration

- Closed windows- 2ach/h
- Sealed windows-0.5ach/h
- Normal condition…-10ach/h at night and -2ach/h in the day

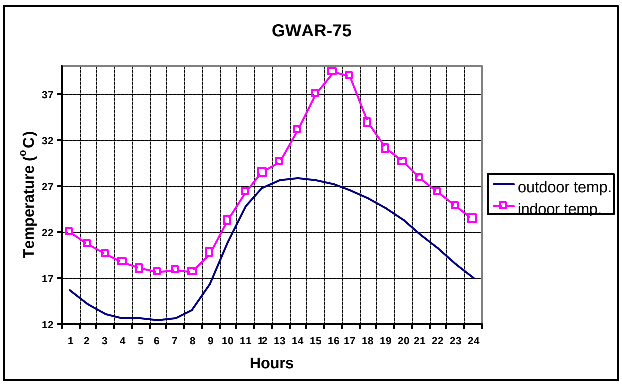
SIMULATION SCHEME



Results & Description

CASE 1: Glass to Wall Area Ratio (GWAR)

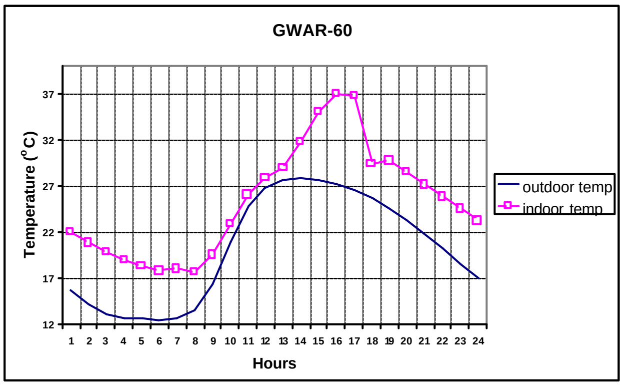
GWAR 75%



- This large opening is typical of most Nairobi office spaces. The recorded temperatures reach 39.3oC, an uncomfortably high figure for this city. Whereas the accuracy of the model may not be taken for granted, it acts as a good pointer to the reality.
- The peak temperatures at 16.00hrs. confirm the increased direct solar radiation incident on the window. It differs to the external temperature because of the time lag between incidence of the rays and the actual impact in the space.
- Between 8.00hrs and 13.00hrs the gap between the internal temperatures reduces because this is the time for increased air infiltration due to the opening of windows. This reversed at 17.00hrs. almost coinciding with reduced solar radiation due to the setting sun.

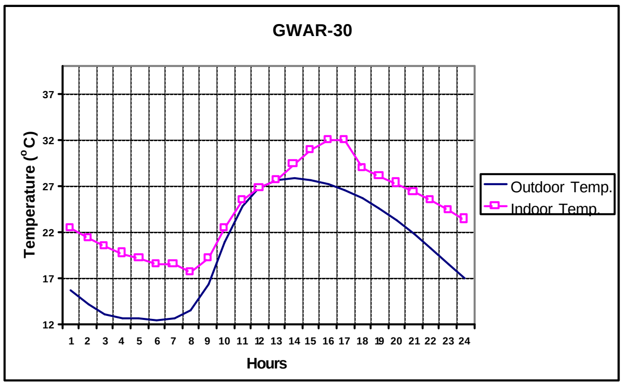
The gap between outdoor and indoor temperatures is maintained at night, as only minimal ventilation is possible through permanent vents and gaps in windows lining.

GWAR 60%



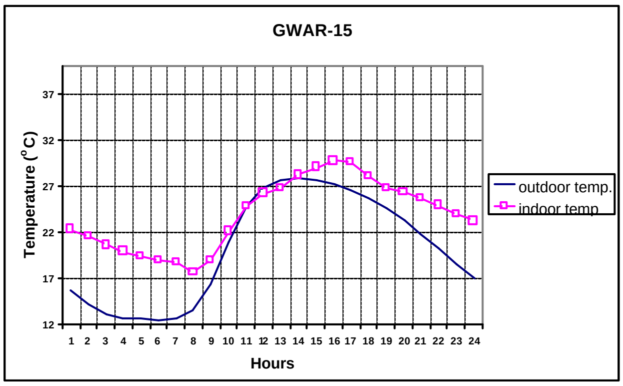
- The trend explained above is repeated in the GWAR 60% condition.
- The peak is lower given the lower however.

GWAR 30%



- The impact ventilation felt in this case as outdoor temperature for once coincide with outdoor temperatures at 12.00hrs.
- The gaps between indoor and outdoor temperature of about 5oC outside of the ventilation period is however maintained

GWAR 15%



- In the unlikely scenario when we reduce the opening size to 15%, we encounter significant drops in temperature during office hours.
- The variation between the peaks of low and high temperature is more even.

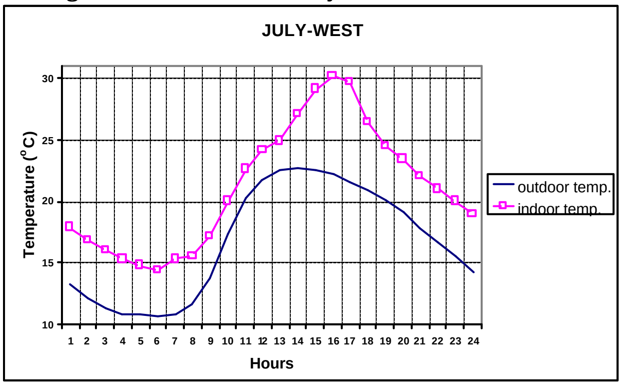
- The impact of natural ventilation is felt when for once we achieve lower indoor temperatures between 11.00hrs and 13.00hrs.

It can be stated that the glazing size significantly affects the indoor temperature. This is not only in the period of the direct radiation but als o well after the offices are vacant due to the time lag.

By decreasing the glazing area we can achieve lowered internal temperatures. Another passive method evident from this case is the capacity to use natural ventilation to cool the room.

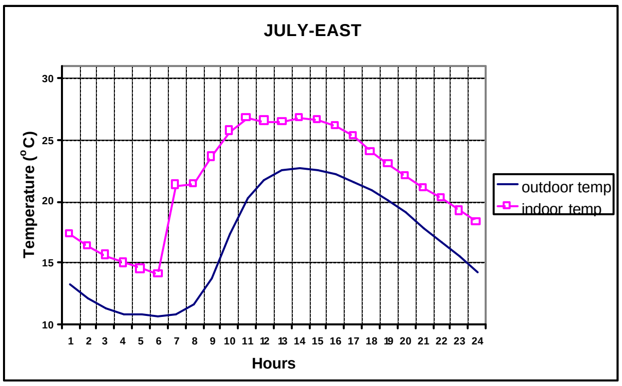
Case 2B: Orie ntation

During the cold months of July West



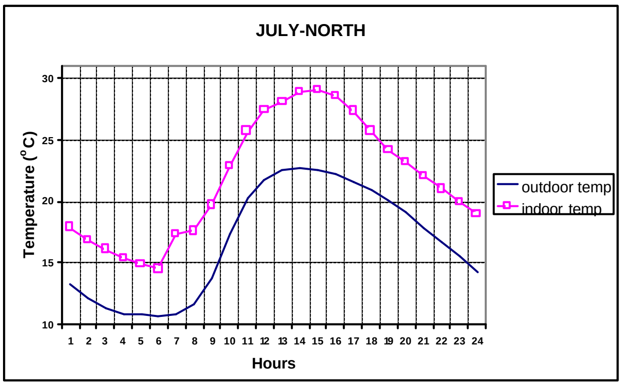
- The highest indoor temperatures were recorded in the Western facing façade. The time of the maximum temperature of 30.1oC is at 1700hrs.
- The main contributors to this are the direct solar penetration into the office from the west in the afternoon.
- In the course of the day through ventilation temperatures are controlled.

East



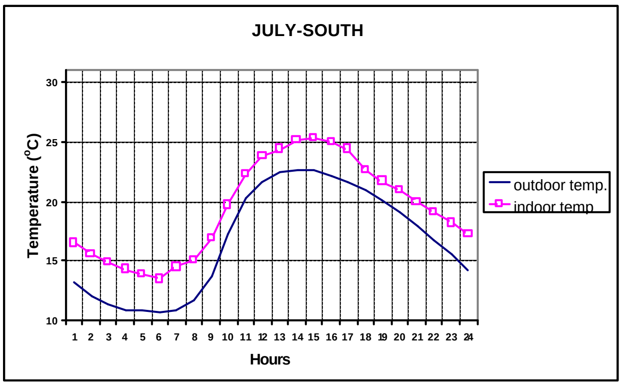
- The impact of the morning sun shifts the top temperatures to between 11.00hrs and 17.00hrs.
- The impact of ventilation in the morning is not significant given the direct radiation.
- The high temperatures in the afternoon are attributable to the time lag effect from morning sun incident on the office.

North



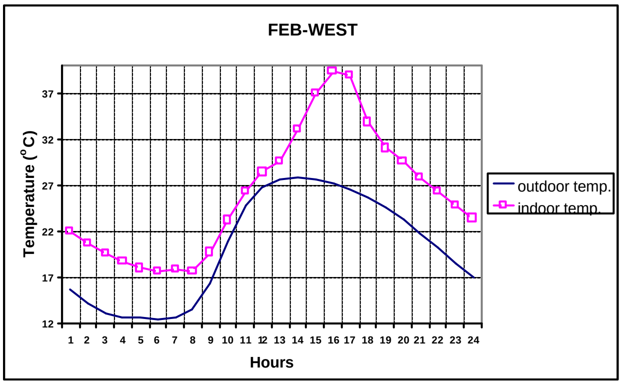
- The North façade shows an even gap between the indoor temperature and the ext erior. This is mainly so because during July the sun is in the North and direct radiation is experienced.
- The higher temperatures are mainly because of direct from the sun

South



- The South façade experiences even but lower temperatures than the North. This is because during this month the sun is in the Northern hemisphere.
- The temperature rise is mainly through indirect radiation.

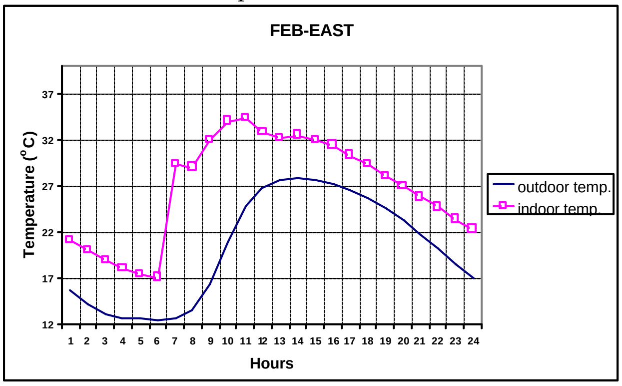
Case 2B: Orientation
During warm months



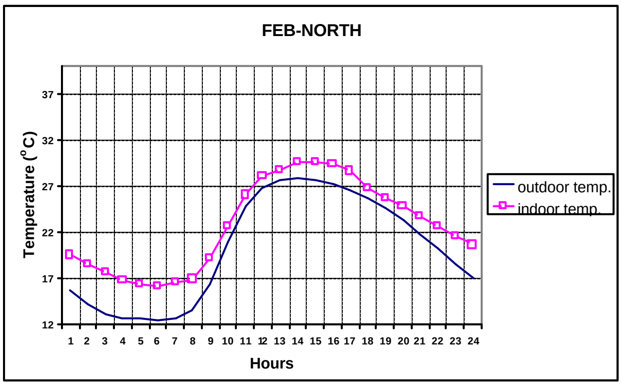
The warmest month chosen is February

- The highest indoor temperatures were recorded in the Western facing façade. The time of the maximum temperature of 39.3 is at 1700hrs.

- The main contributors to this are the direct solar penetration into the office from the west in the afternoon. In the course of the day through ventilation temperatures are controlled.

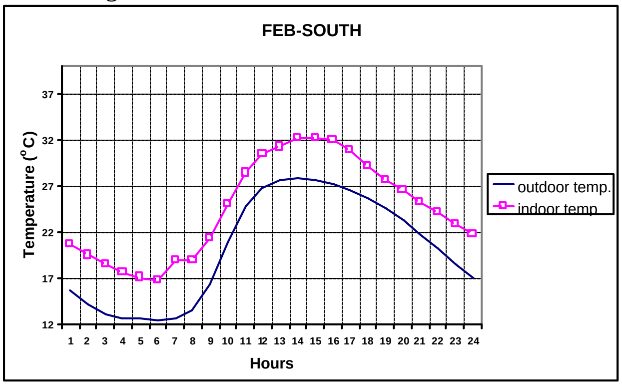


- The impact of the morning sun shifts the top temperatures to between 11.00hrs and 17.00hrs.
- The impact of ventilation in the morning is not significant given the direct radiation.
- The high temperatures in the afternoon are attributable to the time lag effect from morning sun incident on the office.



- The North façade shows an even gap between the indoor temperature and the exterior. This is mainly so because during July the sun is in the North and direct radiation is experienced.

The higher temperatures are mainly because of indirect outdoor light and not direct from the sun



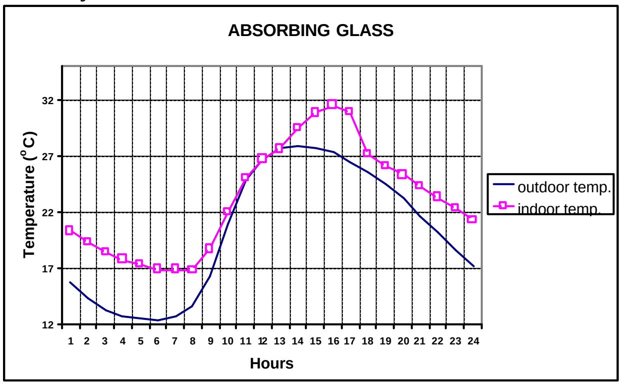
- The South façade experiences even but lower temperatures than the North. This is because during this month the sun is in the Northern hemisphere.
- The temperature rise is mainly through indirect radiation

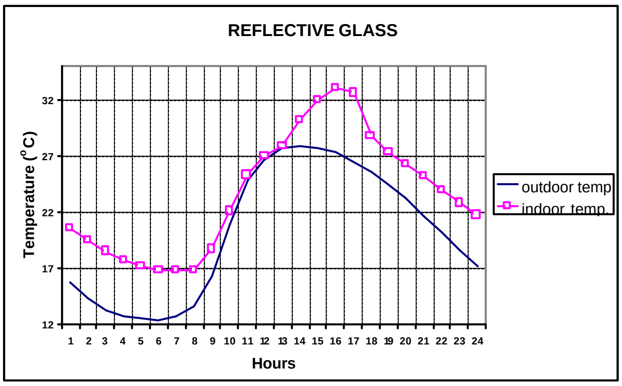
In summary the orientation is crucial in determining internal temperatures and comfort. One could be well advised to avoid west and to a lesser extend south facing windows in the month of February.

Case 3: Gl ass Types

In this case we first of all simulated the temperatures for different types of glazing for a west facing window and of 75% wall area.

- The temperature recorded of 39. 3oC could only be reduced by 6oC for the reflective glass and by 9oC if absorbing glass is used.
- There is a significant reduction in the gap between the indoor temperature and the outside by either option.
- The peak temperatures are still experienced at 16.00hrs meaning that direct radiation is still significant.
- Both absorbing and reflective glass are more effective in lowering thermal conditions in the office than clear glass.
- However the temperatures are still high hence we may still need mechanical methods

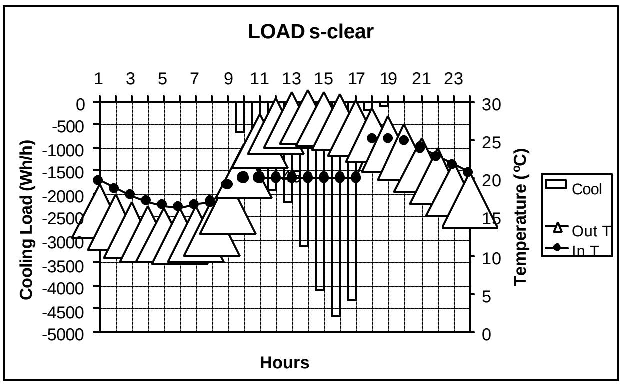




Case 3A: Glass Types and Energy Loads

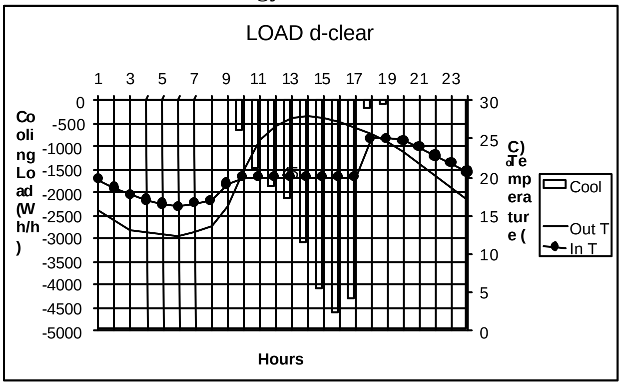
In the second simulation with different glass types we tried to asses the energy implication to the office for the single glass and possible double glazing. We set out temperature levels at 20oC and 25oC.

Single Glass- energy loads



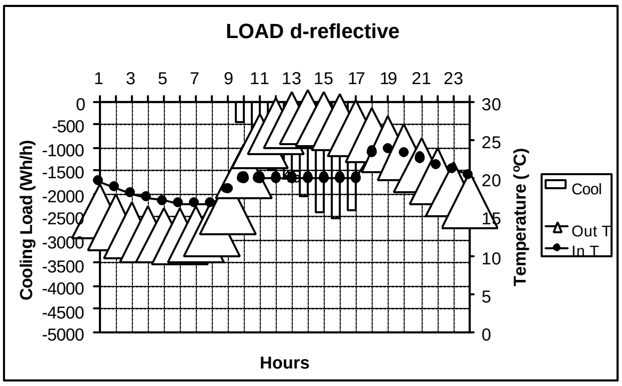
- To achieve comfort levels of between 20oC and 25oC during office hours, using single glazing up to 4500 Wh/h were required as cooling.

Double Clear Glass-energy load



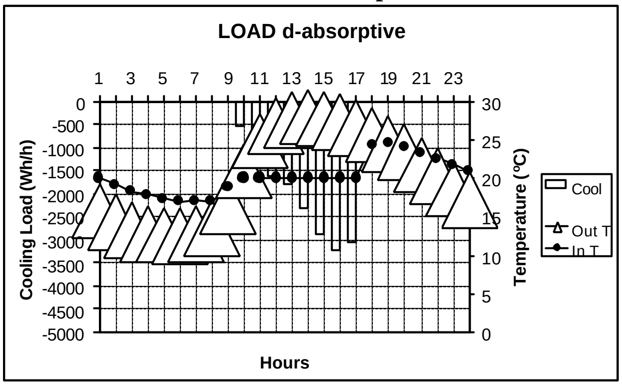
- No significant change was possible with double clear glazing. Only 500Wh7H was recorded

Double Glass with Outer Reflective-energy load



- A more significant drop was observed if one used double glazing but with an outer reflective glass sheet. Up to 2000Wh/h reduction was possible.
- An outer absorbing glazing was less effective in controlling active energy loads with 1000Wh/h.

- **Double Glass with Outer absorptive**



SUMMARY OF SIMULATION RESULTS

			February Case	July Case
	CASE CODE	CASE	max. temp. °C	
OPENING SIZE	base case	GWAR 75	39.3	n/a
		GWAR 60	37.0	n/a
		GWAR 30	32.0	n/a
		GWAR 15	29.7	n/a
SHADING SCREENS		absorbing screen	34.3	n/a
		reflective	31.8	n/a
		clear	41.0	n/a
ORIENTATION	base case	west	39.3	30.2
		south west	38.6	25.5
		south east	34.5	25.8
		south	32.2	25.3
		northwest	32.8	30.6
		northeast	30.6	28.7
		east	34.4	26.7
		north	29.6	29.0
INTERNAL LOADS		150W	38.5	n/a
	base case	330W	39.3	n/a
		660W	40.8	n/a
GLASS TYPE	base case	single clear	39.3	n/a
		single absorbing	31.5	n/a
		single reflecting	33.0	n/a
		double clear	31.8	n/a
		double reflecting	31.8	n/a
		double absorbing	34.5	n/a

Conclusions

It is evident from this study that excessive glazing increases internal temperatures within office spaces studied. We realise that despite the generally agreeable Nairobi climate, architects can and do create spaces that require energy consuming active methods. We have shown that passive methods can be employed to reduce these interior temperatures to a reasonable extend.
The extent to which these methods can be effective varies. We can summarise results as follows:

- **Orientation** of the space should be such that one avoids the western sun in hot period. As has been shown very little can be passively done to reduce indoor temperatures to a comfortable level. Where possible, architects could well locate functions like wet areas in the west façade to avoid this difficult situation.
- The **Glazed Area** of the window should be reduced to functionally acceptable levels. Here in addition to internal comfort we are concerned with lighting levels within the space.
- The **Glass Type** can be used to reduce internal energy requirements in a glass façade. The single absorbing glass seems more effective than the

reflective type as a replacement for single clear glass. Double glazing of any type of glass does not seem to improve indoor conditions considerably despite its extra cost. One should avoid specifying this type of detail for windows. Absorbing glass (tinted) reduces day lighting levels within the space however.

- **Shading Devices** like shading screens reduce indoor temperatures significantly. Though in the worst condition (west orientation) we are still not able to achieve indoor comfort, cooling energy requirements are reduced by use of these shading devices. Shading should however not be at the expense of day lighting levels and views.
- The **internal Loads** do not seem to significantly affect the indoor temperatures as such should not form any serious limitation to design of offices.

As regards the tools used we wish to highlight the limitations or otherwise encountered during the study. DEROB-LTH proved to be a good tool in decision making in the design of a comfortable interior.

With simple form we adopted we managed to make many simulations which enabled us to make otherwise time consuming simulations. The model chosen was well suited for an office space but where a more complex design like a residential unit the method may be limited. This mainly because DEROB does not accommodate complex forms and typologies. Further the number of volumes for simulation are limited to eight.

The program could not simulate convective heat transmission which is another handicap. Thus for instance when using glass screens heat generated between the window and would dissipate away through convection, reducing the indoor temperatures. This way we expect lower indoor temperatures than probably recorded in our results.

The position of traditional tools like Mahoney Tables and Givoni's Comfort graphs serve as guide to climatic design. They may have limited application once computer software like DEREB are sufficiently developed.

Whereas we have been able to asses indoor comfort requirements in this paper, we ought to consider the impact on the urban climate of the use of glazing and other contemporary materials. The heat island created in urban areas like Nairobi is a major concern for all architects, planners and residents alike. This should form a basis for further study.

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- Hans Rosenlund, the course director,
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- Erik Johansson, photographs and guidance
- Entire LCHS staff
- University of Nairobi
- William Busolo, Nairobi Architect
- AEE 98 Course participants
- Family and friends

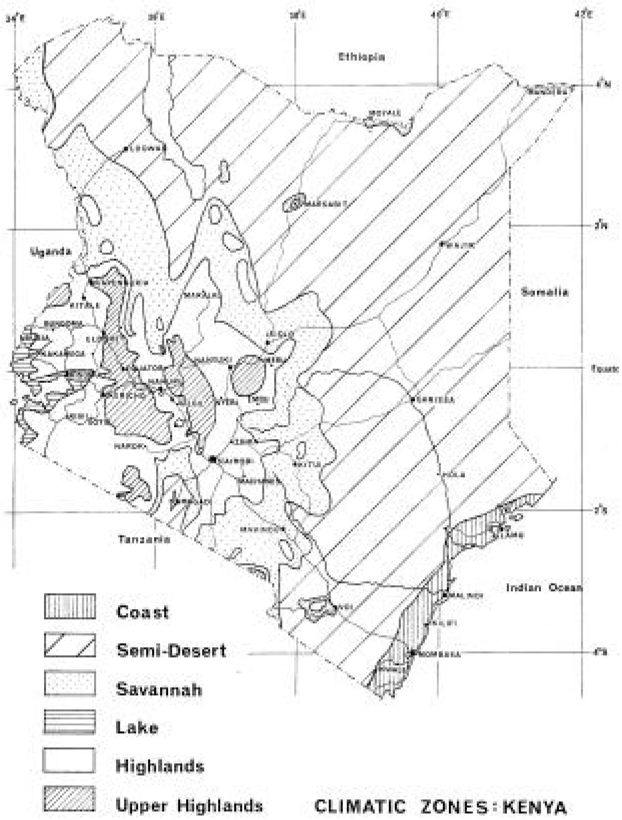
I am grateful to them all.

References

1. 1975: Hooper, C. *Design For Climate*
2. 1998: DEROB Manual

Appendix A: Kenya Climatic Zones

Source: Hooper, C. Design For Climate



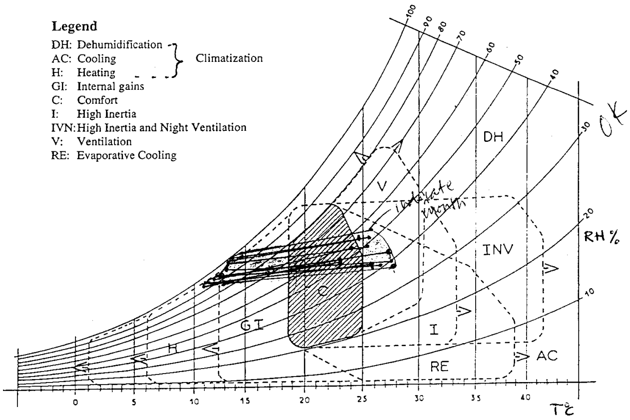
Appendix B: Givoni Chart

Bioclimatic Diagram (Givoni)

Location	NAIROBI (JKIA)
Longitude	36°55' E.
Latitude	1°19' S.
Altitude	1624M.

Climatic data

	Jan	Feb.	Mar	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
Monthly mean max. Temp	26.7	27.9	27.8	25.5	24.5	23.7	21.7	23.3	25.8	26.7	25.3	25.4
Monthly mean min RH	42	37	40	53	55	53	53	51	43	41	52	49
Monthly mean min Temp	12.1	12.4	13.4	14.6	13.7	11.9	10.7	10.9	11.2	12.8	13.4	12.9
Monthly mean max. RH	94	89	94	97	97	95	94	93	94	95	97	97



Recommendations

Appendix C: Traditional dwelling

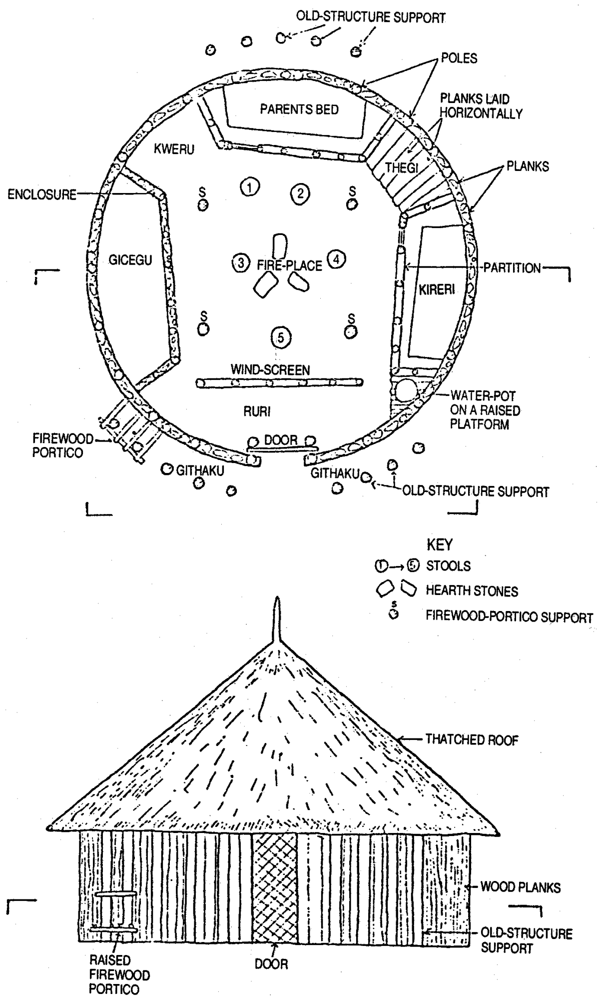


Fig. 8.2 Measured drawing of a Kykuyu hut, E.N. Mboguah, 1971.