ABSTRACT

This Paper makes a commentary between scientiﬁc and architectural design of vernacular architecture in East Africa. It relates the history of architectural theory and contemporary practice of environmental control. Firstly, it describes the climate of East Africa and shows the potential of climatic controls in hot humid conditions. Secondly, it focuses on the physics of heat and light as applied to buildings in achieving interactive comfort. It includes the potentials, limitations, and constraints of using the ASHRAE psychrometric charts for situations where people in developing countries have acclimatized. Finally, it makes observations on vernacular architecture and contemporary trends on interaction between climate, site conditions and building form.

Key words: Heat sinks, lighting, and thermal mass.

INTRODUCTION

The development of green thinking in architecture in Africa is a relatively new phenomenon. However, it has often revolved around thermal, ecological and issues of the environment resulting from current strides now being made in high technology.

Climates make architecture, at least in part. All buildings are solar. All built-environments on earth, as well as human extra-terrestrial constructions are strongly inﬂuenced by the sun as they are by gravity. In cool climates, solar heat gains can be made use of. In the warm climates the problem is different; unwanted heat and how to get rid of it. In passive heating, options on how to utilize the sun’s energy are many. In passive cooling there are not too many possibilities. If a building is considered as a closed box exposed to a given temperature regime, there will always be some internal heat gains (from people, lights and equipment) and also some solar heat gains (both through windows and on solid surfaces), so that the indoor temperature will rise. In general, we have little control over the internal heat, but the solar heat gains can be controlled by design.

The thesis of this investigation is that in many hot places in East Africa it is possible to achieve good indoor thermal conditions in non-domestic buildings even without operating air conditioning systems, provided the building has sufﬁcient amount of thermal mass and is ventilated well during the night. Some of the underlying questions at the start of the modeling were:- Is there optimum amount of thermal mass above which the excessive thermal mass degrades the building performance? Is there a difference in the performance of a building when the thermal mass is located in the external walls, or the internal partitions during the hottest period? What is the best place to locate insulation, on the external side or the internal side? In understanding the processes of design in Africa, the architect has to provide due consideration for strength, usefulness and beauty within a valid cultural context. This is summarized in ﬁgure 1 that shows these basics.

The author is currently a graduate student in the Department of Architecture at the University of Florida, Gainesville, FL. He is also a registered architect in Kenya.
Climatic conditions in East Africa differ from region to region with a resultant of varying types of vegetation. The vegetation that covers the country essentially depends on four climatic parameters—temperature, rainfall, humidity, and radiation, which in turn are controlled by altitude. In general, low areas are very hot and tend to have poor rainfall and a dry atmosphere with low humidity. The main exception is the coastal strip and the area along the shores of Lake Victoria which are hot with high rainfall and high humidity.

Located astride the equator on the Indian Ocean East Africa has an astonishingly varying environment. Its climate has equatorial tropical and temperate-like features. About 70% of the population live between the altitude of 1000 and 2400m above sea level. The region is divided into six distinct climatic regions, namely, Coast, Semi-desert, Savannah, Lake, Highland and Upper Highland. Despite being close to the equator, snow is found on Mt. Kilimanjaro and Mt. Kenya daily throughout the year. As one descends, it warms up at a rate of 6.5°C every 1000 metres drop (3.7°F for every 1000 feet).

Seasonal variations are marked as Long Rains (Mar-May) and Short Rains (Oct-Dec). Given the breadth of interpretations, the semi-desert and savannah zones might be described as hot dry climates, the Coast and Lake zones hot humid climates and the Highland and Upper Highland zones warm humid climates. High rainfall occurs with shortest sunshine hours due to cloud cover, and vice versa. July receives the shortest sunshine hours, least monthly radiation, and lowest air temperatures. January and February receive the highest solar radiation and longest sunshine hours.

Response to Climate by Building Design

Figure 2 gives suggestions on how to choose design control approaches for responding to climate.

For communities that live on few resources the need to pursue passive controls overrides that of active controls. In most cases, vernacular architecture has often adapted well by putting the control function in the building envelope. It also uses microclimate, landscape, earth, and water features to green the ambient environment. This fact, consciously, made life in the savannah habitable.

Applying Thermal Mass in Passive Control

East Africa, therefore, faces a challenge in which high air temperature and humidity need to be controlled for human comfort. Thermal mass in the form of adobe walls and roofs are prevalent in the domestic house. The basic principle in applying thermal mass to solve cooling problems is to take advantage of heat capacity of building materials to smooth out peaks and troughs in temperatures that otherwise would occur in that building. Even newer commercial buildings in urban areas have large thermal masses. It is no surprise that a recent design study (Evans, Architects' Journal 5 May 1993) indicates energy costs of offices can be cut by one third by removing air conditioning and using passive techniques such as thermal mass and making greater use of natural ventilation and daylight. In the twenty-year period between 1974 and 1994, approximately 90% of Kenya's conventional energy in buildings were used by the non-domestic sector (GDK 1997).

In the mid-70s there was a flurry of activity with solar absorption air conditioning systems. It led to a cul-de-sac, not only in monetary terms but also in terms of energy accounting.

As well as stabilizing temperatures thermal mass has other benefits; time lag. Peak heat gains typically occur at 1500 hours with peak temperatures occurring at around 1800 hours, when most non-domestic buildings are un-occupied. Thermal mass is another useful role; comfort. Comfortable temperatures are a balance between air temperature and radiant temperature of the surrounding interior surfaces. To some extent they are interchangeable, a cooler structure and warmer air, or vice versa, producing a similar resultant comfort temperature.

2 The Government of Kenya produces a National Development Plan every five years. This document forms the basis of evaluating the preceding period and gives a projection of priorities for the next five years. The Government Printers, Haile Selassie Avenue, Nairobi Kenya, publish it. The current copy is the Eighth since independence from Britain.
For this reason passive-cooling design of non-domestic buildings in East Africa is receiving serious attention today. With the high cost and sometimes-erratic supply of electricity, conventional air-conditioning systems are proving to be an expensive solution. Passive cooling techniques that make use of the building elements to minimize the effects of unwanted solar radiation are now being put in place using an approach that utilizes environmental heat sinks for heat dissipation. These controls are illustrated in Figure 3 which emphasizes the use of passive cooling with treatment. It takes the premise that control of thermal radiation, reduction of internal gains and use of heat sinks had profound ability of enhancing interaction between climate and buildings. Examples of the environmental heat sinks include night air for cooling, evaporative cooling using sprays, and ground-cooling using buried pipes. Passive cooling now represents one of the most important strategies for the replacement of conventional fuels and reduction of environmental pollution in the building sector.

VERNACULAR ARCHITECTURE AND NEW BUILDING TRENDS IN EAST AFRICA

Vernacular buildings in East Africa have been used since time immemorial. The impact of climate on the choice of material has always been a matter needing care. But, with the advent of industrialization and economic development in many tropical countries, there has been an increased demand for both new housing and for buildings to house institutional and business activities. Many of the buildings that have ensued have embodied "modern" design features from buildings in temperate climates. As a result, many of these new buildings have been unusually hot and stuffy - a problem that has often been solved by installing refrigerated air conditioning systems. However, the high cost, erratic supply and limited availability of large amounts of electrical energy needed for air conditioning has posed a serious constraint regionally. Internationally, there is concern for the impact of chloro-fluorocarbon (CFC) refrigerants on global atmosphere has posed an added problem for those who have chosen the air-conditioning feature for their buildings. The World Health Organization has already declared 30% of the world's buildings as "sick" due to the Sick Building Syndrome that is connected with interiors maintained under mechanical systems. The generally agreeable climate of most parts of East Africa offer a means of achieving a better climate-sensitive architecture and thus make a rich built-environment for all. The choice of materials is part of the normal duty for an architect. These choices are made from many choices depending on their performance, availability, and cost. Most important of factors is performance because they must protect human beings from adverse effects of the climate for the entire life-span of the building. In designing a building, the Architect must meet a large number of design considerations outlined in Figure 3. Also important is that, it must be designed to be technically correct, "it must work". Climate-sensitive design as seen in vernacular African Architecture, provides age-old insight to design and therefore should be of paramount importance to Architect's design process, towards green-sensibility in African Architecture.
ASHRAE's Comfort Standards

Most people in East Africa live in un-air conditioned buildings. They have acclimatized to, and can tolerate, higher temperatures and/or humidity than those used to cool temperate conditions. The problem associated with application of the ASHRAE comfort standards in hot humid places can be illustrated on a psychrometric profile for a not-to-severe warm-humid place, say, the city of Eldoret, East Africa. The Chart reveals some interest from April to July (the long-rain season) even the minimum temperatures would be considered uncomfortable by the ASHRAE comfort zone. This has often led building projects with high budgets to implement use of air conditioning systems without further reference to peoples' expectations.

Clearly, the use of ASHRAE comfort standards in hot humid climates is a good starting point before making design solutions but they must be evaluated carefully before final implementation. Givoni (1994, 1998) has attempted to suggest new boundaries that are needed for un-air conditioned buildings. See Figure 4. Three regions where most people of East Africa live are marked on the chart. Warm humid region A needs comfort ventilation as the main strategy of thermal control. Hot humid region B also needs comfort ventilation. Hot dry region C requires large thermal mass and evaporative cooling. However, due to the scarcity of water resources local people in these regions do not utilize evaporative cooling for thermal control because the merger water resources are used for other necessities of life rather than just "cooling" the building. In the equatorial highlands of East Africa diurnal temperature ranges are high and people living in such conditions have come to be used to such drastic changes. In some places the diurnal temperature range is equal to the seasonal range.

Givoni (1998, 38) notes that temperature boundaries at low or medium humidities (region C) are independent of the humidity level because in this range of humidity it does not affect the comfort of sedentary persons with ordinary clothing. At higher humidities the effects of temperature and humidity are interrelated and the upper temperature decreases with higher humidity (region A & B). The people of East Africa normally wear fairly light cloths. The suggested temperature limits of acceptable thermal conditions are from 20 to 27°C (68 to 80.6°F) in the cooler period and 22 to 29°C (71.6 to 84.2°F) in the hotter period. This takes account of the factor of acclimatization resulting from people who live in un-air conditioned buildings.

Figure 4 Regional conditions plotted over the Boundaries of acceptable conditions for still area (After Givoni 1998, 38)

Baker and Standeven (1993, 1994) have made some observation on this study. While this author studied under Baker at the University of Cambridge, UK awareness was created that prompted an interest with actual subjects on ground. This other study is still inconclusive it lends some hope that comfort zones vary from place to place. Therefore, tools being used currently in the trade and relevant comfort standards have to be modified to reflect this reality. As research progresses this matter will be abridged.

Achieving Thermal Comfort

Thermal properties are used to great advantage in the choice of building materials. They are local. This means that a transport component in overall building costs can be reduced significantly. They are easy to work on by local craftsmen who have years of experience in this work. A variety of options exist in which to choose from. Thermal capacity of a building, being a property proportional to its mass, is measured as the amount of heat energy required to raise the temperature of an element by one degree. Applying this to, say, "makuti", roofing is achieved

3 Makuti is the local name of a building material used chiefly for roofing. It comes from palm trees leaves.
cheaply with good thermal properties. Thermal conductivity of a material, being a measure of the rate of heat flow through unit thickness of the material, when there is a unit temperature difference between the two sides also has its place in performance of makuti. It is light and has good thermal resistance. The lower the conductivity, the higher the resistivity, the better the insulation value of the material is. In this regard makuti is locally available, affordable and performs with the climatic context. Most homes and even tourist hotels employ the use of this material. Although there is no direct relationship between the density and resistivity, dense materials tend to have a low insulation value while lightweight materials, which are likely to be more porous and thus contain more air, tend to have a high resistivity and high insulation value.

Using Time-lag
Since in nature the variation of climatic conditions produces a non-steady state, diurnal changes produces an approximately 24-hour cycle of increasing and decreasing temperatures. Knowledge of the decrement factor and time lag for different materials, thickness and combination of materials in various constructional elements, is important for the designer. In practice, this concept has been used very effectively in vernacular African roundhouses that utilize materials like masonry, earth and concrete. They have quite lags of approximately 8 to 10 hours for every 300-mm thickness to deal with the problem of thermal radiation. The selection of material compliments where natural ventilation and other thermal controls cannot adequately complete the task. The use of construction material with an appropriate time lag is an essential factor in "balancing of time". So for a material with long time lag the maximum temperatures occurring at mid-afternoon are felt at around midnight when ambient temperatures are low and heating is desirable. This passive approach saves energy and cuts down maintenance costs. Depending on the decrement factor the period can be lengthened or shortened to meet any desired needs.

Achieving lighting comfort
Daylight is desirable not only for energy conservation but also because it is considered superior to artificial light. When the filament lamp was invented the world was excited about this new gadget and over years it has often symbolically it is dried then treated and laid over timber battens on the roof. It is lightweight with high insulation value. replaced use of natural daylight. Until now, Windows provide visual and auditory contact with outdoor. Inevitably, the more the sky component viewable at a work plane the more the lighting level. Consequently, the natural eye having been used to this type of light expects the same when artificial lamps be used. Natural light falling at a work plane through tall trees or buildings, or some form of screen will surely be less intense. People may react differently by cutting down some branches in case of a tree, or moving to another building altogether. This problem must be addressed by designers in the East African region because foreign trade investment comes with architectural options that do not meet unique local conditions.

As stated before, green thinking in architecture in Africa is a relatively new phenomenon. It has often revolved around thermal, ecological and issues of the environment resulting from strides made in high technology. Light and lighting in context of African architecture is somewhat different. Light is a guide around places, paths and objects in general. The roundhouse was designed more as a sleeping place than a place for work. Most work was done socially in small groups. Makuti was held outside. Groceries, craft work and farm implements are displayed and sold outside. Therefore the concept of lighting the interior spaces was never a matter of serious concern. A fire burning while cooking did several things at once: it gave energy for cooking, provided heat in the room space, drove away harmful insects (smoke is a repellent) and provided enough light to see around as one moved within the house. Due to changes in peoples' lifestyles over the recent years, houses have increased their roles. Natural daylight must now be admitted into the interior for the hours of daylight. This has meant the use of more glazed areas that must be shaded for thermal reasons. Being on the equator, the length of day and night are roughly the same throughout the year. This implies that one can rely on the supply of natural daylight from 6.15 am to 6.45 PM daily. Most non-domestic buildings fit in this category. Providing lighting needs and matching it to concerns for heat gains has profound architectural implications in building form and aesthetics, symbolic of green values. In developed countries electric lighting allows ease and flexibility on floor plans by ignoring window

4 Baraza is a gathering of village elders under a tree in the village dance arena. It can also be held in the Chief's compound. It is always outdoors.

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locations. In East Africa, thermal reasons and economic considerations demand that windows play a vital role in comfort. But there is adequate daylight owing to the sun falling evenly throughout the year at the equator. In most parts of the region the maximum demand for electricity in non-domestic buildings occur on a hot afternoon when daylighting is plentiful (Figure 5).

Today, the return to nature can be seen as a source of inspiration in developing lighting science that will benefit local people. The issue of daylighting, and its relationship to building form, has special emphasis in office, commercial and industrial buildings where electrical lighting, appliances and fixtures constitute a major expense. This use of electrical energy also adds to the cooling load. One of the ways of solving this problem of meeting lighting needs and controlling the thermal environment is by introducing projections (e.g. balconies, etc.), and by recesses. This increases the overall length of the building walls thereby exposing the building more to natural wind currents necessary for ventilation. More shaded windows exposed to outdoor environment is a good solution.

When the orientation of building needs to catch scenery outside, windows provide that means. When it necessary to control glare, the need to exclude noise must also be addressed. Well-shaded operable windows are “natural” green means of control. They help to articulate and more fully define architectural character of a building. A desirable building is one that meets standards of comfort.

Observations on Climate-Sensitive Design found in Vernacular African Architecture

Figure 6 shows some observations made from a typical African traditional house. These units come in many shapes and have different finishes externally, on floors and in ceilings. The important thing to note is the principles to be derived from the architectural response made to the climate of yesteryear’s experiences and not necessarily to see them as prototypes for our time.

The walls are made of thick earth reinforced with timber twigs and tied together using organic strings locally available. They are later given a protective finish to keep out insects and any parasitic invasion. The floors are rammed hard to provide a solid base which also has a protective finish. The roof is kept at a high pitch so that it can provide a quick run-off since this area has high rainfall. The conical roof is the most appropriate basic design element that could cover the ground cylindrical-shaped walls. The internal environment is constantly comfortable regardless of the outdoor conditions. The equator crosses Kenya at about its midpoint. Solar radiation is therefore very high. The temperatures during the day are very high, and very low during the night. Diurnal temperature range can be as high as 15 °C. This is equal to the temperature range in annual seasonal variation. Therefore, controlling the day-night cycle effectively means one can control conditions in the house for the rest of the year.

Walls are made of materials of low thermal capacity meaning that they do not allow quick heat passage of the high day thermal radiation. Their thermal mass ability means that when they gain heat they have a large time lag of, say, nine hours. This translates in a most interesting way. High afternoon (3 PM) sun is not seriously felt until late at night (mid-night) when it is very cold and the heat is most desirable. This manner of balancing-of-time makes the roundhouse very comfortable to live in. The roof material is grass thatch. This material is light and an effective insulator of the high noon sun.
Walls and roofs have heavy structures of a high thermal capacity are used to bring peak period limits of indoor heat gain during the hours of strong sunshine, and to store some of the day’s heat so that it is re-emitted to interiors during the cool night.

Floor Plan of a Luhyia house

Houses are compact in form so as to reduce solar heat gains and minimize nocturnal heat losses.

Use of materials that allow openness in plan for freedom of air movement and ventilation, and improve thermal comfort.

Ceilings greatly reduce coldness at night and overheating by day in light roofed houses. Thatch is more stable.

Use of deep overhangs to reduce impact of strong solar radiation.

A simple horizontal ceiling underneath the thatch roof provided space for storage and an effective way to reduce heat gain during the day and heat loss during the night, thereby maintaining almost steady-state conditions inside throughout the day. This space also acts as a buffer from direct sun.

Shading devices and prevention of heat transmission to the interiors
CONTEMPORARY TRENDS TODAY

Form and Planning

Heavy rainfall of the region have tended traditionally to demand pitched roofs, i.e. roofs have been water SHEDDING more than waterPROOFING. Pitched conical roofs were found to be the best solution for a round-plan house. Pitched roofs offer advantages that:-

- [a] there is not a waterproof membrane which is vulnerable to damage and degradation,
- [b] avoiding a horizontal ceiling offers good possibilities for ventilation.

Proper consideration must be given to the exclusion of insects. Roofing material - banana leaves, reed, palm - all possess the near ideal properties of being lightweight and porous to air movement. But thatch has a number of disadvantages:

- [a] being organic it is subject to decay,
- [b] also ideal for harbouiring vermin, insects and unwanted insects,
- [c] Very vulnerable to damage from hurricane and fire,
- [d] it is labour intensive.

Today galvanized corrugated iron (GCI) sheets are very widespread everywhere in the country. However, some severe disadvantages exist in GCI sheets. They are:

- [a] very low thermal resistance,
- [b] low reflectance [after rusting],
- [c] impervious to air flow,
- [d] ironically if GCI sheets are painted with red oxide paints for aesthetic reasons heat build-up is enormous. Light coloured paint are better.

Most institutional non-domestic buildings, sadly, do not use local materials very well. This is partly due to the influence of investors who come with their own complete "aid" package that ignores local concerns. Hotel buildings on the other hand, to a some degree, have integrated well. Improvements to the design of roofs have been made that include using high reflective paints on GCI sheets, ventilated voids in the ceiling space, ceiling insulation has been adapted and used. The use of clay or concrete has definite thermal advantage but it is prohibitive in terms of cost.

Ventilation

By ventilating a roof space it is possible to prevent undue heating up of the air in roof spaces, and to reduce, and possibly eliminate, the convective heat transfer. Hence, a roof with ventilated attic space and a horizontal ceiling offers slightly greater resistance to heat flow than a roof with a ceiling fitting directly to the underside of the rafters. However, the need for cross-ventilation has an immediate impact on the house form, since it suggests the adoption of single-banked houses. This is harder to achieve in non-domestic buildings. Due to the accompanying high thermal radiation, over-lighting usually means overheating which in turn causes greater discomfort than under-lighting.

Orientation

Orientation and major openings can greatly influence solar heat gain. Solar radiation intensity for north and south facing walls is least. The one facing away from equator (N) receives least. East, southwest, Northwest receive the same amount of radiation and the west will receive the most. On this basis, with an oblong shaped plan, longer walls should face north and south and major openings should be located in these walls. Windows facing east admit morning sun, and this acceptable to some degree. Windows facing west must be avoided.

Towns are also changing. Figure 6 is an example of an office/bank building with large glazed openings (for views) and flat roof. The setting is lakeside town of Kisumu that has a hot humid climate. Deep overhangs are used to shade the glazing.

Figure 7 Office building in Kisumu City

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CONCLUSIONS

Contemporary buildings in East Africa, like those found elsewhere, should lift the raw environmental load of the physical world to create another microenvironment that is conducive for long-term survival. The building has to perform the functions of harmonizing the outdoor and indoor climate in order to support human life. Traditional methods and building materials offered limited means of thermal control. Nevertheless they attempted with some degree of success to use the available resources to adapt. Trends today in which technology is going across the globe at a high rate should subject it to sensible regional contexts. Cultures are also mixing at a much higher rate than ever before. They affect the language of architecture.

Architecture involves the building, its systems and the occupants. The building factors, such as materials, orientation and shape, influence the building performance little more than half as much as the joint influence of systems and occupants factors. Building and systems play the biggest combined role. Special consideration for the building factors must be made. This is because occupants can be educated to adjust their clothing and activity levels. Systems can be made more efficient. Building factors are hard to change once they have been built. Major remodeling of the building can be avoided by giving due consideration at design stage.

Buildings create their own internal environments, and are part of the larger external environment with which they interact with (Figure 8). Direct sunlight is excluded for thermal reasons. Provision of daylighting is quite complex since some of these buildings may be lightweight. Openings ensure cross-ventilation and air movement, but deep overhangs and sun shading elements cut-off most sunlight. A compromise is made to deal with the distribution by external and internal reflection rather than by viewing the sky!

Figure 8 Effect of solar radiation on surface

REFERENCES