INFORMAL SETTLEMENTS IN KENYA: PERFORMANCE ASSESSMENT OF TYPICAL BUILDING ENVELOPES

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ABSTRACT

Urban informal settlements within tropical climates are usually unplanned and evolve spontaneously, causing lack of attention for a lot of important factors such as local climate, site characteristics, urban surroundings, choice of building materials, orientation and architectural design of the building. Consequently these buildings often have a poor indoor climate, which affects comfort, health and efficiency.

This paper looks at the various construction materials used in Kenyan informal settlements to assess the indoor thermal environment they produce. Energy plus-Building simulation programme is used to analyse and assess the different building envelope construction systems' performance depending on the location (Nairobi, Mombasa and Kisumu). Heat index, adaptive thermal comfort index and radiant asymmetry index are used in the simulation.

The outcome indicates that a combination of earth/mud wall with thatch roof offers a better indoor thermal comfort, while oxidised Galvanised Corrugated Iron (GCI) sheets building envelope is not conducive for thermal comfort.

Keywords: Building envelope, Informal settlements Performance assessment, Tropical Climate

Theme: Built Environment and Sustainability

1.0 INTRODUCTION

Informal settlements in urban areas of Kenya are characterised by poor planning and are constructed using building materials that are of questionable properties and poor qualities. Most of the buildings within these settlements are not designed as standard dwelling units and the number of people it accommodates at a particular time is undefined. This compromises the thermal comfort of the inhabitants and results to poor health conditions. The problems are compounded further by lack of proper physical infrastructure.

The government in collaboration with some donor agencies has embarked on a vigorous campaign to upgrade these settlements so as to improve the living standards of the dwellers. Many solutions have been proposed including the construction of high-rise buildings in areas of high population densities and single detached units in areas where space for improvement still exists.

Currently there are several ongoing slum upgrading projects in Nairobi, Mombasa and Kisumu. The challenges faced are the varying climatic conditions of these areas due to their geographic location and altitude above the sea level. The upgrading buildings are constructed without considering the climatic differences that exist which eventually affects the house inhabitants.

A model house of about 60 m^2 in surface area proposed for construction to alleviate this problem is simulated using various available materials for building construction within the informal settlements and in varying climatic conditions is assessed to gauge the envelope performance.

2.0 LOCATION

Kenya is situated to the East of the African continent with a coastline to the Indian Ocean. She borders Somalia, Ethiopia and Sudan to the North, Uganda to the West and Tanzania to the South. With an estimated area of 582,000 square kilometres, the Equator divides the country into two, between latitude 5.6 °N to 5 °S and longitudes 34 - 42 °E. The Great Rift Valley that splits the country from North to South is the most prominent feature of Kenya's topography, others include Mt. Kenya (5,200m) located in the central part of the country; Mt. Elgon (4,300m) to the western border with Uganda and Lake Victoria to the west as indicated in Figure 1 below (World Factbook 2002).

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.

Figure 1: Map of Kenya

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 and 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.

2.1 Climate

Kenya's different topographical regions experience distinct climates. Generally, the hottest time is in February and March and the coldest in July and August. The coastal region where Mombasa is located is largely hot and humid while the low plateau area is the driest part of the country. Higher elevation areas within the highlands where Nairobi is part of receive much larger amounts of rainfall. The Lake Victoria basin in western Kenya is generally the wettest region in the country, particularly the highland regions to the north and south of Kisumu.

Table 1 below gives a summary of the major climatic conditions for the three cities in Kenya and their respective geographic locations.

Table 1: Climatic data for cities in Kenya.

City	Latitude	Longitude	Elevation (m)	Dry-Bulb Temp (° C) HMA	CMA	Relative Humidity (%) HMA	CMA	Av. annual Precipitation (mm)	Sunshine (Hours)
Nairobi	1° 17'	36° 49'	1661	23	10	76	51	960	10.1
Kisumu	0° 10'	34° 74'	1145.7	35	14	68	47	1140	10
Mombasa	4° 3'	39° 69'	54.8	34	20	79	69	1200	10.2

CMA= coldest month average; HMA = hottest month average

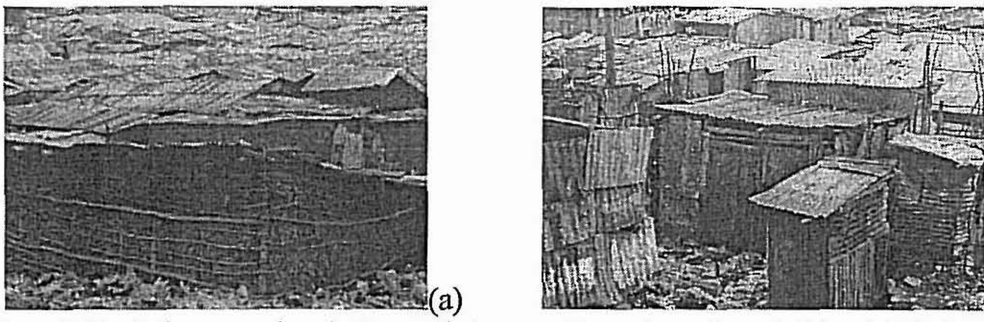
2.2 Building Materials

Building materials in Kenya can be classified in three broad groups based on their nature, origin, context and use. Traditional building materials are mainly organic in nature, obtained easily and cost less such as wood, grass and palm leaves used as thatch and earth or mud for walling. Contemporary materials are those that have undergone some modification process or factory produced. These include cement, Galvanized Corrugated Iron Sheets, nails, tiles among others. Finally, appropriate technology materials are a combination of traditional and contemporary materials such as Stabilized Soil Blocks (SSB) made from compressed admixture of soil and cement; Fibre Cement Roofing Tiles (FCRT) where cement sand mixture is reinforced using sisal fibres. The most commonly used building materials in informal settlements are: earth/mud, coral stones, GCI sheets and thatch.

2.2.1 Earth Mud

Earth or mud is a preferred building material in informal settlement areas. Floors and walls of many structures in slum areas are constructed using this material because it's fire resistant, added to favourable climatic performance in most regions, due to high thermal capacity, low thermal conductivity and porosity which enables it to subdue extreme external temperatures while maintaining satisfactory moisture balance. Its availability, cost and workability makes it the easier option for many. (Roland and Kiran, 1993).

It has the advantage of sustainability and environmental appropriateness. Its main disadvantages are low tensile strength and low resistance to abrasion and impact if not sufficiently stabilized or reinforced. Figure 2a below shows a house made of earth and reinforced using timber. No skill is required in the construction of earth wall so long as the necessary supporting timber frames are in position. It's used in all the regions in informal settlements.



(a) (b)

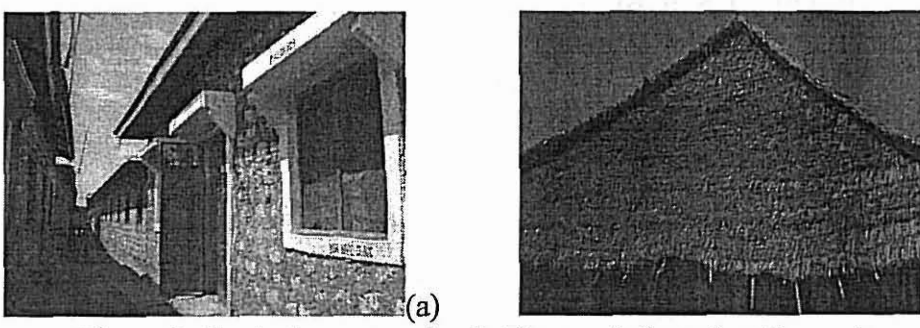
Figure 2: Typical constructions in Kenyan informal settlements: earth walls (a) and GCI sheets (b).

2.2.2 Galvanized Corrugated Iron Sheets

GCI sheets are used as walling and roofing material. The corrugations make the sheets stiff to span large spans with minimum support. They are mostly galvanized iron or aluminum sheets. Their major problem apart from the initial cost is immense heat transmission in hot weather and condensation in cold weather. In humid climates like Mombasa, they tend to oxidize and loose reflection properties, therefore its preferred building material in Nairobi and Kisumu. Some skill is required during fixing because poor workmanship leads to roof leakages. Most GCI sheets used in slum areas are recycled. Figure 2b above shows some structures constructed using GCI sheets.

2.2.3 Coral Stones

Mainly used at the Coastal region of Kenya in Mombasa since it available in plenty. Its use is restricted to wall construction because of its thermal properties and durability. Its resistance to abrasion and impact force makes it a preferred choice, but the only obstacle is the choice of mortar for binding the masonry pieces together. Either lime or cement mortar is used, whose cost is prohibitive and many resort to mud instead whose binding properties are not as strong as cement or lime mortars. The laying of these units also requires some masonry skill so very few people in slums make use of it. Figure 3a below shows walls constructed of coral stone units.



(a) (b)

Figure 3: Typical construction in Kenyan informal settlements:
(a) coral stone walls (b) palm leaves thatch

2.2.4 Thatch

Grass, palm leaves and reeds are the most common types of thatch used (figure 3b). They are locally available and abundantly and when properly laid, are waterproof and possess good thermal and acoustic properties. Skilled labor is required for laying the thatch. Major drawback to roof thatch is durability, since frequent repairs have to be done to avoid total degradation of the material which has proved to be expensive in the long run.

2.2.5 Tiles

Variety of clay tiles in different colours, shades and sizes are available in Kenya. As a choice of roofing material its use is limited due to fragile characteristics and skill needed to hang them on the roofs. When not properly done it may result to roof leakages and damage due to self weight.

BUILDING MODEL DESCRIPTION

The model building consists of a naturally ventilated single detached unit with a net surface area of 59.50 m^2 and a net volume of 204.80 m^3, and its floor plan and geometrical representations are shown in Figure 4.

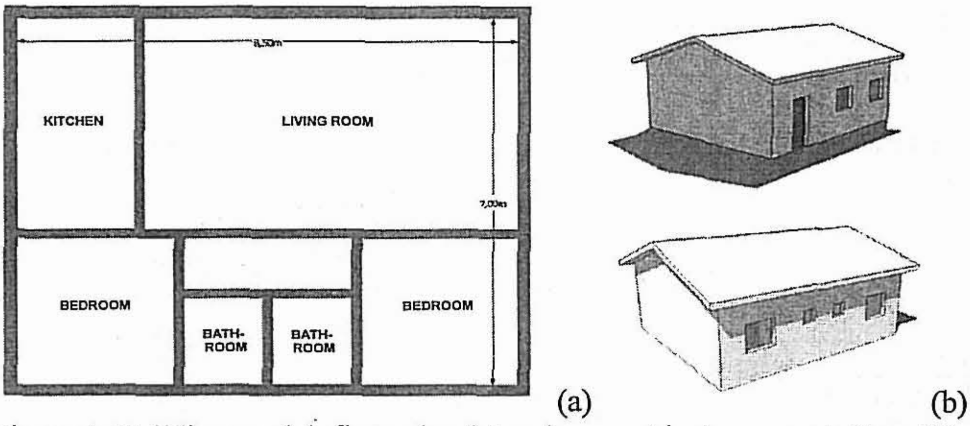


Figure 4: Building model: floor plan (a) and geometrical representations (b).

The building envelope consists of the following elements: 89.35 m^2 of opaque walls, 5.40 m^2 single glazed windows, 2.00 m^2 doors and 62.75 m^2 roof. Local shading for the windows is provided by the 0.50m gable roof overhangs (eaves). The internal partitions were simulated as 114.20 m^2 of internal thermal mass characterised by the same construction as walls.

The set up of the building surroundings is considered as a detached unit inside a neighbourhood of a 3x3 matrix of similar buildings. Three scenarios have been planned: first, with the building at the centre of a dense neighbourhood, secondly, set at the edge of a street or at the corner of two crossing streets (Figure 5). The distance between buildings without a street is set at 1.5m, while the streets width is 5m. The surroundings buildings are set with similar shape as the model house and with a general surface reflection factor of 0.2, the default value used by the simulation software. Every surrounding scenario has been simulated both with a North-South and an East-West orientation.

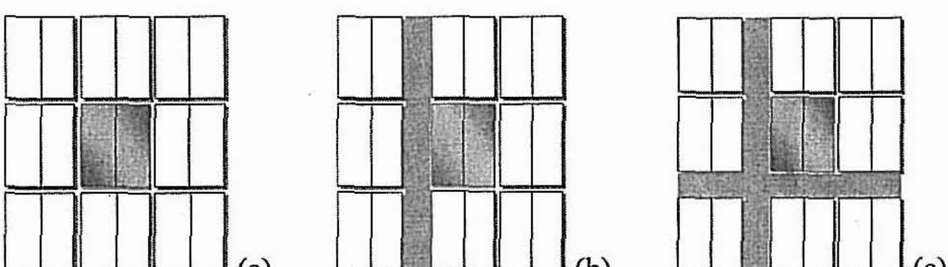


Figure 5: Model building at centre (a), edge (b) and corner (c).

3.1 Input Data

Internal heat loads for the building were inferred from two sources and applied on a daily schedule with regards to a typical house in informal settlements as shown in Table 2.

Table 2: Internal heat loads schedules for a residential building

Heat source	Reference value		Daily schedules 00:00 06:00	06:00 07:00	07:00 17:00	17:00 18:00	18:00 20:00	20:00 21:00	21:00 24:00
Occupancy	Density (a): 0.085 ppl/m^2	Activity (b): 90 W/ppl	100%	100%	20%	100%	100%	100%	100%
Kitchen supplies	8.000 W/m^2 (b)		0%	100%	0%	0%	0%	100%	0%
Lighting	11.000 W/m^2 (a)		0%	50%	0%	0%	50%	50%	50%

Reference values (a) are calculated, while (b) are obtained from ASHRAE (2001)

The materials data used for the model building have been derived from SKAT (1993) and are listed in Table 3.

Table 3: Material properties used in the simulations.

Material	Conductivity [W/mK]	Density [kg/m^3]	Specific Heat [J/kgK]	Coefficient Absorption	Emissivity
Earth/Mud	2,1000	1800	1250	0,60	0,90
GCI Sheet (Zinc new)	112,0000	7200	390	0,30	0,25
GCI Sheet (Zinc oxidised)				0,90	0,25
Coral Stones	2,3000	2600	1080	0,40	0,90
Thatch	0,0420	200	1050	0,80	0,90
Tiles	0,8261	1920	920	0,70	0,90
Concrete	1,1600	2000	880	0,60	0,90

From the materials value in table 3, the following constructions with consequent U-values have been used in the calculations:

- 20 cm earth/mud walls (3.770 W/m^{2}K), 5cm thatch roof (0.752 W/m^{2}K) and earth slab;
- 1mm GCI sheet walls (5.882 W/m^{2}K) and roof (7.142 W/m2K), and earth slab;
- 20cm coral stones wall (3.892 W/m^{2}K), 2 cm tiles (6.135 W/m^{2}K) and concrete slab.

Since buildings in informal settlements are not properly planned and sealed, general infiltration of constant 1 air charge rate (ach) is assumed for air tightness, while 3 additional ach is set in case of indoor temperature exceeds 26°C and outdoor temperature is lower than indoor one, to allow free cooling through ventilation. The floor slab is set as directly built on the ground, while ground temperatures are calculated monthly using the "slab" tool in Energy Plus.

3.2 Performance Index

Building performance indices usually refer to the building energy use, but for buildings in informal settlements, it is difficult to find a performance index to assess and compare buildings without HVAC systems, since they have no significant impact on energy consumption (Yannas, 1996).

To assess the performance of such buildings which are not conditioned, the indices used consider the impact of the indoor environment on the occupants, and are related to the occupants comfort and health. The assessment focused on general indoor thermal environment, indoor radiative thermal environment, discomfort due to fast indoor temperature changes and health hazard caused by heat stress.

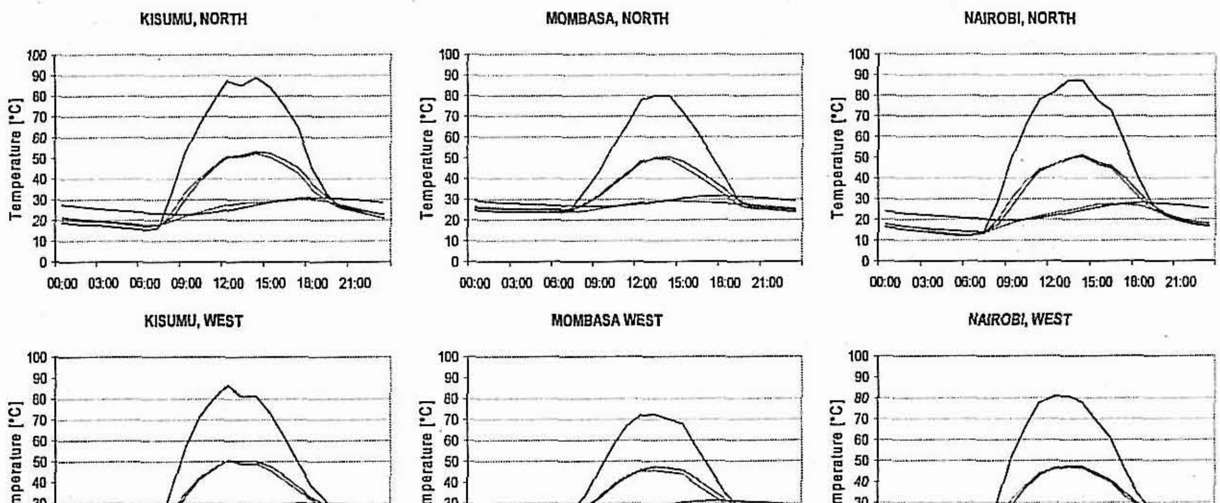
4.0 SIMULATION CASES AND RESULTS

Hourly calculations were performed with the Energy-Plus simulation software for a set of models with variations in building envelope materials, orientations, neighbourhood type and location. The most affecting variables are envelope materials and geographic location, while neighbourhood type and building orientation had little effect on the indoor environment. Therefore, buildings oriented along the East-West axis and located at the centre of the neighbourhood matrix are discussed. The comparisons are made first for the single envelope materials, secondly for the thermal comfort and finally for the health conditions caused by the complete construction.

4.1 Materials Comparison

In order to assess the influence on the indoor climate when single material is used in the envelope construction, the indoor surface temperatures was collected, that took into account both the insulation potential, relevant during the cold seasons, and the heat capacity, which is essential in warm and sunny conditions. Since the neighbourhood simulated is really dense and the sun radiation in the tropical region is extremely high, the results concerning the roof construction are shown.

Figure 6, shows the ceiling temperatures for different roof orientation for a sunny hot dry season day (January 15th) for the model building located in Kisumu, Mombasa and Nairobi. The different roofing materials compared are: thatch, tiles and GCI sheets (oxidised and non-oxidised).



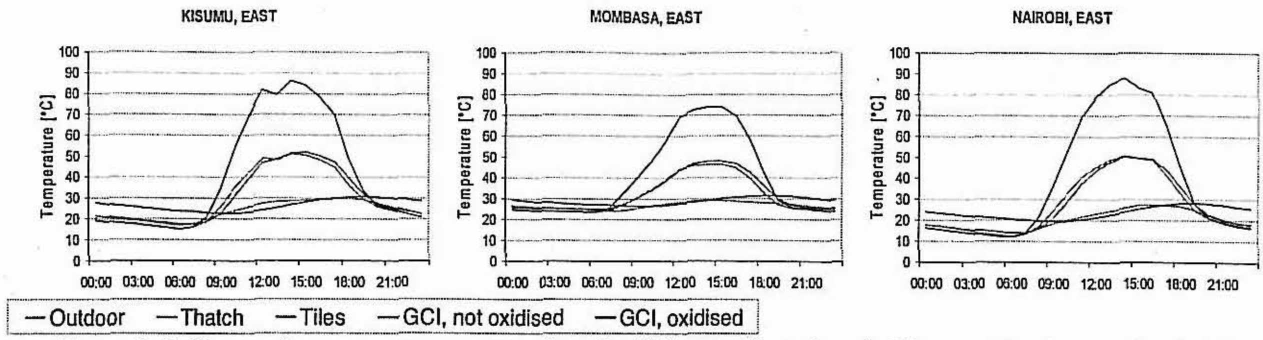


Figure 6: Ceiling surface temperature comparison for different orientations in Kisumu, Mombasa and Nairobi.

Oxidised GCI sheets give the highest ceiling surface temperatures, ranging between 12°C to 88°C, while thatch offers the most regular and acceptable temperatures, which range between 20°C and 30°C, and are really close to the air temperature.

4.1.1 Radiant Temperature Asymmetry

The presence of hot or cold surfaces can create a nonuniform thermal radiation field, with a consequent local discomfort and reduction of the thermal acceptability of the space. This phenomenon is called "radiant temperature asymmetry" and it is measured as the temperature difference between two facing surfaces, such as floor and ceiling, northern and southern walls, eastern and western walls. Generally speaking, people are more sensitive to asymmetric radiation caused by warm ceiling and cold floors (ASHRAE Standard 55, 2004).

To assess the local thermal discomfort due to radiant asymmetry, the occupants' percentage of dissatisfaction caused by the difference between ceiling and floor temperatures was calculated through the following equation (ISO 7730, 2005)

$$PD = \frac{100}{1+e^{2.84-0.174\cdot\Delta T_{pr}}} + 5.5 \qquad (1)$$

Where $\Delta T_{pr} < 23°C$ and ΔT_{pr} is the difference between ceiling and floor temperature [°C].

In case $\Delta T_{pr} \geq 23°C$, the default value of 100% percentage of dissatisfied has been considered.

Figure 7 shows the occupants' percentage of dissatisfied related to radiant asymmetry due to hourly ceiling and floor temperatures mean for the different orientations, in Kisumu, Mombasa and Nairobi for January the 15th.

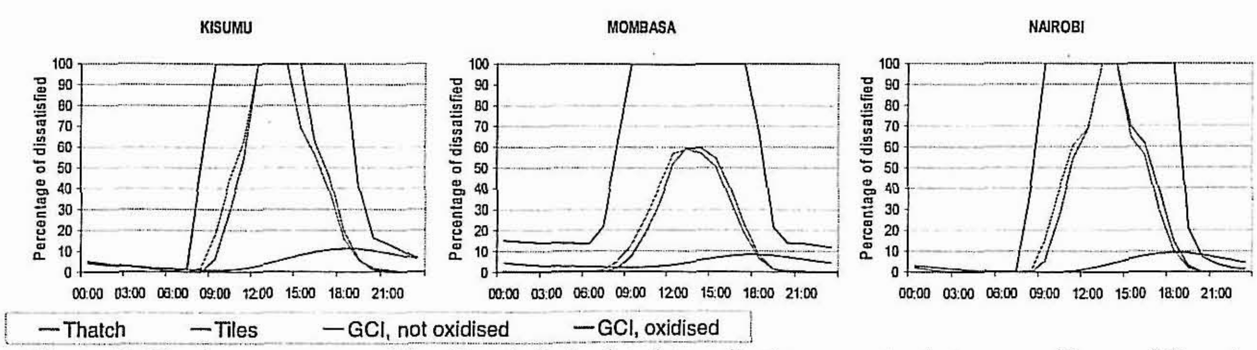


Figure 7: Hourly percentage of the dissatisfied related to radiant asymmetry between ceiling and floor in Kisumu, Mombasa and Nairobi.

The results of the simulations show that thatch is the only roof construction that does not cause a significant increase in dissatisfaction of thermal environment related to radiant asymmetry, while all the other materials tend to have a peak of dissatisfaction caused by overheating due to direct solar radiation on the roof surface. This means that, even with an indoor air temperature which can be defined as "comfortable" according to general indexes, the occupants may not feel comfortable. This is true in particular for the oxidised GCI sheets.

Thatch is the best roofing material, since it is insulating and has a high heat capacity; therefore, it attenuates the effect of outdoor climatic conditions in both the cold-wet and the hot-dry seasons, while GCI sheets and tiles tend to emphasize the hourly variability of the climatic conditions.

Regarding wall construction, earth/mud and coral stones offer the best performance in attenuating the outdoor climate conditions, while oxidised GCI sheets give extreme fluctuating performances especially when oxidised.

4.2 Complete House Comparison

Informal settlement buildings do not have HVAC systems, therefore, are referred to as "naturally ventilated buildings". Considering this characteristic, the adaptive thermal comfort model has been used to assess the general indoor thermal conditions, since it has been developed specifically for such kind of buildings in extreme warm weather conditions (De Dear *et al*, 1997). The principle of the adaptive model is that the thermal sensation of the occupants is strongly affected by their expectations, which depend on their long-term and short-term thermal experience.

The indoor operative temperature derived from the simulation results has been compared with adaptive comfort temperature limits. Equation to calculate adaptive temperature limits, for this work is the one developed by De Dear *et al* (1997) for ASHRAE (2004), which defines equations both for the warm and the cool seasons. The boundary conditions regarding the acceptability range have been chosen as stated by Van der Linden *et al* (2006) for the ATL (Adaptive Thermal Limit) index used in the Netherlands. The consequent adaptive temperature limits are summarized in Table 4.

Table 4: Adaptive temperature limits.

Acceptability range	Lower limit	Upper limit
90%	$T_{op}>17.80+0.11T_{e,ref}$	$T_{op}<20.30+0.31T_{e,ref}$ if $T_{e,ref}>12°C$ $T_{op}<22.7+0.11T_{e,ref}$
80%	$T_{op}>17.05+0.11T_{e,ref}$	$T_{op}<21.30+0.31T_{e,ref}$ if $T_{e,ref}>12°C$ $T_{op}<23.45+0.11T_{e,ref}$
65%	$T_{op}>16.55+0.11T_{e,ref}$	$T_{op}<22.00+0.31T_{e,ref}$ if $T_{e,ref}>12°C$ $T_{op}<23.95+0.11T_{e,ref}$

The reference outdoor temperature ($T_{e,ref}$) is the external running mean temperature, which is an exponentially weighted mean of the daily air temperatures of the preceding days. It is used to represent the short-term thermal experience of the occupants as a history series of the external temperature. It can be calculated from the following equation (EN 15251, 2007).

$$\theta_{rm,n} = \frac{\theta_{dm,n-1} + 0.8\cdot\theta_{dm,n-2} + 0.6\cdot\theta_{dm,n-3} + 0.5\cdot\theta_{dm,n-4} + 0.4\cdot\theta_{dm,n-5} + 0.3\cdot\theta_{dm,n-6} + 0.2\cdot\theta_{dm,n-7}}{3.8} \quad (2)$$

Where:

$\theta_{rm,n}$ is the running mean temperature in the n^{th} day [°C];

$\theta_{dm,n-1}$ is the daily mean temperature in the $(n-1)^{th}$ day [°C].

The acceptability range is then translated, as shown in Table 5, to the qualitative definition of the 7-point ASHRAE thermal sensation scale, that defines the occupants' mean vote (predicted or surveyed) on the thermal environment (ASHRAE, 2004).

Table 5: Conversion of the adaptive acceptability range to the thermal sensation scale.

Adaptive acceptability range	Vote	Definition
T_{op}>65% upper limit	+3	Hot
T_{op}>80% upper limit	+2	Warm
T_{op}>90% upper limit	+1	Slightly warm
90% lower limit<T_{op}<90% upper limit	0	Neutral
T_{op}<90% lower limit	-1	Slightly cool
T_{op}<80% lower limit	-2	Cool
T_{op}<65% lower limit	-3	cold

Figure 8 below illustrates the year-time (as percentage of the whole yearly hours) characterized by different indoor thermal conditions induced by various construction materials in Kisumu, Mombasa and Nairobi.

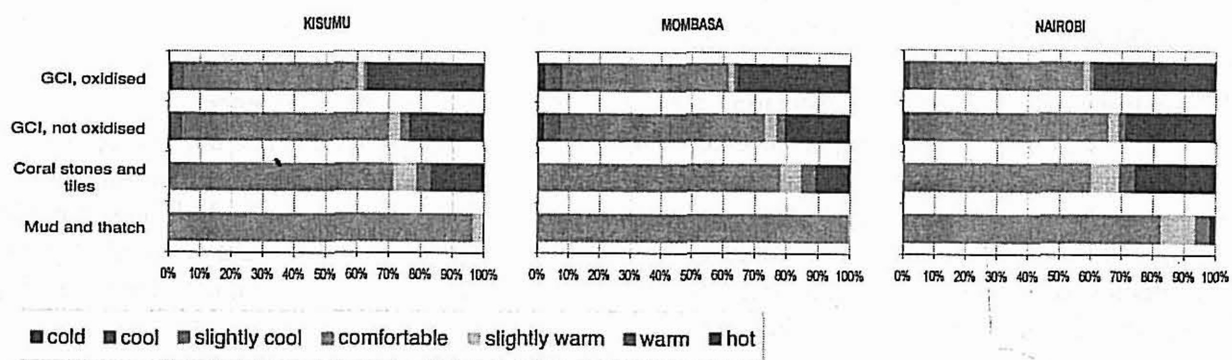


Figure 8: General comfort conditions in Kisumu (a), Mombasa (b) and Nairobi (c). The values show the percentage of the year time characterized by each category of the thermal sensation scale.

Apart from the graphic representation of the indoor thermal condition, EN 15251 proposes several criteria to evaluate the long term performance of buildings based on simulation results. One criterion is "degree hours criteria" and uses the degree hours beyond the upper and lower boundary for the comfort condition. Considering values for the upper and lower at 90% acceptability levels as boundary for the comfort condition, Table 6 shows the discomfort degree hours related to the different constructions.

Table 6: Discomfort degree hours compared to the 90% adaptive acceptability range.

Construction	Kisumu	Mombasa	Nairobi
Mud and thatch	140.65	18.82	1,338.75
Coral stones and tiles	5,553.09	3,577.07	9,539.72
GCI sheet, not oxidised	11,690.73	9,973.72	14,887.32
GCI sheet, oxidised	45,053.49	42,435.79	49,299.37

The discomfort degree hours graphically represent the integral of the distance between the indoor operative temperature obtained in the building and the 90% acceptability limit calculated as according to the equations in table 4. The degree hour value can be considered a preliminary assessment of the climatization need in the building and of the predictable related energy consumption.

It is significant how the climatization need changes for the GCI sheet construction with time, due to the oxidation process, which is a strong indication that choosing the construction materials to use should take into account the performance decrease related to degradation. Adaptive model states thermal comfort as sufficient attenuation of the outdoor climatic conditions by the building envelope, and the mud and thatch construction offers the best attenuation performances.

4.2.1 Drifts

Temperature fluctuations that occur due to factors not under the direct control of the individual occupant may have negative effect on comfort, too. Temperature drifts are passive monotonic, steady, non-cyclic changes in operative temperature that apply to variations with periods greater than 15 minutes. ASHRAE (2004) gives the maximum change allowed during different periods of time. Considering that the simulation results are given at hourly steps, the limit of 2.2°C per hour (ASHRAE, 2004) has been assumed and compared to the hourly operative temperature change resulting from the simulation.

Table 7 gives the drifts occurrence for Kisumu, Mombasa and Nairobi calculated as a percentage of yearly hours.

Table 7 : Drifts occurrence calculated as percentage of yearly hours.

Construction	Kisumu	Mombasa	Nairobi
Mud and thatch	0%	0%	0%
Coral stones and tiles	3%	1%	1%
GCI sheet, not oxidised	17%	10%	10%
GCI sheet, oxidised	39%	37%	36%

Since drifts can affect occupants' thermal sensation, their occurrence probability should be considered when choosing the construction to use. As already seen in the materials' comparison, different materials have different response to the outdoor conditions (i.e. air temperature and solar radiation) variability and if they are too fast in the response this may cause discomfort sensation to the occupants, who cannot adapt to the new conditions fast enough.

Predictably, the mud and thatch construction that has the best attenuation properties, does not show occurrence of such phenomenon, while coral stones and tiles construction shows a slight probability of drifts occurrence, probably caused by the roofing material.

GCI sheet construction, on the other hand, does not attenuate the external conditions at all showing a usual occurrence of the phenomenon, which emphasizes the general thermal discomfort already analysed.

4.3 Heat Index

Considering the kind of climate in Kenya, the effects of the indoor microclimate on the health conditions are investigated by calculating the heat index, which is derived by the apparent temperature index (Steadman, 1984) and combines the effects of high temperatures with high air humidity to predict the chances of heat-strokes as stated in the following equation:

$$HI = -c_1 + c_2T + c_3R + c_4TR + c_5T^2 + c_6RH^2 + c_7T^2RH + c_8TRH^2 + c_9T^2RH^2 \qquad (3)$$

Where:

c is coefficient inferred by linear regression approximation

T is air temperature [°F]

RH is relative humidity [%]

The value resulting from the equation (3) can be considered as a temperature value and is usually measured in Fahrenheit degrees. Though it has not demonstrated a sufficient reliability to be used as an index which synthetically represents all the climatic variables of the indoor environments, heat index is commonly used in the U.S. to assess the summer outdoor climatic conditions. The values resulting from equation (3) are then compared to a range of sets connected to related health hazards, as shown in Table 8.

Table 8: Heat index ranges used to assess the effects of microclimate on the health conditions.

HI range [°F]	HI range [°C]	Effects on health
HI<80°F	HI<27°C	HEALTH, no effects due to temperature and humidity
80°F<HI<90°F	27°C<HI<32°C	CAUTION, related to possible fatigue
90°F<HI<105°F	32°C<HI<41°C	EXTREME CAUTION, related to possible negative effects
105°F<HI<130°F	41°C<HI<54°C	DANGER, related to likely negative effects and possible heat strokes
HI>130°F	HI>54°C	EXTREME DANGER, related to likely heat strokes

The same index with the same value ranges was applied to this work to understand the probability of health hazard occurrence related to indoor environmental variables such as air temperature and humidity. The percentage of yearly time which results in each range was calculated for the various constructions and climates and shown in Figure 9.

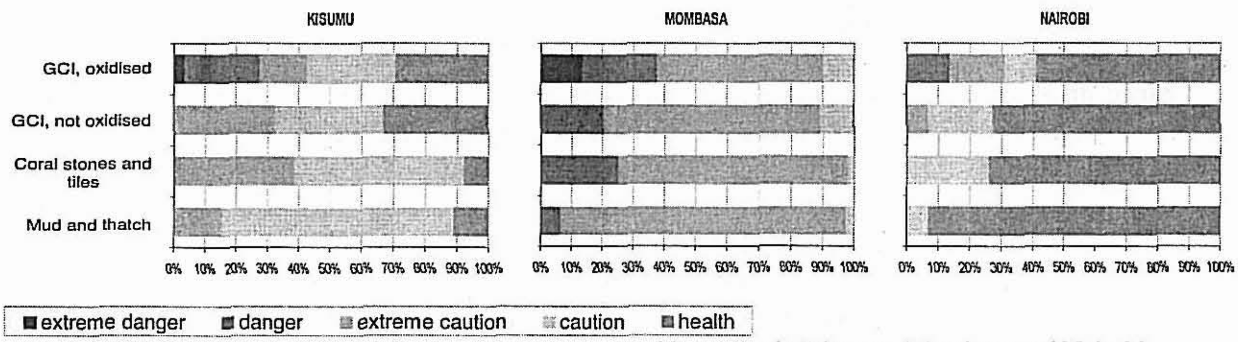


Figure 9: Health hazard due to air temperature and humidity in Kisumu , Mombasa and Nairobi. The values show the percentage of the year time and Heat Index conditions.

In Nairobi, where temperatures are not as high, the health hazard occurrence is extremely low, compared to Mombasa, where humidity is a major issue, since it is high for all the constructions considered.

The earth/mud with thatch construction and coral stones with tiles construction show the same behaviour, though the mud with thatch has better performances. GCI sheets constructions, on the other hand, gives a variety and indicate both longer time of healthy conditions and risky conditions.

In Mombasa the oxidised GCI, in particular, give more than 13% of yearly time, equal to 50 days, of extremely dangerous conditions.

5.0 CONCLUSION

The results obtained indicate that GCI sheets performance deteriorates with time as the sheets get oxidised. Its properties can be improved if an insulation layer is applied to the inside to militate on drastic temperature changes that affects indoor thermal comfort. Same can be applied when tiles are used as a roofing material which will allow the circulation of air beneath the tiles and thus regulating the indoor temperatures.

Earth/mud wall and thatch roof construction combination offers the best indoor thermal comfort consideration, but the challenge is on the durability of thatch which deteriorates very fast during the wet season. Different construction technologies can be applied in different climatic conditions to achieve the desired indoor environment.

REFERENCES

ANSI/ASHRAE Standard 55 (2004) – *Thermal environmental conditions for human occupancy.*

ASHRAE Handbook (2001) – *Fundamentals (SI).*

De Dear R.J., Brager G.S., Cooper D. (1997), *Developing an adaptive model of thermal comfort and preference*, ASHRAE Final Report RP-884.

EN 15251 (2007), *Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.*

Fountain M.E., Bauman F.S., Arens E., Oguru M. and Tengfang X. (1999) *An investigation of thermal comfort at high humidities*, ASHRAE Transaction, vol 105, part 2.

ISO 7730 (2005) – *Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria.*

Ogunsote O.O. and Prucnal-Ogunsote B. (2003) "Choice of a thermal index for architectural design with climate in Nigeria" *Habitat International*, No 27, pp.63-81.

Roland, S. and Kiran, M. (1993) Appropriate *Building Materials: Catalogue of Potential Solutions*, Swiss Centre for Development Cooperation in Technology and Management (SKAT).

Steadman R.G. (1984) "A universal scale of apparent temperature" *Journal of Climate and Applied Meteorology*, Vol 23, pp.1674-1687.

Van der Linden A.C., Boerstra A.C., Raue A.K., Kurvers S.R. and De Dear R.J. (2006) "Adaptive temperature limits: a new guideline in the Netherlands. A new approach for the assessment of building performance with respect to thermal indoor climate" *Energy and Buildings*, No 38, pp.8-17.

World factbook (2002) Kenya. Central Intelligence Agency (CIA), U.S.

Yannas, S. (1996) "Energy Indices and performance targets for housing design" *Energy and Building*, No 23, pp.237-249.