SENSITIVITY ANALYSIS OF A TRADITIONAL ROUND HUT IN THE TROPICAL UPLAND CLIMATE

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ABSTRACT

The traditional round hut has been analysed by simulating the sensitivity of its different components in order to establish their relative performance. This has been done using SERIRES, a thermal simulation package suitable for warm climates. The hut is simulated in the climate of Zambia which has a tropical upland climate. The results show that the mud and pole wall is the most influential element of the house. The opening sizes have been found to be quite dominant too, hence the small openings of the hut are quite suitable. The thatch roof has been found to be unsuitable for the climate. Increasing the ventilation rate in the hut produced the largest proportional increase in internal thermal discomfort.

INTRODUCTION

Zambia is a country lying in the middle of Central Southern Africa at an altitude ranging from 1000 - 1300m above sea level. It experiences a tropical upland climate with the year being classified into three main seasons: warm wet, cool and hot dry seasons, although its altitude and location have a modifying influence on its climate. The main discomfort seasons are the cool and hot dry seasons when it gets very cold and very hot. This study has therefore been restricted to these two seasons.

Traditional housing in tropical regions is generally considered to be more climate sensitive than contemporary housing [Konya; 1980]. On going housing research in the tropical upland climate centred on Zambia has proved this to be true [Malama; 1997]. Thus it is important to study traditional housing. This paper gives some results from simulations done using SERIRES on a traditional round hut. The round hut was selected because it represents the typical traditional house of the tropical upland region [Denyer; 1978]. The house model used is one of a typical round hut with a thatched roof and pole and mud walls. The hut used in the experiment had its door orientated towards the S.W and it is discussed in detail below (see also Figure 1).

Walls: The walls are made of poles and plastered with mud, both inside and outside making the wall about 200mm thick. The external colour of the house is dark brown. The walls are 2m high.

Floor: The floor is of mud laid on bare ground after the walls have been built; it is about 100mm thick. The total internal floor surface area covered by the house is $9.9m^2$.

Openings: There is a small window opening in the wall facing the NE directly opposite the door. It is about 200mm wide and 150mm high. The window head has a sawn timber lintel and the door frame is also of sawn timber. The door leaf is a purchased wooden door with a steel bolt lock.

There is another opening between the wall plate and the roof. This opening goes around the hut. It is of variable size but is about 250mm wide on average. This is a feature common to most traditional houses in Zambia [Mwiinga; 1979].

Roof: The roof structure consists of wooden poles which are then covered with thatch. The thatch is about 120mm thick and about 2.25m in vertical height from the eavesline with a slope of 1:1.3 and has a light amber colour.

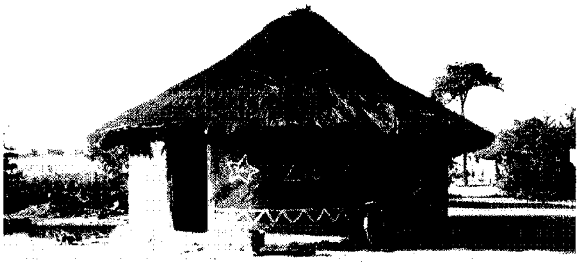

Figure 1. Round hut used in the experiment

OBJECTIVE

The main objective of the sensitivity analysis was to develop a performance index for the house by attaching a performance value to all the elements in the house. The relative contribution of each element could then be understood. Understanding the thermal behaviour of the traditional housing would help establish the important aspects of the house which would be useful in subsequent house designs. The best performing aspects of the house could be incorporated into future house designs in the tropical upland climates. This idea was motivated by the general belief that traditional housing world wide is climate sensitive and so there are important lessons that can be learnt from them, Konya [1980] and Evans [1980].

METHOD

Parametric analysis has been used in many studies e.g. Kolokotroni [1989]; Kolokotroni and Young [1990]; Rosenlund [1989] and Adamson [1991] and involves varying one element in the model while holding all other elements constant. Thus, the change in results is solely as a result of the variation in the element. Air temperature is usually taken as the main measure of effectiveness. The main reason is because temperature is considered to be the most important variable in the measure of thermal comfort [Hensen 1990 and Humphreys 1976]. In many cases in warm climates, the lowest temperature is taken as the most effective since the main objective in a warm climate is cooling.

In this study the method described above could not be used because it is designed more for optimisation, where the lowest or highest temperature resulting from a set of perturbations is taken as best. The method that has been used in this study is that of Lam and Hui [1996] which is designed for assessing the sensitivity coefficients of different elements of a building. It involves the use of the sensitivity coefficient formula shown in equation (1) below:

$$\frac{\text{Percentage change in A}}{\text{Percentage change in B}} \qquad (1)$$

where A is the element being varied (perturbed);

B is the temperature or any other measure of effectiveness used

This method calculates the percentage change in the results due to a given change in the element being investigated. This information gives a picture of the performance of the various elements of the house. Lam and Hui [1996] noted that in strict terms it is not possible to compare different results if the perturbations are in different quantities and of a different nature e.g. how does one compare the results of perturbations in the external wall absorption coefficient and the wall thickness or opening sizes, all of which are in different quantities?

The solution adopted in this study entailed the use of the elements of the house in their extreme limits as far as was practical. Thus, all elements used in the simulation were varied to their practical limits e.g. 100 - 300mm for walls, 0 - 100% for openings[1], 5 - 50ach for ventilation rate [Evans; 1980] and 0.3 (whitewash) - 0.85 (black paint) for external colour [Koeningsberger et al; 1974]. The reasoning is that, regardless of the quantity and nature of the change, if all the elements are taken to their practical extremes, it is possible to make comparison between the results from these changes. This means that the equation (1) above will change since the magnitude and nature of change in the purtabations will no longer be important. Thus, only two values were obtained as there were no intermediate perturbations. Furthermore, unlike in the method of Lam and Hui [1996], where the percentage changes in both the elements and the temperature were used, this method uses the ratio of the old (base case) and new (new case). Additionally, the percentage change method could not be used as it distorted the results especially when dealing with elements whose base case is 0. A new measure of sensitivity was therefore devised and is shown in equation 2.

Furthermore, a different variable has been used to assess the sensitivity coefficients of the elements other than the lowest air temperature. A concept called "discomfort degree hours" has been devised. The duration and number of degrees when the environmental temperature (output from SERIRES) falls outside the comfort zone are aggregated to get the "discomfort degree hours". This method was

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[1] Opening in this context means window and according to Schmetzer [1987] most houses do not have windows but have an opening between the wall plate and roof for ventilation and light. Thus 0% (i.e. zero opening) is practical. 100% is taken to be the whole of the side of the hexagon (hut has been simulated as an hexagon) facing a particular orientation.

considered to be more comprehensive in that it considered all the hours outside the comfort zone and not just the peak temperature or the temperature range. Since the objective of the research was to achieve comfort by reducing discomfort it makes sense to use the level of discomfort/comfort as a measure of the effectiveness of an element. The usual method of averaging the peak and diurnal range as a measure of thermal performance has the disadvantage of dealing with this problem in a very approximate way. Neither the peak temperature nor the diurnal range gives the exact picture of the level of discomfort being experienced in a building as a result of changes to the fabric or introduction of a comfort improving strategy. The new equation for the discomfort coefficient (DC) is:

$$DC = \frac{\text{New degree hours of discomfort}}{\text{Base case degree hours of discomfort}} \qquad (2)$$

This equation yielded the "discomfort coefficient" which indicates the performance of the elements simulated.

In the simulation a circular building could not be simulated and so the house was assumed to be a hexagon. Furthermore, ventilation was held constant at typical values for a windy day. 13ach was approximated from the CIBSE guide [CIBSE Guide; 1986].

The thermal simulation package used was SERIRES, which was developed by the Solar Energy Research Institute in the USA and has been used in warm climates before e.g. Yakubu [1990]. It was also included in the building energy simulation test (BESTEST) intermodel validation project which involved the testing of eight models for a range of single zoned building subjected to the weather conditions of Denver, USA [Bunn; 1995].

A test to determine the accuracy of prediction of SERIRES in this climate was performed. It involved a comparison of the predicted interior temperatures with those measured in the actual hut in Zambia for the two main seasons for which simulations were performed. The correlation coefficients between the predicted and measured results were 0.86 for the cool season and 0.92 for the warm season, indicating a high level of agreement between the two sets of temperatures (see Figure 2). The predicted and measured temperatures could be compared despite being different. The predicted was environmental temperature and observed was air temperature. The high correlation between globe and air temperature measured in both seasons in the hut (0.92 in the cool season and 0.98 in the warm season) means that the environmental and air temperatures would be very similar as the environmental temperature is a combination of air and globe temperature. From Figure 2 it can be observed that in the cool season SERIRES overpredicted the internal temperatures, especially during the mid morning and afternoon. However, the general patterns were very similar for both measured, and predicted. It is worth noting that the internal temperatures were underpredicted in the warm season. This is the time when the level of solar radiation increases considerably. It could be that SERIRES could not predict with a high level of accuracy the activities of the solar radiation in this climate. Overall, however, the prediction was accurate enough for SERIRES to be used in this climate.

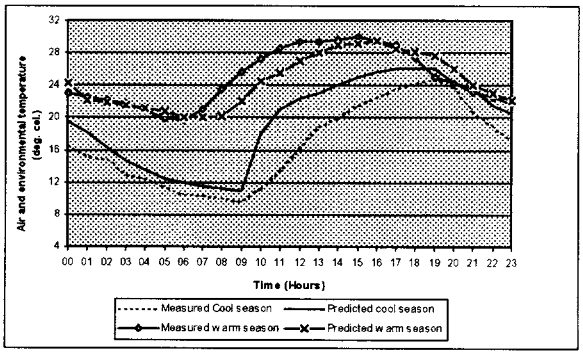

Figure 2. The measured and predicted internal temperatures for both the cool and warm seasons

SIMULATION

The simulation involved the selection of the elements and strategies to be used in the sensitivity analysis. The materials of the fabric and also other materials that are commonly used in traditional houses in the climate were simulated. Furthermore, important building elements e.g. openings were also simulated. The full list of the materials and elements simulated is shown in Table 1. below.

The procedure for simulation adopted was the classic one where one element was varied and the others held constant at their base values shown in Table 1 above. If, for example, the base case of "thatch wall 200mm" is compared with the "thatch wall 350mm" the values of the other elements will be at their base case level so that the resulting change in output is solely due to the change in the wall thickness.

Table 1. Elements and strategies used in the simulation of the round hut

House element simulated	Base case	New case
Opening sizes N	100%	0%
Opening sizes E	100%	0%
Opening sizes S	100%	0%
Opening sizes W	100%	0%
Shading of openings N	0%	100%
Shading of openings E	0%	100%
Shading of openings S	0%	100%
Shading of openings W	0%	100%
Mud and pole wall	100mm	300mm
Bamboo wall	100mm	300mm
Thatch wall	200mm	350mm
Mud wall	150mm	300mm
Floor thickness	50mm	200mm
Roof absorptivity	0.3	0.8
Wall absorptivity	0.3	0.8
Aspect ratio	Existing	Double
Thatch ceiling	50mm	150mm
Ventilation	5ach	50ach
Thatch roof size	50mm	150mm

The coefficients for the cool season and the warm season were calculated separately. Figure 3 shows the coefficients for each season for each simulation. Since it was important to get an annual picture for the hut the two discomfort coefficients for the two seasons had to be combined. However, as the two main seasons are not of the same duration, it would be illogical to just combine them. It was therefore, decided to give weightings in terms of the duration of the season. Eight months are either warm or hot whereas four months are either cool or cold from the definition of seasons in Zambia. Thus, the weightings were as follows: H (warm season) = 2/3 and C (cool season) = 1/3. Thus the discomfort coefficients were multiplied by 0.33 in the cool season and by 0.67 in the warm season, resulting in weighted discomfort coefficients for the cool season and warm seasons. Since the aim was to get a single annual figure these two coefficients were then added to get the annual weighted discomfort coefficients shown in Figure 4.

ANALYSIS

The results are presented under the headings of the various elements of the house i.e. walls, roof openings, external colour, floor, ventilation and aspect ratio.

Warm and cool seasons:

Figure 3 shows both seasons together for the traditional hut. The hut has consistently lower discomfort coefficients in the warm season than in the cool season, except for the last five elements which were bamboo and thatch walls, thatch roof and ventilation and mud blocks. It can be concluded, therefore, that the traditional house generally performs better in the warm season than in the cool season. A thermal performance survey which looked at the round hut in Zambia showed that it performed poorly in the cool season [Sharples and Malama; 1996]. The discomfort coefficients of the elements of traditional hut are 1.8 times higher in the warm season than in the cool season.

The results show that contrary to the general belief that traditional architecture is climate sensitive [Evans; 1980] the traditional hut is not so climate sensitive in one of the two main seasons. It would appear that the traditional hut was designed more to deal with warm than cool conditions. This makes sense given the fact that the warm season is twice as long as the cool season.

Changes to the openings yielded the lowest discomfort coefficients in the warm season and had some of the highest discomfort coefficients in the cool season indicating that the changes in discomfort coefficients between the two seasons were highest with openings. This means that changes to the opening size are less effective in the cool season than in the warm season. Thus other elements maybe more effective in the cool season e.g. the mud and pole walls and mud block walls. The mud and poles walls had the lowest levels of discomfort between the two seasons therefore was overall the most effective material and/or element of the traditional hut.

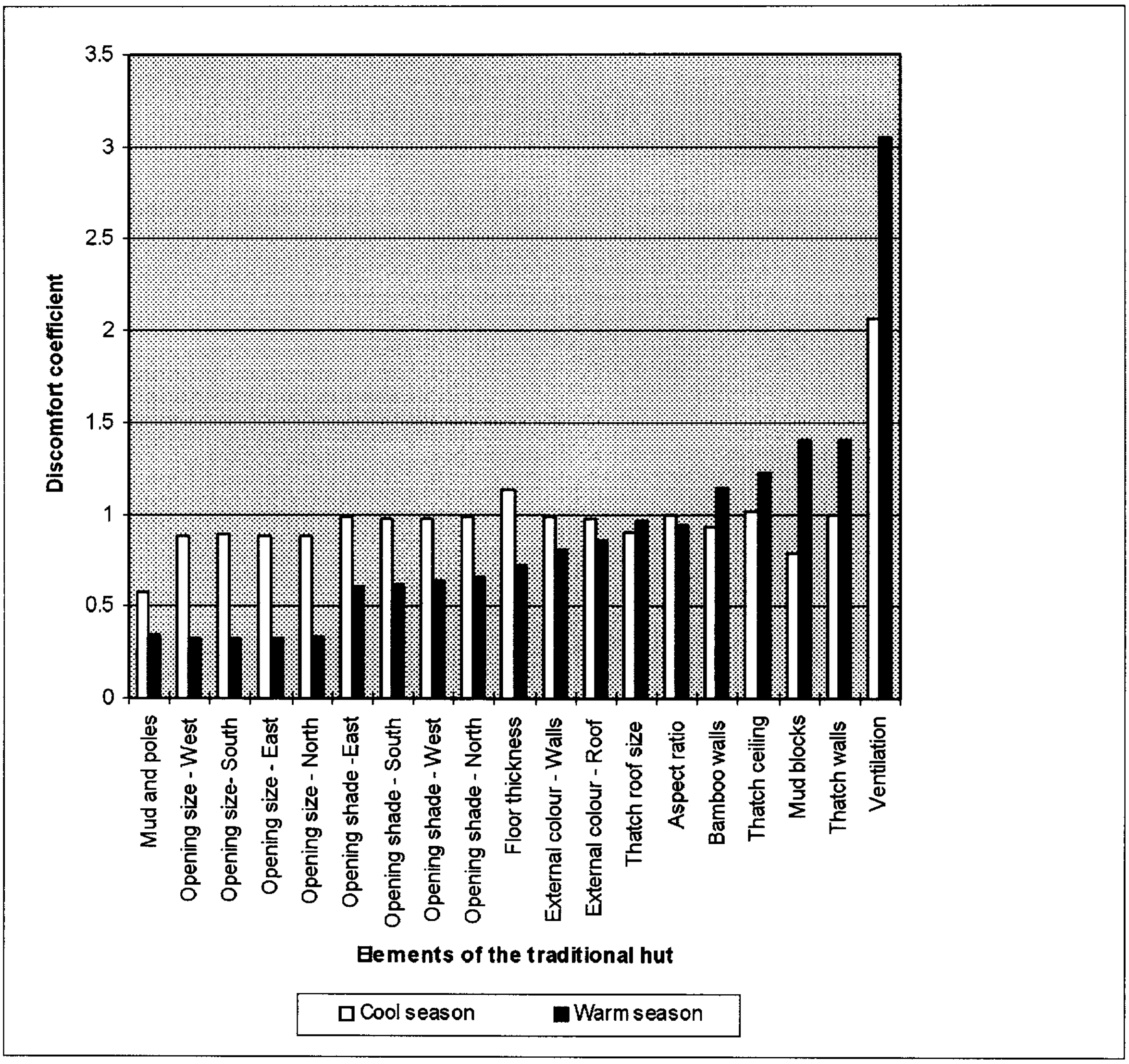

Figure 3. The discomfort coefficients of the elements of the round hut in the cool and warm seasons

Annualised coefficients

The ranking of the various elements simulated according to the annual discomfort coefficients are shown in Figure 4 below. The total number of simulations were 19 so the ranking is out of 19 with a ranking of 1 representing the best performance.

Walls: The mud and poles wall produced the least discomfort of all elements simulated. The other wall materials performed poorly - bamboo wall was ranked 15 while the mud blocks and thatch walls were 17 and 18 respectively. Thus, the mud and poles wall gave the best performance overall. It appears therefore that the people who generated this house over the generations picked the best material for the climate.

Opening sizes: The size of openings produced low levels of discomfort and came close after the mud and pole walls in the following sequence: west, east, south and north. This means that the opening sizes are quite important in the design of the traditional hut. The actual openings are quite small in the traditional hut, which is in keeping with the reduction of the entry of solar radiation. The majority of openings, however, are in the west wall [Mwiinga; 1979] which potentially would result in high levels of interior thermal discomfort.

Shading of openings: The shading of the openings gave moderate levels of discomfort and their discomfort coefficients did not vary very much between the four orientations. Thus as a thermal control strategy shading of openings would not be very effective. In any case the small size of opening in the huts means that this strategy is not very crucial in the traditional house.

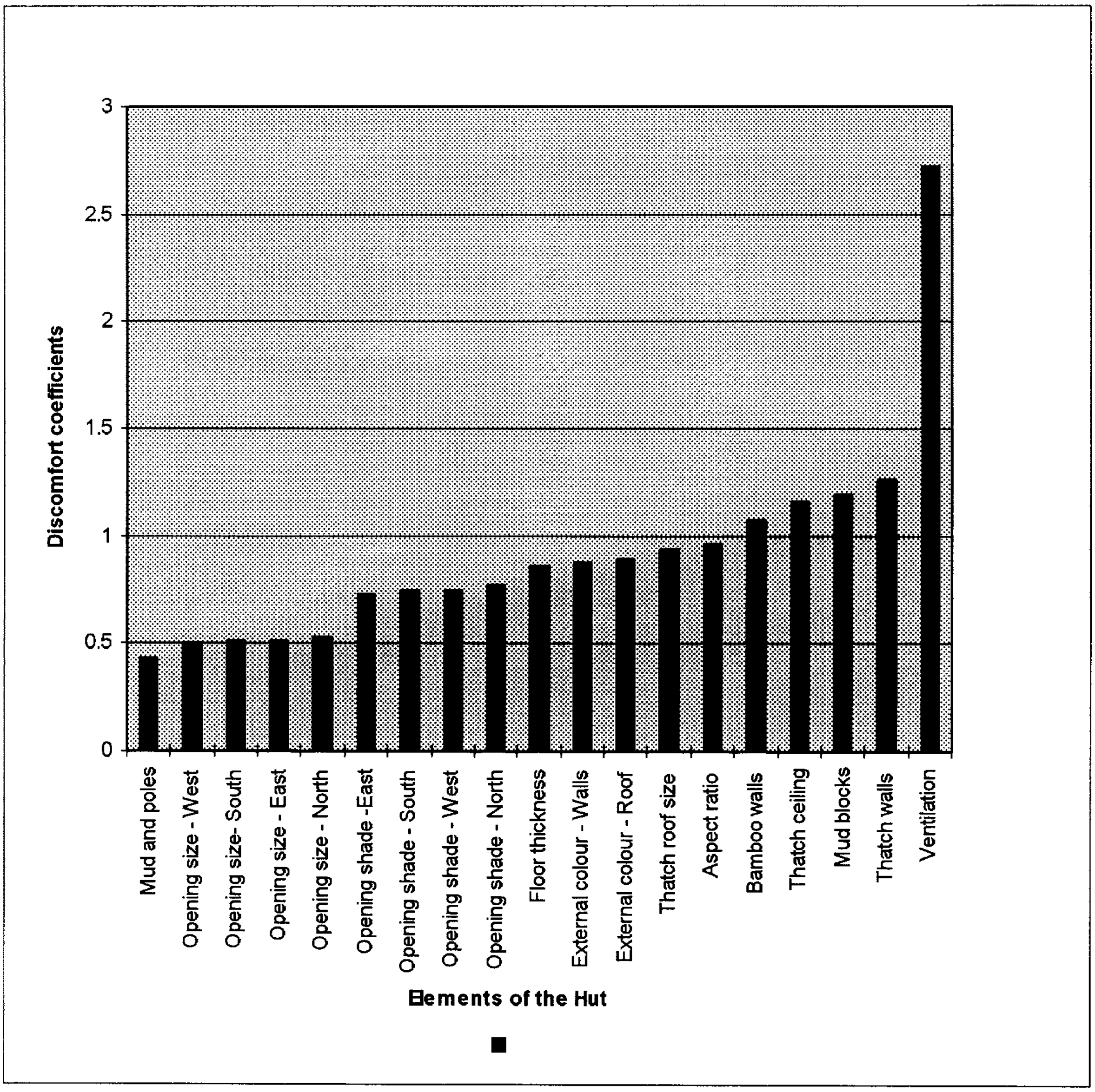

Figure 4. The ranked annual discomfort coefficients of the elements of the traditional hut.

Roof: Thatch size was placed 13th while the thatch ceiling was 16th which means that both produced high levels of discomfort. Using a thatch ceiling would not be an effective strategy in this climate for the traditional housing and neither is the existing thatch roof. It would appear that the material which the roof of the traditional house is made from is not a very effective material in keeping the internal conditions comfortable.

Colour (roof and wall): The colours of roof and wall both produced moderate levels of discomfort and were placed 11 and 12. Thus, they are not very effective annually. In a traditional hut, therefore, the colour of the fabric is not very effective in reducing the internal thermal discomfort from both the roof and the walls.

Floor thickness: The floor thickness was ranked 10 which means it produced a moderate level of discomfort. Increasing the thermal inertia of the hut by increasing the thickness of the floor will not be a very effective thermal control strategy in this climate despite the conclusion of Koeningsberger et al [1974] that high thermal inertia materials will produce the best results in the tropical upland climate.

Ventilation: Increasing the level of ventilation resulted in the highest level of discomfort. This means that the use of ventilation as a thermal control strategy should be judicious and will be useful during the night-time when the temperatures plummet and the cool external air can be used to cool the structure at night. This is called nocturnal ventilation and has been discussed in Givoni [1992 and 1994].

The results from this study show that in terms of performance the walls performed better than the thatch roof i.e. the mud and pole wall had lower discomfort coefficients than the roof. It would appear that the mud and pole walls are more suitable for this climate than the thatch used in the roof. This confirms the conclusions of Koeningsberger et al [1974] that heavyweight materials will perform well in this climate because of the high diurnal range of temperature. It is worth noting that the mud block wall performed well in the cool season but poorly in the warm season. This is probably because it is too heavy and absorbs too much heat which it reradiates at night thereby increasing the night-time temperature which is already high.

CONCLUSIONS

The traditional house has been shown to be more thermally comfortable in the warm season than in the cool season. Most of the elements of the house produced lower discomfort coefficients in the warm season as compared to the cool season indicating better performance in the warm season. Over the two seasons the pole and mud walls were found to have produced the least amount of internal discomfort (i.e. had the lowest discomfort coefficient) while the thatch and bamboo wall materials produced high levels of internal discomfort i.e. had very high discomfort coefficients.

Openings sizes were also very dominant in affecting the interior thermal conditions. The west opening was the most influential followed by the east and the south and north. This is expected as the west and east receive more solar radiation than the other two orientations. Shading of the openings is not an effective method of controlling the interior thermal comfort conditions.

The thatch roof produced high discomfort coefficients in both seasons and overall, an indication that it is not the best material for roofing in terms of thermal comfort in this climate. A material of high thermal inertia would probably produce lower levels of internal discomfort. Ventilation in both seasons produced the highest discomfort coefficients and is responsible for the poor performance of the house in the cool season as the cold night and hot day air circulate freely into the interior.

Overall the mud and pole walls and the small openings of the house were the most dominant aspects of the house and were responsible for its good annual climatic performance. Therefore the main lessons that can be learnt from this study by the present day designers (in line with the main objective of this study) are: (a) the mud and pole wall is a very good material for the house and the use of a material with similar thermophysical qualities will be beneficial to present day housing; (b) thatch both for the roof and walls is not a suitable material for the traditional hut in the tropical upland climate. Apart from its being a fire hazard it does not perform well in terms of thermal comfort; (c) small openings are the best for this climate, and (d) use of ventilation in this climate has to be done very judiciously and will probably be beneficial in thermal comfort terms if used in form of nocturnal ventilation.

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