IMPACT OF MOSQUITO-PROOFING HOUSES UPON MOSQUITO ENTRY AS WELL AS INVESTMENT AND MOTIVATION BY HOUSEHOLDERS

BY

BARASA OGOMA SHEILA

B.Sc. (Zoology), University of Nairobi

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DECLARATION

Candidate

This thesis is my original work and has not been presented for a degree in any other university or any other award.

Signed:....Barasa............ Date:...22 April 2009.

Barasa Ogoma Sheila

Supervisors

This thesis has been submitted with our approval as Supervisors.

Signed:....................... Date: 22 April 2009

Dr. Wolfgang Richard Mukabana,

Senior Lecturer, School of Biological Sciences,

University of Nairobi, Nairobi Kenya.

Signed: Gerry Killeen Date: 22/04/09

Dr. Gerard Francis Killeen,

Research Scientist,

Ifakara Health Institute United Republic of Tanzania.

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DEDICATION

I dedicate this thesis to my late husband Peter Leo Agweli, you always believed in me, you would have been so proud of me.

Rest in peace P. L. O.

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ABSTRACT

The quality of housing has been shown to influence malaria transmission, which in most African settings, takes place at home with around 80% occurring indoors. *Anopheles gambiae* mosquitoes are usually nocturnal, endophilic and endophagic and therefore seek entry to dwellings occupied by humans at night. The experiments conducted using local huts and specially designed experimental huts in Lupiro village in southern Tanzania, evaluated the benefit of each entry point (eaves, windows and doors) in terms of reduced indoor densities of mosquitoes. Cross-sectional household surveys were conducted in Dar es Salaam to estimate usage levels of available options for house proofing, namely window screens, ceilings and blocking of eaves. These surveys also enabled evaluation of household expenditure on screens and ceilings and the motivation behind their installation. Blocking eaves reduced *Anopheles gambiae*, *Culex* spp, *Mansonia* spp, densities by 51% [95% CI ± 31 to 79], 27% [55 to 97] and 43% [38 to86], respectively, but blocking doors and windows had no significant impact on indoor mosquito densities. Over three quarters (81.4 %, 306/376) of the sampled houses in Dar es Salaam had window screens while almost half (49.7%, 187/376) had ceilings. Prevention of entry of mosquitoes into houses was cited for installation of window screens by 97.3%, (253/260) and ceilings by 54.2%, (77/142). The median cost of window screens was between US $ 21 and 30 while that of ceilings was between US $301 and 400. Blocking of eaves is beneficial in terms of reduced indoor densities of both malaria vectors and culicine mosquitoes. Householders seem to understand the importance of protecting their houses with window screens and/or ceilings as an option for protecting themselves against mosquito bites, thus high acceptability of this intervention by a large population in urban settings. Policy makers should be engaged in promotion of mosquito-proofing houses into integrated malaria control.

CHAPTER ONE

1.0. INTRODUCTION AND LITERATURE REVIEW

1.1. Introduction

Malaria is one of the worlds leading killer diseases caused by protozoan parasites which belong to the genus *Plasmodium*. There are five species of *Plasmodium* that infect humans, namely, *P. falciparum, P. vivax, P. ovale, P. malariae*, *P. knowlesi,* with *P. falciparum* causing the most lethal form of the disease (WHO/UNICEF 2008; Cox-Singh *et al*., 2008). Malaria is transmitted to humans by an infectious bite of a blood seeking female mosquito of the genus *Anopheles*. The *Anopheles* genus consists of approximately 484 species (Krzywinski and Bensasky 2001). A small subset of just over sixty *Anopheles* species are the only vectors of human malaria, often occurring in sympatry with *P. falciparum* (Kiszewski *et al.,* 2004).

Despite the tremendous challenges which remain, significant progress in the battle against malaria has been made in many regions. Following the initial phase of developing national control plans and obtaining financial support for these plans, most countries have begun to implement the recommended tools and strategies in an effort to reach those most at risk of malaria, as witnessed at the Kenyan coast and on the island of Zanzibar (WHO/UNICEF 2008a) .

The key element in the control of malaria is to reduce transmission rates. This can be accomplished by reducing human-vector contact by encouraging personal protection against malaria mosquitoes. The quality of housing has been shown to influence malaria transmission, due to the fact that, in most settings, it takes place at home with around 80%

occurring indoors. This is especially true for African vectors like *Anopheles gambiae* which are usually nocturnal (active at night), endophilic (rest indoors) and endophagic (feed indoors) and therefore seek entry to dwellings occupied by humans at night (Lindsay and Snow, 1988).

1.2. Literature review

1.2.1 Malaria vectors

The most important vector of malaria in the world is the *Anopheles gambiae* species complex (Coetzee and Fontenille, 2004). The complex comprises of seven sibling species. These are *An. gambiae*, *An. arabiensis*, *An. quadriannulatus*, *An. melas*, *An. merus An. bwambae* and *An. quadriannulatus* spp B. Within the complex, *An. gambiae* and *An. arabiensis* are most responsible for malaria transmission in Africa (Besansky *et al.,* 1994; Kiswewski *et al.*, 2004; Hunt *et al.,*1998). *An. gambiae* is a very efficient vector mainly because of its endophagic and anthropophagic characteristics (Gillies and DeMeillon, 1968). Though the vectorial efficiency of *An. arabiensis* is slightly lower than that of *An. gambiae*, it can also contribute to high transmission of malaria where it is the dominant vector and where there is minimal cattle rearing (Killeen *et al.,* 2001). These two species often occur in sympatry, although *An. arabiensis* is more widely distributed in southern Africa and along the Sahel and savannah belts of North Africa, particularly in dry areas where it is typically responsible for the bulk of malaria transmission. *An. quadriannulatus* species A occurs in southern and central Africa while species B is restricted to the Ethiopian highlands (Hunt *et al.*, 1998). *An. bwambae* is uniquely found in hot springs in Uganda while *An. melas* is common in coastal areas of central and West Africa. *An. merus* occupies along the coasts of southern and eastern Africa (Levine and Benedict, 2004). The distribution of *An. gambiae* species complex mosquitoes is shown in figure 1. *Anopheles funestus* species complex is a complementary vector and it maintains intense perennial transmission in many endemic areas (Kiswewski *et al.*, 2004).

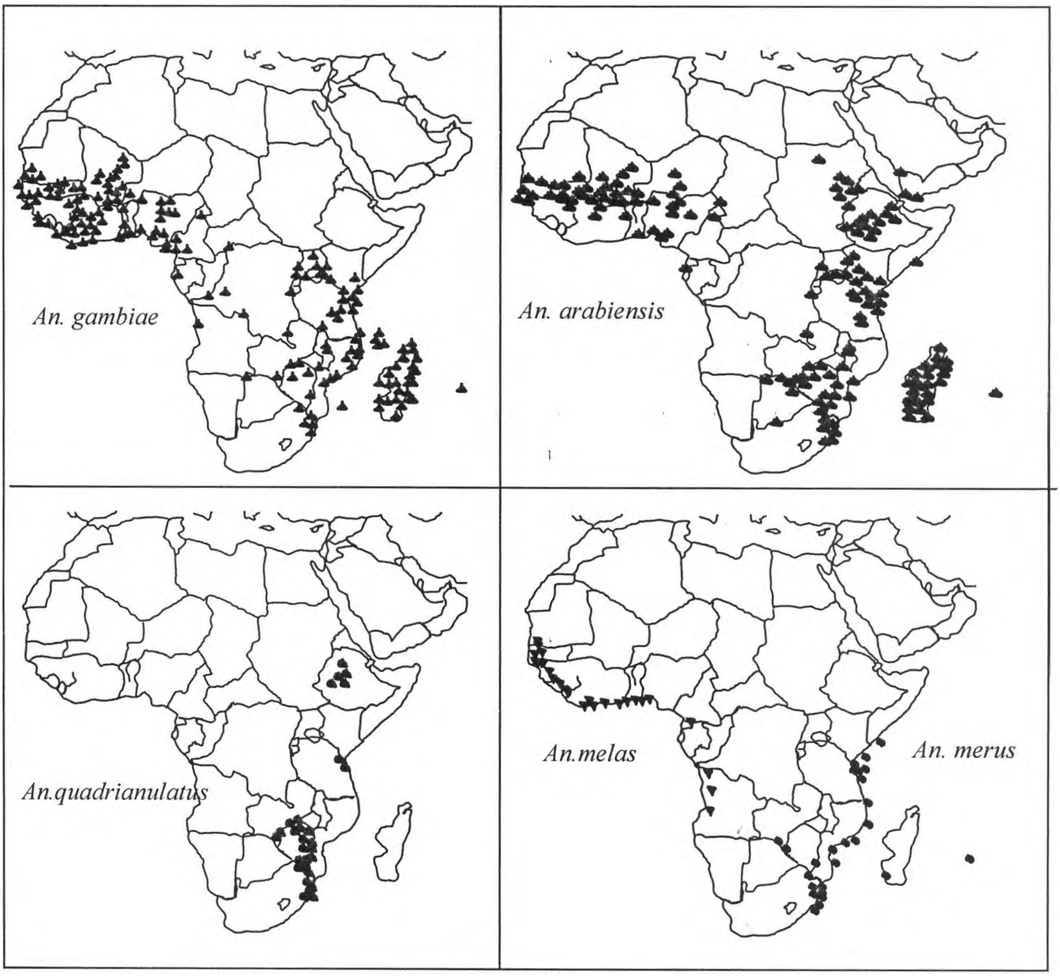

Figure.1: Map of Africa showing distribution of *Anopheles gambiae* species complex mosquitoes. *Anopheles melas* and *Anopheles merus* appear on the west and east coasts, respectively (Coetzee *et al.*, 2000).

1.2.2. Public health importance of malaria

The malaria burden is generally falling but to varying degrees across all regions of the world. This is attributed to high coverage of malaria interventions, especially in sub-Saharan Africa (WHO/UNICEF 2008b). In 2007 an estimated 3.3 billion people were at risk of contracting malaria causing nearly 1 million deaths most of which were children under 5 years of age (WHO/UNICEF 2008b).

1.2.3. Malaria transmission and control in urban sub Saharan Africa

High malaria transmission in Africa is largely attributed to the economic factors and the climatic conditions thought to support survival of the vectors (Hay *et al.,* 2004; Hay *et al.,* 2005). The pattern of malaria transmission is not homogenous, it varies widely from place to place. However, areas of high transmission also tend to have high vector densities (Hay *et al.*, 2004).

Malaria transmission, which is higher in rural than in urban areas (Keiser *et al.,* 2004; Hay and Tatem, 2005; Robert *et al.,* 2003), is often measured by the entomologic inoculation rate (EIR) i.e. the number of infectious bites received per person per unit time. EIR mainly depends on the human population density (being the denominator in the model equation). The primary reason why there is low malaria transmission in urban areas is due to the high human population densities per square km compared to low mosquito densities. This provides easy access to a large choice of potential human blood sources by mosquitoes and therefore reducing the chance of any single host receiving an infective bite and lowering the overall biting rate (Killeen *et al,*. 2000; Smith and McKenzie, 2004). The ability of most residents of the urban areas to protect themselves against mosquitoes via use of ITNs, repellents and screening also reduces the chances of infection and thus contributes towards low transmission rates. In addition improved health care in urban areas also contributes to the low intensities of transmission (Robert *et al*., 2003). High rates of EIR in rural areas are attributed to low human population per km^2 in comparison to high mosquito densities, and therefore, the likelihood of people receiving multiple infectious bites is higher (Smith and McKenzie, 2004; Smith *et al.,* 2007). High mosquito densities in rural areas are attributed to favorable habitats for the survival of *Anopheles* mosquitoes. Among the highest EIR ever recorded in rural areas in history is an estimated 2700 infectious bites per year which in the Kilombero valley in southern Tanzania (Smith *et al.,* 1993).

Despite relatively low transmission in urban Africa, it is increasingly becoming an area of much interest because an increasing proportion of the population lives there and it is realistically possible to eliminate malaria in many such areas (Keiser *et al*., 2004; WHO/UNICEF 2008b). More than half of the African population will live in urban areas by 2030 (UN 2002), so a growing number of people will be exposed to reduced malaria transmission with the particular challenges and opportunities which are unique to towns and cities. This growing population is attributed to the rapid growth of cities in sub-Saharan Africa, much of which is driven by rural to urban migration, leading to complex transformations of the ecosystems and an intricate, poorly understood set of challenges for malaria control (Castro *et al.,* 2004). Until recently, urban development was generally believed to reduce the risk of vector breeding, and thus malaria transmission. However, many African countries have declining economies and most cities are struggling to cope with the pace and extent of urbanization, resulting to poor housing and lack of sanitation or drainage, which increase vector breeding and human vector contact. Although habitats may often be scarce or sub-optimal in urban areas, malaria vectors have consequently adapted accordingly. Chinery (1984) observed adaptation of *An. gambiae s.s.* to urban aquatic habitats, such as water-filled domestic containers and polluted water habitats created as a result of urbanization in Accra, Ghana. *An. arabiensis* has also readily adapted to urban ecosystems by ovipositing and developing in atypical larval habitats such as domestic containers and polluted water bodies (Chinery 1984; Sattler *et al.,* 2005; Vanek *et al,.* 2006). In addition, the presence of substantial non-immune populations and therefore the danger of resurgent epidemics in urban areas places people of all ages at comparable levels of risk (Castro *et al.,* 2004). Despite these factors, malaria in urban areas should be fundamentally much easier to control due to the generally better infrastructure and institutional support available which facilitate increased coverage and impact of both intervention and health education programs (Donnelly *et al.*, 2005). In addition, improved housing in urban areas has great potential as an intervention tool. Increasing coverage of window screening and ceiling boards in Dar es Salaam coupled with a simultaneous reduction of malaria prevalence has led to renewed interest in this classical intervention tool (Geissbühler *et al.,* 2007).

1.2.4. Malaria control strategies

In the United Nations Millennium Project, a select number of key interventions for the control of malaria were recommended but the targets set differed according to the intensity of malaria transmission which varies over a huge range from place to place (UN, 2005). Some regions of high or stable transmission are controlling the transmission intensities, while others are heading towards elimination (WHO/UNICEF 2008a). The currently recommended priority interventions include use of long lasting insecticide treated nets (LLIN), indoor residual spraying (IRS) and artemisinin-based combination therapy (ACT) as well as intermittent preventive treatment in pregnancy (IPT) (WHO/UNICEF 2008b).

In the bid to fight malaria, all African countries have committed themselves to ensure intervention coverage exceeds 80% of the people at risk by the end of 2010. Achieving these targets has been an uphill task due to financial constraints and weak capacity of recipient countries to utilize available funds and lack of better strategies for distribution (Roberts, 2007). Nevertheless, progress is being made. Coverage of ITNs in Tanzania steadily rose from 3% in 2000 to 26% in 2002 and an estimated 39% in 2007, but still falls far short of even the 2005 target of 60% (WHO/UNICEF, 2008b; Kiszewski *et al.,* 2007). Despite these shortcomings, there has been substantial practical benefit of increased ITN use. A study of large-scale programmatic (Fegan *et al.,* 2007) application in rural Kenya indicated a 44% reduction in mortality with the scaling up of ITN. ITN coverage also increased at the coast of Kenya due to the scaling up of malaria interventions, one of them being the distribution of ITNs leading to decreased pediatric malaria cases (Okiro *et al.,* 2007). Even more impressively, the distribution of long-lasting insecticide treated nets (LLIN) in Zanzibar in early 2006 resulted in a 10–fold reduction of malaria parasite prevalence (Bhattarai *et al.,* 2007). Together with indoor spraying of all the homes and the use of Artemesinin-based combination therapies (ACTs), this has resulted in the near elimination of malaria from these islands (Glass and Fauci, 2007).

Introduction of indoor residual spraying (IRS) has had a huge impact on the malaria situation in southern Africa where other control measures such as attempts at drug prophylaxis, environmental sanitation and larviciding were tried prior to IRS but with limited success (MabasoSharp and Lengeler, 2004; Sharp *et al.,* 2007). Currently, IRS is largely implemented in areas of unstable malaria transmission with risk of epidemics (WHO/UNICEF 2008b).

Microbial larvicides have been recently shown to significantly reduce *Anopheles* mosquito densities and malaria transmission intensity in Africa. Areas in Kenya treated with larvicides experienced a 95% reduction in *Anopheles* larval density and a 92% decline in human exposure to mosquito bites (Fillinger and Lindsay, 2006). Large-scale application of microbial larvicides can contribute substantially to reducing *Plasmodium falciparum* infection prevalence under operational conditions (Geissbuhler *et al.* ,2009).

1.2.5. Public health importance of culicine mosquitoes

Despite the unambiguous evidence of protection against malaria vectors, the potential of improved housing in reducing indoor biting densities of culicine mosquitoes has received little attention. This is despite the fact that several of these taxa are known vectors of diseases that cause significant morbidity and mortality. The most abundant of these mosquitoes is *Culex quinquefasciatus*, a vector of *Wuchereria bancrofti* which causes Bancroftian filariasis, in Africa. This disease causes significant morbidity, contributing to an estimated 2,011,000 disability adjusted life years lost per year for the African region (WHO 2004) through incapacity which leads to loss of earnings and economic hardship (Gasarasi *et al.,* 2000). *Cx.*

quinquefasciatus is notably associated with poorly planned urbanization which leads to creation of conducive larval habitats containing highly polluted water such as pit latrines and soakage pits which, in turn, leads to very high densities of biting adults (Subra, 1981). They are the main vectors of Bancroftian filariasis in urban areas, but also contribute to rural transmission, although the latter is dominated by *An. gambiae* and *An. funestus* (Mwandawiro *et al.,* 1997; Subra, 1981).

Other culicines are involved in the transmission of arboviruses (Table 1), the most notable of these being Rift Valley Fever (RVF). Outbreaks of this disease, associated with high mortality, have been reported in many sub-Saharan tropical countries (Gerdes, 2004). While they transmit several important arboviruses, culicines are notably a major cause of nuisance biting in the tropics because of their abundance, irritating feeding behaviours and painful bites. Several studies have shown that indeed Insecticide treated nets (ITNs) uptake is based upon prevention of nuisance bites and that there is reduction in the use of ITNs when seasonal mosquito densities decline (Frey *et al.,* 2006; Aikins *et al.,* 1993). There have been reports of increased biting nuisance due to high culicine densities, which has been attributed to low levels of susceptibility of *Cx. quinquefasciatus* to pyrethroid insecticides (Kulkami *et al.,* 2007; Mosha *et a.,* 2008). The reduced efficacy of insecticide-treated nets (ITNs) against this widespread nuisance-biting species may undermine public acceptance of this top-priority intervention against malaria vectors and transmission (Schellenberg *et al.,* 1999; Myamba *et al.,* 2002).

Table 1: Culicine vectors and the diseases they transmit in southern and eastern Africa.

Species	**Disease carried**	**Country**	**Reference**
Mansonia africana	Rift Valley Fever	Kenya	(Logan *et al.,* 1991)
		Uganda	(Hernderson *et al.,* 1972)
	Chikungunya	Uganda	(CDC 2009)
Culex pipiens quinquefasciatus	West Nile Virus	Madagascar	(Burt *et al.,* 2002)
	Chikungunya	Tanzania	(Ross, 1956)
	Bancroftian filariasis	Tanzania	(White, 1971)
Culex univittatus complex	Sindbis Virus	South Africa	(Jupp *et al.,* 1986)
	West Nile Virus	South Africa	(Jupp *et al*., 1986 , McIntosh and Blackburn 1986)
		Madagascar	(Burt *et al*., 2002)
		Kenya	(Burt *et al.* 2002, Wongsrichanalai *et al.*, 2003)
Culex theileri	West Nile Virus	South Africa	(Burt *et al.,* 2002, CDC 2009)
	Rift Valley Fever	South Africa	(Worth and De Meillon 1960)
Culex neavei	Sindbis Wesselbron	South Africa	(McIntosh and De Sousa 1972, Jupp *et al*., 1986)
Culex rubinotus	Witswatersrand	Uganda Mozambique South Africa	(Hernderson *et al.,* 1972, CDC 2009)

1.2.6. Housing and public health

Housing is so fundamental to human existence that it has been used as an indirect proxy indicator or correlate of health and well being. It is also considered to be a proxy indicator for material or socioeconomic status of an individual or household (Sclar, 2003). Human housing has changed over time due to the industrial revolution that changed the living conditions of a large proportion of people (Shaw, 2004). Housing conditions have greatly improved in the affluent industrial nations through the second half of the twentieth century, but more than two thirds of the world's population is in developing countries, the great majority of them in rural areas where housing is mostly poor. The proportion of people living in urban areas is rising (Castro *et al.*, 2004), leading to increasing numbers of people living in the slums of Africa, Latin America, and southern Asia (Sclar, 2003), where living conditions are appalling due to poor housing and lack of sanitation or clean water supply. It is thought that poor housing conditions are associated with a wide range of health conditions, including respiratory infections, asthma, lead poisoning, injuries, and mental health. Most health officials in the 19th century targeted poor sanitation, crowding, and inadequate ventilation as an approach to the reduction of infectious diseases (Krieger *et al.,* 2002).

1.2.6.1 House design and mosquitoes

Houses are the main site for contact between humans and night biting mosquito vectors of disease (Gamage-Mendis *et al.,* 1991, Snow, 1987). Fortunately even very simple changes in house design can protect people against exposure to malaria vectors, transmission and infection (Lindsay *et al,*. 2003; Kirby *et al.,* 2008a; Lindsay and Charlwood, 2002). The nocturnal malaria vectors of Africa that prefer feeding on humans (Gillies and DeMeillon 1968) have to gain access to their hosts who are safely confined in their homes at this time, therefore forcing these mosquitoes to find their way into the houses.

In the early twentieth century improved housing and screening were regarded as some of the main methods of controlling malaria. Italian field experiments on proofing houses against mosquitoes were the very first successful malaria control trials (Lindsay *et al*, 2002). In Sri Lanka, people living in poor houses (incomplete or with walls and roofs made of palm thatch and mud) had a higher exposure to malaria than people occupying houses with complete brick and plaster walls and tile roofs (Konradsen *et al.,* 2003). Poor homes also experience a higher mean mosquito density both during the wet and dry seasons (Ghebreyesus *et al.,* 2000; Gamage-Mendis *et al*., 1991). Other studies conducted in Ugandan refugee camps also indicated reduction of landing rate of culicines inside mosquito-proofed shelters as compared to being outdoors. The use of insecticide treated netting on the ceilings and over the eaves inside shelters significantly reduced the incidence of mosquito biting (Medlock and Bean, 2007). House screening was also found to reduce mosquito human biting rates as well as malaria infections in settings as diverse as the United States, Greece and Italy (Lindsay *et al*, 2002).

1.2.6.2. The potential of blocking of eaves as an option for malaria control

An. gambiae mosquitoes are well adapted to entering houses because they fly upwards when encountering a vertical surface (Snow, 1987). Attracted by human odor from inside the house, many reach the wall and enter through the open eaves (Figure 2). This observation is reinforced by studies showing that houses with open eaves and those lacking ceilings are associated with increased mosquito numbers and higher levels of malaria compared to the ones with closed eaves and those with ceilings (Lindsay and Charlwood, 2002; Kirby *et al*., 2008a). In The Gambia, children who lived in houses with closed eaves and metal roofs but slept without bed nets had fewer *P. falciparum* malarial attacks than children who slept in houses with open eaves and also had no bed nets (Lindsay and Snow, 1988).

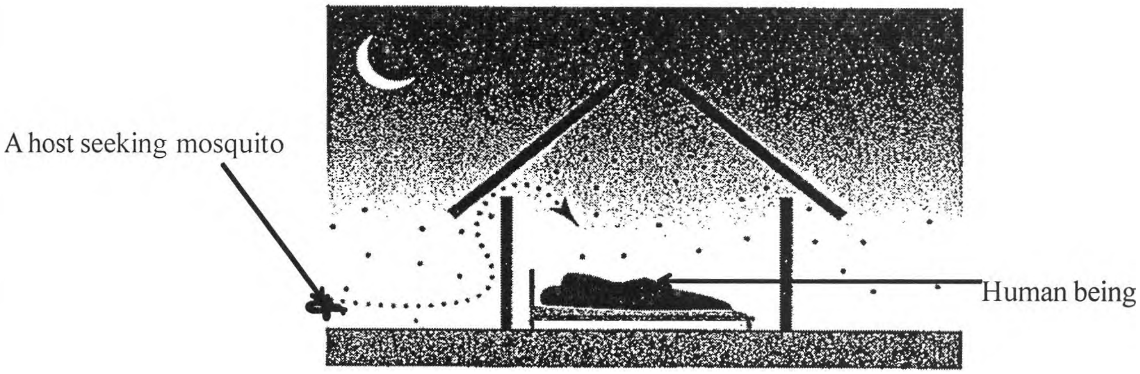

Figure 2: A diagrammatic representation of *Anopheles gambiae* entering the house when attracted by odor emitted from a sleeping human (Lindsay and Charlwood 2002).

1.2.7. Contribution of improved housing to malaria prevention in Dar es Salaam

In Dar es Salaam, overall ITN usage has remained consistently and disappointingly low but window screening and ceiling boards became increasingly common between 2004 and 2006 (Figure 3) (Geissbuhler *et al.*, 2009). This was coupled with a simultaneous decline in malaria prevalence. Consequently, this has stimulated an interest in further research on the protective efficacy of window screening, ceiling boards and blocking of eaves (Geissbuhler *et al.*, 2009).

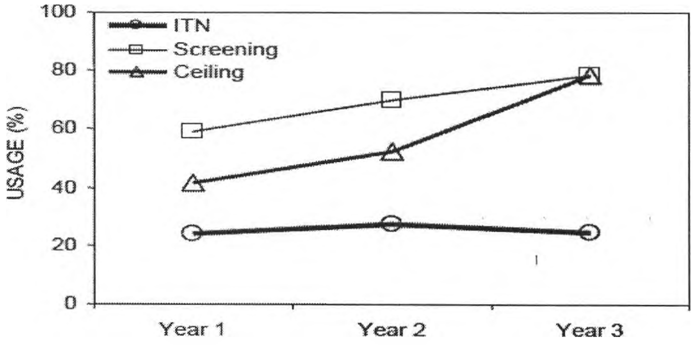

Figure 3: Time trends of protective measures in the survey areas of the Urban Malaria Control Program (Geissbuhler *et al.*, 2009)

1.2.8. Justification and significance of the study

Despite the unambiguous evidence of protection against malaria vectors, the potential of improved housing in reducing indoor biting densities of culicine mosquitoes has received little attention. This is despite the fact that several of these taxa are known vectors of diseases that cause significant morbidity and mortality, including Bancroftian filariasis, Rift Valley Fever, West Nile Virus, Chikungunya and Sindbis virus. While they transmit several important arboviruses, culicines are notably a major cause of nuisance biting in the tropics because of their abundance, irritating feeding behaviours and painful bites. It is therefore important to study the impact of reduced indoor densities of culicine mosquitoes with the aim of reducing transmission of the diseases they transmit. Control of nuisance caused by mosquitoes is essential in the control of diseases transmitted by mosquitoes. This is reinforced by the fact that there is increased uptake and use of protection measures when there is a high density of mosquitoes thus increased nuisance biting. The reverse is also true, when mosquito densities decline usage of personal protection measures reduces, despite the fact that even very low densities of mosquitoes still sustain the transmission of mosquito borne diseases.

Therefore, there is an urgent need to combine these two benefits (protection against both malaria vectors and nuisance biting mosquitoes) in any intervention or suite of interventions in order to enhance trust, acceptance, uptake, perceived benefit and therefore cooperation or even investment by the community in the control of malaria. Consequently, the house entry habits of the main malaria vectors and nuisance biting mosquitoes, primarily *Culex* sp. and *Mansonia* sp. were investigated.

It is also crucial to understand the motive behind installation of different types of ceilings and different types of screens by community members. This study investigated the human preferences for blocking specific mosquito entry points and the preferences of mosquitoes for various points of entry into the house. The results obtained from the desirability of different types of window screens and ceilings enable understanding and further improvement of the social acceptability of this intervention if it is to be incorporated into integrated malaria control. The primary motive for installation of ceilings and window screens was investigated as well as amount of money spent on their installation.

1.3. OBJECTIVES

1.3.1. Overall objective

To evaluate the impact of mosquito-proofing houses upon mosquito entry as well as motivation and investment by householders.

1.3.2. Specific objectives

1. To evaluate the benefits of blocking various entry points in terms of reduced indoor densities of malaria vectors as well as culicine mosquitoes.
2. To determine the primary motivation of households for installing window screens, ceilings and closed eaves in their houses.
3. To determine the cost of installation and distribution of household expenditure on window screens and ceilings.

1.3.3. Hypothesis

Prevention of indoor biting by mosquitoes is the main motivation behind installation of window screens and ceilings but is dependent upon resident's perception of benefit and ability to install them.

CHAPTER TWO

2.0. MATERIALS AND METHODS

2.1. Study sites

This study was carried out in two different study sites. This included Lupiro village which is found in South Eastern Tanzania and Dar es Salaam city, Tanzania.

2.1.1. Lupiro Village, Kilombero, South Eastern Tanzania

Lupiro village (8.01°S and 36.63°E) is located in Ulanga district, in the south eastern part of Tanzania. The village lies 300 meters above sea level on the flood plain of Kilombero River, approximately 26 km south of Ifakara town. The climate is hot and humid experiencing annual rainfall ranging between 1200-1800mm and annual mean temperature between 20-32°C. This climate and the clearance of a perennial swamp for rice farming support perennially abundant populations of both *An. gambiae* and *An. arabiensis* (Killeen *et al.,* 2006). This village has consistently high malaria transmission levels with EIR ranging between 414-851 infectious bites per person per year (Killeen *et al.,* 2007b).

2.1.2. Physical and demographic characteristics of Dar es Salaam city, Tanzania

Dar es Salaam is the commercial capital of Tanzania, located on the southern coast of Tanzania. The city covers an area of almost 1,400 km^2, with about 2.7 million inhabitants (UN 2002). It is administratively divided into 3 municipalities, namely Ilala, Temeke, and Kinondoni. These municipalities are further subdivided into wards, therefore giving a total of 73 wards. Each ward is divided into several neighborhoods which are referred to in Kiswahili language as *mitaa* (*mtaa* singular), meaning street. These neighborhoods are divided into ten-cell-units (TCUs) and are the smallest administrative units headed by an elected leader known as a *Mjumbe*. The TCUs typically comprise of at least 10 to 20 houses, although some may contain even up to 100 houses (Dongus *et al.,* 2007). This study site covers an area of 56 km^2 and consists of 15 wards, 67 neighborhoods and more than 3000 TCUs with more than 610,000 residents. It has a hot and humid tropical climate with two rainy seasons; an intense one during the months of March, April and May, and a milder one occurring in November and December. The temperatures range between 22°C and 32°C and are typically suitable for the survival of the main malaria vectors, as well as for the sporogonic stages of the parasites.

2.2. Experimental huts

The huts were designed to represent local housing in southern Tanzania constructed with bricks or mud walls with corrugated iron sheets or thatched roofing. The huts have been designed in kit form for ease of portability, and the entire hut can be flat-packed. The structure has a galvanized pipe framework. The roof is corrugated iron sheets lined with grass, to simulate the temperature of thatched roofing. The outer walls have been constructed from wooden planks or canvas. The inner walls are removable panels coated with mud, to simulate local mud walls. Two huts were constructed to mimic some of the larger local huts in the village (Figure 4). These were 6.5 m long, 3.5 m wide and 2 m high, (the size of these huts was determined by measuring 100 houses in Lupiro and calculating the average dimensions). The remaining two were smaller; at 3m long, 3.5m wide and 2 m high. The height of each structure measured 2.5m at the roof apex. Each experimental hut had one door. The smaller huts had two windows while the large ones had six windows with only two functional ones. This was in conformity to most houses in the village which had either one or two windows.

Figure 4: A wooden experimental hut.

2.3. Local huts

Most of the local huts had mud walls, while a few were made of bricks. The roofs were mostly thatched, few were corrugated. The huts chosen for the experiments were made of mud walls and thatch roofs with open eaves and one or two windows (Figure 5). Cooking was mainly done outside the hut under the shade of a tree.

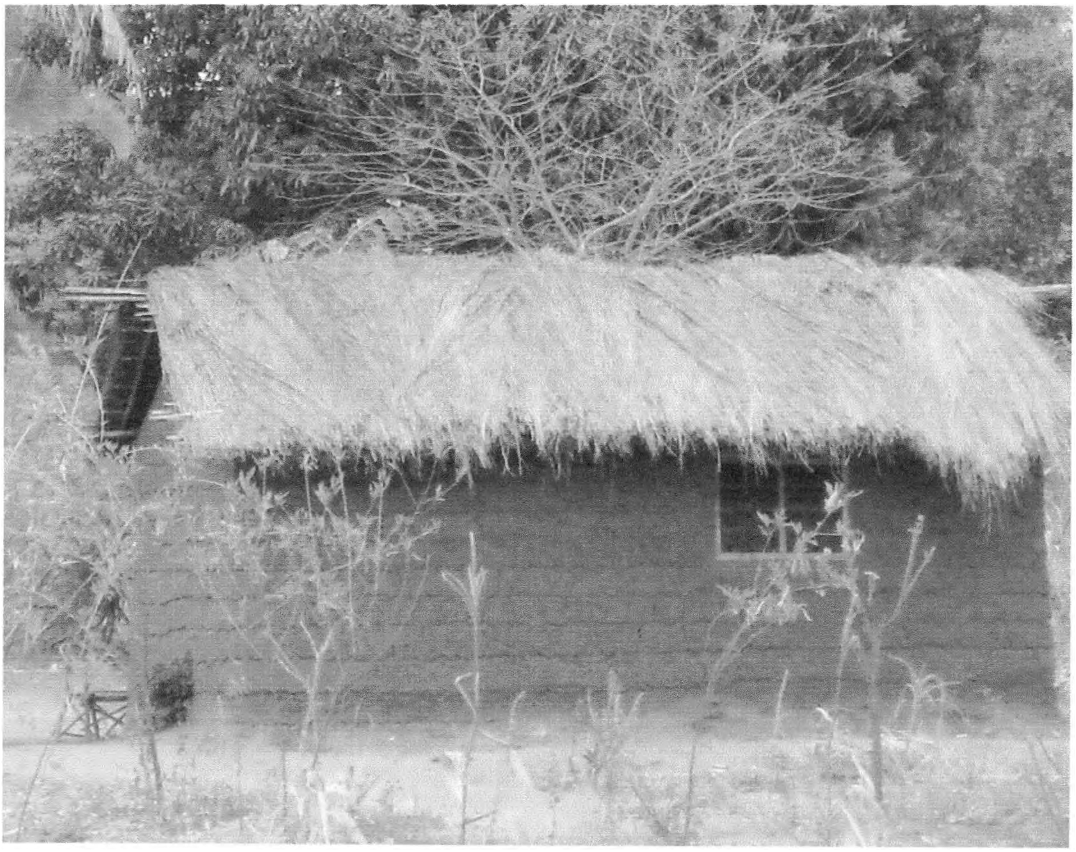

Figure 5; Local hut with open eaves, one door and two windows.

2.4. Experimental design

Two blocks of four huts were used for these experiments: one block of four local huts and one block of four experimental huts. The local huts were chosen from the houses which were found near the experimental huts about 50m apart from each other. Two volunteers slept in each experimental hut. For each of the two blocks of four houses, four repetitions of four experimental treatment arrangements were completed over 16 nights. Each repetition consisted of three nights during which three of the four houses had the same one of the three potential entry points blocked while the fourth house was completely unblocked. On the first night eaves of only three huts were blocked while on the second night only windows of the three huts were blocked and lastly on the third night only doors of the three huts were blocked. For the first three nights of each repetition, the hut that was allocated to be completely unblocked remained the same while the treatment allocated to the other three houses was changed each night from eaves to windows and then doors, in that order. On the fourth night, all huts remained completely unblocked. For each repetition, a different hut was chosen within each block to have no entry points blocked so that at the end of the four repetitions, all four huts had acted as these contemporaneous controls.

2.5. Mosquito collection

A CDC miniature light trap (model 512) was positioned 1m above the ground within 1m of the foot end of a bed protected with a new untreated bed net occupied by an adult male volunteer. Occupants operated the light traps from 19:00 to 07:00 hours each night

Two men slept in each experimental hut from 19:00 to 07:00. The number of occupants in the local huts was recorded but it never exceeded three. The traps were collected from each sampling unit every morning at 07.00 hours hours. They were placed in a plastic bucket, and then a piece of cotton wool previously soaked in chloroform was placed in this bucket in order to kill the mosquitoes so that they could be easily identified. After 45 minutes, the cotton wool was removed from the bucket.

2.6. Mosquito identification

Mosquitoes were identified every morning in the field in one of the experimental huts. *An. gambiae* and *An. funestus* mosquitoes were identified according to the morphological characteristics stipulated by Gillies and Coetzee (1987). The results were recorded in data sheet and finally the mosquitoes were transported to the laboratory for storage.

2.7. Sampling design for the household surveys in Dar es Salaam

This study was based within the project area of the Urban Malaria Control Project implemented by the Dar es Salaam City Council. A total of 150 Ten cell units were randomly sampled (10 TCUs from each ward). All the houses found in each sampled TCU were surveyed between March and August 2008. A questionnaire was designed in English and later translated into *kiSwahili* (see appendix I and II), the national language of Tanzania. It was pretested for feasibility and clarity and results used to update the questionnaire before the main survey.

The personal interview questionnaire was administered to household heads, or in their absence, the next responsible person, assuming that was an adult aged 18 years or above. The survey took place within the home/house of the respondent. Respondents were not prompted with any possible answers during the interview. Information was collected about the condition of the house, including direct observation of the house, the presence or absence of window screens, ceilings and whether the houses had open or closed eaves was recorded. (Eaves are spaces found between the top of the wall and the roof in a typical traditional African house). The respondents were asked to rank in order of importance without being presented with a list of alternatives, the reasons for use/installation of different types of window screens and ceilings. Where there was no ceiling and/or screen, they were asked to give reasons for the absence. Information on ownership of the houses was recorded.

The total reported cost of purchasing screens and/or ceilings was recorded in houses that had them. On the other hand, the total amount of money respondents expected to spend if they were to install screens and ceilings was recorded for those whose houses did not have them.

2.8. Data analysis

2.8.1. Impact of blocking main entry points on the relative biting rate of different mosquito species.

Generalized Estimating equations (GEE) were used to determine the relative biting rates observed when specific entry points were blocked. All the mosquito catches (x) were transformed to $\log_{10}(x)$, in order to normalize distribution and minimize the heterogeneity of variance, owing to the naturally aggregated distribution of mosquitoes across space and time. This transformation was also necessary to convert the multiplicative model of these relationships into an additive one that could be fitted using standard GEE methods as explained in the following description:

At the onset, a linear proportional relationship was assumed between the mosquito catch for each treatment. A simple multiplicative model was formulated as follows:

$$C_{i,j,t} = \alpha_{i,}\alpha_{j\,,}\alpha_t C_t$$

Where subscripts i, and j, denote the treatment and the sampling huts where the experiments were done, which was blocked on the same night (t). $C_{i,j}$ signifies the catch in hut j with treatment i on night t while C_t denotes the catch in the contemporaneous control reference hut on the same night.

Log transforming this equation:

$$\mathrm{Log}_{10}(C_{i,j}) = \mathrm{Log}_{10}(\alpha_i) + \mathrm{Log}_{10}(\alpha_j) + \mathrm{Log}_{10}(C_t)$$

The GEE was then fitted:

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3$$

Where $y = \mathrm{Log}_{10}(C_{i,j})$, which is the dependent variable, in these case the mosquito catch.

$$\beta_1 = \mathrm{Log}_{10}(\alpha_i)$$

$$\beta_2 = \mathrm{Log}_{10}(\alpha_j)$$

$$\beta_3 = \mathrm{Log}_{10}(C_t)$$

and x_1, x_2 and x_3 are sets of dummy variables reflecting specific values of i, j, and t, respectively.

The relative biting rate for each treatment, hut or night was respectively calculated as the odds ratios (α_i, α_j, and α_t) from the output parameter estimate (β_1, β_2 and β_3).

2.8.2. Qualitative and quantitative analysis of the questionnaire

The semi-structured part of the questionnaire was coded after completion of the survey. Qualitative analysis and descriptive statistics were processed using Microsoft Excel. All data were entered and analyzed using SPSS 15.0. Analyses of the outcome variables were performed excluding non-responders or missing data points, therefore only valid percentages of the responses were accepted so that the total number of respondents (n) varied between questions. Spearmans Rho-correlation test was used to examine the associations between the presence of ceilings, window screens and closed eaves. All pair-wise comparisons between the three variables were tested to examine the association. Partial correlation was also executed in order to establish the relationship between each of the two variables more rigorously by controlling for the effect of the other third variable.

CHAPTER THREE

3.0. RESULTS

3.1. Mosquito collections

During the cumulative 16 nights of sampling a total of 23,027 mosquitoes were caught with the CDC light traps, of which 77.9% (17,929) were *An. gambiae s.l*, 10.2% (2359) were *Culex* sp and 11.6% (2664) were *Mansonia* sp. There was a low indoor density of *An. funestus* 0.2% (50). The remainder was unidentified mosquitoes 0.1% (25), (table 2). Table 2 shows mosquito catches combined for both experimental huts and local huts.

3.1.2. Comparison of *Anopheles gambiae* catches between experimental and local huts

There were consistently less *An. gambiae* mosquitoes entering experimental huts than the local huts (figure 6), despite the fact that experimental huts were constructed to mimic the local huts as much as possible. This could be due to three possible reasons. First, the materials which were used to build these huts were quite different from the locally available ones. Secondly, lack of residual human odor similar to that in the local huts .Thirdly, the fact that the huts were raised on stilts. The confidence intervals were calculated from standard errors of the geometric means of catches for each house. Catches varied more widely in absolute terms in the local huts as depicted by the large confidence intervals, though this did not differ significantly from one local hut to another. This, however, is simply the result of a much higher mean catch which inevitably has a higher absolute variance. Both the experimental and local huts had similar levels of variance relative to the mean of the log of catch size. This demonstrates that the experimental huts are suitable for studying mosquito behavior. In figure 6, the means for the log transformed data have been back transformed and reported as geometric means.

Table 2:- Indoor mosquito densities in experimental and local huts.

Blocked Entry point	Hut nights % (N)	*An. gambiae s.l.* % (n)	*An. funestus* sp. % (n)	*Culex* sp % (n)	*Mansonia* sp. % (n)	Others % (n)
None[b]	44.4 (56)	46.5 (8341)	44.0 (22)	50.2 (1185)	47.9 (1277)	40.0 (10)
Eaves	19.1 (24)	15.1 (2708)	14.0 (7)	23.3 (549)	12.4 (331)	32.0 (8)
Windows	17.5 (22)[a]	16.4 (2946)	24.0 (12)	13.0 (306)	14.5 (385)	16.0 (4)
Doors	19.1 (24)	21.9 (3934)	18.0 (9)	13.5 (319)	25.2 (671)	12.0 (3)
Total	100.0 (126)	100.0 (17929)	100.0 (50)	100.0 (2359)	100.0 (2664)	100.0 (25)

N=Number of hut nights for sampling.

n=number of mosquitoes caught.

[a] A CDC Light trap was attacked by ants on one of the nights therefore no mosquitoes were recorded.

[b] Reference group (No entry point was blocked).

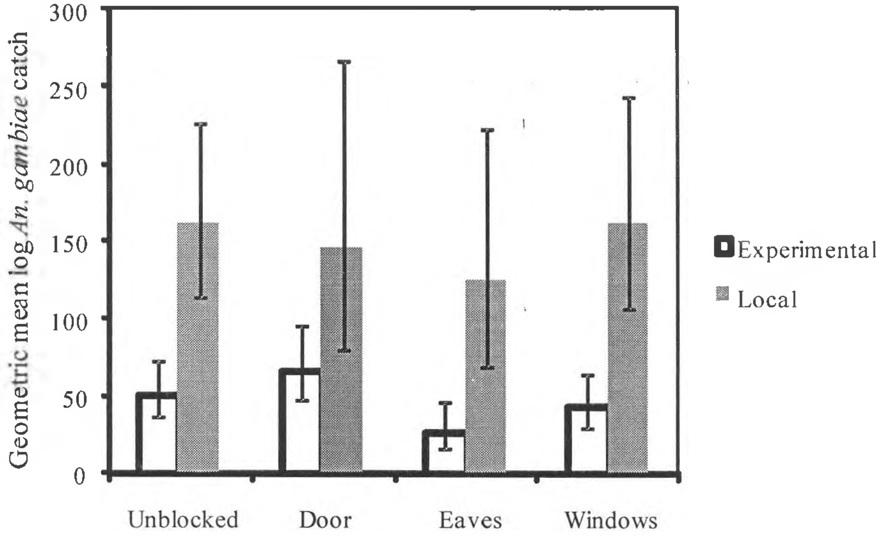

Figure 6:- Geometric mean of *Anopheles gambiae s.l.* catches in experimental and local huts.

3.1.3. Effect of blocking different entry points on *Anopheles gambiae s.l.* and *Culex* sp. indoor catches

Blocking of eaves halved (51%) entry rates of *An. gambiae s.l.* in both local and experimental huts (table 3 and figure 7). *Culex* sp. mosquitoes were reduced by approximately one quarter when the eaves were blocked (table 3 and figure 7). However, when the doors or windows were blocked, catches of *An. gambiae s.l.* and *Culex* sp. were not reduced.

3.1.4. Effect of blocking different entry points on *Mansonia* sp. indoor catches

Indoor catches of *Mansonia* sp. were almost halved when the eaves were blocked (table 3) suggesting that this is a primary entry point for this genus too. Blocking of windows reduced these catches by almost quarter while blocking of the doors had no impact (table 3 and figure 7).

Table.3: Relative biting rate (α) of *Anopheles gambiae s.l.* and *Culex* sp. as a function of blocking entry points as estimated by generalized estimated equations including treatment (P = 0.002, 0.193 and <0.001 respectively), night (P < 0.001 in all cases) and hut (P < 0.001 in all cases) as sources of variation.

Blocked Entry point	*Anopheles gambiae s.l.*			*Culex* sp.			*Mansonia* sp.		
	α	95% CI	P	α	95% CI	P	α	95% CI	P
None[a]	1[a]	NA	NA	1	NA	NA	1	NA	NA
Eaves	0.49	[0.31,0.79]	0.003	0.73	[0.55,0.97]	0.031	0.57	[0.38,0.86]	0.007
Windows	0.94	[0.42,2.08]	0.872	1.10	[0.54,2.24]	0.785	0.79	[0.42,1.49]	0.460
Doors	1.13	[0.88,1.45]	0.339	1.15	[0.53,2.52]	0.721	1.07	[0.59,1.94]	0.829

α Exponential of beta estimated using Generalized Estimating Equations

[a] Reference group (when no entry point is blocked).

NA Not applicable

CI Confidence interval

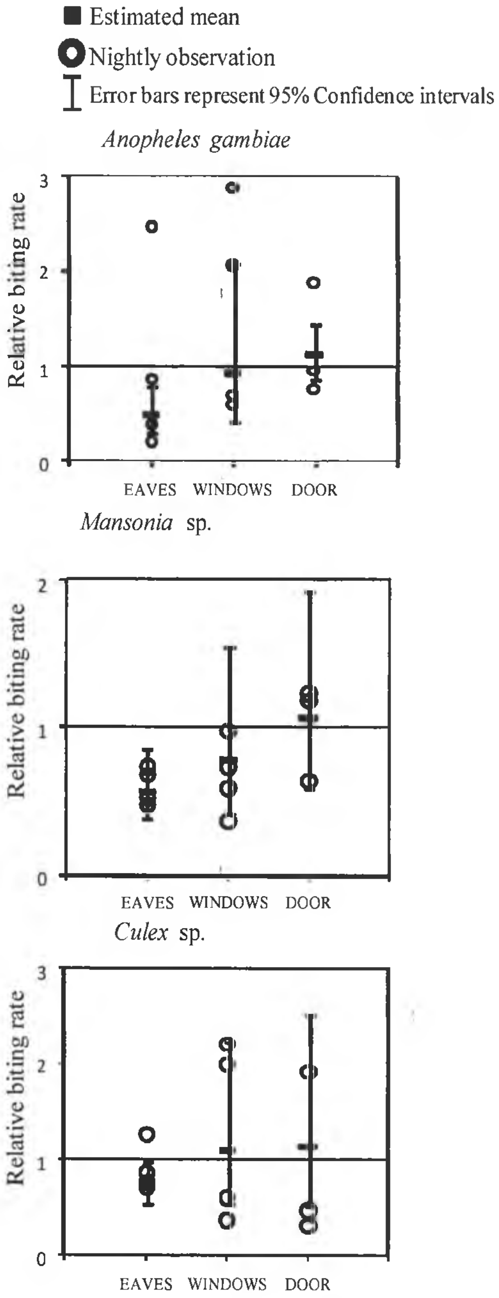

Figure 7:- Relative biting rate of mosquitoes caught indoors as a function of blocking entry points. Mean and 95% confidence intervals estimated by generalized estimated equations.

3.2. Different ways of mosquito proofing houses

The common ways of house proofing in this study area were installation of ceilings, window screens and closed eaves. A house was considered mosquito proofed completely if it had a ceiling, screened windows and closed eaves, while a house with no ceiling, no window screens and open eaves was considered to be unscreened. Eighty two point four percent (82.4%) of the houses had a ceiling or closed eaves or both (Table 4). Over three quarters of the sampled houses in Dar es Salaam had window screens while almost half had ceilings and more than half had closed eaves (Table 4).

3.2.1 Associations between alternative ways of mosquito proofing houses.

A statistical test was carried out to determine whether the use of window screens, ceilings or closing of eaves was associated. There were consistent positive correlations between houses having ceilings, window screens and closed eaves when a bivariate correlation test was applied (table 5). Partial correlation analyses also revealed similar but less dramatic associations in all cases (Table 5).

Table 4:- The proportion of houses with different combinations of mosquito proofing.

Eaves	Ceiling	Windows		Total
		Open % (n)	Screened % (n)	
Open	Open	13.8%(52)	18.9%(71)	*32.7%(123)*
	Closed	0.5%(2)	9.6%(36)	*10.1%(38)*
	Subtotal	*14.3%(54)*	*28.5%(107)*	*42.8(161)*
Closed	Open	2.9%(11)	14.6%(55)	*17.6%(66)*
	Closed	1.3%(5)	38.3%(144)	*39.6%(149)*
	Subtotal	*4.2%(16)*	*52.9%(199)*	*57.2%(215)*
Total	Open	63	126	189
	Closed	7	180	187
	Total	18.5% (70)	81.4% (306)	**100(376)**

Table 5:- Association between different uses of window screening, closed eaves and ceilings.

Condition of the house	Screened		Closed eaves	
Spearmans P test	r	P	r	P
Ceilinged	0.380	< 0.001	0.452	< 0.001
Screened			0.332	< 0.001
Partial correlation controlling for remaining measures				
Ceilinged	0.273	<0.001	0.374	<0.001
Screened			0.194	<0.001

3.2.2. Different types of ceilings

Different types of ceilings were made from the various types of materials available locally. The most common type of ceiling material was plywood boards found in more than nine tenths (88.8%, 166/187) of sampled houses (figure 8). Other types were the ceiling made from thin wooden panels which are commonly known as "tongue'n groove" (TNG) (4.3%, 8/187), gypsum based on calcium chloride rock) (4.3%, (8/187) and two types of traditional ceiling made from mud (0.5%, 1/187) and palm leaves (2.7%, 5/187).

3.2.3. Different types of window screens

More than three quarters of the houses representing 81.4% (306/376) had screened windows. Out of this, more than three quarters representing (79.7%, 244/306) were made from plastic netting, while the rest constituting 17.7% (54/306) were made from fine metal mesh and synthetic fiber netting screens were used in 2.6% (8/306) (figure 9).

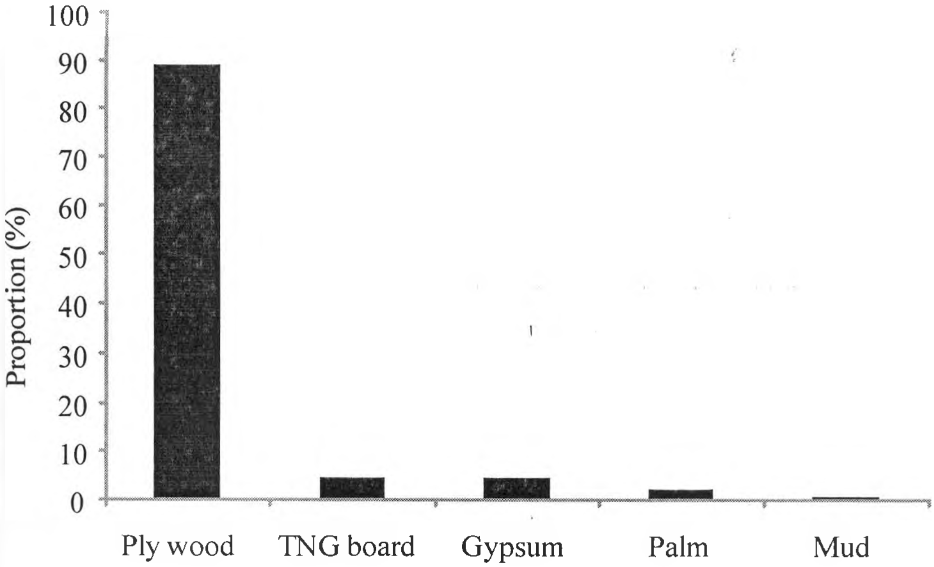

Figure 8:- Proportion of houses with different types of ceilings.

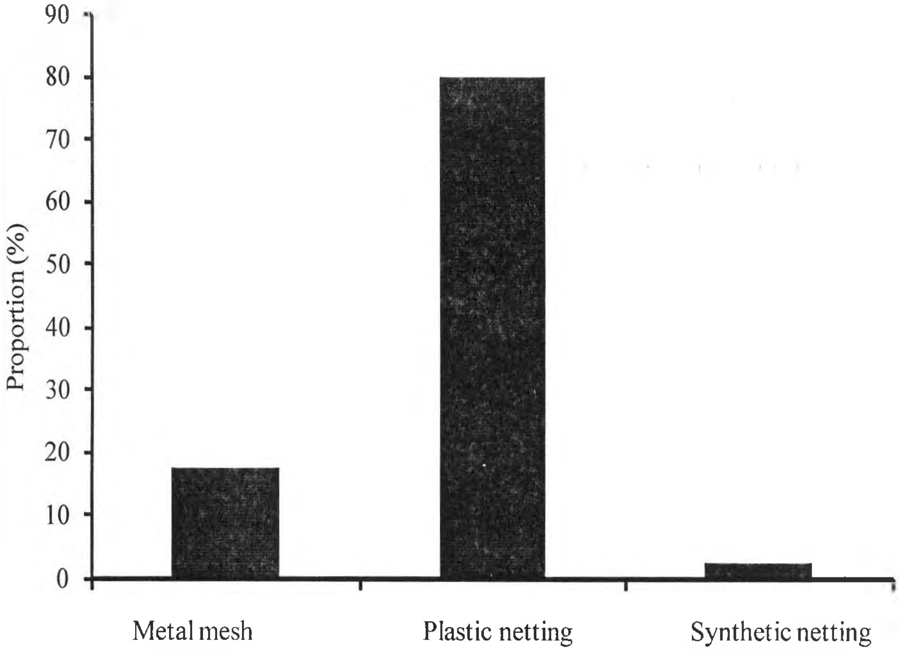

Figure 9: Proportion of houses with different types of window screens.

3.2.4. Motivation for installing ceilings

Information about reasons for having a particular type of ceiling was obtained from questions addressed to only those respondents whose houses had ceilings. More than half (54.2%, 77/147) of the respondents cited mosquito entry prevention as a motive. More than a quarter 40.1% of the respondents cited prevention of entry of mosquitoes as their most important reason and this was the most commonly cited reason (table 6). This was closely followed by almost a quarter (28.2%) of the respondents who cited keeping the house cool as their most important reason. Keeping the house cool was also cited by about a quarter of the respondents as the second most important reason, while more than half of the respondents said it was more fashionable to install ceilings and cited this as their third most important reason (table 6). Overall, preventing mosquito entry, keeping the house cool, and fashionability accounted for almost four fifths (79.5%, 207/255) of all reasons cited. Although preventing mosquito entry is of high relevance to public health and was the most common motivation it is notable that fashion/style/house design and keeping the house cool contribute substantially to the desirability of this intervention and most probably played a major role in to the high coverage achieved. Prevention of malaria was also cited as a reason for installation but only by a very small proportion of 2.3% (6/255) respondents.

3.2.5. Motivation for installing window screens

The most commonly cited reason for having window screens was also prevention of entry of mosquitoes but this was much more of a singular, overriding motivation than was the case for ceilings. Almost three quarters (90.4%, 235/343) of the respondents with screens cited this reason as their first most important reason. Four fifths of the respondents who cited a secondary reason indicated it was prevention of mosquito entry. Thus, the vast majority 97.3% (253/260) of the respondents quoted prevention of mosquito entry as their primary or secondary reason (Table 7).

3.2.6. Reasons for lack of screens or ceilings

More than three quarters (84.5%, 155/212) of the respondents lacking screens or ceilings considered these to be expensive. A small minority said they had no choice of screens and/or ceilings because they were just tenants. Only a small proportion said they did not like having either screens and/or ceilings (Table 8).

Table 6: The proportion of respondents who cited different reasons for installing and/or renting a house with a ceiling

Reason	Importance of reason				Total Citations
	Most	Second Most	Third Most	Fourth Most	
	% (n)	% (n)	% (n)	% (n)	% (n)
Prevents entry of mosquitoes	40.1 (57)	20.5 (16)	9.1 (2)	22.2 (2)	29.5 (77)
Keeps the house cool	28.2 (40)	29.5 (23)	13.6 (3)	22.2 (2)	26.1 (68)
Its fashionable	17.6 (25)	30.8 (24)	59.1 (13)	0.0 (0)	23.9 (62)
Its durable	7.7 (11)	5.0 (4)	0.0 (0)	33.3 (3)	6.9 (18)
Prevents entry of dust	4.9 (7)	3.8 (3)	0.0 (0)	0.0 (0)	3.8 (10)
Prevents entry of other insects	1.4 (2)	0.0 (0)	0.0 (0)	0.0 (0)	0.8 (2)
Prevents people from contracting malaria	0.0 (0)	7.7 (6)	0.0 (0)	0.0 (0)	2.3 (6)
Reduces noise from outside	0.0 (0)	0.0 (0)	18.2 (4)	22.2 (2)	2.3 (6)
Its affordable	0.0 (0)	2.6 (2)	0.0 (0)	0.0 (0)	0.8 (2)
Total	100.0 (142)	100.0 (78)	100.0 (22)	100.0 (9)	100.0 (251)

Table.7: The proportion of respondents who cited different reasons for installing and or renting houses with window screens

Reason	**Importance of Reason**				**Total citations**
	Most	**Second Most**	**Third Most**	**Fourth Most**	
	% (n)	% (n)	% (n)	% (n)	% (n)
Prevents entry of mosquitoes	90.4 (235)	40.0 (18)	0.0 (0)	0.0 (0)	73.8 (253)
Keeps the house cool	0.0 (0)	18.9 (10)	11.8 (2)	28.6 (2)	4.1 (14)
Its fashionable	0.4 (1)	13.2 (7)	17.6 (3)	42.9 (3)	4.1 (14)
Its durable	3.8 (10)	3.8 (2)	5.9 (1)	14.3 (1)	4.1 (14)
Prevents entry of dust	0.4 (1)	1.9 (1)	0.0 (0)	0.0 (0)	0.6 (2)
Prevents entry of other insects	0.4 (1)	0.0 (0)	5.9 (1)	0.0 (0)	0.6 (2)
Prevents people from contracting malaria	4.2 (11)	22.6 (12)	0.0 (0)	0.0 (0)	6.8 (23)
It enhances security	0.4 (1)	0.0 (0)	0.0 (0)	0.0 (0)	0.3 (1)
Reduces noise from outside	0.0 (0)	0.0 (0)	58.8 (10)	14.3 (1)	3.2 (11)
Its affordable	0.0 (0)	5.7 (3)	0.0 (0)	0.0 (0)	0.9 (3)
Total	100.0 (260)	100 (53)	100.0 (17)	100.0 (7)	100.0 (343)

Table: 8 Reasons for lack of window screens and ceilings.

Reasons	Ceilings % (n)	Window screens % (n)	Total citations % (n)
Expensive	85.6 (155)	81.4 (57)	84.5 (212)
Rented	14.4 (26)	14.3 (10)	14.3 (36)
Don't like	0.0 (0)	1.4 (1)	0.4 (1)
Glass windows	0.0 (0)	1.4 (1)	0.4 (1)
Under construction	0.0 (0)	1.4 (1)	0.4 (1)
Total	100.0 (191)	100.0 (71)	100.0 (251)

3.2.7. Household expenditure on window screens and ceilings

More than three quarters of the respondents did not know or could not remember the cost of installing screens and ceilings. The median amount of money that the remainder who could remember having paid for window screens was US $ 21-30 and ranged from $ 0.9 to 695 (Figure 10). Interestingly, the majority of the people who did not have screens expected to pay more than US $ 100. This indicates that most people who lacked screens overestimated the likely cost. The amount of money respondents reported they had paid for or expected to pay for ceilings was very similar and ranged between US $ 8 and 870 with a median of US $ 301.0 and 400.0 for both actual costs incurred and the costs expected by those lacking ceilings (Figure 11).

3.2.7.1. Comparison of expenditure on bed nets, window screens and ceilings

The median number of inhabitants per house was 11 and the total expenditure on window screens per house was approximately US $ 25 while that of ceilings was US $ 400. Expenditure for window screens per person was almost the same as that of bed nets (table 9) while for ceilings it was 14 fold higher than of bed nets (Table 9).

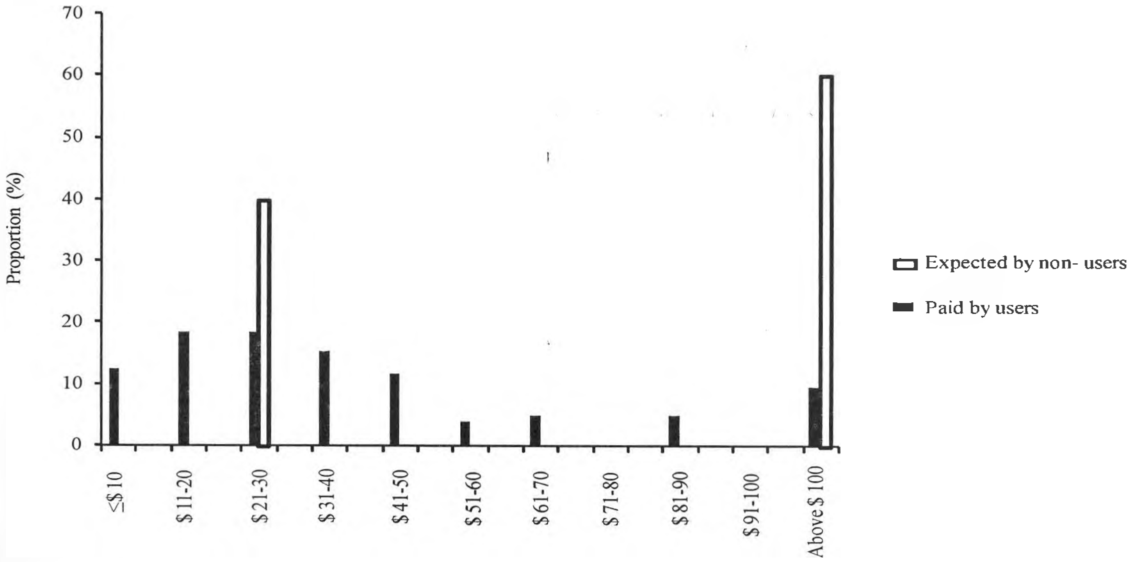

Figure 10: The cost paid (n =103) and expected to pay (n = 5) for window screens by respondents

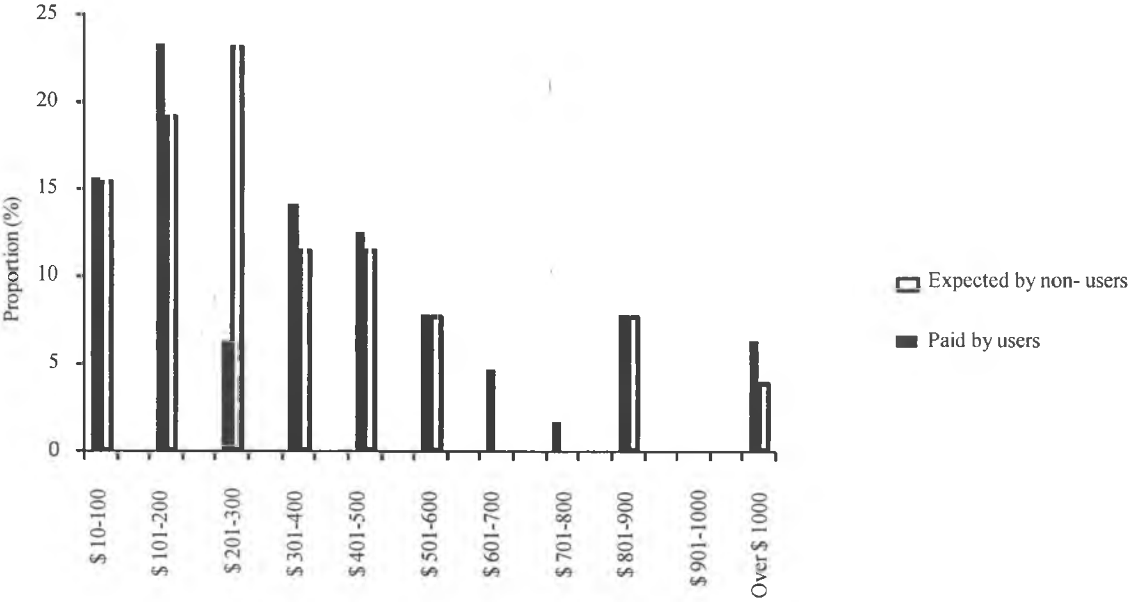

Figure 11: The cost paid (n = 64) and expected to pay (n = 26) for ceilings by respondents

Table 9:- Comparison of total expenditure between different interventions.

Type of intervention	Expenditure per person protected US $	Total expenditure for the population of the city US $
Bed nets	2.6	1,825,200
Window screens	2.3	5,054,940
Ceilings	31.9	42,806,610

Expenditure per person = Cost of intervention/Number of people protected.

Expenditure for the city = Cost per person × Population size × Mean coverage of the intervention.

CHAPTER FOUR

4.0. Discussion

This study has demonstrated that the main malaria vector *Anopheles gambiae* s.l. prefered the eaves as an entry point as evidenced by their reduced indoor densities when this particular entry point was blocked. This is consistent with previous findings (Lindsay and Charlwood, 2002; Lindsay *et al*., 2003; Kirby *et al*., 2008a). These results reinforce the proven value of closing eaves or blocking with netting, or of installing ceilings as a means to prevent malaria. Blocking of windows and doors had no discernible impact on mosquito densities.

This study also revealed that *Culex* and *Mansonia* mosquito species prefer entry into houses via eaves shown by their reduced indoor densities when this particular entry point was blocked. A study carried out in The Gambia observed a reduction in culicine indoor resting densities in houses with closed eaves but in association with horses' tethered outside and increased room height. Indoor *Cx. pipiens s.l.* densities were reduced by 38% when eaves were closed (Kirby *et al.,* 2008b). On the contrary, a second study recently carried out in The Gambia measured the impact of closing eaves in addition to screening the doors in houses with no windows. The study indicated that there was no additional reduction in *Culicine* mosquito densities when eaves where blocked (Njie *et al.,* In press). However, in the present study we considered the impact of blocking each entry point on its own rather than in association with other entry points and other household factors.

In our study, 80% of the *Cx. pipiens s.l.* mosquitoes were *Cx. p. quinquefasciatus* which could have influenced the observed effect of blocking entry points on indoor *Culex* sp. densities. The impact of house proofing on *Cx. p. quinquefasciatus* depends on its feeding behaviour. The level of observed endophily of this species differs from one region to another. However, in East and West Africa this species shows more endophily (Subra, 1981). This is reflected in our findings and reinforces the importance of screening houses to prevent mosquito entry.

We demonstrate that blocking and/or screening of open eaves has a clear overall benefit and can contribute to reduced indoor biting densities of culicines and thus reduce transmission rates of filariasis, arboviruses and other neglected tropical diseases carried by mosquitoes. Crucially, culicines are also the major cause of nuisance biting in rural and especially urban areas (Chavasse *et al.,* 1995). Several studies have shown that the community is sensitive to changes in biting nuisance as reflected by increased personal protection measures associated with an increase in mosquito densities (Chavasse, 1996; Thomson *et al.,* 1994). Therefore, their control will encourage the uptake of ITNs and other control interventions which rely on acceptance, participation or even investment by the community. This in return reduces transmission of the major diseases of which the nuisance biting mosquitoes are vectors. This is particularly important in areas where disappointing coverage of ITNs may result from negative perceptions arising from informal observations by community members of the reduced susceptibility of *Cx. quinquefasciatus* to the pyrethroids used to treat nets (Kulkami *et al.*, 2007).

Understanding the interactions of the main malaria vectors with the changing self-protection behaviors' of human is essential to success in the control of malaria. In this cross-sectional study, more people lived in houses with screened windows than in houses with ceilings or closed eaves. The general perception of people in this community was that complete proofing of their houses was more beneficial than just partial house proofing, as was illustrated by the positive correlation between ceilings, window screens and closed eaves. Many residents of Dar es Salaam clearly understand that installation of ceilings protects them from mosquitoes and some even associate this with protection against malaria infection, yet this intervention has not been explicitly encouraged in most urban areas where it is probably most appropriate. Other motives for installation of ceilings mentioned included fashion and or style especially the gypsum type of ceiling which was considered quite stylish as well as keeping the house cool. This shows that ceilings are perceived to serve more than one function. This suggests the plausibility of incorporating house screening as a form of house design and therefore, making it relatively easy to promote them as a useful strategy for protecting households against mosquito bites and even achieving community-level suppression of malaria so that even a remaining minority lacking them benefit from the "mass effect" (Killeen and Smith, 2007; Killeen *et al.,* 2007a).

In fact, in Dar es Salaam this may be already happening and may readily contribute to the steady decrease in malaria prevalence observed in recent years (Geissbuhler *et al*., 2009). Generally the residents of the city appear to try as much as possible to protect themselves against mosquito bites by blocking entry to their houses, as depicted by the small proportion of houses (13.8%) which did not have ceilings, or windows screens and had open eaves. Perhaps most exciting is the prospect of what might be possible if these materials could be treated with effective, long-lasting insecticide formulations to achieve a substantially enhanced level of household and community-level transmission as reported by Killeen and Smith (2007).

Protection of all members within a household, beyond merely those young children and pregnant women at great risk is essential to achieve maximum control and even elimination of malaria (Killeen *et al.*, 2007). Mosquito proofing houses therefore offers the significant advantage of protecting all members of a particular household, even those that are not sleeping under a bed net. The high coverage of screens and ceilings already attained in Dar es Salaam suggests this is a vector control measure which can be readily delivered to large populations in many towns and cities across Africa. However, high initial costs may hamper its implementation. The present study has shown that the initial cost of installing window screens is comparable with that of providing bed nets for all the occupants. Interestingly most houses which neither had ceilings nor window screens but had closed eaves were initially built with closed eaves only, and therefore no additional cost was required for blocking the eaves. Blocking of eaves might well be one the cheapest of the three options but schemes for promoting awareness and understanding of these accessible options for household-based control need to be developed and evaluated. Mosquito-proofing of houses has an advantage of protecting all the members of a particular household who are awake and active, and therefore indoors but not using a bednet. The value of this particular facet is bolstered by the observation that residents of houses with ceilings, screened windows, and especially the combination of both take advantage of this protection by spending more time indoors at night (Geissbühler *et al.*, 2007).

4.1. Conclusion and Recommendations

This study has shown that screening of eaves reduces indoor densities of anopheline as well as culicine mosquitoes namely, *Culex* spp. and *Mansonia* spp.

Due to high coverage of screens and ceilings, we can conclude that people have readily accepted this method as a way of protecting themselves from mosquito bites and, perhaps inadvertently in many cases, reducing malaria transmission. Although cost is the most important constraint on the choice and degree of use of these methods, it is remarkable that coverage with a combination of closed eaves or ceilings equals the 2010 RBM target for ITNs of 80% while that of ITNs remains stagnant at a mere 26%. This is all the more notable because this particular intervention doesn't feature in the National Medium Term Strategic Plan and is neither subsidized nor actively promoted.

It seems that most people know about the value of mosquito-proofing houses but need access to and information about cheaper and more durable materials which would ideally have insecticidal and/or excitorepellent properties which would kill adult mosquitoes directly or act as more effective barriers for preventing house entry (Killeen and Smith 2007). Moreover, since blocking of eaves seems to be a particularly effective and affordable option, netting materials used for window screening could also be used for screening or blocking eaves, since they would interfere less with airflow and indoor temperatures.

We propose that further studies on the impact of blocking different entry points to investigate their impact on individual culicine mosquito species may be valuable to ascertain their entry behaviour and identify optimal proofing strategies for such vectors of numerous neglected pathogens.

In order to fully understand the cost-effectiveness of house screening, additional information is required on the durability of the materials used for ceilings and window screens so that the effectiveness and long term costs per person per year of this intervention can be determined. In addition, inquiry into effective models for promotion and subsidization should be made. Lastly, there is need to engage policy makers in promotion of mosquito-proofing houses as one of the tools for integrated control, and perhaps one that can be considered as “low hanging fruit” in the urban context.

5.0. REFERENCES

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APPENDIX I: English version of the household survey questionnaire

Municipality: [ ], Ward: [ ], Mtaa: [ ], TCU: [ ], [ ], [ ], [ ], [ ]

Interviewer: ________________________________ **Date: [/ /]**

Identification

Use the following codification: I=Ilala, T=Temeke, K=Kinondoni

Use the following codification:

ILALA

1-Buguruni

2-Ilala

3-Kipawa

4-Mchikichini

5-Vingunguti

KINONDONI

1-Magomeni

2-Mikocheni

3-Mwananyamala

4-Mzimuni

5-Ndugumbi

TEMEKE

1-Azimio

2-Keko

3-Kurasini

4-Miburani

5-Mtoni

A. CEILING

1. Does the house have a ceiling? [ ]

Do not ask this question, inspect and record.

1=Yes

2=No

2. What type of ceiling is found in the house? [ ]

Do not ask this question, inspect the house and record.

1=Palm woven ceiling

2=Ceiling board

3=TNG Board

4=Gypsum.

5= Other, specify ______________________________

3. Primary reason for using this kind of ceiling (*Arrange them in order starting with the most important reason first. List other reasons mentioned).*

1(Most important reason) **3(Third most important reason)**

2(Second most important reason) **4(Fourth most important reason)**

[ ] Didn't install/ Not my choice

[ ] It's affordable

[ ] It's durable

[ ] Prevents mosquito entry

[ ] Its fashionable/Stylish, makes the house look good.

[ ] It keeps the house cool

[ ] It protects one from contracting malaria

[ ] Don’t know

Other specify ______________________________

4. If no ceiling, why not [ ]

1=It’s too expensive

2=Rented house

3=Don’t like it

4=Other, specify_________________________________

99=Don’t know

5. How much have you spent on installation of the ceiling? (Shillings Tanzania)

____

99=Don’t know

6. How much do you expect to pay if you were to install a ceiling? (Shillings Tanzania) ____

99=Don’t Know

C: WINDOW SCREENS

7. Does the house have a window screens? [ ]

Do not ask this question, inspect and record.

1=Yes

2=No

8. What type of window screens are found in the house? [ ]

Do not ask this question, inspect the house and record.

1=Wire mesh

2=Synthetic

3=Gauze

4=Other, specify_______________________________

9. Primary reason for having this type of window screen? (*Arrange them in order starting with the most important reason first. List other reasons mentioned).*

1(Most important reason)	**3(Third most important reason)**
2(Second most important reason)	**4(Fourth most important reason)**

[ ] Didn't install/ Not my choice

[ ] It's affordable

[ ] It's durable

[ ] Prevents mosquito entry

[ ] It's fashionable/Stylish, makes the house look good

[ ] It keeps the house cool

[ ] It protects one from contracting malaria

[ ] Don't know

Other specify ______________________________

10. If the no window screens, why not [ ]

1= It's too expensive

2= Rented house

3= Don't like it

4= Other, specify______________________________

99= Don't know

11. 5. How much have you spent on installation of the window screens? (Shillings Tanzania) ______________________________

99=Don't know

12. How much do you expect to pay if you were to install a window screens? (Shillings Tanzania) ______________________________

99=Don't Know

D: EAVES

13. Is there an opening between the wall and the roof? [ ]

Do not ask this question, inspect the house and record.

1= Yes

2= No

APPENDIX II: Swahili version of the household survey questionnaire.

Manispaa: [ ], Kata: [ ], Mtaa: [ ], Na. ya shina: [ ], Na. ya nyuma [ ]

Mdodosaji: ____: Tarehe[/ /]

B. Utambulisho

Tumia alama zifuatazo: I=Ilala, T=Temeke, K=Kinondoni

Tumia alama zifuatazo:

ILALA

1-Buguruni

2-Ilala

3-Kipawa

4-Mchikichini

5-Vingunguti

KINONDONI

1-Magomeni

2-Mikocheni

3-Mwananyamala

4-Mzimuni

5-Ndugumbi

TEMEKE

1-Azimio

2-Keko

3-Kurasini

4-Miburani

5-Mtoni

C. MASWALI KUHUSU DARI

1. Je nyumba hii ina dari? [ ]

Usiulize swali hili;chunguza na andika unachokiona

1=Ndio

2=Hapana

2. Je nyumba hii ina dari la aina gani? [ ]

Usiulize swali hili;chunguza na andika unachokiona

1=Dari la mkeka

2=Ceiling board

3=TNG Board

4=Gypsum.

5=Aina nyigine fafanua: ______________________________

99=Sijui

3. Taja sababu za kutumia dari la aina hii:*(Zipange kwa Umuhimu kwa kuanzia na sababu Kuu zaidi kwa kujaza namba 1 hadi 4. Sababu ambayo haikujazwa hapo chini ijaze kama sababu nyingine.)*

1(sababu kuu)	**3(Sababu kuu ya tatu)**
2(sababu kuu ya pili)	**4(sababu kuu ya nne)**

[ ]Nimelikuta/ Si chaguo langu

[ ]Ni rahisi kununua/liko ndani ya uwezo wangu

[ ]Ni imara

[ ]Inazuia mbu kuingia

[ ]Inapendeza/ ya kisasa

[ ]Inafanya nyumba kuwa na ubaridi/inafanya nyumba kutokuwa na joto

[ ]Inakinga kupata malaria

[ ]Sijui

Vinginevyo. fafanua______________________________

4. Kama hakuna dari, nini sababu? [ ]

1=Ni gh'ali

2=Ni nyumba ya kupanga

3=Sipendi

4=Vinginevyo. Fafanua: ______________________________________

99=Sijui

5. Umetumia kiasi gani cha fedha kuweka dari ? (Shilingi za Tanzania)___________________________________

99=Sijui

6. Unategemea kutumia kiasi kipi cha fedha kuweka dari (Shilingi za Tanzania)

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99=Sijui

C: MASWALI KUHUSU WAVU

7. Je nyumba hii ina nyavu? [ ]

1= Ndio

2=Hapana

8. Je ni aina gani za nyavu zilizoko kwenye madirisha na sehemu nyingine za wazi? [ ]

Usiulize swali hili;chunguza na andika unachokiona

1=Wire meshi

2=Plastiki

3=Gauze/kama chandararua

4=Aina nyigine fafanua: ______________________________

99=Sijui

9. Sababu kuu ya kutumia nyavu za aina hii .(*Yapange kwa Umuhimu kwa kuanzia na sababu Kuu zaidi kwa kujaza namba 1 hadi 4. Sababu ambayo haikujazwa hapo chini ijaze kama sababu nyingine.)*

1(sababu kuu)	**3(Sababu kuu ya tatu)**
2(sababu kuu ya pili)	**4(sababu kuu ya nne)**

[ ]Nimeikuta/ Si chaguo langu

[ ]Ni rahisi kununua/ iko ndani ya uwezo wangu

[ ]Ni imara

[ ]Huzuilia mbu kuingia ndani

[ ]Iko kwenye wakati wa sasa/ ya kisasa

[ ]Inafanya nyumba kuwa na ubaridi /huifanya nyumba kutokuwa na joto

[ ]Inakinga kupata malaria

[ ]Sijui

Vinginevyo. Fafanua_________________________

10. Kama hakuna nyavu nini sababu?

[ ]

1=Ni gh'ali sana

2=Ni nyumba ya kupanga

3=Sipendi

4=Vinginevyo. Fafanua__________________________

99=Sijui

11. *Umetumia* kiasi gani cha fedha kuweka nyavu? (Shilingi za Tanzania)____

99= Sijui

12. Unategemea kutumia kiasi gani cha fedha kuweka nyavu? (Shilingi za Tanzania)____

99=Sijui

D: MASWALI KUHUSU NAFASI ILIYOKO KATI YA KUTA NA PAA

13. Ipo nafasi kati ya paa na kuta? [ ]

Usiulize swali hili;chunguza na andika unachokiona

1=Ndio

2=Hapana