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Optimizing Mosquito Screening Systems for Malaria Control in Tropical Environments

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Abstract – The culture of housing in tropical African regions requires that windows are created and operated for natural ventilation and aeration of internal room spaces. However, the threats posed by malaria carrying vectors makes natural ventilation more risky that comforting. As a result of this, windows are designed to integrate both the functions of passive (natural) ventilation and mosquito repelling, through the adoption of mosquito screening systems (referred to as MSS for the purpose of this study). A review of conventional mosquito screening systems (MSS) was conducted within Nigerian cities, and this enabled the identification of the most commonly adopted designs. The operational mode of the identified systems indicated the existence of a break referred to as interludes, between the opening of netted screens and operation of the window panes. This minute interlude periods (when the window opening is totally exposed to the open environment) is responsible for the admission of malaria carrying mosquitos into the indoor living spaces. This study presents an optimized mosquito screening system which provides homes with constant aeration periods and zero contact with malaria vectors. A comparative review of the screening systems indicated a total mosquito blockage by the optimized MSS compared to the conventional MSS.

Keywords – Mosquito Screening System, Malaria Control, Mosquito Control, Window Design.

I. INTRODUCTION

Significant global data identified that annually, an estimated 1.21 million people die of severe malaria [1]. Mosquitoes are the primary vectors of parasitic protozoa (plasmodia) and filarial worms [2]. Amongst the diseases transmitted by mosquitoes, the deadliest in the Sub-Saharan region of Africa is 'Malaria'. According to reports from WHO, malaria is notable for about 31% of global deaths. In 2021 alone, it reported about 80% of these deaths in children under the age of 5 years as well as about 40% fatality in the WHO African Region [3]. The risk of malaria deaths is relative to age as well as severity of originating conditions. Amongst adults, studies show that mortality stands at about 36.5% among the patients aged above 50 years [4]. The WHO identifies Africa as the continent with the most recorded cases of malaria globally [5]. Conversely, WHO reports on Nigeria, identified Malaria as the major public health concern. Nigeria recorded an estimated 68 million cases and about 194,000 fatalities due to the disease in the year 2021. Current data likewise identified Nigeria as the nation with the highest malaria burden globally, as the recorded cases in 2022 accounted for approximately 27% of the global malaria burden and 28% in the WHO African Region [6] (fig 1 shows malaria incidence report and prevalence).

Owing to this menace, the Nigerian government initiated a mass campaign against malaria in 2010. The campaign focused on measures towards averting the malaria menace in the country. To achieve the results of the campaign, the Government of Nigeria under the guidance of the coordinating body (the National Malaria Elimination Programme NMEP), took considerable steps in scaling up preventive and curative interventions. Amongst the most notable measures includes the introduction of insecticide treated nets (ITNs), whereby about 220 million ITNs were distributed across the 37 States of the country. Despite the significant drop in fatalities over the years, malaria cases and deaths in significant numbers continued to rise since 2016 to date. Study attributes this rise to a probable combination of reduced intervention coverage, the unexpected rise and spread of insecticide resistant variants which resulted in reducing the effectiveness of ITNs as well as the relatively high population growth.

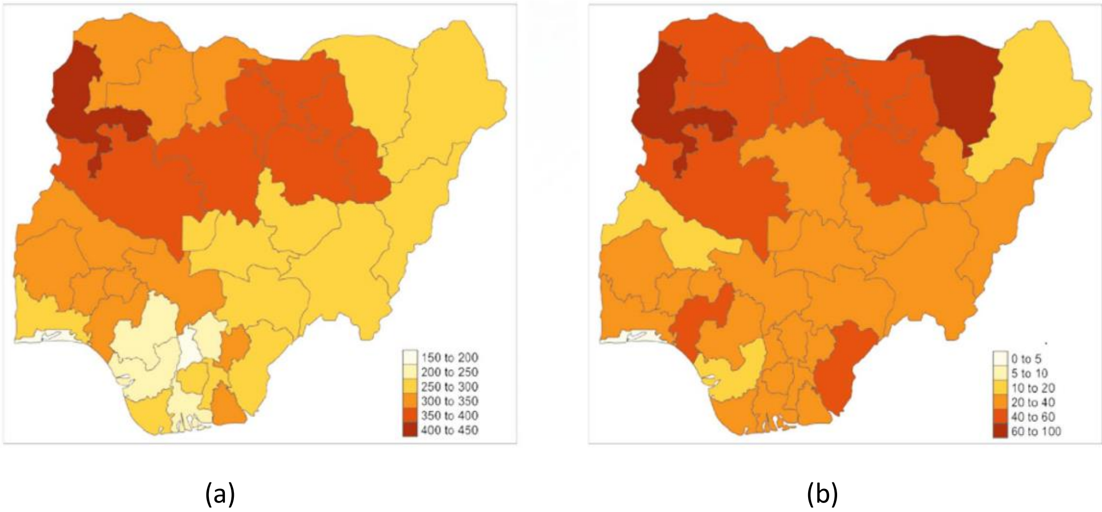


Fig. 1. (a) Estimated malaria incidence per 1000 population in 2021, (b) Malaria prevalence in children under the ages of 5 [6].

II. BACKGROUND OF STUDY

Mosquito behaviours within the human occupied environments can be classified into indoor and outdoor exposure. While the class of mosquitoes that transmit malaria fall into the category that feed indoors, such as the An. gambiae (sensu stricto), the Asian vector commonly known as An. stephensi sensu stricto and the An. funestus sensu stricto, the other class such as the An. arabiensis feed both indoors and outdoors [7]. Understanding the behaviours of mosquitos is significant in the fight against the malaria burden, this facilitates minimizing the risk of exposure to humans in known endemic areas [8]. Study identified that Mosquitos are known to be mostly active towards the evening and night times than during the daytimes [9]. Common practices observed in African homes suggest that windows are mostly shut once evening time approaches (as mosquitos are fond of roaming after sunset). This practice often observed as preventive measures against mosquitos admittance however prove to be detrimental to indoor air quality conditions, as a result, most homes are shut off from natural ventilation from 6:00PM to 6:00AM as illustrated in Fig. 2.

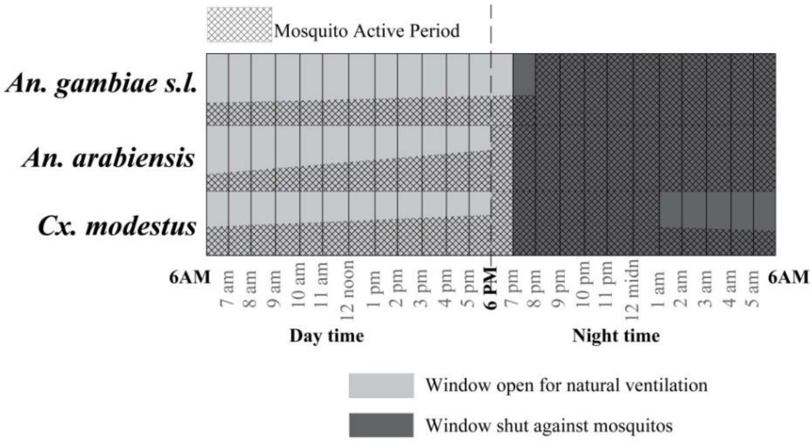


Fig. 2. Daily activity of dominant mosquito species against window opening periods in most Nigerian homes

In recent times, the most commonly used malaria prevention techniques comprise of the Indoor Residual Sprays (IRS) and the Insecticide Treated Netting (ITNs) [10,11]. Records from the year 2010 indicated that communities protected by the use of IRS in malaria-endemic countries declined from 3.2% to 2.6%, which was observed by the World Health Organization in its 2021 report as representing a change in prevention strategies [12]. This realization is consequent to the fact that these prevention methods only target mosquitos which have gained access to the home, thus the challenge still lies in identifying measures for keeping mosquitos away from homes. This challenge is critical owing to the massive need for natural ventilation through windows and openings in most homes in sub-Saharan Africa. This is the case as windows are the most common means of introducing wind driven ventilation into these homes for the purposes of cooling and aeration. Studies suggest growing concern over the prevalence of insecticide resistance by mosquitoes could lead to increase in cases of malaria and subsequent rise in fatalities in endemic communities such as sub-Saharan Africa. Owing to these, there is the need for increase in research to identify effective and more environmentally friendly measures that may not be dependent on IRS [13,14]. Study shows that the practice of effecting improvements in housing designs towards combating mosquito influx has resulted in significant reductions of the malaria burden. Likewise, reviews of housing stocks identified that the potential for further reducing transmission through housing improvements such as the application of mosquito screening doors and windows has added significantly in reduction of endemic malaria [15]. The impact of these studies is seen in the WHO's recommendation of the use of untreated screening of windows and ventilation openings in homes [16,17]. Since the adoption of improved housing components that interfaces with the external environment has been identified as a key contributor to improving public health against malaria, this principle ought to be given central consideration in malaria control. Studies have established that most mosquito bites occur indoors, most often at evening and night times in countries of Sub-Saharan Africa location; this then highlights the necessity for ensuring mosquito-proof homes as means of protection against vectors [17, 18].

III. STUDY METHODOLOGY

Despite the high rate of malaria transmission in sub-Saharan Africa, with up to 80–100% of which occurs indoors, only a handful of experimental studies have investigated the impacts of house design on mosquito entry into homes, with even fewer studies considering how the design of houses in sub-Saharan Africa affects indoor climate [17, 19]. This study intends to identify the most common mosquito screening design options adopted in the study area (Nigeria). It goes further to analyse their effectiveness in performing the dual tasks of mosquito screening and indoor ventilation. Through the analyses, optimization design option is presented which aims to provide houses in this region with constant aeration via open windows while simultaneously accomplishing the task of mosquito screening. The study adopts a descriptive analysis method through the physical observation and analysis of existing MSS.

- The methodology adopted includes:
- Identification of conventional mosquito screening systems (MSS) in the study area.
- Classification of identified MSS as operable (movable) models for mosquito blockage.
- Observation of screening techniques and analysis of identified operable models.
- Review of observed conventional operable screening system and comparative studies against an optimized static (non-operable) system of screening.

IV. STUDY AREA

This study focused on identifying the various conventional window designs and their characteristics with regards to the adoption of mosquito screening systems within the tropical Nigerian environment. The choice of the Nigerian environment is significant due to its high malaria burden attributed to the high mosquito presence as well as its significant climatic properties that justifies the necessities for mosquito screening in homes. Naturally, the tropical zones of the world are referred to as climatically overheated regions. These regions are characterized by high temperatures and humidity [20]. In the case of Nigerian which is located on 10° N and 8° E, it is classified as hot-humid climate. The hot-humid climate of Nigeria similar to those of other sub-Saharan West African countries is controlled by two main factors which includes the daily heating/cooling of the land mass of the Sahara Desert and the heating/cooling of the large body of water in the Atlantic Ocean. This phenomenon creates two distinctive seasons in the regions which are classified as dry and wet seasons. While the dry season often lasts for a period of 5 months (November to March), the rainy or wet season lasts up to 7 months (from April to October) [21]. Usually, the peak malaria season in Nigeria takes place during the wet/rainy season when mosquitoes breed and thrive owing to the humid and wet environments. Fig. 3,4,5, shows the significant relationships between mosquito breeding and the climate of Nigeria. Studies by Okorie et al., suggests that quantity of mosquitoes decreased as rainfall increased (Fig. 3), while the reverse was seen in the case of temperature and relative humidity whereby quantity decreased as temperature decreased (Fig. 4 and 5) [22].

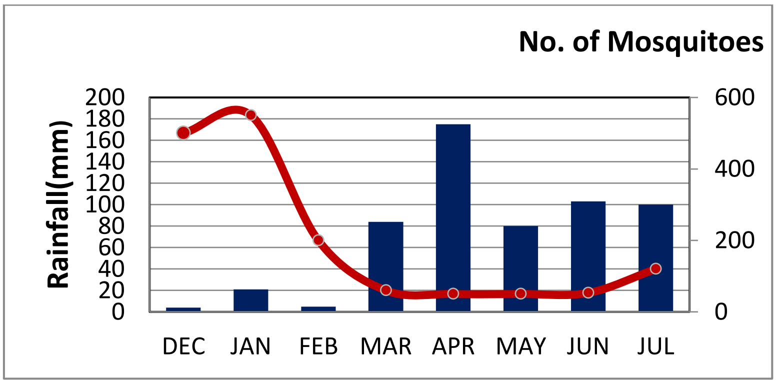


Fig. 3. Relationship between rainfall and mosquito swarm

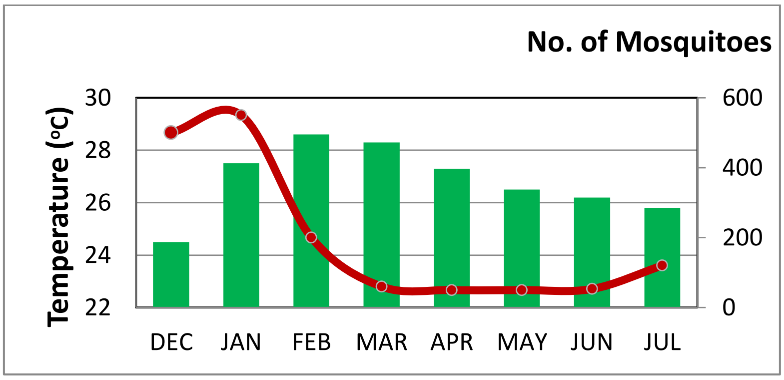


Fig. 4. Relationship between temperature and mosquito swarm

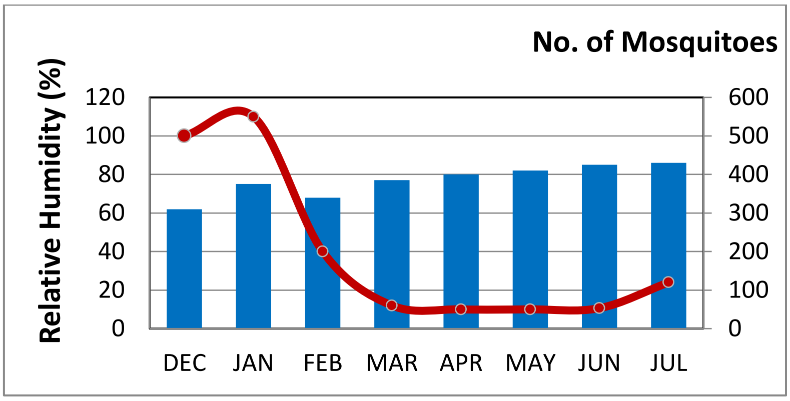
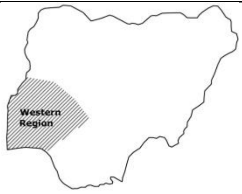
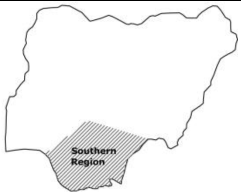


Fig. 5 Relationship between relative humidity and mosquito swarm

V. CLASSIFICATION OF WINDOWS AND MSS IN THE STUDY AREA.

A review of the basic window types adopted in buildings in the study area identified four major classifications which includes; Casement windows (swinging type), Sliding Windows, Louvre Windows and Projected windows [23]. To justify this classification, a survey of the most commonly adopted window types in the study area was conducted by visiting the major window manufacturers in each of the three major regions in order to ascertain the realities of window design and application in the study area. Table 1, shows the distribution of the visited window manufacturers across Nigeria.

Table 1. Distribution of window manufacturers across Nigeria and the classification of major window types

Distribution of major window manufacturers in Nigeria according to regions			
Region	**Manufacturers**	**Location**	**Coverage map**
Northern Nigeria	Abuja Glazing company	Abuja	
	Abumet Nig. ltd	Abuja	
	EBM Systems	Abuja	
	Obyeron & co ltd	Jos	
	China Kanod Windows And Doors Co., Ltd.	Kano	
Western Nigeria	OMNIA Nig. ltd	Lagos	
	Loni windows	Lagos	
	EBM Systems	Lagos	
	Critall Hope Nig. ltd	Lagos	
	Adetech Aluminium	Ibadan	
Southern Nigeria	Golden Keny windows/doors	Onitsha	
	AMCO ltd	Enugu	
	Orion Aluminium co.	Enugu	
	Dave Aluminium co.	Asaba	
	DESTEC Engineering	Abakaliki	

Classification of Major Window Types in Nigeria			
TYPE-A Casement	**TYPE-B Sliding**	**TYPE-C Louvre**	**TYPE-D Projected**
			

VI. DESCRIPTION OF CONVENTIONAL MOSQUITO SCREENING SYSTEM

The visit to manufacturers' sites and review of each typical window type identified the integration of mosquito netted screens embedded within the window panes. These mosquito screening systems (MSS) often made of the same material with the window frames filled with a mesh/net fabric is intended to keep off mosquitos and other vectors from gaining access to the interior spaces in homes. However, it is evident that manufacturers or installers of the conventional MSS often disregard the probability of influx of mosquitos and other insects resulting from the interlude between the operating times of the window and screening panels. Observation of the conventional window with MSS identified a composite unit with two or more layers of openings which harbour tendencies of exposure to the outdoors. The two main layers consist of the main window component and the netted screen (mosquito screening system) which are combined together to form a single unitized system as seen in fig. 6. Also observed were different operating features for each of the conventional window systems identified. An analysis of the different MSS suitable for each window type is shown in Table 2.

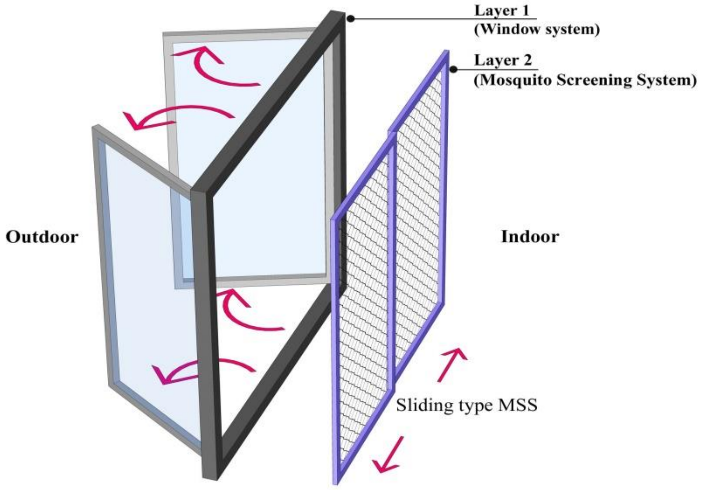
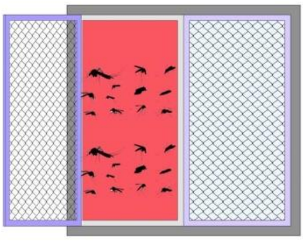
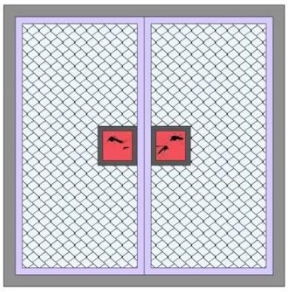
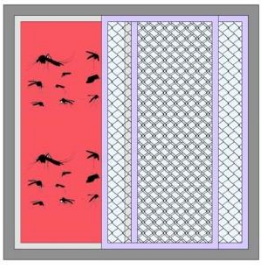
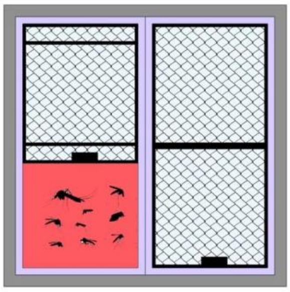


Fig. 6. Illustration of a two layered Mosquito Screening System (MSS), using a slide opening mode. The two layers (window system & MSS) are merged to form a unitized window system

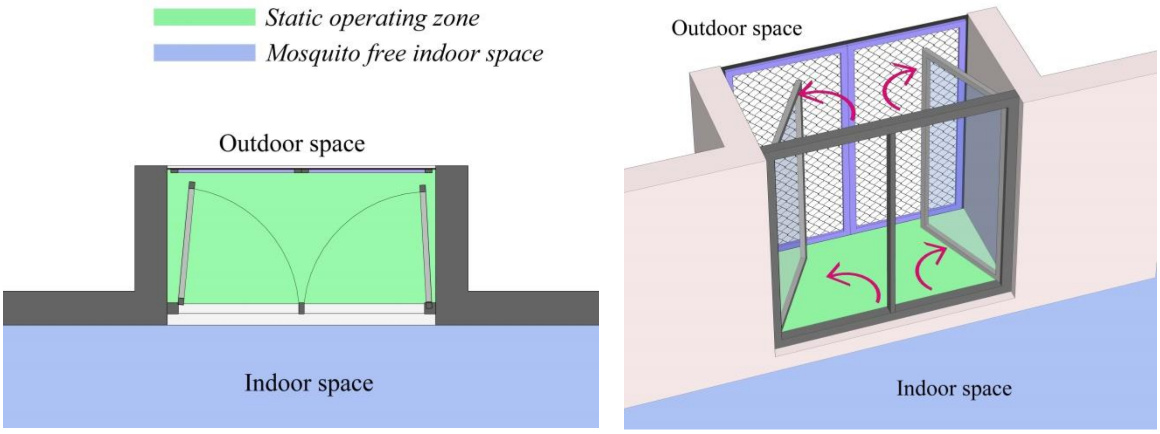
Table 2. Analysis of window types and MSS in the study region

Types of conventional MSS in study area	**No. of operating layers**	**Estimated interlude between operating layers**	**Average size of exposed window opening**	**Probability of Mosquito influx during operating interlude**
TYPE 1 Swing system 	2	11 Seconds	50% 	High
TYPE 2 Slit system 	2	8 Seconds	<10% 	Very Low
TYPE 3 Sliding system 	2	12 Seconds	<50% 	High
TYPE 4 Lift system 	2	8 Seconds	<25% 	Low

From the analysis of the MSS types, it is observed that in the course of operating the netted and main window panels of conventional screening systems, the interlude period provides sufficient time frame often within a range of about 10 seconds, which is time enough for the influx of vectors. This typical lag observed in the operating time is suggested as a flaw in the design of MSS when considered as solution for repelling mosquitoes from homes. The need to optimize the MSS design with the goal of minimizing the lag in the operating time is essential in achieving a mosquito free indoor environment. The author thus presents the design of an optimized screening system which targets eliminating the flaws in operating time.

VII. DESCRIPTION OF THE OPTIMIZED (BOX TYPE) MOSQUITO SCREENING SYSTEM

Study suggests that in order to get a good air exchange in building interior spaces, windows should be opened for a period of five to ten minutes in every three hours of the day [24]. Having explored each of the available MSS in the study area, the author presents the design of a static MSS, which exhibits a lesser probability for the influx of mosquitos than the conventional types when opening the windows as required. This is significant as most homes in the tropical Nigerian environment depend principally on opened windows for natural cooling and ventilation; hence the need of operating window systems without upsetting the MSS. Similar to the conventional MSS, the design of the Box type MSS is composed of a double layered system, which can be combined with a normal casement, louvered, sliding or projected window as shown in fig. 7. However, with the intention of achieving a 100% wind flow rate through the windows (for effective natural ventilation purposes), the option of the casement type (swinging) window is recommended in the design of the Box type MSS as indicated in fig. 7(a).



(a) Plan view (b) Isometric view

Fig. 7. Design of the Static (Box type) Mosquito screening system proposed by the author

VIII. COMPARATIVE STUDY OF THE OPTIMIZED STATIC AND CONVENTIONAL MSS

From the study of the mosquito screening systems presented in this paper, the significant qualities of the optimized (Box type) static MSS that carries the potential for improving mosquito repellence can be identified. These significant properties are presented in Table 3, following a comparative study of the MSS identified in this study. Conversely, it is believed that the operable (conventional) mosquito screening systems all possess certain levels of window aperture-exposure to the outdoor environment that ranges from 8 to 12 seconds, which increases the probability of mosquito influx through the windows. On the other hand, the optimized static (Box type) MSS lacks aperture-exposure which guarantees zero mosquito influx through the windows. This justifies the conclusion that the static (box system) MSS is more effective in mosquito screening than the conventional types.

Table 3. Comparative study of the mosquito screening systems as solution for reducing mosquito/malaria exposure

	Type of MSS	Adaptable Window Type	Operating Efficiency	Estimated exposure time during operation	Size of exposure aperture	Mosquito screening potential
1	Swing system	All window types	Moderate	11 seconds	50% of window opening	Moderate
2	Slit system	- Louvre window - Casement window	Good	8 seconds	<10% of window opening	Fairly effective
3	Sliding system	All window types	Moderate	12 seconds	<50% of window opening	Moderate
4	Lift system	All window types	Good	8 seconds	<25% of window opening	Fairly effective
5	Box (static) system	All window types	Best (zero operation required)	0 seconds	0% of window opening	Effective

IX. CONCLUSION

The application of improved housing features like doors and windows, which interfaces with the external environment, has been identified as a key contributor to improving public health against malaria. This condition should be considered immensely in malaria control. Through the study of the various window types and mosquito screening systems presented in this paper, the significant properties of the static (Box type) MSS are identified. These properties include the potential for improving mosquito blockage by eliminating the exposure of the indoor spaces to mosquitos through windows, hence achieving malaria reduction. The design of this optimized MSS is recommended for adoption in residential house designs where the prevalence of mosquito bites is more prominent. Finally, with the application of affordable materials in its construction, the Box type MSS could be seen as an effective option for malaria control in tropical location like Nigeria where the malaria burden is a public health threat.

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