MC 2020 Proceedings of 10th Masters Conference: **People and Buildings**
Online, 18th December 2020
Network for Comfort and Energy Use in Buildings: http://www.nceub.org.uk

Assessing Sub-Saharan African Dwellings for Resilience against mosquitoes: Developing and Testing the tool

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Abstract: Since over 80% of mosquito bites take place indoors, more needs to be done to protect people from mosquitoes within their homes. In this paper, we review the existing literature on key findings which relate the homes and the built environment to mosquitoes. Following this, we create and test a tool by which attributes of homes and their surroundings can be assessed for likelihood of mosquito ingress and occupant's contracting mosquito-transmitted illnesses. Through the answers to a series of carefully collated questions, the tool highlights the areas that require attention within a home to make it more reliant from mosquitoes. This research found that: (i) The quality of innovation in the design of mosquitoes resilient homes and the environment is negatively affected by the limited number of field studies in this area (ii) Mosquito resilience should be prioritised along with affordability and sustainability in new and existing homes in SSA.

Keywords: Sub-Sharan Africa (SSA), Mosquito-transmitted illnesses, Build environment and Homes.

1. Introduction

There is a great emphasis being placed on "building out Malaria" in Sub-Saharan Africa (SSA). However, malaria and other mosquito-borne diseases threaten the health of everyone in our increasingly globalised and interconnected world. So why is Africa the focus? Eighty per cent of global malaria deaths occur in just 17 countries, mostly in Africa (UN, 2015). From 2017 to 2050, the global population is set to increase by over 2.2 billion and more than half of that growth is attributed to Africa alone (United Nations, 2019). The issues arising from these affect urban areas and rural areas, albeit in slightly different ways and measures.

The growing rate of urbanisation in SSA has resulted in rapid rural-urban migration. Consequently, an increase in a poorly built housing stock. The housing and social services arm of many governments is struggling to cater for the migrants in cities. This lack of adequate administration and logistics has led to an increase in informal settlements and unhealthy living conditions in selected cities (UN-Habitat, 2003)(UN-Habitat & WHO, 2016). Examples of these areas are seen in some of the most populous cities in Africa, such as Lagos in Nigeria and Cairo in Egypt (Njoku & Okoro, 2014).

Mosquito-borne disease transmission happens mostly during night-time sleeping (Sherrard-Smith, et al., 2019). Therefore, the condition of the homes and environment in which people reside must be targeted if mosquito-borne transmission is to be reduced. When the statistics of fatalities due to death caused by mosquito-transmitted illness is analysed, it is clear to see that this is truly an issue of life and death. In order to gain traction and gain ground on the issues that have been highlighted, there must be a targeted-approach to reduced mosquito-ingress and mosquito survival in and around homes and environments that people reside in by improving the design of new homes, as well as the condition of the existing.

Even with all the best of intentions and thorough scientific research, the use of any proposed intervention hinges upon the acceptability and suitability to the people and environment for which it has been created. This research aimed to create a mosquito-resilience assessment tool for homes and their environment, which can be used by architects and designers to assess their proposed designs, by researchers to evaluate their fields of studies or by s residents to assess their dwellings.

2. Literature review

Second to human beings, mosquitoes are the world's deadliest animals. They account for about one million deaths annually, and around 700 million others are debilitated by the diseases that they cause (Monash University, 2020). Malaria, which is a parasitic infection transmitted by the *Anopheline* mosquitoes is the most prevalent of all the diseases. Approximately 228 million people are affected by malaria every year and it claims about 400,00 lives of which children under 5 years of age form the majority. Dengue fever, which is the most prevalent of viral infections, is caused by *Aedes* mosquitoes and poses a threat to over 3.9 billion people and 129 countries. Dengue is projected to affect 96 million people and accrue a death tool of 40, 000 people, annually. Other mosquitoes-borne diseases include Zika, Yellow fever and Chikungunya, amongst others.

Although decades of studies have been conducted on mosquito behaviour and anatomy, humanity remains on the defensive in the war against these deadly animals. The species of mosquitoes are vast and varied and due to the nuances that exist in their behaviour, the challenge to design interventions that wholly prevent mosquito-transmitted diseases, especially where multiple species exist in the same geographical location, cannot be overstated. Multiple interventions must be used simultaneously to prevent transmission. Mosquitoes are intelligent and adapt their feeding patterns to human behaviour (Chaki, 2014). Malaria prevalence has decreased over the years as a result of great strides being made in the efforts to control it. However, because of the mosquito's ability to adapt, many species have developed insecticide resilience. This could be highly problematic as the reliance on Long-Lasting Insecticide-Treated Nets (LLIN) is increasing even though their efficacy is being threatened. Other insecticide-based interventions, such as Treated building materials and Indoor Residual Spray (IRS) are at risk of being undermined. This is indicative of the need to increase research and information gathering surrounding mosquito-control measures that cannot be countered by their adaptability or further evolution. In response to this, the Global Plan for Insecticide Resistance Management in Malaria Vectors (GPIRM) (WHO & RBM, 2012) admits a focus on non-insecticide-based vector-control is crucial in the long-term.

3. Methodology

3.1. Specific literature Review

Following the initial literature review which demonstrated that the design of homes was critical in the fight again mosquito-borne diseases, the next step was to find out if there was information from research and field studies which were specific to the features of dwellings that work to reduce mosquito-borne illnesses. Over 90 research papers were reviews in the quest to understand the relationship between the homes and mosquito-borne diseases and transmission. From these research papers and other sources, it was then decided that the assessment tool will focus on the following:

Gaps in the building envelope: The greater the number of openings in any home, the more avenues created for mosquito-ingress. Field studies showed that closing the gaps in the sample building envelopes accounted for reductions in mosquito entry -96% (Lindsay, et al.,

2020) and human biting rate -52% (Wanzirah, et al., 2015). Closing the gaps has ranged from simply installing screenings over gaps to totally filling in open eaves to installing better-fitted doors and windows. However, it is seen in some studies that the negative effects of closing gaps could be offset by screening instead of fully closing doors, windows or eaves; allowing for the house cooler at night.

Elevation: Outside of culicine mosquitoes, 80% of all other flying mosquitoes are said to be found below the 1m height (Snow, 1979). Using this knowledge about mosquito behaviour, various methods have been employed to prevent ingress. An example of this is circular mosquito fences around people or inhabited houses to guide the mosquitoes upward and therefore act as deterrent past the height at which they would typically fly (Gilles & Wilkes, 1978). In a separate experiment, it was noted an increase in wall high deterred mosquitoes from entering the houses (Snow, 1979). The principal malaria mosquitoes in SSA prefer to feed closer to the ground. Therefore, lifting the house off the ground either on stilts or simply placing the bedroom on the higher floor(s) could contribute to a reduction in mosquito ingress (Charlwood, et al., 1984). This has been tested and tried in Asia (Knudsen, et al., 2014).

Insecticide Treatments: The popularity of LLIN and other insecticide treatment has been proven over the decades. Although insecticide resistance is gaining ground, this is still an effective tool and its continued use is recommended. It is understood that this assessment area does not have any direct relationship to how the home has been constructed.

Ventilation (and screening): Trying to mitigate the effects of hot weather is an inescapable consideration when constructing homes in tropic and sub-tropical housing (Knudsen, et al., 2014) and therefore, ventilation must be an assessment area. Cross ventilation is vital in getting good airflow through the house and sizeable windows on opposite sides of the room facilitate this.

Environmental Factors and Infrastructure: This category covers the WASH services, climate and building positioning. Without water, there can be no mosquitoes (Blosser & Burkett-Cadena, 2017). Having functioning drainage and sewage systems reduces the risk of mosquitoes breeding because it creates a less habitable environment for them. Eradicating water scarcity will deter people from storing water in small storage containers for domestic purposes. The poor maintenance of such water systems create a habitat for mosquitoes. If they are cleaned out regularly, the risk of mosquito inhabiting such places is reduced.

Building Material and Design: Materials used to construct the walls of the house are a strong determinant of the indoor temperature and hereby, indoor thermal comfort. Materials such as cement and mud absorb heat from the sunlight during the day and release the absorbed heat during the night. Consequently, this increases the likelihood of occupants disregarding the interventions put in place to sleep comfortably. Although metal roofs are becoming more popular, a study has shown that closing the eaves (of houses with metal roofs) can result in more mosquitoes, warmer indoor temperature and greater concentrations of carbon dioxide than houses with thatched roofs (Lindsay, et al., 2020). When houses are too hot, occupants try different adjustments to make themselves more comfortable. Examples include removing LLINs, opening the windows and corresponding screening and sleeping outdoors (Ahorlu, et al., 2019).

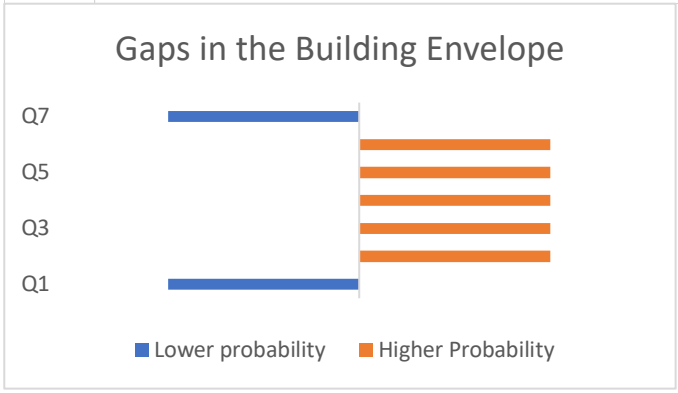
Carbon dioxide: It was noted that higher levels of carbon dioxide (25% more) were reached in houses with metal roofs than those with thatched roofs. The number of people within the home or room increases the amount of $CO2$ if there is insufficient ventilation. The number of people in a room increases the temperature in that room; coupling this with the heat caused by metal roofs as well as high thermal mass building material, the occupants will

begin to sweat during the night. Sweat contains human odour and this increases the chance of mosquitoes detecting the host (Gilles, 1980). The fact that levels of carbon dioxide can be attributed to the number of human beings exhaling in the dwellings, (Jatta, et al., 2018) means that overcrowding would be cause for mosquito density in that vicinity. The relationship between the presence of carbon dioxide and mosquitoes has been proven by numerous studies over recent years. However, there is very limited evidence from field test to validate these theories. As opposed to many other factors that vary for mosquito species, it has been proven that carbon dioxide attracts at least 90% of all mosquito types (Shenton, et al., 2019). The identification of carbon dioxide as a main attractant of mosquitoes requires it to be at the very forefront of any intervention proposal and design.

3.2. Tool development

Based on the findings for each of the above areas, questions were created to interrogate the dwellings (as seen in Figure 1.) As this tool had never been used, a benchmark was based on the results of homes that have been specifically designed to reduce mosquito ingress and mosquito-illness transmission. They were tested to verify the strength or weakness of the assessment tool. Additionally, the deviation from the benchmark scores (either negative or positive) was an initial indication of the condition of the house, with regards to the risk of mosquito ingress. The results of other houses not necessarily designed for mosquito control were measured and compared against this criterion.

	Gaps in Building Envelope	Lower probability	Higher Probability
Q1	Are the doors poorly fitted?	No	Yes
Q2	Are there any holes or openings on the doors greter than 1.5mm?	No	Yes
Q3	Are there more than two doors purposed for passage to and from external areas?	No	Yes
Q4	Are the doors fitted with spring hinges?	Yes	No
Q5	Are the eaves open or closed? (if any)	Closed	Open
Q6	Where do the eaves lead? (if opened)	Ceiling Void	Living space
	Are any openings made for the passage of mechanical and electrical services filled?	Yes	No



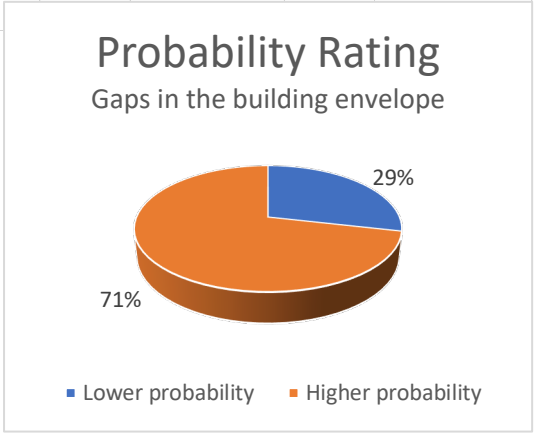


Figure 1. Extract of results from assessment carried out on a dwelling (The Magoda Project)

4. Discussion

The assessment was applied to homes in Ghana, Nigeria and Tanzania. All homes assessed were at various stages of design and construction. The results of the assessment proved successful in identifying which of the areas where effective and which needed improvements.

The questions asked under each assessment area diversified the analysis and allowed for both wider and specific thinking as opposed to a reinforce that one-size-does -not-fit- all. For example, the results of the assessment on the selected houses showed that houses could have the same amount of probability of mosquito ingress but differ on which intervention is required

The methodology used in this paper could be with the introduction of "Severity" for each question. For simplicity, the answers were binary with mostly "yes" or "no" responses available to the assessor to determine the probability of ingress. For example, accounting for the facts that 9 doors give a higher probability of ingress than 6 doors should be reflected in the results. However, the difficulty in accounting for this is the lack of precise information. This tool is elementary in its approach and analysis and all improvements to it will be borne out of further research.

Beyond insecticides, eaves and all the other areas mentioned, there are more depths of research to be sought, especially in the relevant countries. As more evidence is acquired, more relevant questions will come to light. To further the work reported in this paper, more specific details need to be added, and speculations need to be clarified. Consequently, this assessment tool can be scaled up and used in the field by any assessor to gauge how resilient a home is against mosquitoes and what interventions should be prioritised.

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