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Investigation of thermal comfort and Mosquito resilience in new dwellings of urban Accra that adapt natural ventilation.

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Abstract: The world stands the peril of self-inflicted global climate change from the rising emissions of greenhouse gases (GHGs). The Intergovernmental Panel on Climate Change (IPCC) predicts over 1.5°C temperature rise globally by the year 2025 if current greenhouse gas (GHGs) emissions from human activities are not reduced by about 60%. The impact of global warming is likely to increase the spread of vector-borne diseases such as malaria and dengue. This research project investigates the thermal comfort and mosquito activity in new dwellings in Accra. Three scenarios with varied occupancy density were established and assessed using criterion ranges for temperature, CO2 concentration and humidity. Thermal comfort and mosquito activities were assessed according to the criteria. IES-VE (Apache sim) simulation was used to determined conditions within the criteria ranges. The research found that naturally ventilated houses in urban Accra had better thermal comfort and reduced mosquito biting rates and flight indoors.

Keywords: Mosquito activity, Natural ventilation, Air temperature, CO2 concentration, Relative humidity.

1. Introduction

Globally humanity stands the danger of self-inflicted climate change from rising greenhouse gases (GHGs) emission, namely methane, carbon dioxide (CO2), chlorofluorocarbons etc. This arguably, is the greatest threat humanity seem to be facing at present. The Intergovernmental Panel on Climate Change (IPPC) stipulates a rise in global temperature of about 1.5°C by the year 2025 if emissions from human activities are not reduced by about 60%. The consequences of this global warming are dire, ranging from rising sea levels, changes in ocean current, desertification, melting of the polar ice and the widening of latitudes and altitudes which evidently may increase the spread of vector-borne disease such as malaria, yellow fever, dengue fever, Zika etc. (French, 1998; Salam *et al.*, 2018).

The WHO Africa Regional office in 2018 recorded 85% of the total cases of mosquito's vector-borne disease (i.e., malaria) and a staggering 94% related death globally in sub-Saharan Africa. Ghana recorded some 272,200 deaths in the year 2018 alone. (World Health Organization, 2018).

Accra, the capital city of Ghana, has seen a steep urbanizing youth and expanding middle class which may suggest opportunities in the housing sector (Centre for Affordable Housing in Africa, 2019), however, housing remains a challenge till date as the country's housing deficit stands at over 1.7 million. The housing typologies found in Accra pre-dates the 1950s when the country became a republic. However, new dwellings in the Ghanaian context refer to buildings constructed from the 1990s when development started at the urban periphery (Yeboah, 2003).

This research aims to investigate the thermal comfort and mosquito activity occurring in new dwellings in Accra, which are designed with natural ventilation and passive cooling strategies. The objectives of the study were to a) Establish critical criteria/ranges of indoor air temperatures, CO2 concentration and relative humidity to guide in assessing thermal comfort and mosquito activities in the dwellings. b) Explore the implication of indoor air temperature and relative humidity on mosquito optimum survival/mortality, mosquitos' activities (i.e., biting rate, flight) and occupancy comfort /occupancy discomfort c) Evaluate the impact of various indoor CO2 concentration ranges on mosquito activity intensity (i.e., to lure mosquitoes toward dwellings), indoor air quality classification and body odour intensity to determine occupancy comfort.

2. Mosquitoes

Mosquito's life cycle consists mainly of four principal life stages; egg stage, larva, pupa, and the mature stage (i.e., adult mosquitoes). All stages are temperature-dependent and vary for each stage. The egg stage, however, is also dependent on water bodies (aquatic).

A study in Asia (Shapiro, Whitehead and Thomas, 2017), showed that temperature highly affects mosquitoes biting rate, vector competence, daily mortality, and parasitic development. At lower temperatures, the biting rate is low but increases with increasing temperature to a threshold temperature of >28°C to <35°C at which point the rate of biting starts to plunge (Fig1a). The mortality rate of mosquitoes was lowest at 20°C to <25°C which was denoted as the optimum temperature for the survival of the insect although mortality increases at lower temperatures of <20°C and higher temperatures of >25°C (Fig 1b). This agrees with Ngarakana-Gwasira, Bhunu and Mashonjowa, (2014) study, which observed that mosquito mortality was high at <17°C and diminished to a base range at temperatures between 20 and 25°C. Vector competence is optimum at about 26°C and dips to a less potent parasitic capacity at 35°C (Fig 1c).

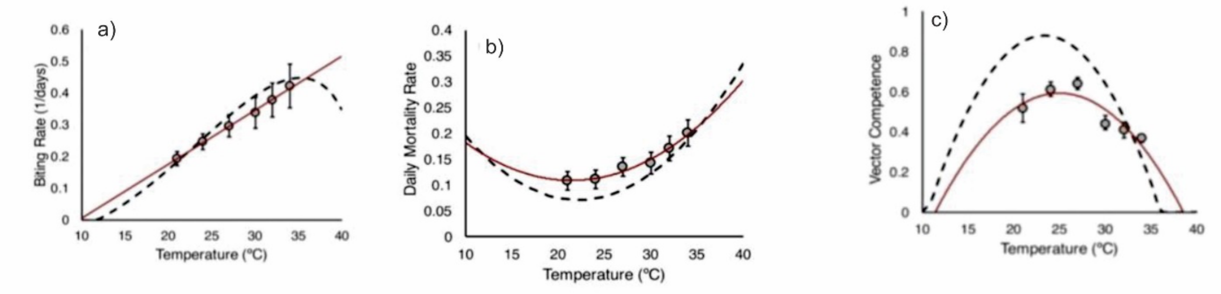

Figure 1. Comparing thermal performance of a) mosquito biting rate b) mortality rate of mosquito c) vectorial competence. *Source;*(Mordecai *et al.*, 2013; Shapiro, Whitehead and Thomas, 2017)

3. Method

This section seeks to explain the type of analysis that was followed to answer the research aim.

a. The case study analyzed was a 3-bedroom detached house from the Saglemi affordable housing project in Greater Accra. The total floor area of the dwelling is 95.3 m2, with an external opening area of 16.3m2. The dynamic of a typical Ghanaian family was tested. Two hypotheticals occupancy were investigated and categorized as; scenario A had a total of 5 persons with light physical activities while the second scenario B was an overcrowded household of 12 persons with high physical activity. The final scenario C had the same occupancy and activity intensity as scenario B but with interventions to the building fabric (i.e., heavyweight thermal mass envelope, night purge ventilation, external shading, and orientation)

b. An assessment criterion was developed which investigated occupancy thermal comfort and mosquitos' activities based on (e.g., temperature, indoor CO2 concentration and humidity ranges for occupancy comfort and mosquito activities indoors).
c. The IES-VE dynamic simulation (Apache Sim) was used to assess the three scenarios with macroflo link and SunCast link. The base case scenario building fabric had its wall made of Insulated Concrete Forms (ICF) of 280mm thickness, a lightweight thermal mass of 22 kJ/ (m2.K), U-value of 0.2W/m2 and 0.45 ACH envelope infiltration at a moderately tight building of 7m3/h/m2 at 50 Pa air permeability. The roof was a double roof with the first layer (i.e., concrete deck) of 150mm thickness, u-value of 3.3W/m2. K and a mediumweight thermal mass of 190 kJ/ (m2. K) while the outer layer of was metallic sheets with insulated stud purlins and rafter with a U-value of 0.6 W/m2. K and a thermal mass of 2 kJ/ (m2.K). The internal gains included equipment/appliance (power consumed/W full operation of 3907), lighting maximum sensible gain of 8W/m2 and radiation fraction of 0.45 in all rooms. Internal heat gains of occupants for heatwave condition of 26°C was 513W for sensible heat and latent heat of 542W as the sum in all rooms whiles that of scenario B and C was internal heat gains of occupants of 662W sensible heat and 1304W latent heat. The final scenario C saw an improvement to its envelope i.e., wall u-value of 2.3W/m2. K, a heavyweight thermal mass of 225kJ/ (m2. K). (CIBSE Guide A, 2019).
d. The percentage of hours within the defined criteria were calculated from the simulation results and compared for each scenario.

The Köppen-Geiger climate classification describes climatic conditions in Ghana as tropical weather with a wet and dry climate. The dry periods having a long and extended dry climate and are usually hot with low sun periods (hot season) whilst the wet periods are characterized by high sun periods with cool outdoor air temperatures (cool season). Accra lies on the coast and the equatorial belt hence there is less extreme fluctuation in seasonal temperature. Monthly mean temperatures are greater than 18°C. The cold months are from June to September with a minimum temperature of 23°C and a maximum of 26°C. The wet season experiences the maximum precipitation <1000mm whilst the dry season has the least precipitation of <60mm. Humidity in Accra ranges from 89%-92% for almost 11 months of the year (i.e., Jan.26-Dec. 28). The prevailing wind direction is mostly from the south-west.

3.1 Assessment Criteria and Assumptions

Table 1. indicates specific occupancy thermal comfort based on 90% acceptable limit as specified in ASHRAE-55, (2017) and category II limits of BS EN 16798-1, (2019). From the above literature mosquito's activity bands, optimum survival range of temperature and the mortality/inactive bands temperatures thresholds were established. The generally acceptable range of relative humidity for occupancy comfort is 40%-70% and ranges outside this as occupancy discomfort. (Gagge, Stolwijk and Hardy, 1967). From the above literature review, mosquito population seemed to decrease significantly at a relative humidity of <42%; therefore, its survival band was set at >42-100%.

Table 1. Thermal comfort threshold and indoor relative humidity targets

Occupancy comfort criteria for Indoor Temperature				
Hot season comfort band - 21 Nov – 7 May	Cool season comfort band - 01 Jun – 30 Sep	Annual comfort band - 01 Jan - 31 Dec	Annual discomfort range - 01 Jan - 31 Dec	Reference
24.4-31.4°C	23.4-30.4°C	24-31°C	>31°C and <24°C	(ASHRAE-55, 2017; BS EN 16798-1, 2019)
Mosquitoes activity criteria for Indoor Temperature				
Activity band	Optimum survival band	Mortality/inactive Range		
25°C to 35°C	20°C to 25°C	>35°C and <20°C		(Shapiro, Whitehead and Thomas, 2017)
Occupancy comfort criteria for Indoor Relative Humidity				
Comfort band	Discomfort band			
40-70%	<40% and >70%			(CIBSE Guide A, 2019)
Mosquitoes activity criteria for Indoor Relative Humidity				
Survival band	Mortality/Inactive			
>42-100%	<42%			(Yamana and Eltahir, 2013)

From the literature review above the moderate odour is enough to lure mosquito indoors, hence Table 2, below provides some assumed metrics based on CIBSE Guide A IAQ classification. Occupancy odour intensity was adopted partly from Gutierrez-Osuna, Schiffman and Nagle, (2001) which were then matched with the hypothetical levels of activities exhibited by the mosquitoes indoors, based on its affinity to CO2 and bio effluents (Okumu *et al.*, 2010)

Table 2. Indoor CO2 concentration classification, odour intensity and mosquito's activity adapted from CIBSE Guide A and Gutierrez-Osuna, Schiffman and Nagle, (2001)

Indoor CO2 concentration (ppm)	**Occupancy odour intensity**	**Indoor air quality classification**	**Mosquito activity grading**
< 600	Very weak	First class	Inactive / sedentary
>600 to <=850	weak		Lightly active
>850 to <=900	Moderate	Second class	Moderately active
>900 to <=1000	Moderately Strong	Third class	Active
>1000 to <=1600	strong	Fourth class	Very active
>1600	Very strong	Fifth class	Most active

4. Results and Discussion.

From Figure 2, Mosquito biting rate band of >25 to <=35°C in Scenario B of bedroom B saw the highest percentage in the range of 99.5% compared with scenario A's 96.8%. Scenario C saw the least percentage in mosquito biting rate band of 80.9% when occupied. The reason for the percentage increase in scenario B compared with A could be linked to the increasing number of occupants and higher physical activity, however, the reduction in the percentage of range in scenario C compared with B could be attributed to improvement in thermal mass of the external wall, external shading, and true north orientation of the building which could account for cooler temperatures.

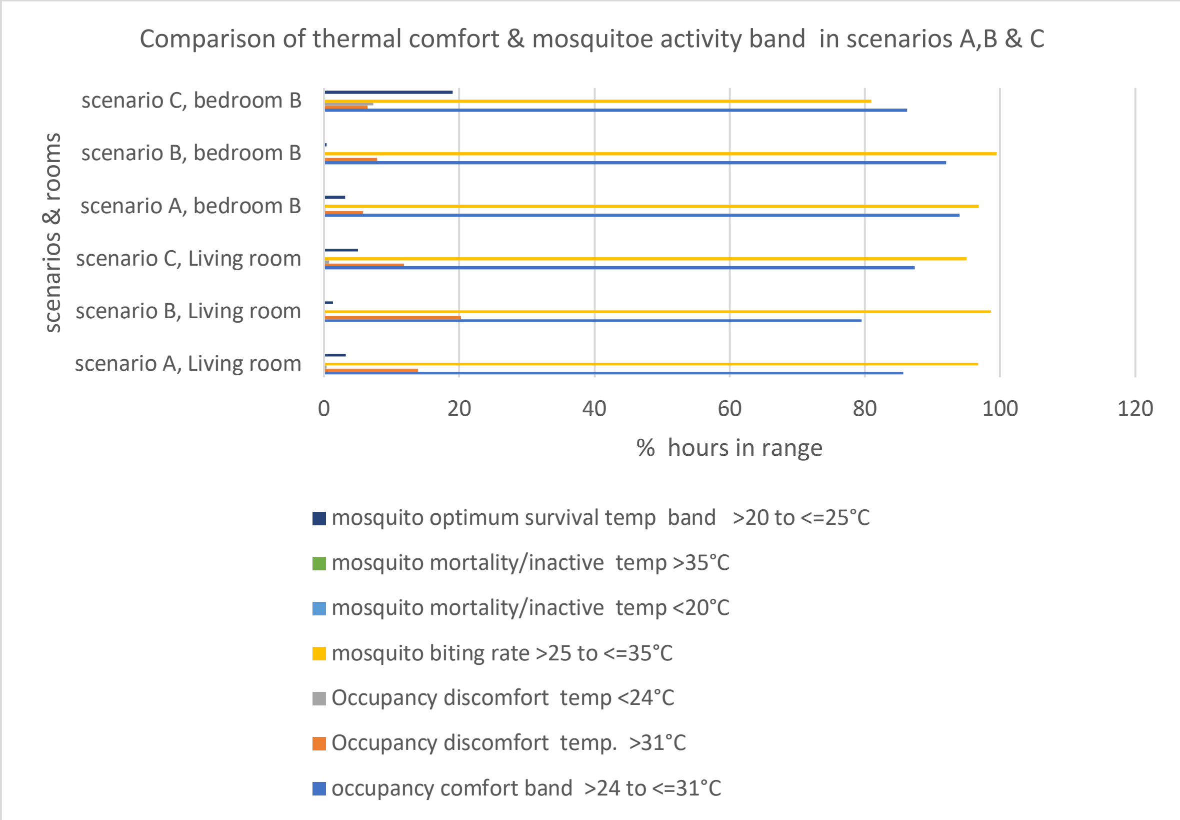

Figure 2. Comparison of scenario A, B &C percentage of total hours in air temperatures ranges.

Indoor CO2 concentration <600ppm in bedroom B saw the most gains in scenario A & C of 91.6% and 99.9% respectively compared with scenario B which had the lowest percentage of 23.2% in scenario B when occupied with a similar number of people in the living room. The indoor CO2 band of >600 to <=850ppm saw the gains swayed towards scenario B which had 25.4%% and 21.4% hours in range of the living room and bedroom B respectively. The band of >850 to <=900ppm, >900 to <=1000ppm, >1000 to <=1600ppm saw the highest percentages in scenario B but almost nil in scenarios A&C. The reason for this, could be the high occupancy density in scenario B coupled with high physical activity. High ventilation rate due to increased external opening area could be the reason for the observation in scenario C.

Lastly, relative humidity (RH) in the band >40 to <=70% saw the highest percentage in scenario A of 32.5% and 13.7% in the living and bedrooms respectively however in the bedroom B both scenarios B and C recorded the same percentage of 12.7% when occupied. Mosquito survival band of RH >42 to <=100% was highest in scenario B with about 0.9% difference between scenario C and A. The least in scenario A of 85.8% in the bedroom B, however in the living room scenario C saw the highest percentage of 72.8% in the comfort band of >40 to <=70%. Mosquito mortality RH < 42% was highest in scenario B and C during occupied hours in the living room, however, the opposite was observed in bedroom B.

5. Conclusion

The study contribute to a deeper understanding of passive strategies that could improve thermal comfort while reducing the impact of mosquitoes' activities in dwellings to help improve strategies aimed at mitigating the health impact of mosquitoes in houses of the tropical region using passive ventilation.

Overcrowding and high physically active seem to increase indoor CO2 concentration and air temperature as was observed in scenario B. The percentage of the occupied hour in the range of mosquito activities/biting rate was increased and occupancy comfort decreased which resulted in an increase in mosquito bites. The interventions tested in scenario C minimized solar gains through the reduction in direct sunshine on the building envelope whiles swinging indoor temperatures. These improvements kept the dwellings cooler and at the same time reduce activities of mosquitoes while improving thermal comfort, even though indoor relative humidity of <42% which was lethal to mosquitoes seemed particularly daunting to achieve through passive strategies in Accra.

6. References

Heating, Refrigeration and Air Conditioning Engineers. https://doi.org/ISSN 1041-2336.

ASHRAE-55. 2017. "Thermal Environmental Conditions for Human Occupancy." ANSI/ASHRAE Standard - 55.

Bayoh, M.N., and S.W. Lindsay. 2003. " Effect of Temperature on the Development of the Aquatic Stages of Anopheles Gambiae Sensu Stricto (Diptera: Culicidae) ." Bulletin of Entomological Research. https://doi.org/10.1079/ber2003259.

BS EN 16798-1. 2019. Energy Performance of Buildings - Ventilation for Buildings. The British Standards Institution 2019.

Centre for Affordable Housing in Africa. 2019. "HOUSING FINANCE IN AFRICA A Review of Africa's Housing Finance Markets Published by the Centre for Affordable Housing Finance in Africa," no. November: 302.

CIBSE Guide A. 2019. Guide A; Environmental Design.

French, D. 1998. "Kyoto Protocol to the United Nations Framework Convention on Climate Change." Journal of Environmental Law. https://doi.org/10.1093/jel/10.1.215.

Gagge, A. P., J. A.J. Stolwijk, and J. D. Hardy. 1967. "Comfort and Thermal Sensations and Associated Physiological Responses at Various Ambient Temperatures." Environmental Research. https://doi.org/10.1016/0013-9351(67)90002-3.

Gutierrez-Osuna, R., S.S. Schiffman, and H.T. Nagle. 2001. "Correlation of Sensory Analysis with Electronic Nose Data for Swine Odor Remediation Assesment." In Proceedings of the 3rd European Congress on Odours, Metrology and Electronic Noses.

Mordecai, Erin A., Krijn P. Paaijmans, Leah R. Johnson, Christian Balzer, Tal Ben-Horin, Emily de Moor, Amy Mcnally, et al. 2013. "Optimal Temperature for Malaria Transmission Is Dramatically Lower than Previously Predicted." Ecology Letters. https://doi.org/10.1111/ele.12015.

Ngarakana-Gwasira, E. T., C. P. Bhunu, and E. Mashonjowa. 2014. "Assessing the Impact of Temperature on Malaria Transmission Dynamics." Afrika Matematika 25 (4): 1095–1112. https://doi.org/10.1007/s13370-013-0178-y.

Okumu, Fredros O., Gerry F. Killeen, Sheila Ogoma, Lubandwa Biswaro, Renate C. Smallegange, Edgar Mbeyela, Emmanuel Titus, et al. 2010. "Development and Field Evaluation of a Synthetic Mosquito Lure That Is More Attractive than Humans." PLoS ONE. https://doi.org/10.1371/journal.pone.0008951.

Salam, Nasir, Shoeb Mustafa, Abdul Hafiz, Anis Ahmad Chaudhary, Farah Deeba, and Shama Parveen. 2018. "Global Prevalence and Distribution of Coinfection of Malaria, Dengue and Chikungunya: A Systematic Review." BMC Public Health. https://doi.org/10.1186/s12889-018-5626-z.

Shapiro, Lillian L.M., Shelley A. Whitehead, and Matthew B. Thomas. 2017. "Quantifying the Effects of Temperature on Mosquito and Parasite Traits That Determine the Transmission Potential of Human Malaria." PLoS Biology. https://doi.org/10.1371/journal.pbio.2003489.

World Health Organization. 2018. The World Malaria Report 2018. Who.

Yamana, Teresa K., and Elfatih A.B. Eltahir. 2013. "Incorporating the Effects of Humidity in a Mechanistic Model of Anopheles Gambiae Mosquito Population Dynamics in the Sahel Region of Africa." Parasites and Vectors. https://doi.org/10.1186/1756-3305-6-235.

Yeboah, Ian E.A. 2003. "Demographic and Housing Aspects of Structural Adjustment and Emerging Urban Form in Accra, Ghana." Africa Today. https://doi.org/10.2979/aft.2003.50.1.106.