The Effects of Roof Design on Mosquito Activity

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Abstract

Focusing mosquito-related public health measures on preventing habitats in which mosquito larvae grow targets mosquito-borne diseases at their source. Studies have shown the correlation between architecture and mosquito populations as to prevent the spread of vector-borne diseases such as malaria or dengue. This paper focuses on four elements– roof shape, roof building materials, how often roof gutters are cleaned, and the presence or absence of a green roof– in order to evaluate what, if any, effect these may have on surrounding mosquito populations and habitats. Through the analysis of GLOBE Mosquito Habitat Mapper data, ArcGIS data, Google Earth Images, a public survey, as well as other scholarly research papers, including "Impacts of Green Roofs on Water, Temperature, and Air Quality: A Bibliometric Review", "Monitoring mosquito nuisance for the development of a citizen science approach for malaria vector surveillance in Rwanda", and others, discussing the consequences of different building models and materials, such information can be compiled to result in effective outcomes for recommended roof designs that may reduce the likelihood of mosquito infestation within our communities. Thus, through changes in fundamental building and housing architecture, communities may take informed mosquito prevention measures. As more urban areas arise, this matter must be addressed to target mosquito sources and reduce the victims of mosquito-borne diseases.

Keywords: roof design, mosquito breeding, urban planning, mosquito habitats

Introduction

Previous research has focused on making adaptations to buildings in order to prevent mosquito entry into the home, such as closing eaves, screening doors, lifting the house off the ground, and replacing a thatched roof with a solid one. These actions are shown to reduce mosquito entry into the home (Lindsay et al.,2019). However, the effect of architecture on mosquito habitats in the surrounding environment has not been as thoroughly researched.

Factors that may have the potential for affecting mosquito populations include roof design, roof building materials, and roof rainwater drainage. Green or vegetated roofs, when implemented, may also influence mosquito abundance.

According to the EPA, mosquitoes often deposit their eggs in bodies of water less than three feet deep. To prevent buildup of shallow water where larvae can develop, buildings should include features in order to ensure that water can drain properly.

The Significance of Roof Composition in Regards to Mosquito Attraction

Roof Gutters

Roof gutters are a flowing water source. Though they are covered, their drainage opening outside of a building can still become an access point for mosquitoes to enter. Due to the fact that the gutters are covered, dark, and have a continuous stream of water flowing through them, they still do have the capacity to become mosquito habitats and breeding sites. Since the water is often shallow and extremely slowly moving, except in times of heavy rainfall, the small amount of water is able to facilitate these mosquito habitats. This may especially be the case in hotter and urban areas, as the covered environment allows for the inside of the gutters to be a more isolated environment, or refuge for mosquitoes from the outside. Moreover, since these areas do not receive as much rain, they are more likely to store still water in their gutters, allowing for mosquitoes to intrude in that area. Nevertheless, the main reason for gutters to become an optimal breeding site for mosquitoes is when the gutters have materials, such as sediments and organic materials (vegetal detritus), accumulated in them. When tested in the islands of Guadeloupe, "The highest numbers of *Ae. aegypti* larvae and pupae were found in roof gutters containing water with sediments and water with vegetal detritus", as shown in Figure 1 below (Gustave et al., 2012). As highlighted in the figure, 65.8% of the gutters observed had water, with 28.4% containing Ae. aegypti larvae and 16.3% containing Ae. aegypti pupae (Gustave et al., 2012). Even in the dry season, about two-thirds of the gutters had water in them and 44% had Ae. aegypti pupae (Gustave et al., 2012). Taking this into account, the likelihood of mosquito breeding sites and habitats forming can be significantly reduced if roof gutters are cleaned regularly.

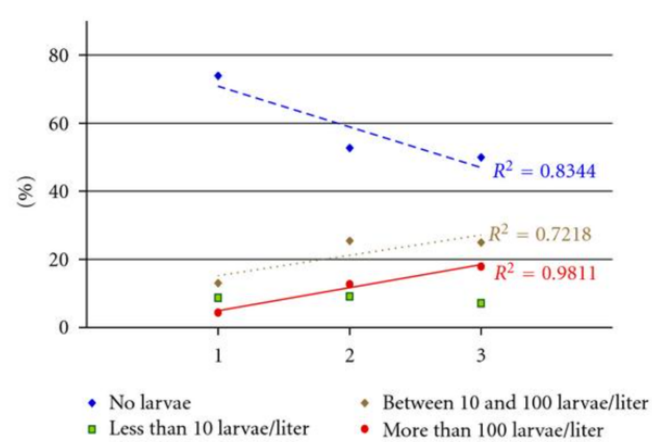


Figure 1

Graphical representation of the abundance of *Ae. aegypti* larvae found in the roof gutters according to the type of water during investigations carried out in Guadeloupe between January and May 2002. (Horizontal axis: 1 = clear water, 2 = water with sediments, 3 = water with vegetal detritus).

Roofing Materials

Roofing materials also play a role in mosquito behavior and infiltration into a house or building. In a study done in Rwanda to survey the malaria vector, one of the criteria surveyed was the type of materials used to build roofs. According to the study, "Houses with tiled roofs were more exposed to mosquitoes than houses with an iron roof" (Murindahabi et al., 2021). Tiles are often made of clay or mud, which are organic materials, as opposed to inorganic materials like iron and other refined metals. Thus, organic shingles or roof tiles that are made of clay, mud, or asphalt will attract mosquitoes more often than inorganic metal roofing plates. However, roofs have more purposes than just as mosquito retardants, such as fire resistance and insulation. Taking this into consideration, it is necessary to investigate further into which materials prevent mosquito attraction, but are still practical.

Shapes of Roofs

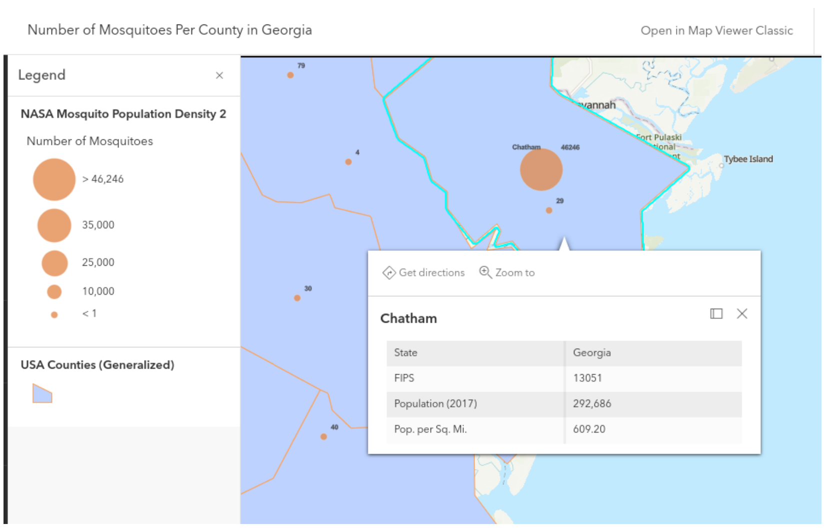
The two most-used roof shapes are the pitch roof, which slopes down at an angle from a ridge, and the flat roof, which lies flat on top of the frame of the building. The importance of the roof shape is that the pitched roofs often allow water to flow down the roofs at a greater velocity than flat roofs. Especially with waterproof flat roofs, water is bound to pool more easily, rather than seeping into the materials of the building. Soon, this sitting water turns into a mosquito habitat. It has been seen that mosquito activity hotspots are more prominent in areas that have flat roofs than those that have pitched roofs (Rinawan et al., 2015). Additionally, the less steep a pitched roof or the larger a flat roof is, the more likely it is for mosquito activity to increase (Rinawan et al., 2015). With this information, governments and housing agencies can plan communitie with pitched roofs such that the likelihood of mosquito habitats and hotspots forming is decreased, especially in tropical areas or areas where rain is a frequent occurrence.

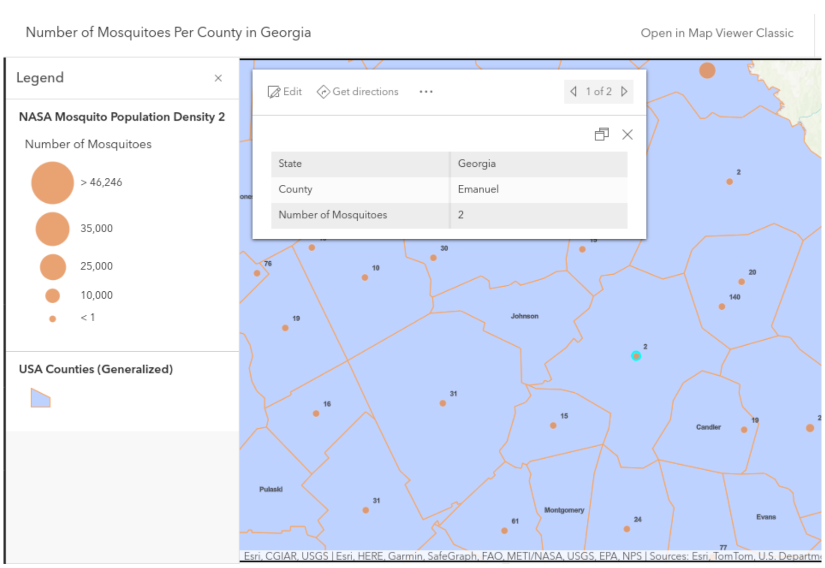
Green Roofs

Green roofs, vegetated rooftops common in dense urban areas, can have an impact on multiple elements of the surrounding environment and microclimate that may affect the prevalence of mosquitoes, including air temperature, wind exposure, and rainwater runoff. Rooftop green spaces are shown to reduce air temperature by reflecting, absorbing, and scattering solar radiation (Liu et al.). Thus, since mosquito activity increases with warm temperatures with peak transmission at approximately 23-29℃, green roofs could partially alleviate high heat conditions in order to reduce mosquito activity (Mordecai et al.). However, it is important to note that there are multiple variables that can affect climate, so it is not a given that green roofs will dispel high temperatures. A study conducted on urban green roofs in Hong Kong found that green roofs have less mosquitos than ground level parks due to exposure to high winds (Wong et al., 2017). Mentens et al. found that “extensive roof greening on just 10% of the buildings would already result in a runoff reduction of 2.7% for the region and of 54% for the individual buildings". Since rainwater retention is increased in green roofs, there is less buildup of water that could host mosquito larvae compared to traditional roofing with impervious materials. For example, a study comparing mosquito abundance on green roofs (GR), bare rooftops (NC), and ground level green spaces (PC), found that “[v]ector abundance was higher in NC than in GR, attributed to the occasional presence of water pools in depressions of roofing membrane after rainfall” (Wong et al., 2016). Implementing green roofing in dense cities with roofs constructed with impervious materials could be beneficial in decreasing water runoff, decreasing air temperatures, and increasing high wind exposure, and therefore reducing potential habitats for mosquitos.

Methods

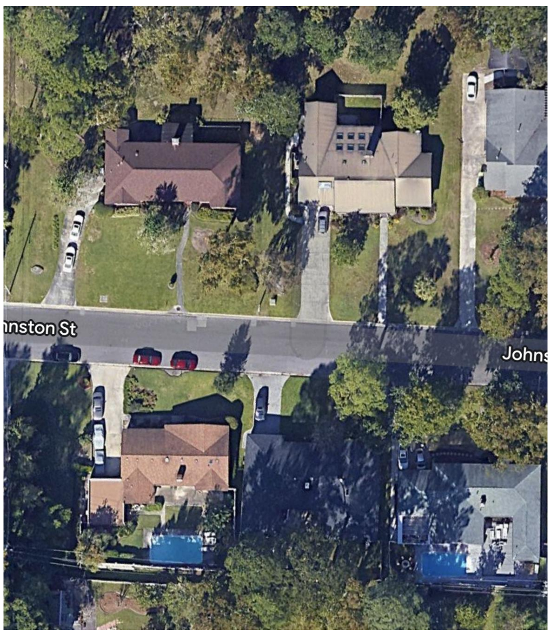
GLOBE Mosquito Habitat Mapper, ArcGIS, and Google Earth data were used in order to determine a correlation between mosquito population density and the most common types of roofs. For example, below is a screenshot taken of the mosquito population density data provided by ArcGIS within the counties of the US state of Georgia.





Here we can see that the county of Chatham has a great mosquito population density compared to other counties such as the county of Emanuel. Using satellite images of each county, we were able to observe the relative layout of cities and towns, as well as commonly used roof designs.

The following trend was found. In Chatam, there were many houses that were very close together and commonly had asphalt shingles or clay tiles. The Google Earth pictures below show the mentioned common type of houses.

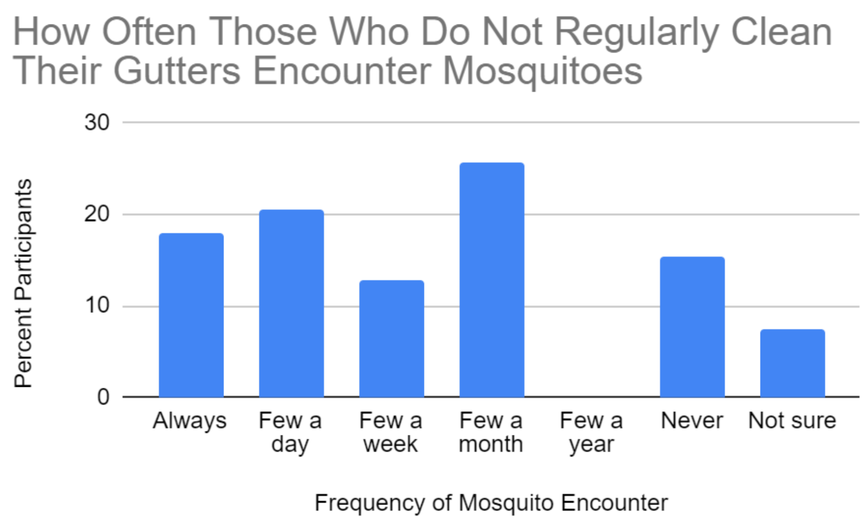


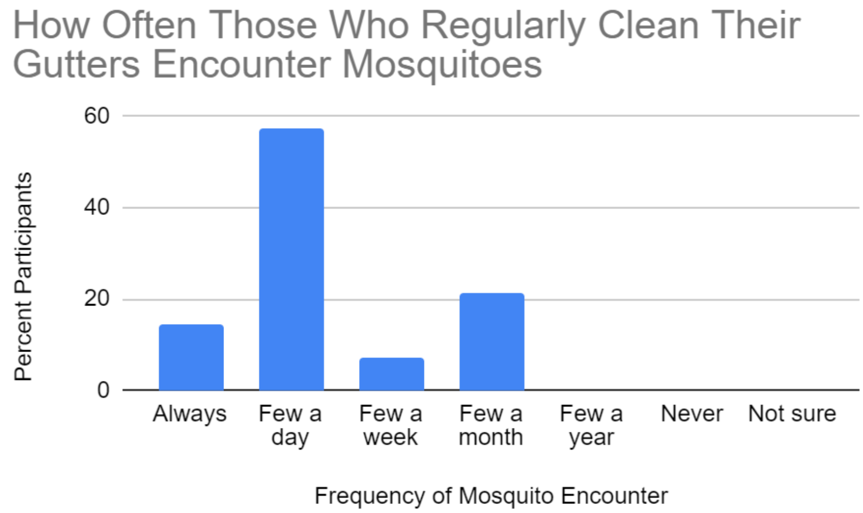
On the other hand, in Emanuel, where there was less mosquito population density, we saw houses that were quite spread apart from each other and commonly had metal roofs, as shown in the Google Earth images below.

Both counties had similar climates due to close proximity and a similar use of pitch roofs, eliminating two variables. However, the county of Emanuel, using metal roofing more often as opposed to asphalt shingles and clay tiles, was shown to have less mosquitoes in the area. This may indicate that the use of metal roofing is more effective than asphalt shingles in keeping mosquitoes out of the area. Yet, there is still the variable of how spread out the houses are from each other. In the county of Emanuel, there is more space between each house, which may have contributed to such an outcome as well. Nevertheless, even with this unaddressed variable, there is a significant difference between the two counties' mosquito population density that the predicted impact of metal roofs is highly likely.

In addition to this, a public survey was conducted in order to evaluate any possible correlation between various elements of roofs and how often respondents encounter mosquitos around their building of residence (Kundurthi et al., 2022). Elements tested include shape of roof (pitch, flat, dome, or cone), roofing material (asphalt shingles, clay/concrete, metal, slate, or rolled), and how often respondents clean their roof gutter (at least once every 6 months, once each year, once every 2 years, once every 3 years, or never). Respondents' climate zones and population density were also surveyed but were not necessarily taken into account in summarizing the data. In total there were 60 people who participated in this survey.

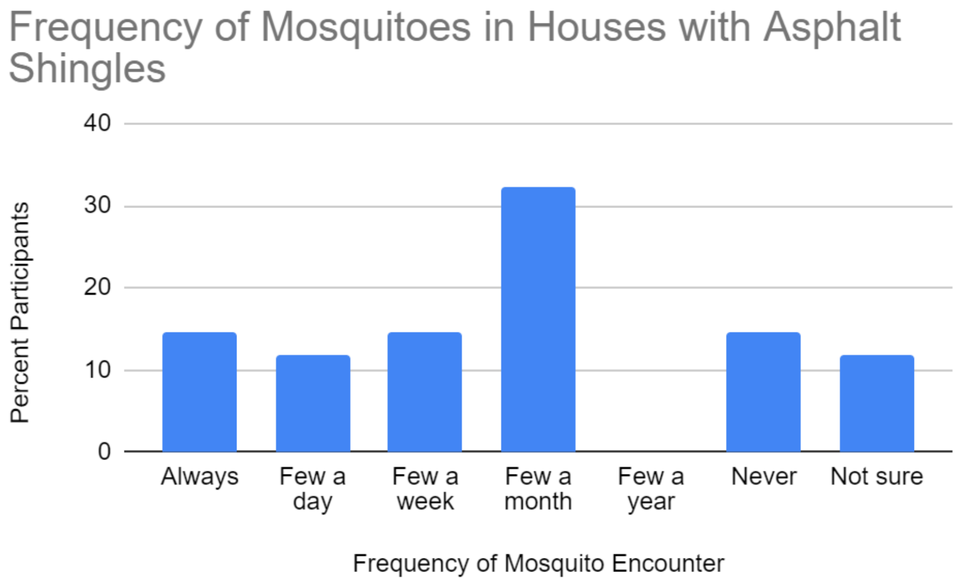
In respect to maintenance of roof gutters, the recommended interval of cleaning gutters is every 6 months. Out of the 60 people who participated in the survey, 14 people cleaned their gutters to meet the recommended standards, while 39 did not. Within these two groups, the following data was gathered.

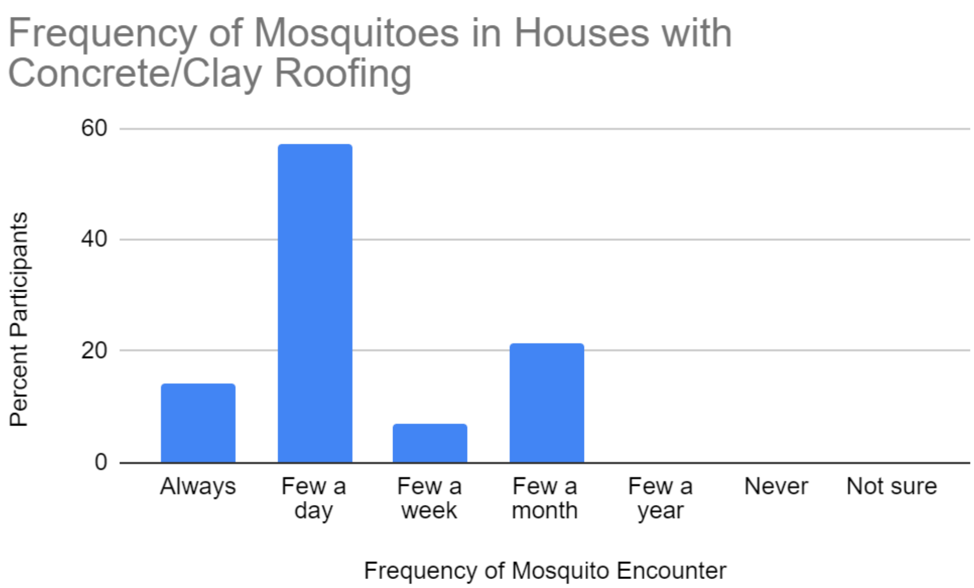




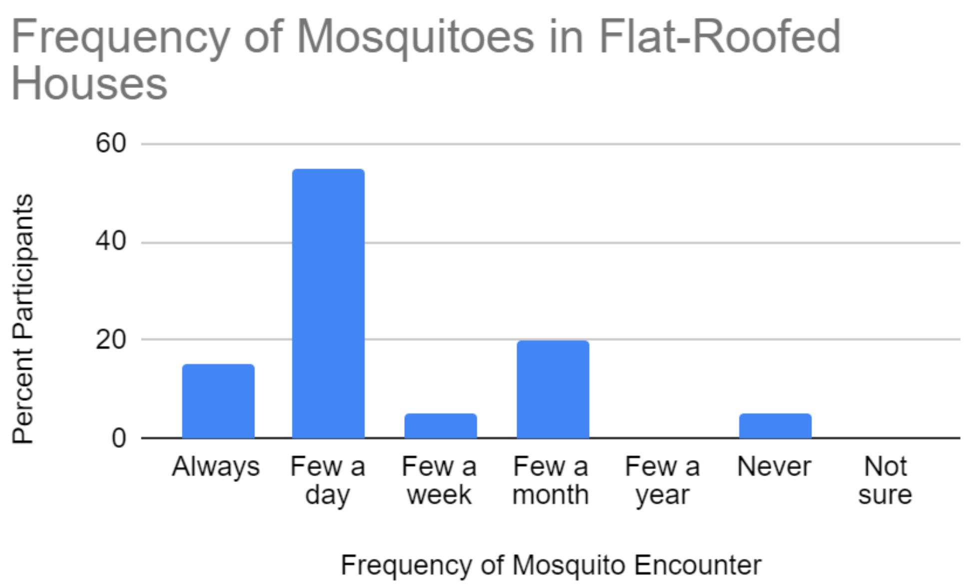
This data seems to contradict the hypothesis made based on the articles and research found previously. Rather than the maintenance of gutters resulting in less mosquitoes, the data shows that those who do not clean their gutters at the interval of 6 months are less likely to encounter mosquitoes, with 76.8% of this group reporting encounters with mosquitoes, than those who do clean their gutters regularly, 100% reporting encounters with mosquitoes. However, in respect to this specific factor tested, there were many variables that were not considered, such as the respective climates of each respondent and their relative knowledge of the importance of cleaning their roof gutters and their ability to do so. Thus, this data has been deemed inconclusive.

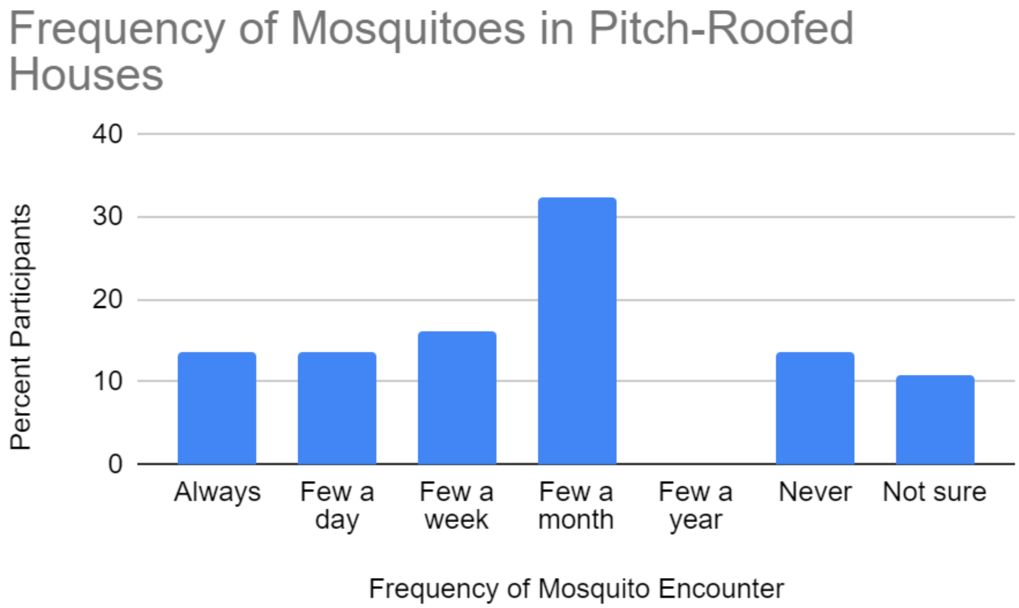
In regards to the type of roofing material used, there were 34 respondents with asphalt shingles, 15 with clay/concrete, 3 with metal, 3 with slate, and 3 with rolled roofing, which contains both asphalt and plastic and/or rubber additives. Due to the lack of conclusivity or significance presented by the amount of data in the metal, slate, and rolled roofing materials, these are not shown below. Nevertheless, according to the data below, between the asphalt shingles and clay/concrete tiles, there was a much greater likelihood that the mosquitoes were encountered where there was clay or concrete roofing, as 100% of those having such roofing reported mosquito encounters, with 57% of these individuals having daily mosquito encounters, while almost 15% of those with asphalt shingles had never encountered mosquitoes, and 32.4% said they had the rare encounter of a few mosquitoes in a month.





Roof shape was the final aspect that we surveyed. Out of the 60 respondents, 57 answered this question. The only two answers chosen were either flat or pitched -- 20 chose flat and 37 chose pitched. As shown in the data below, there is a significant difference between the two groups. Of those with flat roofs, 55% reported that they encountered a few mosquitoes daily, while 32.4% of those with pitched roofs encountered few mosquitoes within a month. Moreover, within the pitched roof group, 13.5% reported never encountering mosquitoes, while only 5% of the flat roof group had the same result.





Error/Improvements

Possible inaccuracies could have potentially occurred as a result of insufficient amount of data. For example, the majority of survey takers had roofs that were asphalt shingled and pitched, meaning that there was not sufficient evidence to draw a correlation between roofing materials or roof shape and mosquito populations from the survey itself because there was not enough data to show a range of samples. Further research of a wider scope is needed, as this data is also limited by the fact that it focuses on residential buildings, which primarily have pitched roofs (on houses) or flat roofs (on apartment buildings), and does not take into account commercial or industrial structures which may have different architectural designs. In future research, it would be more effective to limit a possible survey to a singular region, thereby eliminating the variation in climates and population densities. In our findings, it is difficult to draw a definitive conclusion because there was so much variation in population densities and climate that it could not be determined if mosquito abundance was based on those factors instead of the factors we aimed to focus on. Moreover, the combination of certain aspects, such as a certain roof material paired with a certain roof shape could alter results. In the future, each aspect should be experimented with separately. This might mean that when testing roof shapes, the roofs can have varying shapes, but must still have the same type of roofing and method of maintenance. Additionally, due to the small number of responses to the survey, it is also possible that human error played a role. Overall, with so many variables and lack of sample space, our experiment may not convey a true conclusion. Nevertheless, the results are still significant, especially that of the roof shapes, having the greatest amount of sample space, as they suggest a strong correlation between architectural roofing styles and mosquito abundance.

Conclusion

The findings could be beneficial to future building developments and community planning aspiring to lessen the possibility of an outbreak of a mosquito-borne disease such as dengue or malaria. Mosquito-dense regions can make intentional architectural decisions to ensure that the built environment prevents mosquito breeding sites. These may include implementing more pitched roofs, rather than flat ones. In the case of roofing material, metal should be the most recommended, though asphalt shingles are still significantly better than clay or concrete. Nevertheless, such research should be continued to create more accurate representations of the extent to which roofing can encourage or discourage mosquito activity in comparison to the impact of nearby vegetation and shaded areas.

Badges

Be a Collaborator:

Though all of our team members have been in quite different places, we have been able to come together through this NASA SEES 2022 internship and create something we are proud of. Each of us have different strengths, thus allowing us to collaborate in such a way that each of our skills would contribute to the project uniquely, and most importantly elevating it from an idea to significant findings. Carina excelled in finding articles and materials, as well as compiling them to create a preface for our research. Sreeharshini took interest in launching a survey and was proficient in analyzing and applying both the survey and GLOBE and ArcGIS data to the premise of our paper. This was all while Jesus and Briana explored the data collecting platforms of ArcGIS and GLOBE to find data suitable to the objectives of our research, despite the fact that it was very hard to find much diverse data on the subject of mosquitoes in relation to architecture. Nevertheless, we were all able to go through this journey together and come out as a tight-knit team.

Make an Impact:

Our research presents a possibility to change urban planning and architectural recommendations to assess the spread of mosquito-borne disease throughout our communities. Rather than focusing on factors that cannot necessarily be directly acted on, such as climate and surface temperature, we are providing the public with useful information and thus giving them the ability to act on it individually through their architectural choices and maintenance of roof gutters. If research on roof design and even architecture as a whole is continued, there is a possibility that soon in the future urban planning and architecture will act on mosquito activity so that there is less need for pesticides and a lower probability that people will be victims to mosquito-borne diseases.

Be a STEM Professional:

Throughout our research, we had the guidance of several STEM professionals. Dr. Russanne Low, Cassie Soeffing, Peder Nelson, Dr. Erika Podest, and Andrew Clark all helped by providing access and instruction with the GLOBE Observer and ArcGIS data. Dr. Russanne Low and Cassie Soeffing assisted in providing suggestions to make our survey better for collecting relevant information, as well as providing the space to share the survey with a wide audience of NASA SEES interns.

Be a Data Scientist:

Our project centered around data derived from our public survey, and was supported by analysis of GLOBE Observer and ArcGIS databases. We worked to find a data source that would align with the research questions of our paper as well as provide us with relevant information incorporating building structures and mosquito populations. Our survey was designed to determine the effect of roof designs on mosquito population, but we also acknowledged that regional climate and/or population density could have a larger impact on the data than roof elements. Therefore, we evaluated the survey data with climate and population density in mind.

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