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Energy Performance of Eco-Biomimicry Building Forms

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Abstract

Biomimicry is one of the approaches employed to produce building forms that adapt to a particular climate and hence be energy conscious. This paper presents an investigation into biomimicry and includes the development of a design method based on biomemetic principle that is applied to the design of building forms. Based on the principle that nature rarely moves in a straight line, three main shapes of form which are dome, vault and the combination of both dome and vault are developed and compared to determine the best shape in regulating solar radiation. The effects of different horizontal segments, vertical segments and shrinking level for each shape on solar radiation received were examined. It involved buildings located in two geographical locations with different climatic conditions in Malaysia and the United Kingdom. The energy efficiency of each shape when used in different climatic regions are presented and discussed in this paper.

Keywords;Building Forms, Energy Performance, Biomimicry, Domes, Vaults.

Introduction

Climate responsiveness in architecture is a central goal in the pursuit of new building strategies and increasing the energy efficiency. It has led to the examination of nature which has become a great source of inspiration for many designers, engineers and architects. The growing numbers of nature-inspired innovations lie in the fact that every system in nature is effective (Rankouhi, 2012).

In this study, in search of strategies for energy efficient buildings, three different forms were designed based on a biomemetic principle that nature rarely moves in a straight line (Harman, 2013). The three main shapes of form were dome, vault and the combination of both dome and vault. They were developed and compared to determine the best shape in regulating solar radiation. The effects of different horizontal segments, vertical segments and shrinking level for each shape on solar radiation received were examined. It is hope that this investigation will give valuable insights into the energy efficiency of each shape when applied in the buildings located in two different climatic regions which are Malaysia and the United Kingdom.

Methodology

The whole procedures can be divided into five phases which are illustrated in Figure 1 below.

Phase 1 involved the identification of three main shapes to be examined in this study. They are; 1) dome, 2) vault, and 3) the combination of the dome and vault.

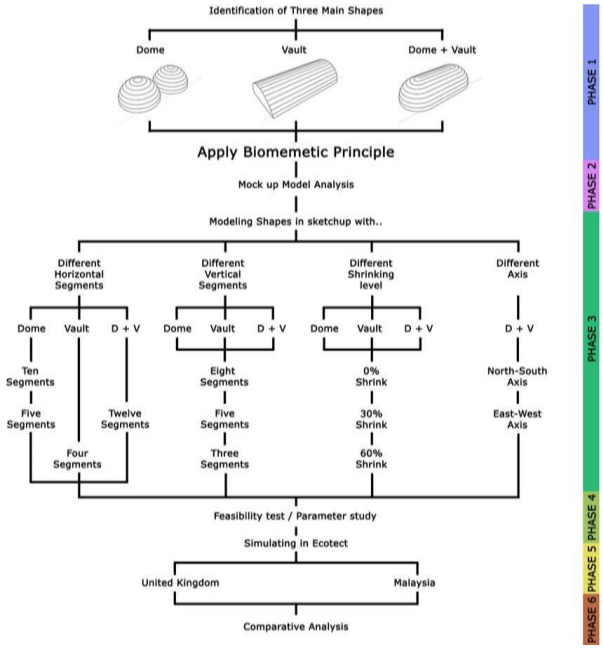

Figure 1 Research Procedures.

Phase 2 was carried out as a preparation for the modeling in sketchup. In this phase, mock model to analyze the feasibility of the shape's shrinking function were created using A4 papers. It is important to ensure that when the shapes shrink, the square meter of each segment is consistent. This is because, if the square meters of the segments become smaller when the shapes shrink, it cannot be built in the real world as it will damage the structure of the form.

In Phase 3, all the three shapes with different horizontal segments, vertical segments, shrinking levels and different axis are modeled in Sketch Up to visualize the forms. Below are the samples of the shapes modeled in this phase:

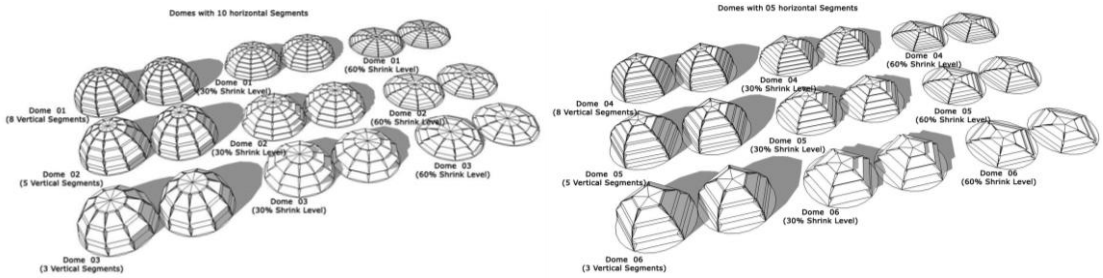

Figure 2 Models of Dome 1, Dome 2 3, 4, 5 and Dome 6 in Sketch Up.

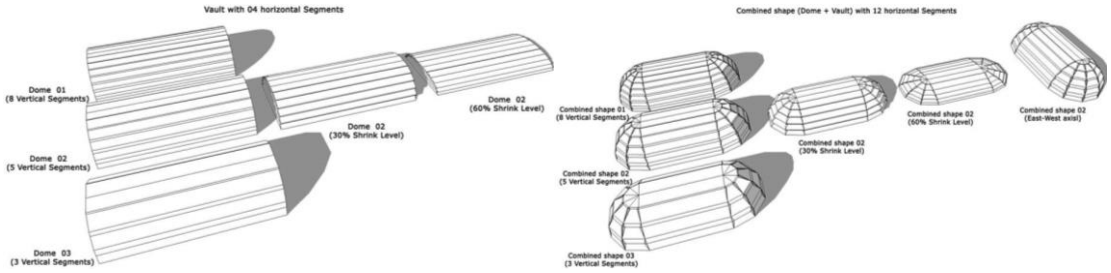

Figure 3 Models of Vault and Combination of Dome and Vault in Sketch Up.

In phase 4, feasibility test was carried out to identify which software can be used effectively to calculate solar radiation. The two softwares tested were Ecotect and EnergyPlus. This was done using a simple shape 20m X 10m X 10 with similar weather file in both software. The result shows that the value of solar radiation obtained from Ecotect is different from the value obtained from EnergyPlus. This is because the details of weather files for the United Kingdom in Ecotect and EnergyPlus are different. For example, the brightest sunny day recorded in Ecotect is on 7th of June at 12noon whereas in EnergyPlus, there is no available information about the brightest sunny day. Because of this, Ecotect is chosen as the simulation

method in this study. All the programs used in this research are taught as part of the MSc course Renewable Energy and Architecture.

In Phase 5, all the shapes are simulated in Ecotect. The simulations were carried out to calculate the value of solar radiation received by each segment. In doing this simulation, the brightest sunny day was chosen to ease the comparison as it has the less cloud in a year. For the UK, the brightest sunny day is on 7th of June whereas for Malaysia, it is on 28th of March. The stored value of solar radiation is 'average daily' on the brightest day in each region.

In phase 6, the value of solar radiation for each segment obtained from the Ecotect simulations are transferred to Excel sheet. After that, the value of the solar radiation for each segment is summed up to calculate the total solar radiation received by each shape. The shapes were then compared and contrasted to identify the best shape in each region.

Results and Discussion

Effects of Segments on Solar Radiation

In this research, it is found that different vertical segments and horizontal segments have different effects on solar radiation received. For instance, dome with more horizontal segments but has the same numbers of vertical segments have higher solar radiation regardless of regions. It is true for both the UK and Malaysia. This can be seen clearly when comparing; Dome 1 and Dome 4, Dome 2 and Dome 5 and last but not least, Dome 3 and Dome 6. All Dome 1, Dome 2, and Dome 3 have higher value of solar radiation compared to Dome 4, Dome 5, and Dome 6.

The possible reasons why domes with more horizontal segments have higher value of solar radiation compared to domes with less horizontal segments when they have the same number of vertical segments is because there will be more surface that receives direct exposure to solar radiation. This phenomenon can be best understood by looking at the illustration in Figure 4 below.

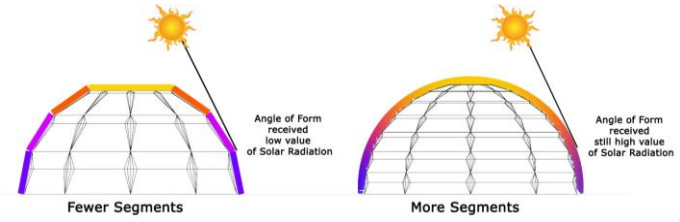

Figure 4 Effects of segments on solar radiation received.

It is also found that changing horizontal segments from ten to five segments decreases the value of solar radiation dramatically. Nonetheless, changing vertical segments from eight to five or from five to three segments does not cause significant change in the value of solar radiation.

Effects of Shrinking Level on Solar Radiation

It can be observed that the more the form shrinks, the lower the value of solar radiation. This is also true regardless of regions that it is applicable both in the UK and Malaysia. Nonetheless, domes in Malaysia constantly receive higher value of solar radiation compared to the UK.

There are two possible reasons that cause the value of received solar radiation to decrease when the forms shrink. The first one is that the shrinking makes the form becomes smaller and thus reduces the square meter exposed to the sun radiation. The second reason is that shadows effects are produced when the form shrinks and this has caused some segments are blocked from receiving direct exposure to solar radiation. These two reasons can be best understood by looking at the illustration in Figure 5 below.

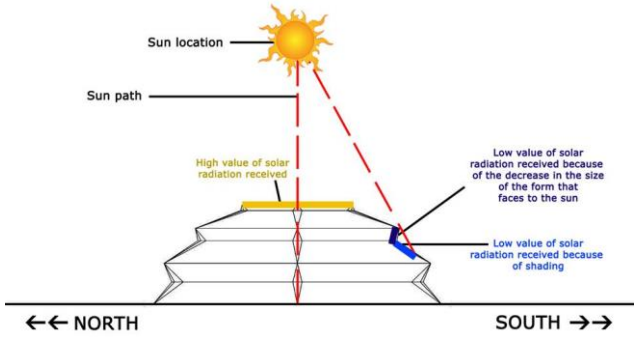

Figure 5 Effects of shrinking level on solar radiation received.

Analyzing what happens to the value of solar radiation received when the forms with different horizontal segments but has the same number of vertical segments, it is found that the forms with less horizontal segments show less loss in solar radiation compared to the form with more horizontal segments when they shrink. For instance, Dome 4 (5 horizontal segments, 8 vertical segments) does not show enormous loss in solar radiation when the form shrinks from 0% to 30%. In contrast, Dome 1 (10 horizontal segments, 8 vertical segments) shows massive loss in solar radiation when the form shrinks from 0% to 30%.

Possible cause of the phenomenon explained above is because when the form shrinks, the percentage of reduction in square meter of the form with more horizontal segments is much higher compared to the percentage of reduction in square meter of the form with less horizontal segments. This means the form with more horizontal segments lost its surface more than the form with less horizontal segments hence make the loss in solar radiation occurs greatly.

Effects of Axes on Solar Radiation

It is found that locating the shapes at east-west axis decreases the value of solar radiation. This is true for both regions, Malaysia and the UK. In this study, the shape tested is the Combined Shape (Dome+Vault) and it is assumed that this result is also true for domes and vaults. This is because the variable in control is the axis, not the particular shapes. Furthermore, all the three shapes have the same width and length of 10m x 20m.The possible reason that causes the value of solar radiation to decrease when the shape is located at east-west axis is that the surface that is exposed to solar radiation is much smaller compared the surface when the shape is located at north-south axis.

Effects of Sun Path in Different Regions on Solar Radiation

In UK, the sun moves 45 degree to the south, from east to west. Because of this, changes in horizontal segments cause higher changes in the value of solar radiation compared to Malaysia with perpendicular sun movement. This can be best understood by looking at the illustration (Figure 6) below. However, the value of solar

radiation in the UK and Malaysia is almost equal when the number of vertical segments is changed as illustrated in Figure 6 below.

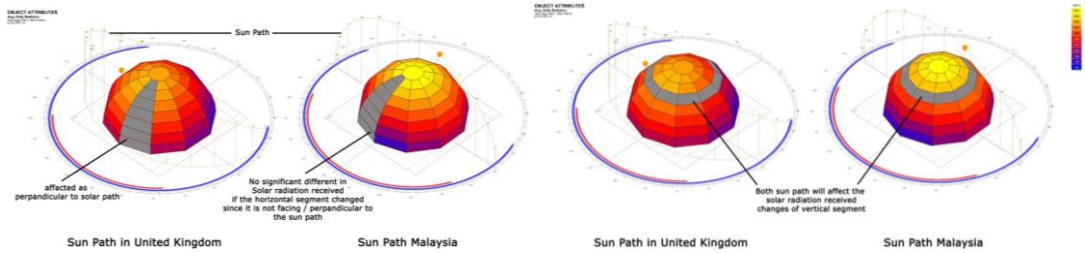

Figure 6 Horizontal and vertical segments are affected by sun path.

In addition, the nature of sun path in Malaysia has caused the shrinking form from 0% to 30% to have significant effect in the value of solar radiation compared to the UK. This is because when the form shrinks, there will be more shadow effects produced and at the same time, there will be fewer surfaces that receive the solar radiation since shrinking makes the size of the form smaller.

Besides that, the different sun movement in the UK and Malaysia also causes different value of solar radiation received by the shape. Shapes tested with Malaysia weather tool files constantly have higher value of solar radiation compared to the shapes tested with UK weather tool files. This phenomenon can be best understood by looking at Figure 7 below.

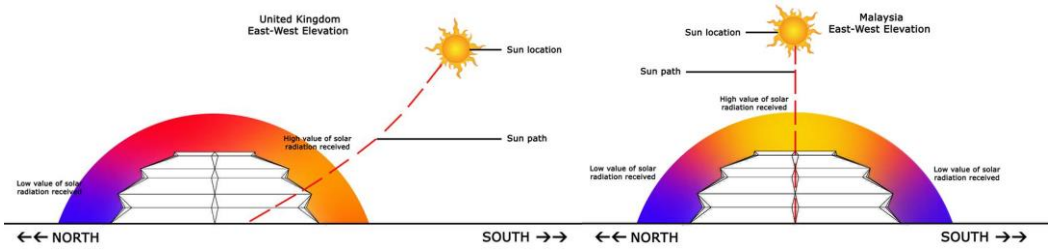

Figure 7 Solar radiation received in influenced by different sun paths in both regions.

The overall results obtained from all the simulations are shown in Figure 8 below. It clearly shows Dome 4 that has 5 horizontal segments and 8 vertical segments, and is located on east-west axis is the best form to be applied in Malaysia as a hot region. This is because there will be more shadow effects produced hence fewer surfaces receive the solar radiation.

On the other hand, in United Kingdom, Vault 01 that has 4 horizontal segments and 8 vertical segments, and is located on north-south axis is the best form to gain the highest solar radiation. This is the best form especially in winter season. Even though the combined shape Both 03 (Combination of dome + vault) is the one that gains highest solar radiation per square meter, it is Vault 01 that gains the highest solar radiation in total as it has the largest surface exposed to the sun. The second best form to be applied in the UK is the combined shape Both 01 and this is followed by Dome 01.

In addition, the shrinking of the form is useful especially in summer to decrease the amount of solar radiation received.

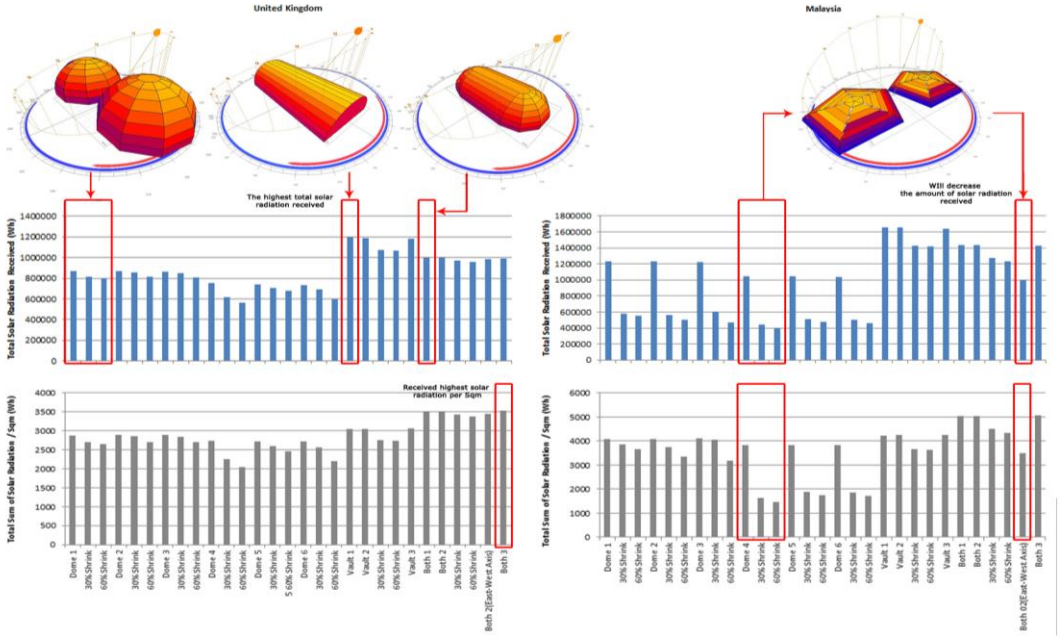

Figure 8 Overall Results.

Conclusions

1. The more segments a form has, no matter horizontal or vertical, the higher the value of solar radiation received.
2. The more the form shrinks, the lower the value of solar radiation received. This is true for both Malaysian and the UK.
3. The bigger the square meter of the building shape, the higher the value of the solar radiation thus reduces the heating loads needed.
4. Locating shapes on east-west axis cause the form to have lower value of solar radiation compared to the north-south axis. This is because the surface exposed to solar radiation is much fewer when the shapes are located at east-west axis.
5. Different sun path in different regions affects the solar radiation received by the shapes in different way. For instance, in the UK where the sun moves 45 degree to the south from east to west, changes in horizontal segments cause higher changes in the value of solar radiation compared to Malaysia with perpendicular sun movement.
6. The form of the buildings plays a crucial role in determining the value of shading coefficient at the wall. It is recommended that the form that does not produce its own shadows is used so that it will not affect the value of solar radiation received.

Refferences

Harman, J. (2013). The shark's paintbrush: Biomimicry and how nature is inspiring innovation (1st editio.). Ashland: White Cloud Press.

Rankouhi, A. R. (2012). Naturally inspired design investigation into the application of biomimicry in architectural design. The Pennsylvania State University. Retrieved from http://issuu.com/azarch/docs/thesis