Journal Homepage: - www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
ArticlenDOI:10.21474/IJAR01/4145
DOI URL: http://dx.doi.org/10.21474/IJAR01/4145

RESEARCH ARTICLE

THE CORRELATION BETWEEN BUILDING SHAPE AND BUILDING ENERGY PERFORMANCE

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Manuscript Info

Manuscript History

Received: 04 March 2017
Final Accepted: 02 April 2017
Published: May 2017

Key words:-
Energy demand, Building shapes, energy efficiency, curved forms, glazing area

Abstract

The shape of a building has a direct effect on the building energy consumption. This study analyzes the impact of the curved shapes on the final energy demand by studying three different shapes. Each of them was simulated for winter and summer and with studying the effect of glazing area and changing the curvature rates. The differences in shape between the buildings is found to have an impact and on the final energy demand. The application of the shapes shows that the horizontal curved shapes is more suitable according to reducing the amount of cooling load for the climate as Abu Dhabi and depending on the result it can be said that with having high curvature rate the curved shapes are more efficient due to energy saving than rectangle with having the same volume and same building characteristics

Introduction:-

The shape of the building is the most noticeable characteristic in a building, and it has a remarkable impact of its energy performance but in the early design stages when the envelope shape is defined, energy performance information is normally nonexistent, due to modeling for energy simulation being a time-consuming task [5].

A curved form is one of the common forms in modern architecture. They have a significant impact on the solar and energy performance of the building and they may increase the energy efficiency of the building and improve indoor environment [9]

There is a relationship between decreasing the amount of the energy demand that needs for providing comfortable environment inside the building with the building shape. The tool of Ourghi et al.[10] was developed to predict the effect of the building shape selection on the annual energy use for limited shapes which are rectangular and L-shapes [10]. In addition, several shapes and floor plans have been developed for the office building and their relationship with the energy demand is studied such as, rectangular shape, L-shape, T-shape, Cross-shape, H-shape, U-shape and Cut-shape in the study done by Al-Anzi,A, Seo D. and Krarti M [1].

In this article the impact of the curved shapes on the building energy performance will analyze by comparing curved shapes with the rectangle shapes according to their energy performance. The reason for chosen curved shapes is that there are limited studies about the thermal and energy performance for these shapes which are commonly used for high-rise buildings in Abu Dhabi and according to the (Abu Dhabi Municipality's Energy Efficiency

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Programme. [2] There are (2000 -2300) High rise buildings in Abu Dhabi Island with new design. At the same time the electricity consumption per household in Abu Dhabi is 10 times the World Average commitments. Therefore, decreasing this amount of energy is crucial. The aim of this research is to assess different shapes energy efficiency and to illustrate the energy performance of curved shapes and the effect of the curvature rate on the decreasing energy load in hot climate, it can be said that the important point of studying the relationship between building shape and energy saving is that it makes the designer to produce the sustainable design.

For the chosen city after simulating the forms it can be shown which one it needs less energy for cooling and as a result it is more appropriate form for this city. For obtaining this goal in first stage three different building shapes (two curved shapes, one rectangle) with the same volume, same and same aspects such as building envelope, building materials only different in the shapes of buildings are modeled. The simulation for these forms are done by using (Energy plus-Software) to show the comparison between these forms according to energy load (heating and cooling). The impact of the relative compactness, glazing size will be found according to glazing-to-floor-area ratio and analyzing their effect on the energy performance for each shape. Finally, the impact of curved façade depth to width (Curvature ratio) on energy performance will be explained by increasing the ratio and comparing it with the shapes in the first stage.

The research questions:-
What is the link between the buildings shapes and their energy consumption?
What is the more suitable shapes according to the energy saving in Abu Dhabi?
What are other factors that have impact on the relation between energy performance and building shapes?

Hypotheses:-
Is using a curved shape for a building can increase the energy efficiency of the building, and decrease the energy demand.

Literature Review:-

The energy Consumption:-
Is the energy that needs to maintain the comfort temperature inside the building and this temperature is nearly 19◦C for the (cube) considered as a reference shape. Moreover, According to United Nations Environmental Program (UNEP), United States Environmental Protection Agency (EPA) energy efficiency is defined as "using less energy without compromising the performance of the building". In addition, there are six factors that impact building energy performance which are, climate, building envelope, building services and energy systems, building operation and maintenance, peoples' activity. [4].

The shape factor of a Building:-
Is a measure of the building's compactness and expresses the proportion between the building's thermal envelope area and its volume (A/V ratio), the area that separates between the indoor and the outdoor environment is called thermal envelope .Buildings with a higher shape factor have a larger surface area in proportion to their volume, which results in larger heat losses in cold climates. In contrast, "buildings with lower shape factor needs lower specific heat demand. However the impact of the shape factor varies for buildings with different thermal envelope properties and for different climate conditions" [7].

In the study done by Depecker et al.[3] the relation between the building shape and energy consumption is limited to the heating season and for specific climate as France, the study summaries that there is a strong connection between the energy consumption and shape coefficient (2001:828). However, their result is just for specific climate and without considering the building orientation and the effect of glazing area on the annual energy demands. Moreover, studying different climate kinds for assessing the results that are obtained may be more useful for designer.

The impact of building shape on total building energy demand depends on three factors according to [1], which are the relative compactness, the window- to-wall ratio and glazing type defined by solar heat gain coefficient, SHGC. However, there are other factor that should be considered because the impact of the properties of the building façade on the energy efficiency is clear such as,'' thermal insulation of materials, sun shading, solar panels, and surface coloring. For these characteristics, some structures can be changed for example compactness, absorbing solar radiation, transferring heat, avoid overheating, generating energy, controlling daylight and provide ventilation"[11].

A limited number of the published paper has depended on optimization of building shape to minimize energy use and cost. However, there are some studies used basic building thermal models and they depend on a mathematical model which is describing heat losses and gains in a building during the heating season , heat losses through walls, roof, floor as well as heat gains due to insolation through partitions are considered to calculate the thermal performance of buildings. In addition, that method is suitable for residential building but may be incorrect in calculating the energy performance of commercial buildings because of the limitation of the forms that can be used by this method.

In the study done by Ourghi, Al-Anzi, Krarti [10] simulation tool is presented to assess the impact of building shape on total annual energy but it is used for office buildings with the rectangle and L shape. Although only two building shapes are analyzed but except of showing the impact of building shape on cooling load in hot region, the type of glazing with it is percentage and the relative compactness are discussed that are effected building total energy use, which is a strength point in this study and they found that the building with higher relative compactness that has low exterior wall areas needs less cooling loads and total energy uses.

Energy simulation in early design stage:-

The two principles that are important during the design stage are the significance of architectural compositional values in design and energy simulation for gaining energy efficient design. The main aim of the study done by Granadeiro [5] was showing the important for measuring the impact of the envelope shape on energy performance in early stage design to give the designer the opportunity to change the design if energy performance is not acceptable. In addition, after getting the energy simulation results two problems may show. First developing the building design for respecting compositional principles. The second problem is the time that needs for modeling and energy simulating for every design. Therefore, Granadeiro et al. [5] proposes a "different design process and a methodology for creating alternative designs for the building shape with considering compactness and providing energy simulation results" (2012:12). Shape grammar based design systems are used for introducing the shape of the building and the energy load is provided by energy simulation of the designs. However, this tool is just use of mass construction because of the determination of creating grammars that limits their application to specific design cases.

The curved wall and energy efficiency:

The relationship between convexity ration and building energy performance was explained in the study which is done for the high rise apartments in Netherlands and the three levels of convexity are analyzed "low convexity by curved volumes, high energy efficiency ,medium convexity by straight volumes, medium energy efficiency, high convexity by straight and inclined volumes, low energy efficiency"[7]. Moreover, this study is done for residential buildings and it shows that to obtain the energy requirement of 15KWh/m2a the compactness ratio needs to be at least 0.2 in terms of energy efficiency and low convexity levels of a building volume parallel to high compactness in surface geometry leading to lower energy requirements. This means that compact forms may not be suitable for getting high solar gain and decreasing energy than needs for providing comfort environment

In studying a model of convex walls it shows that the convex wall with having east and west orientation at latitude 30° N is more efficient than a conventional wall (vertical plane) in both summer and winter. In addition, the convex wall depth –to-width ratio (CSR2) which is used to define the curved surface is analyzed and proved that it has a significant effect on the solar performance because for the east orientation in summer the decrease in the amount of solar radiation that is expected by a curved wall comparing with vertical plane is (10.15/MJ/m2). At the same time, in winter the amount of direct solar gain for convex wall compared with the conventional wall is increased by (5.45MJ/m2) [9].

The link between literature review and research question /hypothesis:-

In the literature review part the impact of different building shapes on building energy performance in various regions is discussed with showing the energy simulation tools that assesse the energy demand, and some studies shows the relationship between convex walls, the convexity levels and solar radiation with minimizing energy demand. In addition, in this study the impact of curved shapes on energy efficiency will expand by studying curved shapes and finding their energy load depending on the ways and methodological approach that were used in the literature review part.

Methodology:-

Illustration of the philosophical underpinnings of the research (ontology and epistemology):-
The method of the research is linked to it is ontological and epistemological position.

Ontology:-
It is related to the researcher's opinions about the really of things.

Constructionism:-
Social phenomena are change continuously and are constructed by the social actors.

Epistemology:-
it is the theory of knowledge. Moreover, Theoretical Perspective for this essay is (**Positivist)** because dealing with phenomena (Energy performance) with natural science method and Quantified phenomena.

Illustration of the Research Approach:-
Deductive, after modeling and simulation the forms that are chosen for this study and analyzing the result it will be shown that if the curved forms improve the energy efficiency of buildings and decrease the energy demand or not, means the hypothesis will be confirmed or rejected. Moreover, the research strategy is quantitative because simulation will done, the data are numbers and the result is analyzing with showing the reason that effect it.

Illustration of the research Design:-
Depending on the other researches that have been done on assessing the energy performance of buildings, the data collection process started by chosen a place (with specific climate) for doing the study inside it, because it has a significant impact on the way that the data will be collected and generated. Studying the energy load demands in Abu Dhabi, the most common building forms and after understanding the problem trying to find a way for analyzing it. Moreover, trying to find a more appropriate methodology to generalize the research questions and answering them.

Illustration of the research methods and reason of its choice:-
The research approach is simulation for the case study in Abu Dhabi and showing the effect of building shape with and without glazing area on the building energy efficiency by designing and simulating different building shapes with the same volume and finding (heating/cooling) load for each of them. The reason for choosing this method is that the previous research done about building energy performance simulation and calculation, Experiments and Survey methods are used but in the study focusing on specific forms simulation methods is chosen (Table 1) However, for finding the energy load in a building and especially in this essay simulating it will be an effective method for getting a reliable result in a short time.
Table 1:- Using simulation method for analyzing specific shapes.

	Ourghi et al. [10]	A simpliciter analysis method to predict the impact of shape on annual energy use for office buildings (Shapes are rectangular and L-shapes)
Simulation	Al Anzi ,Seo , Krarti [1]	Impact of building shape on thermal performance of office buildings (shapes are Rectangular, L, T, Cross, H, U and Cut).

Illustration of the sampling methods and the sample:-
A curved shape can be a form of any building such as commercial building or modern house and this form has a curved in the plan or elevation which is created by a half of the circle or ellipse. The curvature of any wall depends on the dimension of the cross section form (depth, width and height) (Mashina, Gadi 2010).In this study the curved shapes that are analyzed are created from a circle the dimension are shown in figure (1). One horizontal curved form and one vertical are designed with the same size and the area figure (2), their Cross section ratio is (CSR=0.2), and the building contains of six floors. In addition, the heating and cooling set points used in the simulation are (24C°and 29C°) depending on the Abu Dhabi psychometric chart (Weather tool).

The construction that is used for all forms is 200mm concrete block for outside walls, the floor is made of 100mm lightweight concrete with 25mm insulation while 200mm heavy weight material is used for roof of the building models. Finally, all the building is orientated to the east.

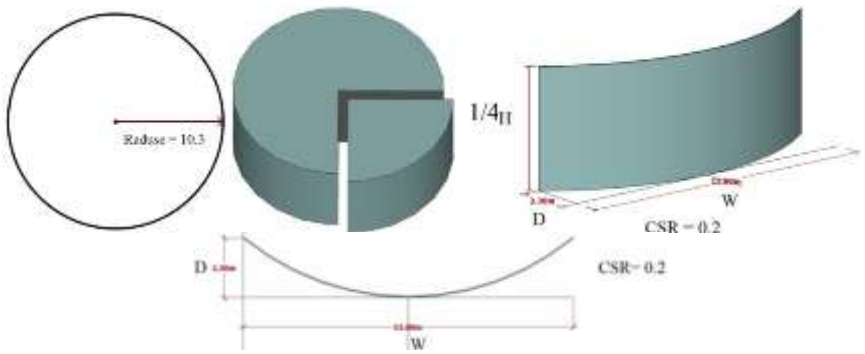
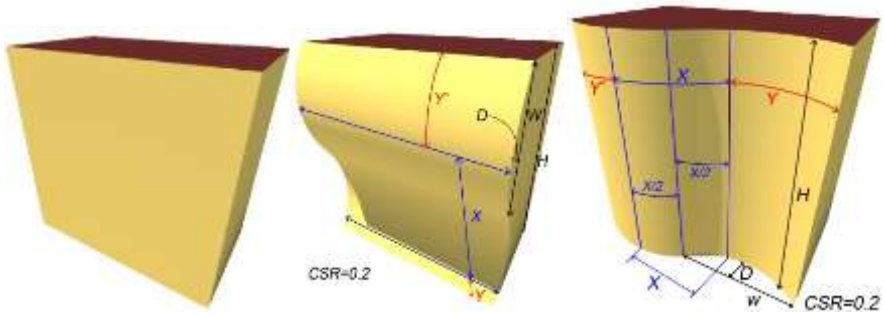


Figure 1:- the dimensions of the circle and curvature rate.



Horizontal curved shape Vertical curved shapes Rectangle shapes

Figure 2:- The different building shapes

Explanation of how the data analysis process will carry out:-

The data will be analyzed by plotting the heating and cooling energy load data around the year that obtained from the building simulation by (Energy plus) software. Firstly, simulation is done for each shapand comparing the result for heating and cooling energy. Secondly, the analysis is carrying out by showing the impact of the window floor ratio on the energy demand in addition to the effect of model forms. Finally, the impact of (CSR) on the energy performance is shown by simulating two different curved forms that their (CSR) is more than those in first stage and comparing their energy demand around a year.

Illustration of the validity and reliability aspects of the Research:-

The strength aspects of this research is that it is explaining the way for reducing the amount of energy consumption by studying the building form means without using other source as a second alternative for obtaining energy. Moreover, after comparing the two different types of curved building with cubic one trying to shows the impact of glazing to floor area ration on increasing or decreasing the amount of energy. Furthermore, chosen Abu Dhabi city and curved forms relate to having high rise modern building and the average energy load in this city is over the World Average commitments. For getting accurate data the simulation is done by (Energy plus) software and the climate data for Abu Dhabi is taken from (Energy plus weather date).

Data and Discussion:-

Comparing between different forms according their energy demand:-

Showing the impact of the difference building forms on the heating and cooling energy demand for Abu Dhabi city will analyzed in this part. Figure (3) shows that the rectangle shape needs less cooling energy around a year comparing with the curved shapes with having (CSR=2). The result of this can related to the effect of solar radiation on the building surface because all the buildings have the same volume but with the different form in their elevations and the surface area of the curved shape is more than rectangle and as a result it influenced by direct solar radiation more than rectangle. In addition, in comparing the horizontal curved form with vertical one it can be seen that cooling energy for horizontal curved form is less than the vertical. Therefore, it can be said that the building shape has a significant impact on the building cooling load.

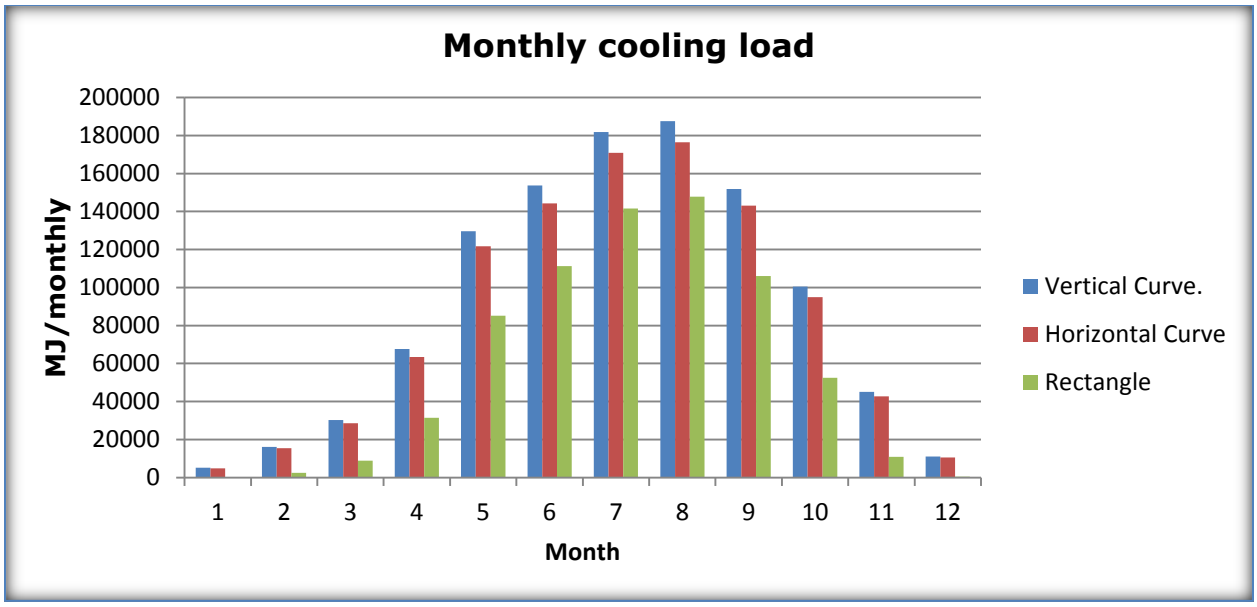


Figure 3:- monthly cooling load without glazing area.

However, the climate in Abu Dhabi is hot and the amount of cooling load is more than heating load for providing comfort environment but in winter there is a clear need for heating energy. In addition, from figure (4) it can be seen that for decreasing heating load curved shapes have a positive effect, this is related to the amount of solar heat that is received by the curved elevations is more than conventional wall and as a result indoor temperature raise and heating energy decrease.

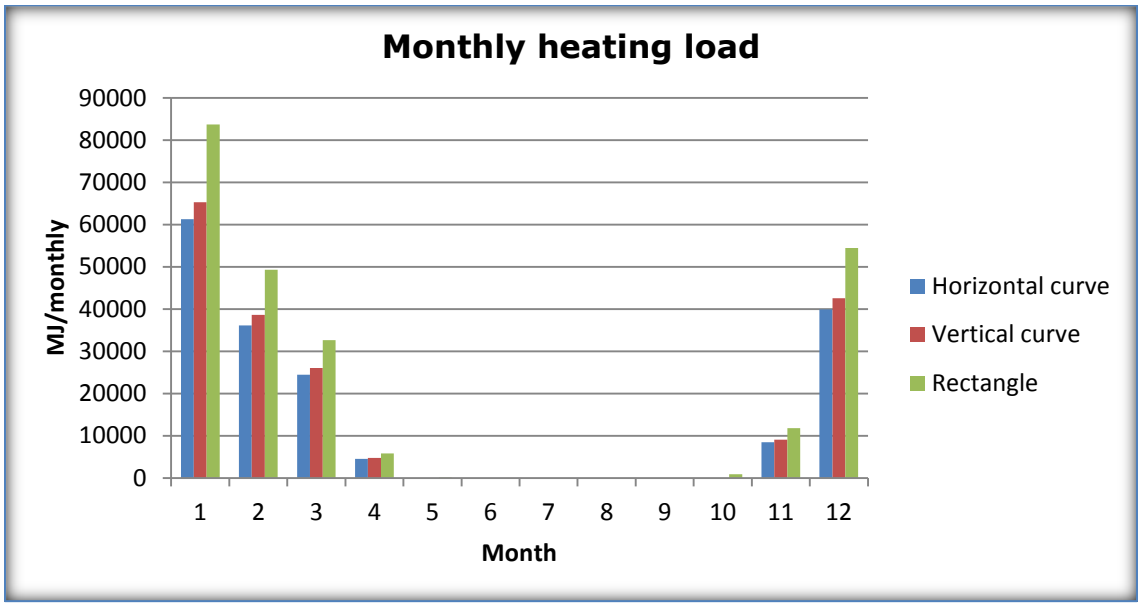


Figure 4:- monthly heating load without glazing area.

The impact of the window on the annual energy Demand:-

For showing the effect of the window on the building energy performance the ratio of 40% of building floor area are designed as a glazing area for all the buildings elevations. According to the figure (5) it can be realized that the amount of cooling load for rectangle and horizontal curved shapes are nearly the same especially in the hottest months. In addition by comparing it with the figure (3) it shows that the effect of adding window on increasing cooling load for horizontal curved shape is less than the rectangle. However, for vertical curved shape adding glazing has a negative impact of the energy performance of the buildings.

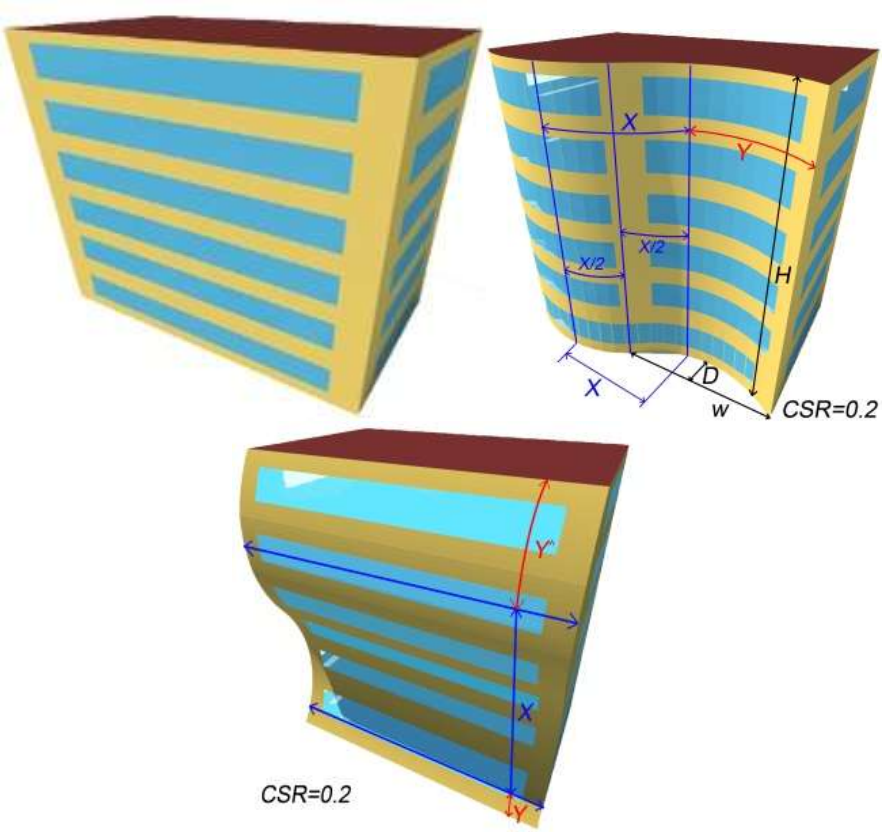


Figure 5:- Adding glazing area according to glazing to floor area ratio.

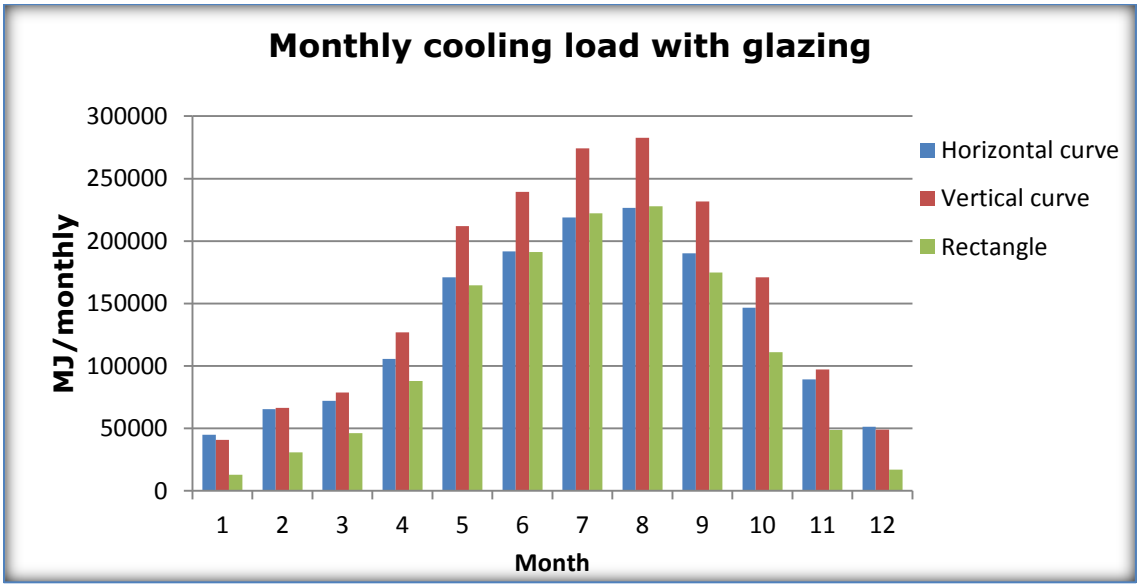


Figure 6:- monthly cooling load after adding glazing area.

For the heating load it is shown that the one that needs less energy is horizontal curved shape the result can related to the impact of the solar radiation on this shape with having east orientation in winter figure(7). However, for the vertical curved the impact on solar radiation is decreased having the convex part of the vertical curved shape in the 4^{th}, 5^{th} floor can influence the amount of the heating load, because in the vertical curve the load in the 2^{nd}, 3^{rd} floor is less than the energy load for the 4^{th} and 5^{th} that increased significantly because of reducing the amount of solar heat gain.

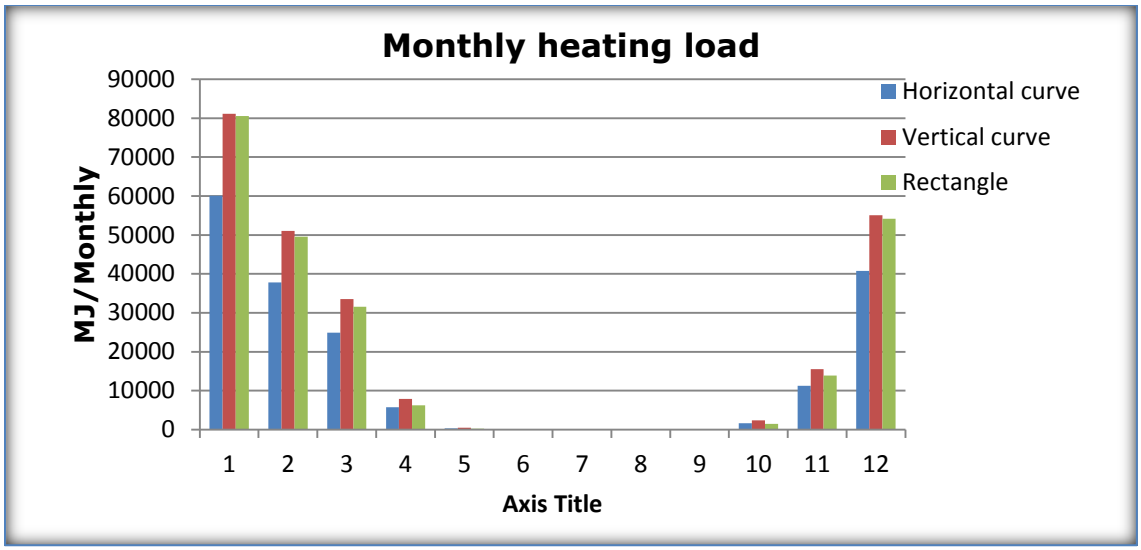


Figure 7:- monthly heating load after adding glazing area

The impact of curved façade depth to width ratio (CSR) on energy performance:-

The objective of this part is to show the effect of curved façade depth to width ration by designing other curved facades(vertical curve, horizontal curve) and increasing the cross section ratio(CSR) to 0.4 and comparing these shapes that are designed in part 1 that have (CSR=0.2) and rectangle shape. The result of the simulation shows that after increasing CSR from (0.2 to 0.4) the cooling energy is decreased in both vertical curved and horizontal curved shapes. The noticeable reduce can be shown in the horizontal curve with (CSR=0.4) this may related to the amount of shading that is increased by raising (CSR) and as a result indoor temperature minimized. In addition, it can be seen that the energy performance of the horizontal curved façade is better than vertical in both (CSR=0.2 and 0.4) but in (0.4) is nearly the same as a rectangle shape.

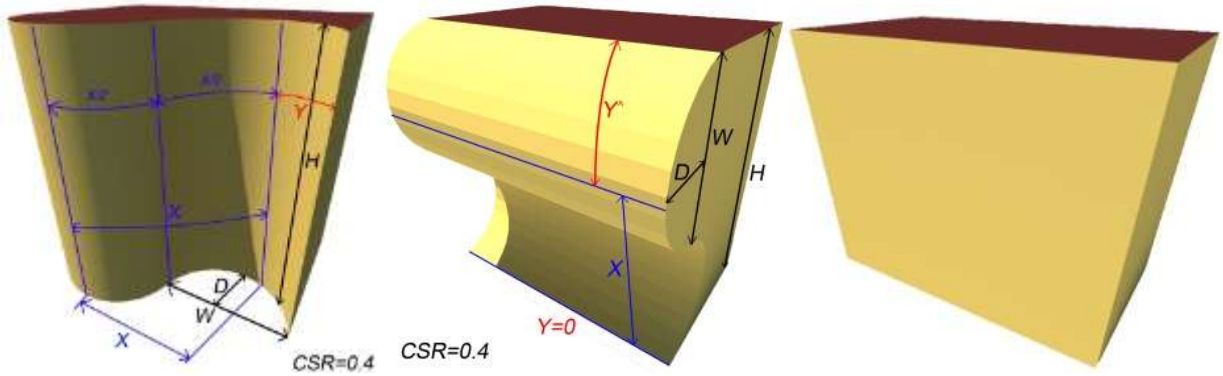


Figure 8:- Increasing the curvature rate for both horizontal and vertical shapes.

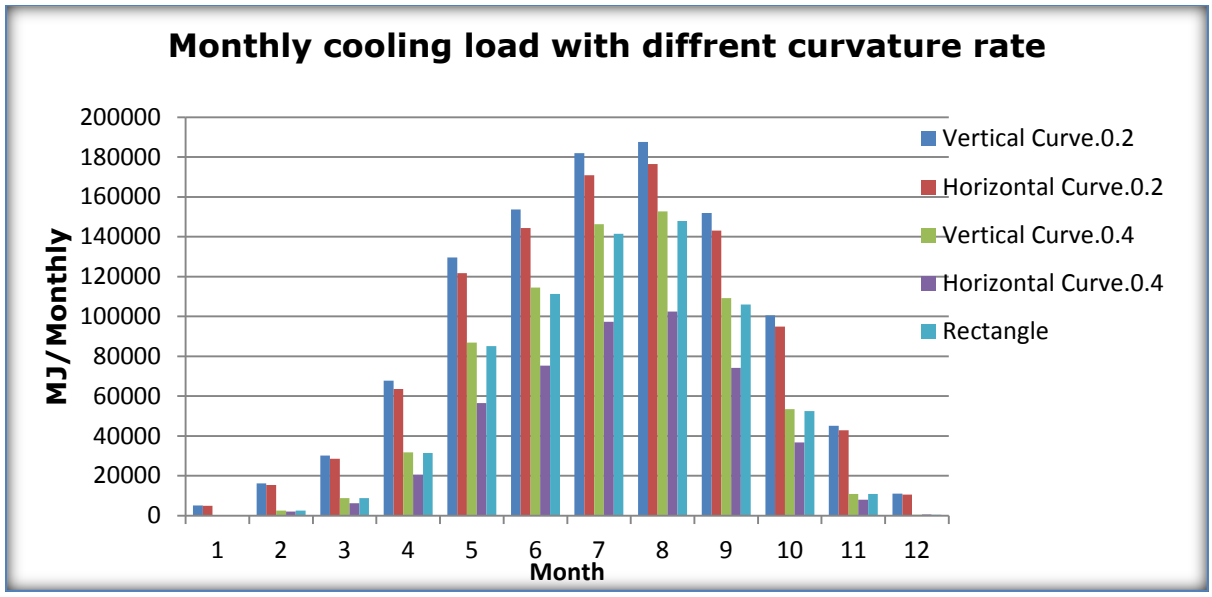


Figure 9:- Comparing monthly cooling load after increasing curvature rate.

For the heating period, the result shows that (0.4 CSR) for horizontal curve is the one that needs higher heating load because it has more shading on all walls comparing with others. In addition, for vertical curve with (0.2 and 0.4) there is not a noticeable difference between their energy demands figure (10). This explains that the effect of solar radiation and shading is one of the most noticeable factors for changing the energy performances for different building shapes.

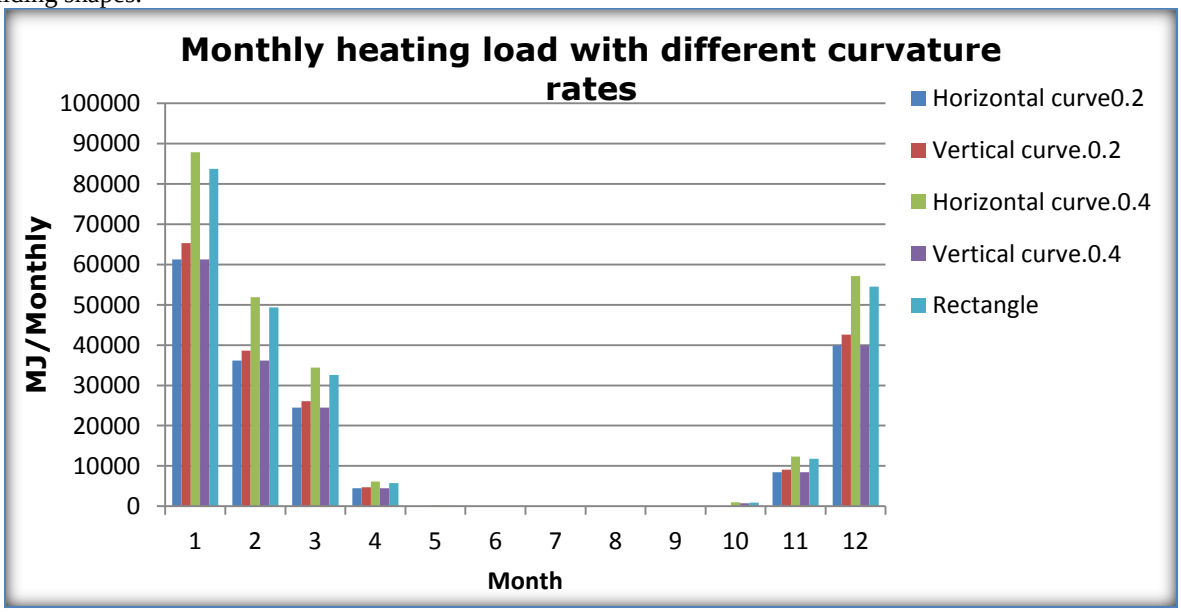


Figure 10:- Comparing monthly heating load after increasing curvature rates

Conclusion:-

In this study, the correlation between specific building shapes and energy consumption is analyzed and the result of the first stage after comparing horizontal curve, vertical curve and rectangle shapes without having glazing area shows that the performance of the rectangle is better than the other curved shapes according to cooling load. However, after adding glazing area the energy performance of horizontal curve shape and rectangle shapes are nearly the same and better than the vertical curve in cooling load but for heating load the horizontal curve needs less energy. Moreover, trying to find the effect of changing the curvature ration on the energy performance by changing the ration and the result shows that by increasing the ratio the amount of cooling load for horizontal curve is reduced

significantly. However, for heating load the result is totally difference this may related to the impact of the shading on the building facades. The summary from this study is that considering the shape of the building is important because of having impact on the final energy demand and for the climate as Abu Dhabi curved shapes can be used as an energy efficiency building shape with considering the type of the curve because it is illustrated that horizontal curved shape is more suitable one comparing with others for hot climate because it decrease the monthly cooling load noticeably.

Research challenging and suggestions for future Research:-

At this stage, because of time restriction and considering the word limitation two types of curved shapes with changing the curvature rate are discussed with one orientation. However, for future study it is it is possible to use other orientation to investigate and showing the performance of these building shapes. Morwover, studying different height of these building shapes may be useful because most of the curved shapes are designed for high rise building. Finally, for complete study about the effect of building shapes on energy performance it is possible to analyze the impact of climate by chosen different climate.

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