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Impact of concave and convex façades on building solar and energy performance

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Abstract:

It is well known that façades play a crucial role in buildings' energy efficiency. Modern architects have designed a wide range of concave and convex building façades which are often prompted only by building aesthetics rather than energy requirements. Predicting solar radiation and energy performance of buildings incorporating flat façades have been widely published. In contrast, curved façades still need more attention from researchers in the field. The lack of published research into concave and convex façades is mostly due to the complex nature of their curvature and the consequent complex physics involved.

This paper assesses the solar and energy performance of concave and convex façades by using (Energy plus) software. Three groups of forms were modeled according to their curvatures (curvature in plan, in section and in both plan and section)**.** ***DSR*** received by each façade and building energy demand were calculated, it proves that for east orientation the performance of curved façades is better than flat .

Keywords: Concave and convex façades, solar performance, energy efficiency, modern architecture, curved surfaces.

Abbreviations: ***DSR*** Direct solar radiation, ***CSR*** Horizontal cross-section –ratio, ***CSRe*** Vertical cross-section-ratio

1. Introduction:

A form is the most noticeable characteristic in any building; a curved form is one of the common forms in modern architecture. It has a remarkable impact on the solar and energy performance of the building and it can increase the energy efficiency of the building, improve indoor comfort (Mashina ,Gadi 2010). Façade as the fundamental part of buildings envelope have effect on the indoor environmental conditions, the energy performance of buildings and the occupants comfort, providing natural light, preventing unwanted solar heat gain are some of their function (Aksamija, 2013).

In this context the paper aims to evaluate the solar and thermal behavior of buildings that have concave and convex façades in their outer skin, and Kuwait city with latitude 29.22° and longitude 47.98°is chosen. The reasons for simulating different forms with curved façades and their solar and energy performance are compared with the flat façades for showing the effect of the façades design on passive design strategies, to investigate the average ***DSR*** received by elevations of curved and rectangular forms. In addition, the

effect of changing the positions of the curvature by studying curvature in plan, in section and combination forms on the amount of ***DSR*** received by the façades, and on annual energy requirements is explained.

2. Methodology:

The methodology approach involved two main parts which are the proper methods for modeling forms with concave and convex façades and simulation this model for assessing their solar and energy performance.

2.1. Modeling of the curved façades form: Open Studio Plug-in for Google Sketch-Up is used to create three types of concave and convex forms and Energy plus software is chosen to model energy performance which is one of five programs taught in the MSc course Renewable Energy and Architecture, at Nottingham University. The term "Curvature" is used to identify the degree of concavity of different curved forms and the curvature of any curved forms depends on the dimensions of the cross section from such as depth (D) width (W) and height (H) (Mashina and Gadi, 2010). The concave and convex building forms that will be designed are generated from a circle and contain numbers of vertical strips the more the number of the strips the more accurate result will be (Elseragy and Gadi 2003), their geometrical shape is rectangular. For forms with curvature in plan all these strips are rounded around a center of the circle and parallel with Y-axis. In addition, they make (90º) angle with both X and Y axis both angles are shown in figure 1. For Curvature in plan's form the depth and width of the forms are changed by increasing the radius of the circle by a regular rate, and ***CSR*** is increased from 0.25 to 0.42 to 0.58.

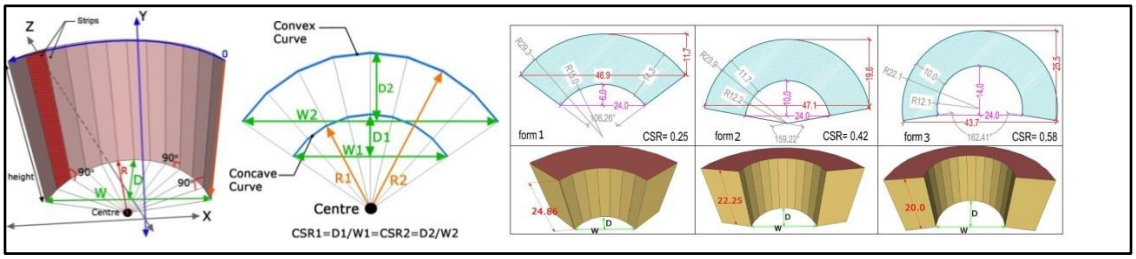

Figure 1 the geometrical shapes for concave and convex with curvature in plan.

For Curvature in section forms the curvature is defined by depth-to-height ratio (D.H) of their cross sections ***CSRe.*** These forms have numbers of horizontal strips that round with the centre of a circle and parallel with X-axis .They have (90º) angle with both Y and Z axis figure 2. The concave and convex forms with both curvature in plan and section contain a number of segments that their geometrical shape is rhombus, these segments rounded around all (X, Y and Z) axis figure 3. Three forms are designed with two different curvature ratios , their ***CSR*** is the same as form (1, 2 and 3) and have the same ***CSRe*** as form (4,5 and 6).

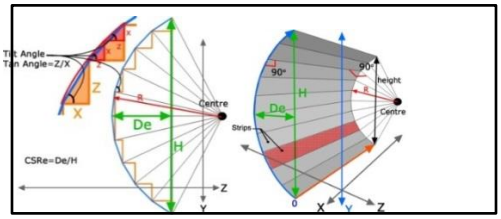

Figure 2 Definition of curvature in sections'

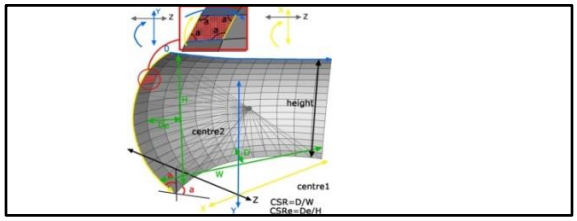

Figure 3 Definition of curvature in plan and section

3. Discussion and result analysis:

Figure (3) proves that concave form 3 has less ***DSR*** received in cooling period by comparing it to other concave façades and flat one with east orientation. However, for the heating season the flat façade and concave façade 1 that has 0.25 ***CSR*** are receive more ***DSR*** by nearly 2 w/m² in December comparing with the concave 2 and 3**.** By comparing concave and convex façades 3 according to their energy performance it proves that in the cooling season there is a decrease in the amount of the ***DSR*** by nearly 1.7 w/m² for the convex facade. However, the performance of the concave and convex1, 2 are similar during summer but in winter the convex façades are more sufficient and by increasing their ***CSR*** from 0.25 to 0.5 for convex one to three their heat gain rise.

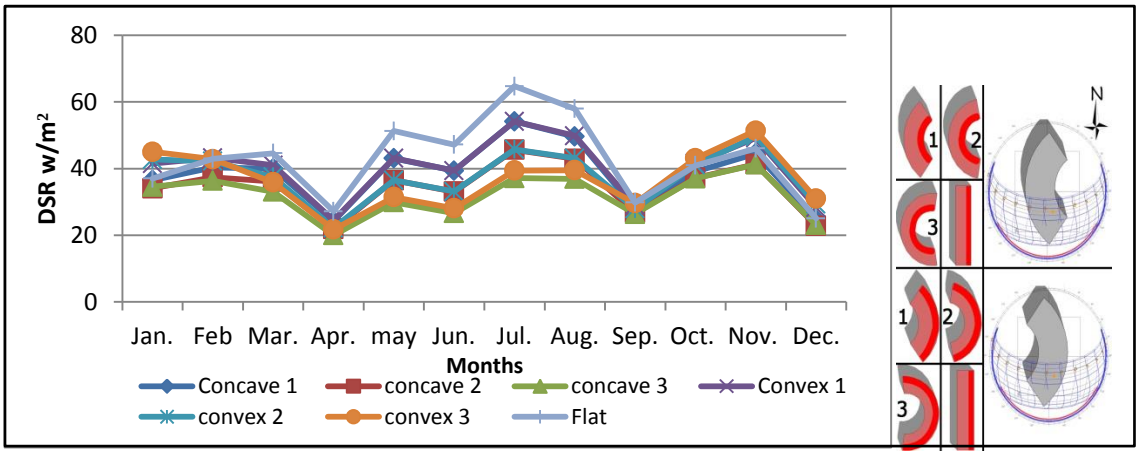

Figure 3 Solar performance of concave and convex 1, 2, 3 and flat façades directed to east orientation.

Concave façades receives more ***DSR*** in summer and less in winter comparing with the flat surface that are directed to the south orientation and with increasing ***CSR*** the amount of ***DSR*** received by concave façades in heating season reduced. Moreover, for cooling season is totally difference. Moreover, by comparing concave and convex façades with same ***CSR***, it can be seen that the performance of the concave façades is better than convex by nearly 8% in the cooling season but for winter the result is difference.

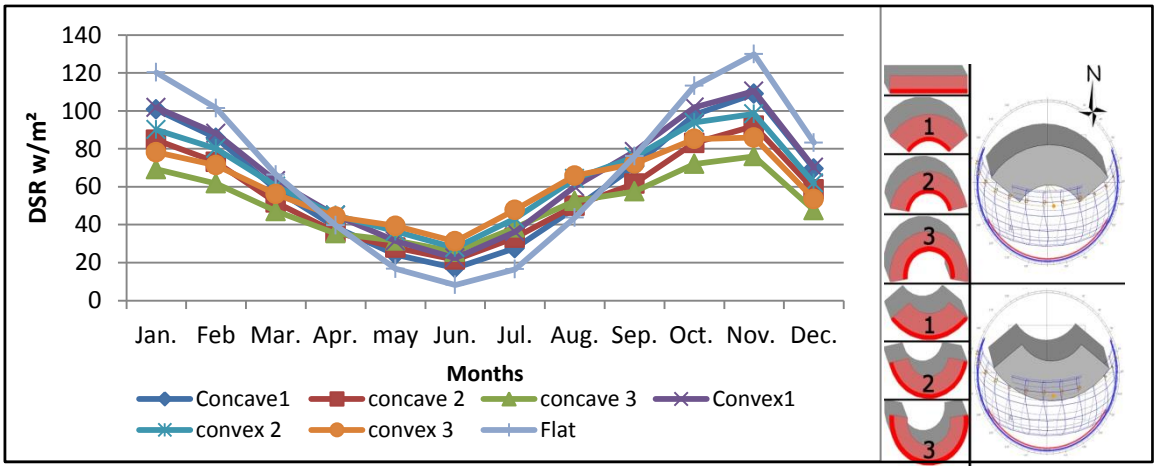

Figure 4 Solar performance of concave and convex 1, 2, 3 and flat façades directed to south orientation

Having concave in section that directed to the east orientation has higher solar performance comparing with the flat in the cooling season because by increasing the depth to high ratio from (0.3 to 0.5) the ***DSR*** received in summer decreased gradually. However, for the heating season the result is difference because in Figure 5 shown that flat surface has better performance according to solar heat gain in winter. Moreover, the result for ***DSR*** of convex façades with curvature in section is totally difference from concave facades, because by increasing ***CSRe*** the amount of ***DSR*** received increased significantly around a year. However, for concave façades raising ***CSRe*** makes the amount of solar heat gain decreased.

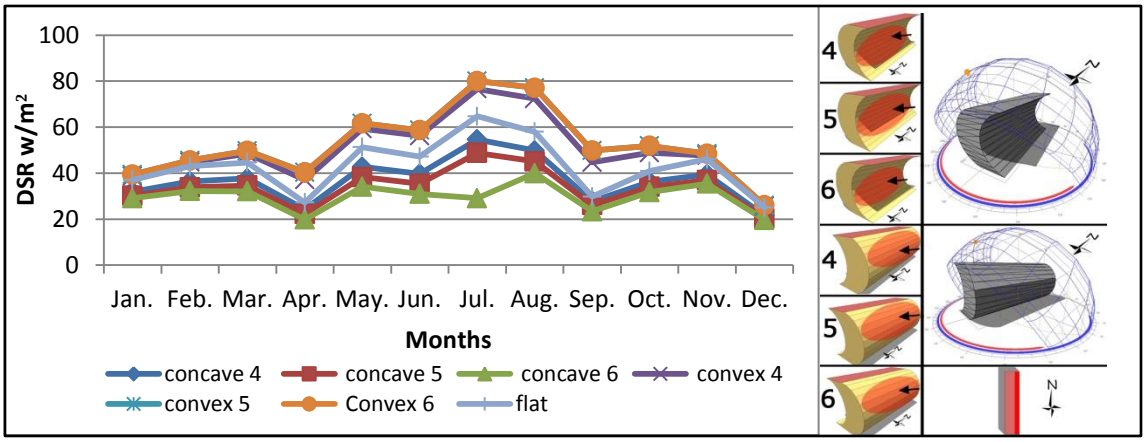

Figure 5 Solar performance of concave and convex 4, 5, 6 and flat façades directed to east orientation.

There is a difference between the amount of ***DSR*** received by the concave and flat surfaces, figure 6 shows that the performance of the flat surface is better than the concave during winter and summer with south orientation. Moreover, with decreasing the ***CSRe*** the ***DSR*** received by concave façade reduced in summer and increased in winter. It is realized that the performance of concave line in section is better than convex because in June the concave with 0.3 ***CSRe*** receive 18.41w/m² and by increasing the curvature to 0.5 the heat gain reduced to 13.71w/m2. However, for convex lines in section the ***DSR*** is 45.85w/m² with 0.5 curvature ratio and this amount reduced to 41w/m² when the ***CSRe*** decreased to 0.3.

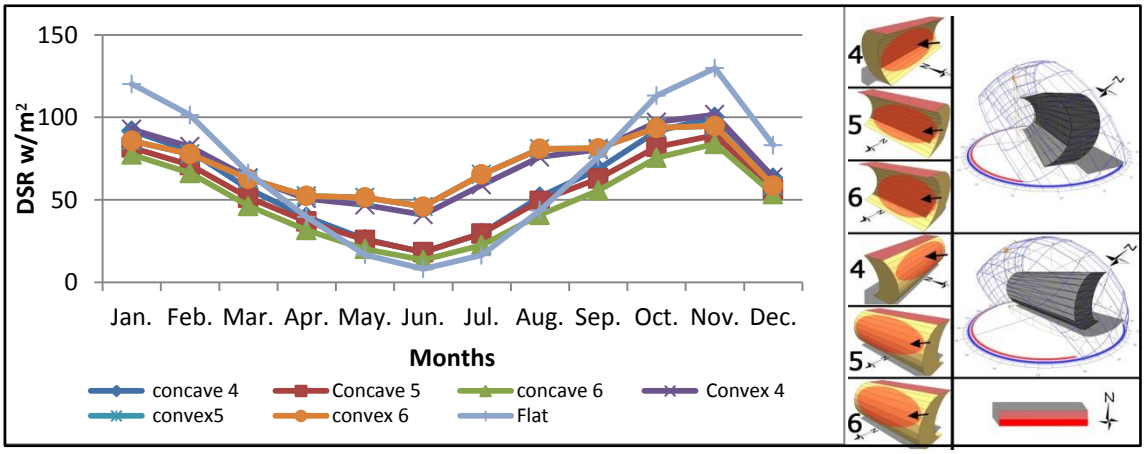

Figure 6 Solar performance of concave and convex 4, 5, 6 and flat façades directed to south orientation

It is proven that concave façades that have curvature in plan and section receives less solar gain by comparing it with others, depending on figure (7), it can be said that the flat façade is more suitable for the heating season but concave façades with high curvature rate reduces heat gain in summer. There is a slightly difference between the amount of the ***DSR*** received by convex façades during the months from (April to September) but with increasing ***CSR*** and ***CSRe*** the intensity is increased. Moreover, by comparing convex facades with flat it can be seen that for hot months flat one receives less ***DSR***. Therefore, the solar performance of the convex façade that designed by combining curvature in plan and section is less than concave and flat façades in summer season.

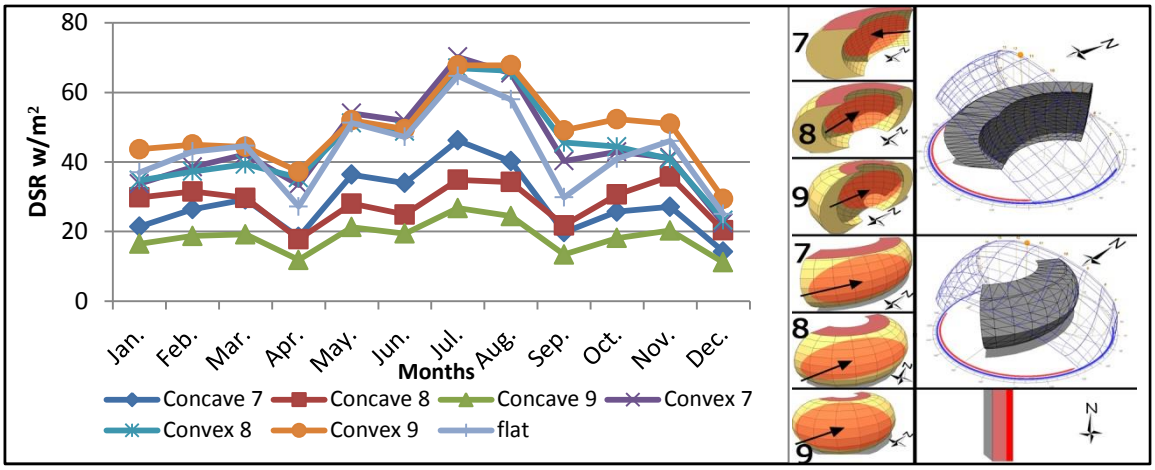

Figure 7 Solar performance of concave and convex 7, 8, 9 and flat façades directed to east orientation.

Concave façades directed to south and with high ***CSR*** are sufficient according to energy saving in summer because it receives less direct solar radiation. Moreover, for the heating season the result is completely different. Although, there is a similarity between the characteristics of the curves for the convex façades directed to the south orientation but their performance is not positive because the heat gain in summer rise with convex forms.

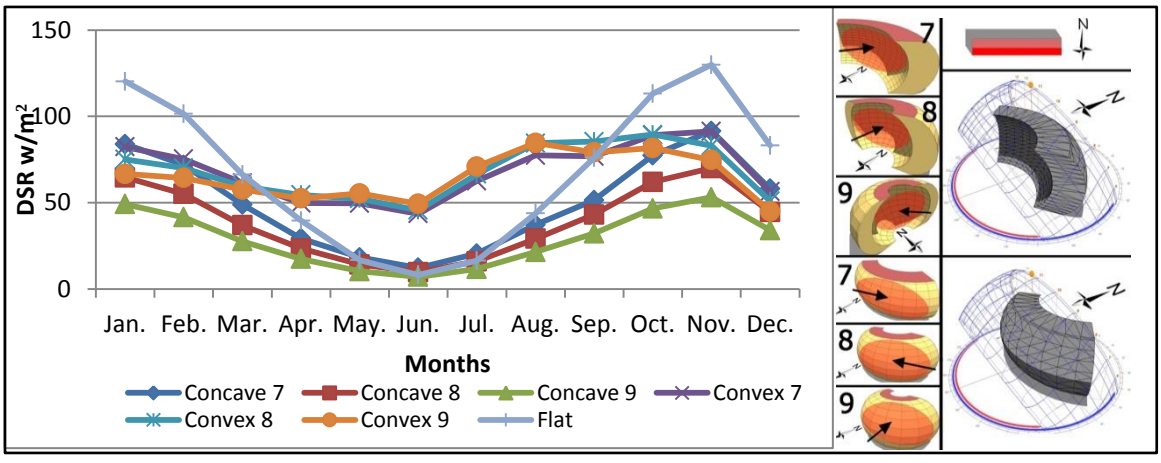

Figure 8 Solar performance of concave and convex 7, 8, 9 and flat façades directed to south orientation

A comparison between heating and cooling loads for curved façades form 1, 4, and 7 illustrates that, the amount of the energy requirements for form 1 is the highest for all

months. In addition, for the heating and cooling periods the energy performance of form4 is better than other forms because it needs lower amount of energy for keeping inside between 24C° to 28C°. It realized that the solar performance of form 4 with south direction is more effective than form 7 according to the amount of the ***DSR*** received by its façades and this result can affect the energy requirements and makes form 4 needs less heating and cooling loads.

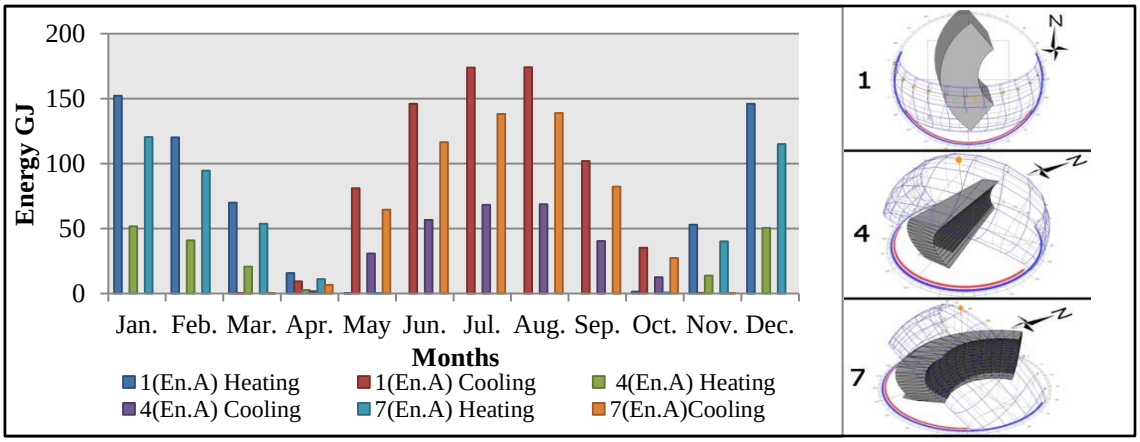

Figure 9 Energy requirements for form 1, 4 and 7

4. Conclusion: The result shows that the performance of concave and convex façades are better than flat façade with east and curvature in plan's form is suitable for winter but for summer season concave design with curvature in section has better solar performance. It is realised that for east orientation combination design of convex façades has a negative effect on the amount of ***DSR*** in summer comparing it with concave design. Moreover, for south façades the solar performance of concave façades forms with curvature in plan and section in summer is better than forms with curvature in plan or in section and similar to flat façades. Finally, it proves that for the cooling and heating periods forms with curvature in plan need more energy. Moreover, combination curvature forms have better energy performance than forms with curvature in plan and around a year the energy requirements for curvature in sections is the lowest.

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