Solar Analysis Of Complex Forms: A Comparison between the Radial Form and the Rectangular U-Shape

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Abstract

It seems evident that the geometry of the urban form as an urban design tool is crucial. Different urban forms result in differing microclimates, offering more or less comfort. The layout of the structure can modify the urban climate through proper design, thus improving thermal comfort both outside and inside buildings and even reducing energy demands for heating and cooling requirements. Some forms, which can create a space surrounded and defined by walls, can offer self-protection against unfavourable weather and create their own microclimate. Such forms are very common within the urban structure and this principle is adequate in residential areas, since such spaces can be used as playgrounds for children and can enhance social activities and human contact. These forms are also characterised by their ability to generate a self-shading effect. The previous studies were mainly concerned to examine simple shapes and less care was given to examine such forms. The forms considered in this experiment are radial forms and the rectangular U-Shape. These forms could be considered as intermediate types between closed and open layouts. In Palestine and other temperate climates, a layout which is semi-closed could be more beneficial, as completely closed or completely open layouts are preferable in arid zones and cold climates respectively. The experiment proves the capability and universality of this comprehensive approach which includes all the points that should be examined in order that the maximum benefit can be derived. In addition, the method illustrates how these analyses could be related to aspects of design and energy. The research finally facilitates and accelerates further research in this field, as this approach can be applicable for different kinds of urban forms.

Introduction

It seems clear that the geometry of the urban form as an urban design tool is more crucial in urban climate amelioration than other factors, at least in the small-to-medium scale. Hence, explicit considerations of urban geometry are very important. The great variation of urban forms produces various kinds of microclimates inside the settlements. Mascaro et al. (1998) stated that each built site interacts with the physical environment and produces particular microclimate conditions. The layout and structure of a settlement affect the climate of the area and can even modify it through a proper design, thus enhancing thermal comfort both outside and inside the buildings, and even reducing energy demands for heating and cooling. Thus, the geometry of the urban form is a variable that may be controlled for the amelioration of bioclimatic conditions. To make a successful integration of renewable energies in established urban structures, the actual performance and the generated shadow pattern of the urban forms have to be precisely defined. Depending on requirements, urban and building forms might be modelled for solar access or shade.

The forms of Buildings can be classified into three basic types (Martin & March, 1972). The first consists of pavilions or isolated buildings, single or in a cluster, surrounded by large open spaces. The second type is the street urban canyon, which comprises long building blocks arranged in parallel rows and separated by actual streets or open spaces. The third one is a type where the forms can create an open space surrounded by walls, such as U-shapes (Figure 1), courts, etc. Previous studies focused more on the first two kinds, i.e. individual buildings and the urban canyon. This study is devoted to covering the third kind of building form: forms creating an open space surrounded by walls. The examined forms are the radial form and the rectangular U-shape. These forms could be midway between the closed and open layouts. Such semi-closed layouts could be more beneficial in Palestine and other temperate climates than completely closed or completely open layouts, which are preferable in arid zones and cold climates respectively.

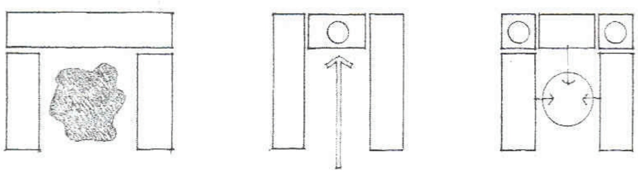
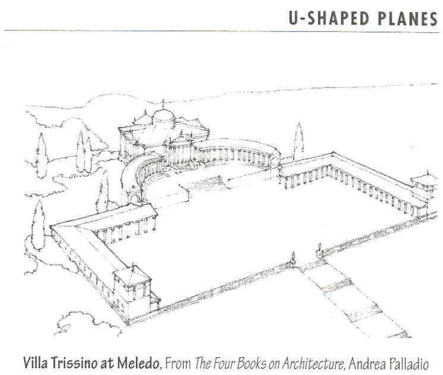


Figure 1: U-shaped Configurations of Building Forms (Ching, 1996)

Courtyards appear in different forms, dimensions and architectural treatments, but all create open space adjacent to buildings. Meir et al. (1995) pointed out that such a space can provide climatic, visual and acoustic protection, as well as the possibility of spending time in the outdoor living space. Ratti et al. (2003) considered the primary characteristic of courts as the ability to create a microclimate that is quieter, cleaner and more private than the street, and where the surrounding interior spaces can interact positively with this improved microclimate. Such characteristics of courts make them a form of building that makes desirable use of land, particularly in an urban context. To improve the thermal behaviour of these forms, the courtyard's geometry, as well as the orientation of the semi-enclosed open spaces, should be designed to provide the highest level of comfort possible.



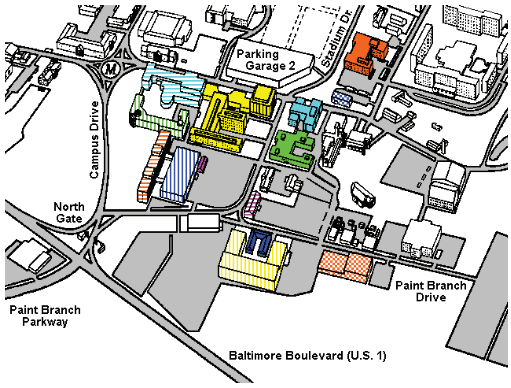


Figure 2: U-shaped Plans within Urban Structure (Ching, 1996, UOM, 2001)

Ching (1996) referred to the U-shape as a configuration which defines a field of space that has an inward focus as well as an outward orientation. U-shapes and semi-enclosed courtyards are popular, as such forms have a high inherent potential for outdoor activities in different climatic regions (Figure 2). "Semi-enclosed forms are part of an architectural language common throughout the history of many regions" (Meir et al., 1995). Semi-courtyards have been incorporated as part of single houses, multi-family complexes and public buildings (Figure 3). Cook (1991) stressed the social and functional aspects of these patterns, such as privacy and security in an open space, or daylighting and ventilation for the surrounding volumes, as well as the importance of microclimate moderation. While the actual insolation performance of the semi-enclosed forms has not been very well investigated through documentation, even less work has been undertaken on understanding the behaviour of the radial semi-enclosed ones.


Figure 3: U-shaped Buildings (Matt Construction, 2001, BAH, 2001)

1. A Comparison between the Radial Form and the Rectangular U-Shape

1.1 South-facing Patterns

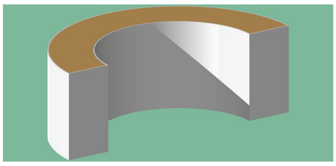
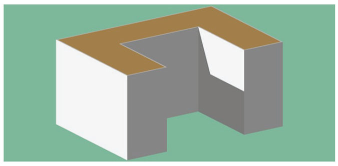
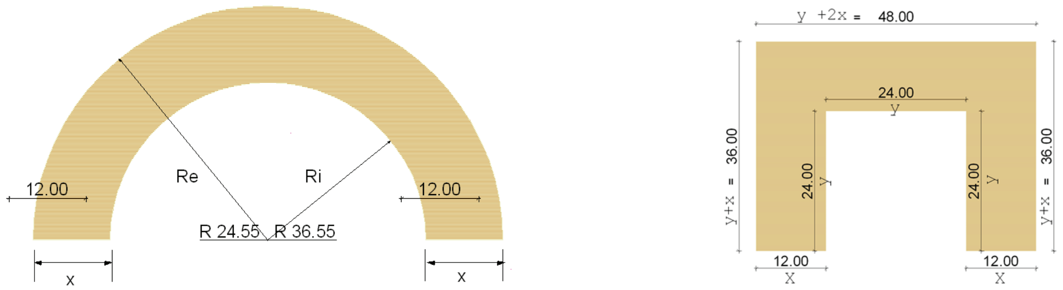



Figure 4: The Radial Form and the U-Shape

The dominant common characteristic of both forms (the radial and the U-shape) is that they can create space which is surrounded and defined by walls (Figure 4). This principle is very useful in residential areas, as these spaces can be used as the main outdoor living space for the children's playgrounds, as well as for some social activities that enhance human contact within the neighbourhood. Although the rectangular U-shape is more common than the radial one in the current urban structure (mainly for constructional and compositional reasons), discovering some advantages of the radial form (from the insolation point of view) could provide the radial form with the opportunity to be used more.

The goal of this experiment is to investigate the main characteristics of the curvilinear form regarding thermal performance and insolation as opposed to the rectangular U-shape. The experiment also aims to clarify the methodology by which the complex forms can be evaluated with regard to the generated shadow pattern. This methodology aims, not only to offer information about the variation of the annual shaded area generated in the two forms, but also to determine the period when this variation is maximal. In addition, it aims to find out the sides where this variation is greater. Moreover, the experiment intends to indicate the specific time during the day where this variation is more significant. This comprehensive approach gives a full explanation of the status of the generated shadow; this allows the best interpretation of the results and the derivation of the maximum benefit from it (Al-Qeeq, 2004).

The Urban Site: The two forms have the same built volume and the same floor area. The height of the two blocks is 16 m and the depth of the two forms is 12 m. The urban canyon section (H/W) for the U-shape is 1:1.5. As the two forms have the same height and perimeter, the external surface areas of the two forms are the same (Figure 5). The experiment will apply patterns with open spaces oriented towards the south.



The Relation between the Dimensions of the Two Forms	
= The Two Forms have the Same Built Volume	$(X (y+2x) + 2xy = ½ (\Pi r_e^2 - \Pi r_i^2$
= The Perimeter of the Rectangular Form	$2x + 3y + 2(x+y) + y+2x = 216m$
= The Perimeter of the Radial Form	$2\Pi r_e) + ½ (2\Pi r_i) + 2x = 216m) ½$
= The External Surfaces Area	$216m*16 = 3456\ m^2$
= The Floor Area of the Forms	m^2 1152
= The Built Volume of the Forms	m^3 18432

Figure 5: The Dimensions of the Radial Form and the Rectangular U-shape

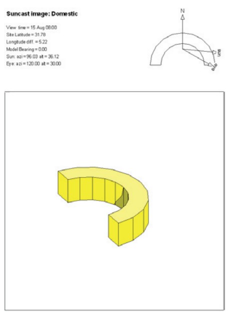
A comparison between the two forms with regard to the generated shadow in both winter, summer and for the whole year, was conducted to find out which form was more suitable for heating requirements and the one that was more suitable for cooling. Consequently, the generated shaded area in the two forms each hour during daytime was summed over the whole year and then for the overheated and underheated periods. This summation was computed firstly for the whole form and secondly for both the inner and outer surfaces separately. Furthermore, a comparison between the two forms was conducted to illustrate the daytime hours that result in more significant variation between the two forms with regard to the generated shaded area.

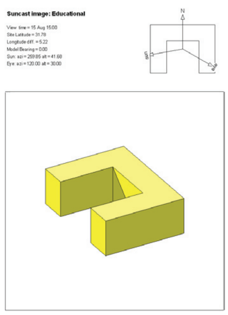
December was considered as representative of the underheated period, while June was considered as representative for the overheated period. The SunCast

Program which was used to conduct the experiments, provides numerical calculations for the shaded surfaces. This assures a high accuracy for the required measurements of this experiment, as the variation in the shaded area between the two forms is expected to be relatively small. Suncast can be used in passive solar design studies and is essential at the planning stage to visualize the effect of the building on surrounding buildings. Suncast performs solar shading and insolation analysis and can generate images and animations. Suncast generates shadows from any sun position defined by date, time, orientation, site latitude and longitude and can investigate: external obstruction and self-shading of a building; solar mapping through windows; solar radiation on external and internal surfaces; and the effects of changing orientation of the building.

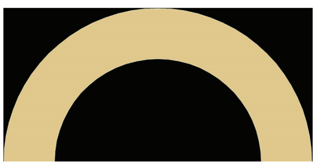
1.1.1 The Evaluation of the Generated Shaded Area in the Two Forms

1.1.1.1 The Annual Shaded Area Generated by the Two Forms





The Average Annual Shaded Percentage per Hour During Daytime – SunCast Simulation	
The Radial Form	The Rectangular U-Shape



53.82%	55.62%
The Radial Form: Less Shaded Area	The Rectangular U-Shape: More Shaded Area
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

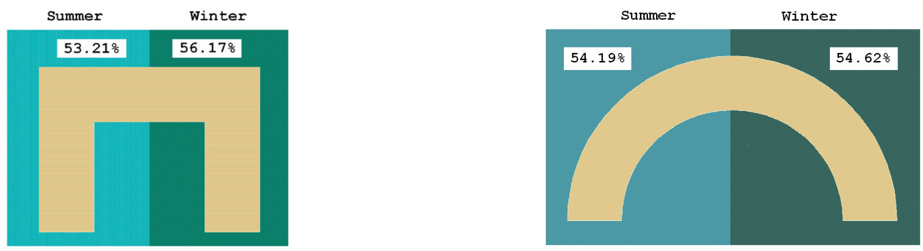
Figure 6: The Average Annual Shaded Area Generated by the Two Forms

Calculating the annual shaded area generated in the two forms shows that the annual shaded area is greater in the case of the rectangular form and smaller in the case of the radial one (Figure 6). Thus, it can be derived that the rectangular U-shape is more suitable for cooling requirements, while the radial form is more suitable for heating.

1.1.1.2 The Distribution of the Shaded Area during Over and Underheated Periods

The Average Daily Shaded Percentage per Hour		
	Summer Period	Winter Period
The Rectangular U-Shape	53.21%	56.17%
The Radial Form	54.19%	54.62%

The Shaded Area in the Two forms in Both Overheated and Underheated Periods



The South-Facing Radial Form is Preferable in Temperate Climates

Figure 7: The Average Daily Shaded Area in Over and Underheated Periods

The south-facing radial form has the least amount of shadow in winter when sun exposure is desirable, and the greatest amount of shadow in summer when sheltering the building from sunrays is required (Figure 7). Thus, in Palestine and other temperate climates, the radial form is preferable. Measuring the shaded area generated in both seasons also reveals that the shaded percentage in both forms is slightly higher in wintertime, this especially applies to the rectangular form. When comparing the shaded area generated in the two forms during the two seasons, it can be observed that the shaded percentage of the radial form is higher in summer, while it is higher with more extension in winter in the case of the rectangular U-shape. Therefore, the greatest variation between the two forms, with regard to the generated shaded area, occurs in wintertime.

For qualitative indicators to compare the relative performance of both forms, the efficiency factor EW can be used. The insolation efficiency (Ew) is a measurement of a building's performance in temperate climates and for those regions where winter heating is a necessity. The insolation efficiency of a building form can be measured by comparing the summer solar exposure with the winter solar exposure (Table 1).

Table 1: Insolation Efficiency of the Radial and Rectangular U-shape

E_W = Winter Solar Exposure/Summer Solar Exposure * 100	
The Rectangular U-Shape	E_W = 43.83/ 46.79* 100 = 93.67%
The Radial Form	E_W = 45.38/ 45.81* 100 = 99.06%

1.1.1.3 The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year

The Shaded Area Generated by the Outer and the Inner Surfaces Over the Year		
	The Outer Surfaces	The Inner Surfaces
The Rectangular U-Shape	% 62.33	% 47.25
The Radial Form	% 66.09	% 39.90

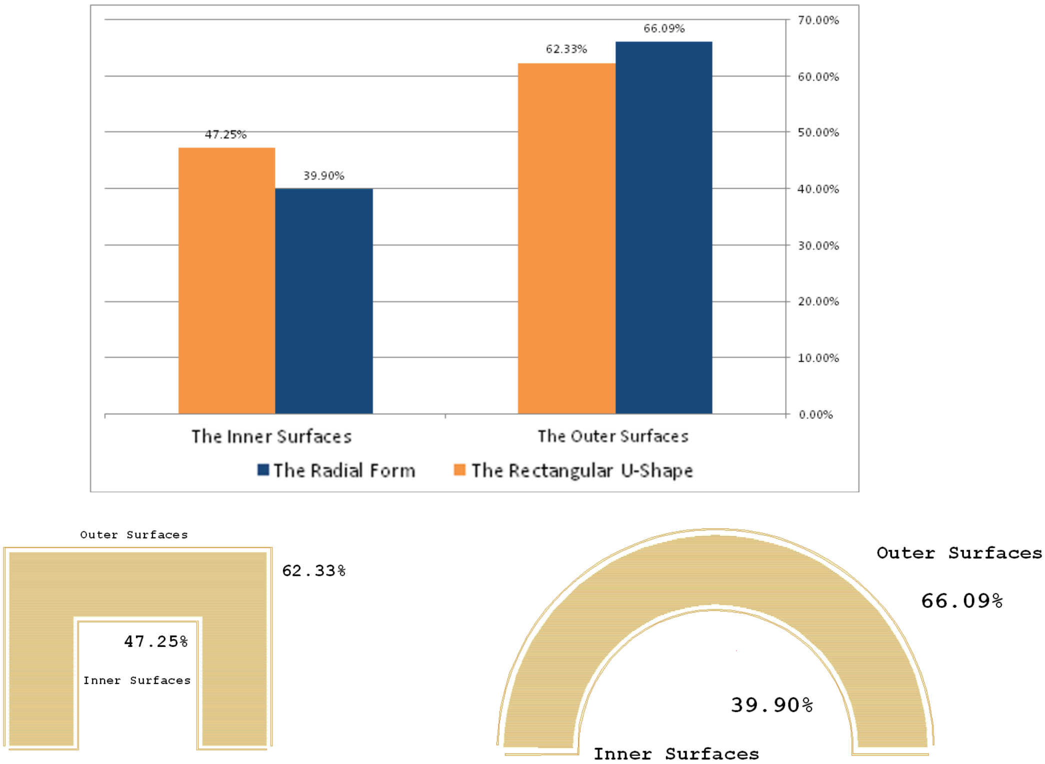
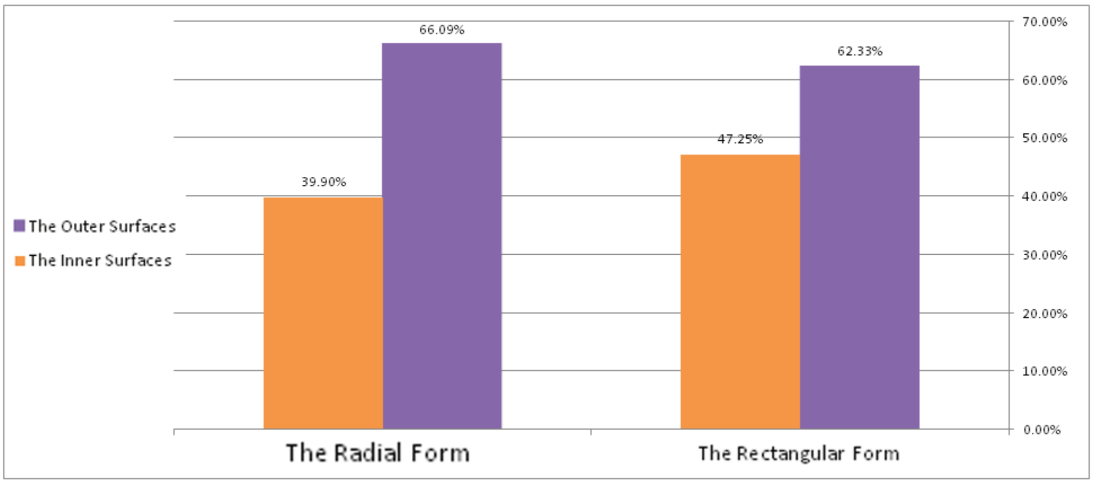


Figure 8: The Average Annual Shaded Percentage per Hour for the Outer and the Inner Surfaces

Figure (8) shows that outer surfaces in both forms have more annual shaded percentage per hour and the inner parts are less shaded, as they are oriented more toward the south in general. Although outer surfaces of the radial form are more shaded than their counterparts in the rectangular one, the inner surfaces of the rectangular form are more shaded, and with greater extension, than their counterparts in the radial one. Consequently, the main variation between the two forms, with regard to the annual generated shaded area, is caused by the inner surfaces.

Table 2: The Variation Between the Outer and the Inner Surfaces of the Two Forms

	(The Outer Surfaces (N	(The Inner Surfaces (S	The Variation
The Rectangular Form	62.33%	47.25%	% 15.08
The Radial Form	66.09%	39.90%	% 26.19



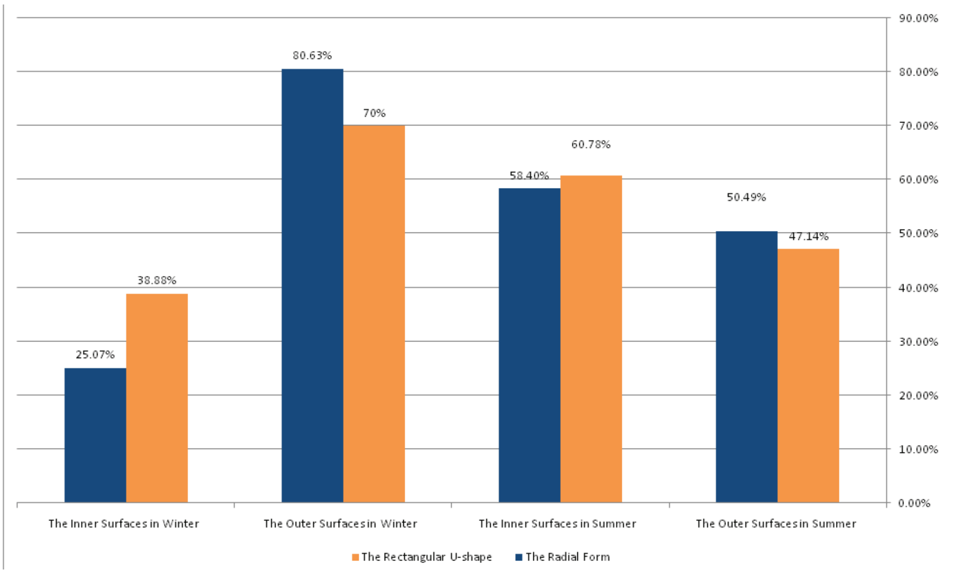
The Rectangular U-Shape is More Suitable for Bilateral Type of Buildings

As the variation between the outer and the inner surfaces, with regard to the annual generated shaded area, is less in the case of the rectangular U-shape (Table 2), this form is more suitable for bilateral buildings, where living areas are located in opposite directions as, it could distribute insolation among all residential units in a more even manner. On the other hand, the radial form is more beneficial for unilateral buildings, as its south facade (the inner surfaces) is less shaded than the south facade of the rectangular U-shape over the year.

1.1.1.4 The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

especially for inner surfaces. Figure 9 also shows that in the summer period, the outer surfaces in both forms are better exposed to sunrays than the inner surfaces. On the other hand, the inner surfaces in both forms are better exposed to sunrays, and with higher extensions, in wintertime. Once the shaded areas generated by the inner and the outer surfaces in the two forms are compared, it can be observed that in summer period the identical sides of both forms receive approximately the same shaded percentage per hour and that the biggest variation always occurs during the winter period (Table 1.3),

The Average Daily Shaded Percentage per Hour	The Outer Surfaces		The Inner Surfaces	
	Summer Period	Winter Period	Summer Period	Winter Period
The Rectangular U-shape	% 47.14	% 70	% 60.78	% 38.88
The Radial Form	% 50.49	% 80.63	% 58.40	% 25.07



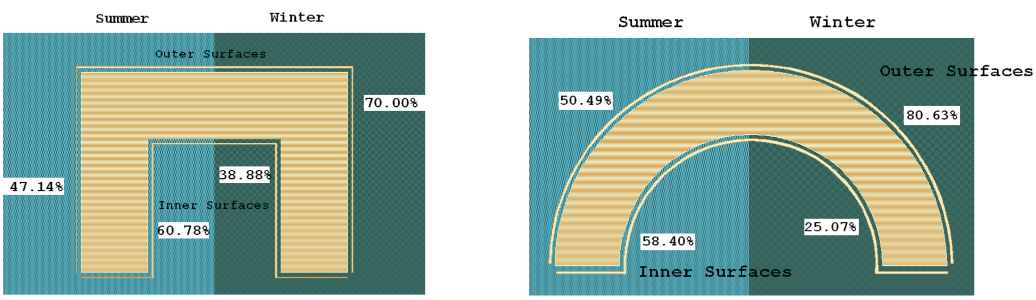
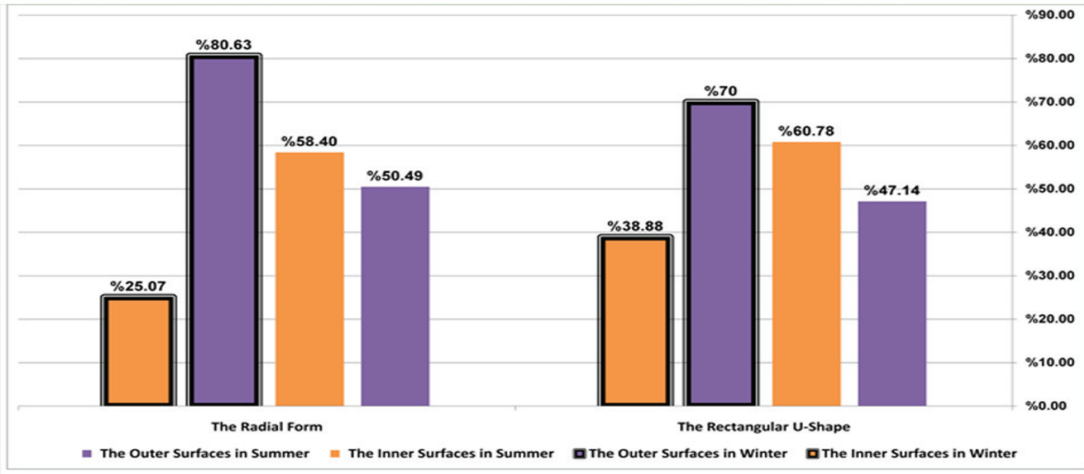


Figure 9: The Shaded Area Generated by the Outer and the Inner Surfaces in the Two Seasons

By studying these results, it can be concluded that the most significant variation of the generated shaded percentage between the outer and inner surfaces for the same form occurs in the case of the radial form in the winter period (Table 3). Also, the biggest variation between the two seasons for the same group of surfaces within the same form takes place in the radial form and especially within its inner surfaces (Figure 9). In addition, it can be noted that the biggest shaded percentage occurs in the outer surfaces of the radial form in the winter period and the smallest shaded percentage occurs in the inner surfaces of the radial form, also during winter.

Table 3: The Variation between the Outer and the Inner Surfaces in the Two Forms

	Summer Period			Winter Period		
	The Outer Surfaces	The Inner Surfaces	The Variation	The Outer Surfaces	The Inner Surfaces	The Varia-tion
The Rectangular U-Shape	% 47.14	% 60.78	% 13.64	% 70	% 38.88	% 31.12
The Radial Form	% 50.49	% 58.40	% 7.91	% 80.63	% 25.07	% 55.56
The Variation	% 3.35	% 2.38		% 10.63	% 13.81	



1.2 North-facing Patterns

1.2.1 The Annual Shaded Area Generated by the Two Forms

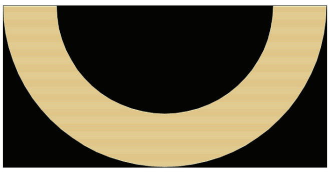
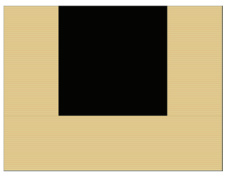
The Average Annual Shaded Percentage per Hour during Daytime	
The Radial Form	The Rectangular U-Shape
The Radial Form: Less Shaded Area	The Rectangular U-Shape: More Shaded Area
	
% 54.89	% 55.76
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 10: North-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

The calculations of the annual shaded area of the north-facing forms demonstrate that the rectangular U-shape produces more shadow than the radial one (Figure 10). This reflects the suitability of the rectangular U-shape for cooling requirements and the higher suitability of the radial form for heating requirements.

1.3 East-facing Patterns

1.3.1 The Average Annual Shaded Area Generated by the Two Forms

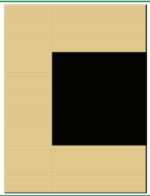
The Average Annual Shaded Percentage per Hour during Daytime	
The Radial Form	The Rectangular U-Shape
	
% 52.18	% 53.96
More Suitable for Heating Requirements	More Suitable for Cooling Requirements

Figure 11: East-facing Patterns: The Average Annual Shaded Area Generated by the Two Forms

Figure 11 reveals that the annual shaded area is bigger in the case of the east-facing rectangular U-shape and smaller in the case of the east-facing radial form. Thus, it can be derived that the rectangular U-shape is more suitable for cooling requirements, while the radial form is more suitable for heating requirements.

1.4 A Comparison Between Radial forms and Rectangular U-Shapes with Different Orientations

1.4.1 A Comparison between the Annual Shaded Area Generated by the Radial Forms and the Rectangular U-shapes

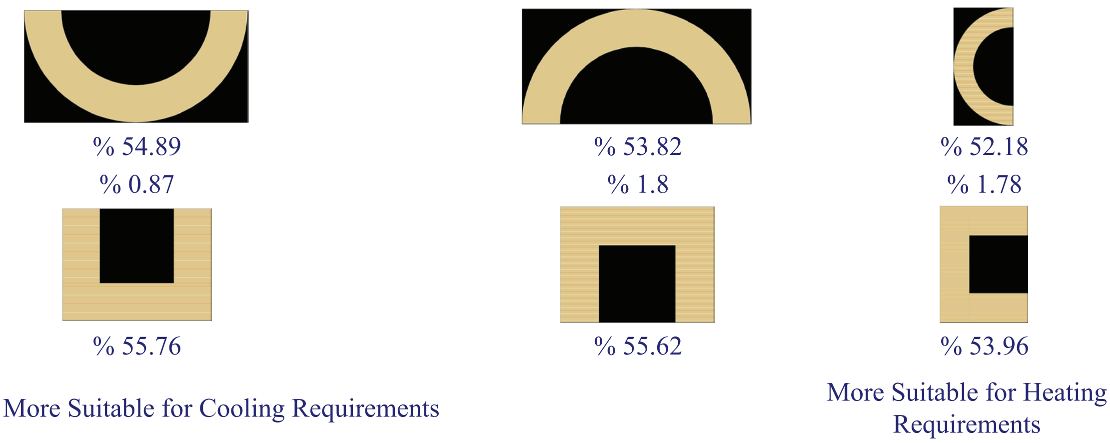


Figure 12: The Shaded Area Generated by the Radial Forms and the Rectangular U-shapes

By studying the resulting calculations of the annual shaded areas of U-shapes and radial forms in the three different orientations, it becomes very obvious that in all identical orientations, the rectangular U-shape is always more shaded than the radial one (Figure 12). In the two patterns, forms oriented towards the north generate more shadow than other forms, while the forms oriented towards the east generate the least amount of shadow. However, the least amount of shaded area is generated by the radial form oriented east (52.18), while the biggest shaded area is generated by the north-facing rectangular U-shape (55.76). Thus, the east-facing radial form is the most preferable form for heating requirements, while the north-facing rectangular U-shape is the most preferable form for cooling requirements.

In Palestine, the preferable orientation of the form has also to be guided by the period of the major concern; the choice between forms also depends on geographical location. The climate along the coastal plain (which has a hot, humid summer and a temperate winter) requires passive solar solutions of a limited extent, the major concern being to avoid summer heat. The mountain area (which has a cold winter and temperate to hot-dry summer) requires better passive solar heating systems for winter, as the major concern is to receive winter sunrays. Thus, in Palestine, the east-facing radial form could be more suitable in the mountain area, while the north-facing rectangular U-shapes could be more advantageous in the coastal plain.

1.5 Conclusion

The measurements of the annual shaded area generated in the two south-facing forms show that the annual shaded area is greater in the case of the rectangular U-shape and therefore it is more suitable for cooling requirements, while the radial form can be more suitable for heating requirements. As the variation between the outer and the inner surfaces is less in the case of the rectangular U-shape, this form is more suitable for bilateral buildings. The radial form is more beneficial in unilateral buildings, as its south-facing inner surfaces are less shaded than the inner surfaces of the rectangular U-shape over the year.

The south-facing radial form has the least amount of shadow in winter when sun exposure is desirable and the greatest amount of shadow in summer when sheltering the building from sunrays is required. Thus, in Palestine and other temperate climates, the radial form may be preferable, as the form has better insolation efficiency. However, the fact that the radial form is less shaded than the rectangular U-shape, predominantly in winter, makes the form more beneficial in the mountain areas. This makes the radial form more effective in gaining winter sunrays and consequently heat when it is crucial in the mountain area.

The calculations of the annual shaded area of the north and east-facing forms demonstrate that the rectangular U-shapes produce more shadow than the radial ones. This reflects the suitability of the rectangular U-shape for cooling requirements and the higher suitability of the radial form for heating requirements.

By studying the calculations of the annual shaded area of the radial and the rectangular forms in the three different orientations, it becomes very obvious that in all identical orientations, the rectangular U-shape is always more shaded than the radial one. In the two patterns, the north-facing forms produce more shadow than other forms, while the east-facing forms generate the least amount of shadow. However, the least amount of shaded area is generated by the east-facing radial form, while the biggest amount of shaded area is generated by the north-facing rectangular U-shape. Thus, the east-facing radial form is preferable for heating requirements, while the north-facing rectangular U-shape is preferable for cooling requirements. In Palestine, the east-facing radial forms could be more suitable in the mountain area, while the north-facing rectangular U-shapes could be more advantageous in the coastal plain.

References

1. Ching, F. (1996) "Architecture: Form, Space, & Order", 2nd ed. New York: Von Nostrand Reinhold.

2. Cook, J. (1991) "Searching for the Bioclimatic City, in Architecture and Urban Space". In: Proceedings of the 9th International PLEA Conference, Seville, Spain, 24-27 September, pp. 7-16.

3. Al-Qeeq, F. (2004). Urban and Solar Design Potential of Buildings with Radial and Rectangular Plans (With Reference to Palestine). PhD Thesis: United Kingdom, Nottingham University.

4. Martin, L. and March, L. (1972) "Urban Space and Structures". London: Cambridge University Press.

5. Mascaro, L., Dutra, G. and Finger, F. (1998) "Environmental Aspects of the Urban Precincts in Subtropical City". In: Environmental Friendly Cities, Proceedings of the 15th PLEA Conference 98, Lisbon, Portugal, June, pp. 99-102.

6. Meir, A. I., Pearlmutter, D. and Etzion, Y. "On the Microclimate Behaviour of Two Semi-enclosed Attached Courtyards in a Hot-dry Region". Building and Environment, Vol. 30, N0. 4, 1995, pp. 563-572.

7. Ratti, C., Raydan, D. and Steemers, K. (2003) "Building form and Environmental Performance: Archetypes, Analysis and an Arid Climate". Energy and Buildings, Vol. 35, No. 1, pp. 49-59.

تحليل أثر التشميس لأشكال عمرانية مركبة :
مقارنة بين الشكل النصف قطري ومستطيل الشكل كحرف (U)

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ملخص

القالب الهندسي للتشكيلات العمرانية المختلفة هو أحد أهم الأدوات التصميمية، فالنماذج العمرانية المختلفة تتسبب في تأثيرات على المناخ الخارجي تنعكس بالسلب أو الإيجاب على راحة الإنسان. لذلك فان التعامل بفهم مع شكل الخطوط الخارجية لمسقط المبنى يمكن أن يسهم في تغيير معطيات المناخ بما يحسن من الراحة الحرارية داخل المبنى وفي محيطه، وبالتالي التقليل من استهلاك الطاقة المستخدمة سواء لتدفئة المبنى أو تبريده. الأشكال العمرانية تستطيع أن تعدل من خصائص المناخ الخارجي وخاصة تلك التي تكون فراغ محاط ومعرف بجدران يساعد في توفير حماية ذاتية ضد عوامل المناخ الغير مرغوب بها. هذه التشكيلات والتي تمتاز بقدرتها على تكوين ظلال ذاتي مألوفة بشكل كبير ضمن النسيج الحضري، وهذه التشكيلات مفيدة للمناطق السكنية، حيث أنها تكون فراغات معيشية مريحة يمكن أن تستخدم كملاعب للأطفال وتعزيز العلاقات الاجتماعية للسكان. الدراسات السابقة في هذا المجال ركزت بشكل أساسي على الأشكال المبسطة ولم تولي اهتمام كافي لدراسة أشكال أكثر تعقيداً، وهذه الدراسة تبحث في التأثيرات المناخية لأشكال مركبة تشمل الشكل النصف قطري والشكل الذي يحاكي الحرف (U)، وهذه الأشكال يمكن اعتبارها كحلقة وسيطة بين النماذج العمرانية المحكمة الإغلاق والمساقط المفتوحة بالكامل. في فلسطين والمناطق المعتدلة مناخياً، فان الأشكال العمرانية النصف مغلقة يمكن أن تكون مناسبة، حيث أن النماذج العمرانية ذات المساقط المفتوحة أو المغلقة بالكامل غالباً ما تكون مناسبة للمناخات الباردة جداً أو الحارة على التوالي. هذه الدراسة تقدم منهج شمولي لكيفية تحليل تأثير التشميس الواقع على الأشكال العمرانية بحيث يتضمن كافة النقاط المطلوب التحقق منها لاستخلاص أقصى الفوائد المرجوة. كذلك توضح الدراسة كيف تمكن هذه المنهجية والتحليلات من ربط تأثير التشميس بعوامل التصميم وحفظ الطاقة في المباني. بالإضافة إلى ذلك فان هذه الدراسة تيسر وتسرع في الأبحاث المستقبلية في هذا المجال كون هذه المنهجية قابلة للتطبيق على كافة النماذج العمرانية بغض النظر عن اختلاف أشكالها.