FROM COMPUTER MODELS TO SIMPLE DESIGN TOOLS:
SOLAR RIGHTS IN THE DESIGN OF URBAN STREETS

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ABSTRACT
This work presents a simple design tool for the consideration of solar rights in urban design that was developed by the use of the computer model SustArc (Capeluto and Shaviv, 1997). This simple design tool allows the generation and evaluation of building configurations, ensuring solar rights of each neighboring building, as well as those of open spaces among them, by using the concept of solar envelopes without the need to be familiar with any specialized software. The idea of the present work is to provide the architect with simple easy to use nomograms that can help him during the early design stages to determine the open spaces and the street profile, based on the desired density level, project location and orientation. The nomograms are based on objective criteria for solar exposure of building facades for different zones of the city like the center or the periphery. The paper presents the creation process of the nomograms, and their use and application by a case study.

INTRODUCTION
The consideration of solar rights in urban design is essential in order to allow passive heating of buildings in winter and to improve the comfort conditions of people in streets, sidewalks and open spaces. A design that doesn't consider the solar rights of buildings and open spaces may cause uncomfortable conditions inside the buildings and in the streets. During the schematic design stages of urban quarters, the designer deals mainly with geometrical characteristics of the buildings i.e. their proportion, height, distance between each other, etc. that have crucial influence on future performance and quality of the built environment. These parameters are related to the profile, dimensions and orientation of streets and open spaces. Various research works have proposed different computer-based methods to deal with this issue: from evaluative tools, like shadow cast programs or sun's view axonometric projections (Kroner and Abrey 1985, Yezioro and Shaviv, 1994), to generative tools, like the solar envelopes. However, the use of such tools depends on profound knowledge of the computer programs, or on the hire of expert consultants, both of them not always affordable by architects during the early stages of the design process. This work presents a simple design tool, which can be used by the designer as a design guide from the very schematic design stages, without the need of using computer models or defining a large amount of input data. The tool was developed through the generative computer model SustArc developed by Capeluto and Shaviv (1997). SustArc allows the generation and evaluation of different building configurations, ensuring solar rights of each neighboring building, and open spaces like sidewalks, gardens and squares. The model presents the maximum available volume in which it is possible to build without violating the solar rights of any existing building, as well as the designed one. The idea of ensuring solar access is not new; the Roman Empire had solar access laws; the "Leyes de Indias" (The Law of the Indies) that were applied on the foundation of new towns in America consider block layout and street orientation to allow solar access, and the Doctrine of Ancient Lights protected landowners’ rights to light in nineteenth-century Britain. Additionally, several U.S. communities adopted solar access regulations in response to the energy crisis and as a way to save energy and reduce air pollution and costs. In these examples, daylight and solar radiation are considered as significant factors in the determination of urban development policies.

Solar Envelopes as a Design Tool
Different research works dealt with the determination of solar envelopes for various design purposes: Shaviv (1975) proposed a computerized model for the design of fixed external sunshades. The method was extended later on for generation of solar rights envelopes for the design of solar communities (Shaviv, 1984). Arumi (1979) developed a computerized model that determines the maximum allowed height of a building that does not violate the solar rights of the existing neighboring buildings. Knowles (1981) suggested a method for assuring solar access to each residential unit in a community. De Kay (1992) made a comparative analysis of various envelopes allowing daylight access. Schiler and Uen-Fang (1993) developed a computer program...
for the generation of solar envelopes for flat-rectangular sites based on Knowles' work, and Koester (1994) presented energy armatures using passive resources like winds and rain water, for urban sustainable development.

Capeluto and Shaviv (1997, 2001) suggested the creation of two different types of solar envelopes, which are ‘The Solar Rights Envelope’ (SRE) and ‘The Solar Collection Envelope’ (SCE). These envelopes are defined for a built area as follows:

‘The Solar Rights Envelope’ presents the maximum buildings’ heights that do not violate the solar rights of any existing buildings, during a given period of the year (Fig. 1).

‘The Solar Collection Envelope’ presents the lowest possible locus of windows and passive solar collectors on the considered building’s envelope, so that they are not shaded by the existing neighboring buildings, during a given period of winter (Fig. 1).

Clearly, it is possible to determine the volume between both envelopes. This volume is called the ‘solar volume’ (SV), and can be defined as follows:

‘The Solar Volume’ contains the maximum buildings’ volume to be designed so that these buildings allow solar access to all the surrounding buildings, and at the same time are not shaded by them, during a given period of the year (Fig. 1).

Figure 1 Solar Envelopes: Solar Rights Envelope (1), Solar Collection Envelope (2), and Solar Volume

In a non–built area, we can define lines on the ground to border each subdivision. In this case, the SRE obtained for each subdivision is also the SV. If all buildings’ heights will be designed below the SRE, the solar rights of each building will be ensured (Fig. 2).

SOLAR ENVELOPES AS A TOOL FOR URBAN DEVELOPMENT

The solar envelopes may be implemented by planning authorities as a mean of controlling development. As an example, the solar envelopes were adopted recently by the planning authorities of Tel Aviv municipality for the development of a 250 dunam new business district (Capeluto et al. 2003).

Solar exposure is undesired in Tel Aviv during the summer but it may transform any open space and park to a very pleasant and enjoyable place in winter. Therefore, permanent shading, even if needed in summer, compromises winter exposure. A dynamic solution, such as planting deciduous trees in open spaces and sidewalks to allow shading in the summer and solar insolation in winter, is preferred. In general, at least one pedestrian sidewalk should be exposed to winter sun to provide thermal comfort in winter. The other sidewalk, which is shaded by the building in winter, can be protected from the summer sun by permanent shading devices, or by evergreen trees. On top of it, in Israel there is a requirement by law, for every residential unit, to install solar panels for hot water. It is mandatory, therefore, that these panels will be exposed to the sun all year around.

In this case the requirement was to achieve solar access during the entire winter, between 8 a.m. and 3.00 p.m., in the existing residential neighborhood, as well as in the main avenue that is the only available existing green open area. The solar envelope that fulfills the above requirement was accepted as a design ordinance for the relocation or reshaping of the tall buildings in the business district. Although the requirements were only to ensure solar access to the residential neighborhood, the demand that the main two avenues from west to east will be exposed to the sun during the same period was considered. This is in
order to ensure that the morning and afternoon walk from the railway station to work, will be in the sun (Fig. 3). Moreover, it was suggested that the main inner street parallel to the main green avenue would have solar access during lunchtime from 12.00 to 13.00. These requirements will allow people to enjoy walking in the sun through the two avenues that lead them to the main green avenue, to have lunch in the garden, or in the planned restaurants along the green avenue.

Figure 3 presents the solar envelope that fulfills these comprehensive requirements. All buildings higher than this envelope (these are the buildings that can be seen above the net of the envelope) must be displaced to another location, or should be reshaped. This is a descriptive approach, in which all possible consistent solutions are given in advance. However, we mixed this descriptive approach with a performance one, by allowing some exceptions, as long as the shading caused by these buildings is not above a given standard. The determination of such a standard should be done considering the influence of solar radiation on the overall energy performance of the buildings as well as taking into account pedestrians comfort conditions in open spaces. Until now, several tall buildings have already been relocated and reshaped, so that they will not stick out from the given solar envelope.

Figure 3 The solar envelope that ensure solar rights in the existing residential neighborhoods as well as in the main avenues and streets.

As said before, there are still no urban standards and legislation in Israel about how much a building may shade its neighboring buildings and open spaces. However, in the new energy code for residential buildings, there are regulations about windows’ insolation requirements as will be described in the next section.

REGULATIONS AND APPLICATIONS

The energy code

A new energy code for residential buildings defines the percentage of solar insolation needed in winter (Shaviv et. al., 2002) (see Table 1). The code was based on a study that examined the effect of solar insolation on energy consumption in buildings. The study showed that exposure to the winter sun may reduce energy consumption significantly. The effect of insolation depends on the orientation of the façade, and was found especially important for all southern orientations (SE, S and SW) and to some extent on the east and west façades (Fig. 4). The energy consumption was only slightly influenced by the amount of insolation on the northern facades.

Figure 4 The effect of winter solar insolation for different orientations for a middle floor apartment in Jerusalem. The northern orientations which are nearly unaffected are in grey

The amount of effective insolation was different for each of the four climatic zones in Israel. Therefore, the energy code defines different requirements for each of these zones.

The energy code also defined two levels of energy conservation: a basic level and a high ("green") one. The requirements relate to these levels as well and indicate full and partial exposures. It is suggested that full exposure will be implemented for the city's peripheral areas to achieve better climatic comfort, while partial exposure will satisfy the requirements for more central areas where high density is desirable.

Methods of application

There are two approaches to apply solar rights regulations:

- The performance method which defines the number of insolation hours needed (Melbourne City Council, 1995, 1998).
- The descriptive method in which the geometry of the buildings that meet the requirements is defined by regulating building heights as in San Francisco (SFgov website).

This work suggests three levels of application for the regulations defined by the energy code, based on the
two mentioned approaches (Cape1uto et al. 2004, Shaviv et al. 2005):

1. The basic level is based on the performance approach. It defines the required amount of radiation for each orientation, urban location and climatic zone (Table 1). This method allows freedom in design, but is complicated for validation by the designers and authorities.

2. The second level, also based on the performance approach, indicates the insolation hours which meet the radiation requirements (Table 2). Validation of keeping the demands is possible but still requires specific knowledge and the use of specific software.

3. The third level is a descriptive method, based on the insolation hours indicated. It presents the use of solar section lines that were developed from the solar envelope by using SustArc. These section lines serve as a simple tool for solar rights design (Fig. 5). This method is easy to validate since designing according to these lines will always keep the requirements.

**Table 1**

<table>
<thead>
<tr>
<th>Orientation</th>
<th>Climatic Zone</th>
<th>Required Radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>Central</td>
<td>0.70</td>
</tr>
<tr>
<td>North-East</td>
<td>Central</td>
<td>0.71</td>
</tr>
<tr>
<td>North-West</td>
<td>Central</td>
<td>0.80</td>
</tr>
<tr>
<td>South</td>
<td>Central</td>
<td>1.18</td>
</tr>
<tr>
<td>South-East</td>
<td>Central</td>
<td>1.28</td>
</tr>
<tr>
<td>South-West</td>
<td>Central</td>
<td>0.72</td>
</tr>
<tr>
<td>East</td>
<td>Central</td>
<td>1.26</td>
</tr>
<tr>
<td>East-West</td>
<td>Central</td>
<td>1.26</td>
</tr>
<tr>
<td>West</td>
<td>Central</td>
<td>0.70</td>
</tr>
<tr>
<td>North</td>
<td>Peripheral</td>
<td>0.70</td>
</tr>
<tr>
<td>North-East</td>
<td>Peripheral</td>
<td>0.70</td>
</tr>
<tr>
<td>North-West</td>
<td>Peripheral</td>
<td>0.70</td>
</tr>
<tr>
<td>South</td>
<td>Peripheral</td>
<td>1.18</td>
</tr>
<tr>
<td>South-East</td>
<td>Peripheral</td>
<td>1.19</td>
</tr>
<tr>
<td>South-West</td>
<td>Peripheral</td>
<td>0.70</td>
</tr>
<tr>
<td>East</td>
<td>Peripheral</td>
<td>1.26</td>
</tr>
<tr>
<td>East-West</td>
<td>Peripheral</td>
<td>1.26</td>
</tr>
<tr>
<td>West</td>
<td>Peripheral</td>
<td>0.70</td>
</tr>
</tbody>
</table>

The solar rights requirements defined by the energy code refer to residential buildings alone, but this work extended the applications for the design of open spaces such as streets, sidewalks and parks as well. When designing open spaces, the amount of radiation is irrelevant, thus one must keep either the required insolation hours or use the section lines.

**THE SIMPLE DESIGN TOOL**

The section lines defined for the descriptive method are based on solar envelopes such as described in the previous sections. The solar envelopes were created to keep the required insolation hours for each orientation, climatic zone and urban location. Each section line represents the critical (lowest) slope of the relevant envelope.

Buildings that are lower than the section lines will keep the required hours of insolation for the relevant orientation. The section lines are used in three ways:

- To keep solar rights of neighboring residential buildings by defining a base point at the lower part of the first residential floor and using it to create the section lines to limit the building’s height (Fig. 6).
- To keep solar rights of sidewalks it is required to expose at least 1 to 2 meters of the sidewalk on one side of the street (1m for central locations and 2m for peripheral). Therefore the base point of each section line is defined accordingly (Fig. 7).
- To keep solar rights of other public open spaces one must follow three steps (Fig. 8):

1. Defining a triangle of the area needed to be insolated in the North-East and North-West sides (30% for central locations and 40% for peripheral (Yezioro et al. 2005)). The hypotenuse should be parallel to the open space’s diagonal.

2. Defining the base points of the section lines in the middle of the triangle’s hypotenuse.
3. Creating the section lines using the angle of the south to limit buildings on the east, south and west sides.

In cases where the open space is positioned 45° from main orientations, there would be only one triangle in the north. The section lines of the south will limit the buildings on the south-east and south-west sides.

![Figure 6 Keeping solar rights of facades: defining base points at the lower part of the first residential floor, and using the section lines from these points to limit building heights. Example for a 12m wide street in Jerusalem](image)

![Figure 7 Keeping solar rights of sidewalks: defining base points at 2m from the edge of the sidewalk, and using the section lines from these points to limit building heights. Example for a 12m wide street in Jerusalem](image)

![Figure 8 Three steps for keeping solar rights in open spaces. 1) defining the area of exposure, 2) defining base points of section lines, and 3) limiting heights on the east, south and west sides](image)

### CASE STUDY

The use of the solar section lines was evaluated by a case study of several examples for Jerusalem. The study defined a simple urban tissue and examined several possible situations in it. The main goal was to assess the urban density that can be achieved while ensuring solar rights using the proposed lines.

The analysis examined three different cases:

1. Different arrangements of row buildings, a typical building block in Israel which was found to be energetically efficient (Capeluto et. al. 2004), in several crossing-streets tissues (Fig. 9),

2. Two types of buildings located perpendicular to different streets (Fig. 10), and

3. Combinations of commercial and residential buildings (Fig. 11).

![Figure 9 Example of an arrangement of row buildings: buildings positioned with long elevation facing northwest-southeast, with a 20m street perpendicular to them, going northwest-southeast](image)
Description of the examined urban tissue

All cases examined refer to the same urban tissue of two crossing streets:

- One 20m wide street including the road, sidewalks and parking on both sides and,
- One 12m wide street including the road and sidewalks but no parking.

Eight lots the size of 30m*67m with buildings are positioned along these streets in the following manner (see Fig. 9):

- Group A - two lots perpendicular to one street (one on each side),
- Group B - two lots parallel to the other street (one on each side) and,
- Group C - four lots on the intersection of the streets (one in each corner).

The evaluations included this tissue oriented in eight possible directions so that each street is positioned in one of four orientations:

- North-South (NS),
- East-West (EW),
- Northeast-Southwest (NESW) and,
- Northwest-Southeast (NWSE).

Exposure requirements

The requirements were to ensure the solar rights of all residential facades from east to west through the south, and to expose at least 1m of sidewalks (on one side of each street at a time).

Densities in a crossing-streets tissue

The analysis showed that buildings' heights reached 5 to 11 floors and FAR (Floor Area Ratio) rates ranging from 170% to nearly 300%, according to the orientation (Fig. 12). In most orientations, buildings that were perpendicular to the street were affected mostly by the section lines from the neighboring buildings, thus the width of the street was insignificant. Nevertheless, buildings that were parallel to the streets were mostly affected by their width.

Analyzing the overall urban tissue for each orientation revealed that the orientations giving the highest FAR rates positioned the buildings with their long elevation facing east-west which is not recommended climatically (Fig. 13). However, tissues with buildings facing north-south resulted in much lower densities. Orientations in 45° from the main are probably the optimal cases giving reasonable densities with good orientations for the buildings.

Figure 12 Density and building heights of row buildings according to orientation of street in Jerusalem

Figure 13 Average densities for urban tissue of row buildings in Jerusalem. Categories represent orientation of long facade of buildings; series represent width of street perpendicular to them
Densities for different types of buildings

Compact buildings with 8 apartments per floor (C8) were also found to be energetically efficient. Since they have quite a different layout than row buildings, they were evaluated as well and compared with row buildings. The comparison was made for buildings perpendicular to the streets (group A).

The results showed that there was no difference in buildings' heights between building types, therefore the C8 buildings gave higher FAR rates since their floor area is larger (Fig. 14).

Urban Density - Summary

![Diagram showing urban density for C8 and R buildings](image1)

**Figure 14** Urban densities of row buildings and compact (C8) buildings according to orientation of street in Jerusalem. The density for each street is the average of densities of buildings on both sides of the road.

C8 buildings have another advantage when positioning them in the orientation giving the highest density (long elevation facing east and west), since their layout allows even in this position, at least half of the apartments to benefit from southern windows. This is much more complex to achieve in the case of row buildings. Nevertheless, row buildings have an advantage in the 45° rotated orientations when all apartments face southeast or southwest (see Fig. 6 and 7).

Residential buildings with commercial floors

Keeping solar rights is important for residential buildings and open spaces. Commercial use and offices do not require as much insolation, therefore, designing buildings with commercial and/or offices in the lower floors, may increase the total density achieved. Naturally, this is relevant in central areas of the city.

The maximal density that can be achieved was calculated for both types of buildings (Fig. 15). Assuming that all neighboring buildings were the same, the only limitation to buildings' heights were the sidewalks which still require insolation. In these cases, the base points for the buildings are elevated along with the first residential floor (see Fig. 11). In these cases the relative residential FAR ratio is significantly decreased while the overall density is highly increased, which is typical to city centers.

DISCUSSION

Using solar envelopes as guidelines for urban design is a powerful tool that relies on the expertise of a consultant. Nevertheless, solar envelopes could be defined by the urban designer together with the expert, and be given to building designers as mandatory ready-to-use instructions. In this case, the envelopes may become quite a simple tool, as was applied by the Tel Aviv planning authorities. Its advantage is that the envelope allows freedom of design within its volume. Using solar envelopes as ready-to-use instructions holds two major disadvantages. The predefined envelopes keep the solar rights of the neighboring buildings and open spaces, but disregard the solar rights needed between buildings in the same project. Moreover, the envelopes are created for a specific designed situation, and become unfit if the urban situation is changed, thus require the rehiring of an expert.

The solar section lines are much easier to handle by the authority. It is also very simple and can be used anywhere with no connection to local urban design. Therefore, changing city plans will not affect the ability to keep solar rights. The solar section lines can be used for ensuring solar rights between buildings of the same project as well as between parts of a single building (Shaviv et al. 2004, Bleiberg et al. 2005). However, the section lines are geometrically limiting.

CONCLUSIONS

This paper discussed the use of solar envelopes to create a simple tool that can be used in design to keep solar rights. It presented the importance of keeping...
solar rights and defining tools that may be easy to use by designers as well as easy to enforce by authorities.

The use of a solar envelope as mandatory guidelines for design was implemented by Tel Aviv municipality for a specific area. This paper discussed the advantages and disadvantages of using the envelopes this way, and presented the solar section lines as an alternative for a simple design tool that is based on solar envelopes but may be used independently.

The case studies made as part of this work confirm that designing to keep solar rights using the solar section lines may achieve quite high densities, and be used in versatile ways. The only disadvantage of the section lines is their geometrical limitation.

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REFERENCES


Melbourne City Council 1995 Building Design Planning Requirements.

Melbourne City Council 1998 Local Planning Policy, Chapter 22, Urban Design.


SFGov - San Francisco City and County web site http://www.ci.sf.ca.us/planning


