Low Energy Urban Block: Morphology and planning guidelines

1.0 Introduction: Relevance of low energy urban block

The clear and persistent threat of climate change urges mankind to charter a direction towards a low carbon society. The "*2 Kilowatt society"* as a vision of a low carbon society requires substantial commitment from the developed nations of the world. Western Europe consumes 4-6Kw/cap of primary energy and substantial efforts are needed to reduce this energy consumption (Winter C.J. 1993). Development of Renewable energy resources is extremely crucial to achieve this target and solar energy is regarded as one most appropriate technology available to achieve a low carbon future. According to the European Commission about 13% -20% of primary energy requirements of its 12 members can be met by passive utilization of solar energy for thermal and lighting needs of domestic and non domestic building stock. In West Germany 1000K/ m² of aggregate wall and roof area is available with southern exposure which has a potential power generation capacity of 100 tetra watt-hours which is equivalent to 25% of the annual electricity production in 1980's (Winter C.J. 1993). Passive solar design can have substantial energetic benefits both at the demand and supply side of energy consumption spectrum. In UK Passive solar homes, without using active solar collectors, can reduce heating energy consumption up to 2000 kWh/annum compared to conventional housing (ETSU figures, Littlefair PJ 2002). Considering this huge photovoltaic potential, designing cities to access light and heat from the sun seems to be a logical decision.

Urban design and planning as form givers of cities play a vital role in realizing this tremendous energetic potential of urban form. Respecting solar access for day lighting and passive heating has been a standard norm for urban design in many cities like Los Angeles or San Francisco. Traditional settlements like the Pueblos of Mesa Verde, Colorado demonstrate a remarkable ability to utilize solar energy by establishing a relationship between the sun path and urban form. Sustainable master planning today is the norm rather than an exception and planers have several sophisticated decision support tools and policies available to their disposal. Energy concerns are even better addressed today especially at the building level through strict building design codes for application of passive solar design through use of sunspaces, advanced glazing, solar thermal collectors, heat pumps and photovoltaic building shells. Research and strict monitoring has resulted in design efficiency at both the ends of the development spectrum. However, a grey area still exists where Urban Planning guidelines and building regulations overlap, especially at the urban block level where neither planning nor building design regulations are effective. The morphology of the urban block has been shaped traditionally by issues like land use, transportation and finance which became more relevant at this scale than the architecture of energy efficiency. However climate change has allowed the planners and urban designers to reinvent the contemporary city and with it, it's constituent- the urban block. An environmental approach of designing the low energy urban block is a prerogative and needs to be addressed through innovative design guidelines. The '*Solar Envelope Concept'* introduced by Knowles (Knowles, 1981, MIT) explores this relationship of energy with urban form and can form the basis of solar access guidelines for Urban blocks.

2.0 The solar envelope:

2.0.1 Theory and construction

The "solar envelope" defines the maximum limits of a three-dimensional buildable volume on a given site that does not obstruct more than any pre defined hours of solar access onto adjacent sites and buildings. As a concept, urban blocks designed as solar envelopes will allow maximum photovoltaic potential for the adjacent buildings. The concept can be extended to "*Iso Solar Rights Envelopes*" and "*Iso Solar Collector Envelopes*" (Shaviv E. et al 2005) which allow maximum mutual solar potential for an escalating scale ranging from a building, parts of a building, an urban block to a full city shaped to harness solar energy. *"Solar Rights Envelope"* (SRE) is the maximum building volume that does not violate the solar rights of any existing buildings, during a given period of the year" *Ibid* (Figure1). *"The Solar Collection Envelope"* (SCE) is the lowest possible locus of the considered building's envelope, which are not shaded simultaneously by the existing neighbouring buildings". *ibid* (Figure 1). The volume between both envelopes, called the "*solar volume"* (SV), contains the maximum buildable volume that can 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 *.ibid.* This "*solar volume"* defines the developable volume and become the basis of drawing the design guidance for mutual solar access in a city. As a concept for design guidance "*solar envelope*" is extremely context specific and more dynamic than standardised urban design guidelines.

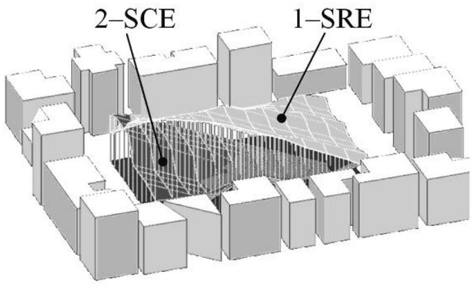


Figure1: Solar Envelopes: Solar Rights Envelope (SRE), Solar Collection Envelope (SCE), and Solar Volume (SV) (Source: Morello E., Ratti C.2008)

The solar envelope of any given site implies a close coupling with the specific solar path of the site and principally should vary even within the districts of a city. However such an ideal situation would be counterproductive and confusing unless computational techniques are used to derive design guidelines. It is perhaps more appropriate to define a limited range of possibilities or even more useful to address the process of arriving at the design guideline for a city rather than trying to specify a common norm or several norms for the city. This paper will thus focus on arriving at the guidance for an urban block through various techniques that can be adopted by planners to draw up guidance rather than discuss any such guidance of a particular city in more detail.

The solar volume is a product of latitude, built context, the size, shape, slope and orientation of the site. Knowles (Knowles, 1974) uses the obstruction angle rule to define the volume of a solar envelope. According to Knowles' definition, the calculation is based on the intersection of 4 boundary solar access conditions that generates a pyramidal volume (fig 2):

- The north face of the volume is generated by the solar angle at noon, winter solstice
- The south face of the volume is defined by the solar angle at noon, summer solstice.
- The west and east boundaries are defined by daily values, depending on the number of hours of guaranteed solar radiation on the surroundings and can be chosen from different seasonal solar paths (i.e. winter solstice or spring equinox)

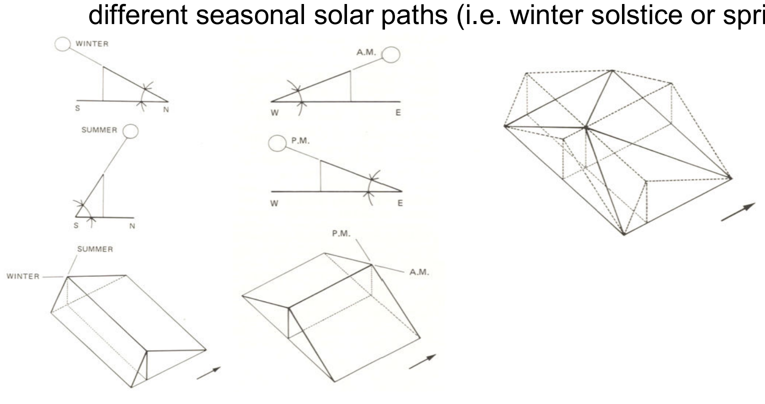


Figure 2: (left) North and South Volume generated from annual limits, (middle), East and West Volume generated by daily limits, (right) Integrated volume (Knowles 1981, p.54-55)

3.0 Spatial constraints of solar envelope

The shape of the "*Solar Envelope*" is defined by desired period of useful insolation in the summer and winter season, the choice of which is the most critical issue. This choice should ideally depend upon a lot of variables co-relating both urban planning and architecture. The time period is decided primarily by the energetic relationship of the concerned urban block and is influenced as much by landuse, built density as it is by its materiality, building use and internal gains etc. The choice also depends upon the desired photovoltaic potential of the built form and should be negotiated against thermal and visual comfort. Various theories exist regarding the choice of the cut-off period. Knowles suggested a weighting of incident solar radiation at different times of the day/year by the sine of the sun's altitude to deduce the useful periods of solar access for energy (Knowles 1981). This requires definition of the term ''Useful" in relation to the technology of energy conversion and solar path. By weighting the solar radiation by α, the solar altitude angle, the incident solar radiation received is deduced a percentage of total solar radiation. Hence

"*When sin 0=0 sun is in the horizon and we receive 0% of total solar energy*
When sin 90=1 sun is in the zenith and we receive 100% of total solar energy". *ibid*

The percentage can then be correlated to absolute radiation levels, plot and decide desired solar radiation levels for different cut-off times in each day, every season.

Cut-off times and thus incident solar radiation can be varied to mitigate variation in climatic zones, shade conditions and building form. By varying the incident radiation it becomes possible, within restrictions, to achieve desirable built form suitable for that radiation level. Theory also suggests that the building parts can be sited purposefully, in space and time, to shade each other as well as provide desired radiation levels.

Apart from Knowles', various other theories exist for determining the cut off period. Pereira and Nome Silva(Pereira et al 2001) suggested a method of combining radiation levels with psycho-physiological requirements by introducing" *pondered radiation*" values over an artificial sky. This method is superior as it introduces the *skydome* which allows the designer to satisfy visual and thermal comfort of building occupants while meeting energy targets. The process is developed further by Ratti and Morello (Ratti et al 2008) where it is now possible to generate iso-solar surfaces to meet any desired radiation levels without using any cut off values.

While the choice of the cut off period of desired solar radiation is most critical various other parameters like latitude, size, shape, orientation and slope of the site are also important.(Figure 3 and 4)

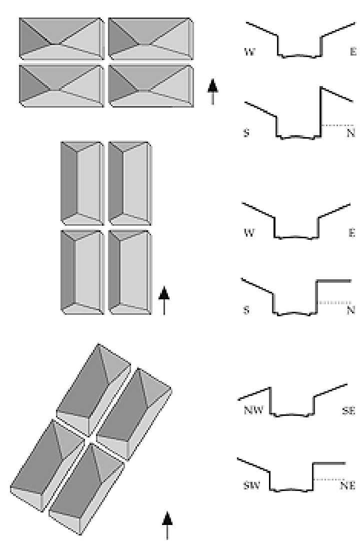


Figure3: Orientation: Three different blocks.

Solar envelopes for East-West oriented blocks have the largest volume and the highest ridges, generally located slightly towards the south face. North-South blocks produce lesser volume with a lower ridge running length-wise down the middle. The diagonal blocks produce the least volume with a ridge along the south-east face. Street sections also vary with orientation. An East-West block orientation is considered better for developmental and photovoltaic potential as it generates 40% more volume and 400% more south surface compared to North-South block orientation. (Knowles 1981, p.64-65)

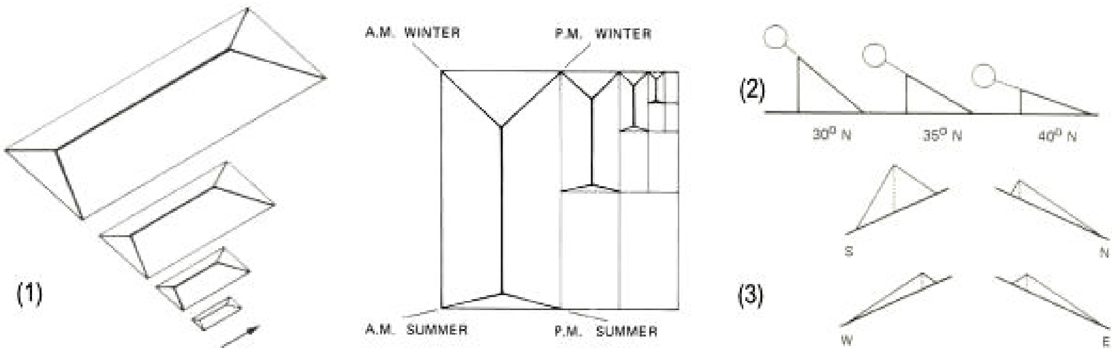


Figure 4: (1) Plot Size: Sites of different size but similar proportion will have solar envelopes of different size but similar proportions, within the same time constraints. (2) Effect of latitude (Left) Mid latitudes are most suitable for solar envelope design. In lower latitudes though allowable volume is larger solar protection rather than solar access is desired. In higher latitudes the solar volume is too low due to low winter sun. (3) Slope: The slope of the site affects both the height and the shape of the envelope. The envelopes over south-facing sites will generally be much higher and have greater volume than those on north slopes. (Knowles 1981, p.64-65)

Other parameters of influence may be summarized as setbacks, fences, streets width, adjacent buildings and landscape elements. Their impact on envelope depends on our attitudes about private and public space as well as about the ethics of solar access. Their impact on solar envelope will be better understood in the next section where the process of solar envelope generation is described.

4.0 Solar envelope generation techniques
There are two ways of generating the solar envelope.

- The *descriptive method* which defines the geometry of the buildings based on solar angles and regulates building heights, setbacks etc Example: San Francisco.
- The *performance method* which defines the number of desired insolation hours or prescribes required radiation levels at the solar envelope, Example: Melbourne.

4.0.1 The descriptive method

4.0.1.1 Geometric construction

The method depends on intersecting the site with vertical planes generated by solar angles. Each plane is generated in accordance with solar azimuth and altitude angles between the defined cut-off times. An example situated at 40°N is presented here in figure 5 below (After Topaloğlu B.2003). Cut-off times are as follows: 09:00 – 15:00 winter (α = 14°, θ = 42° and 318°), 07:00 – 17:00 summer (α = 26°, θ = 100° and 260°). These values can be read off from the sun path or derived from meteorological data. The volume generated with the above mentioned values would not cast shadow beyond the site line (100X75 m) between 9.00-15.00 in winter and 7.00-17.00 in summer.
To increase the built volume even further the planner may decide to shift the shadow line beyond the site, or the R.O.W. to the centre of the road, or the adjacent plot or even the adjacent building lines. By starting the envelop building from a height of 1-2 m above ground the volume can be further enhanced. In fact partial overshadowing of neighbouring facades for part of the year is also feasible. All these measures would increase the buildable volume under the solar envelope.

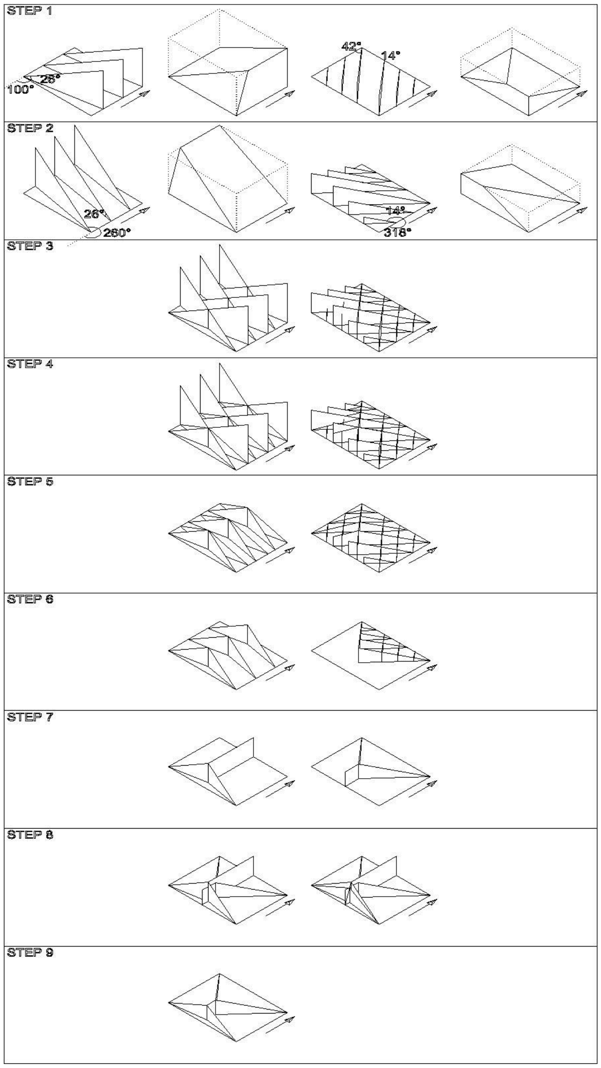


Figure 5:
Solar envelope generated with descriptive method (Topaloğlu B.2003)

Step 1: Planes from Morning Cut-off Times
Step 2: Planes from Afternoon Cutoff Times
Step 3: Intersection of Morning & Afternoon Cut-off planes
Step 4: Indicate Redundancy
Step 5: Eliminate Redundancy
Step 6: Determining the Envelope Hips
Step 7: Determining the Envelope Ridges
Step 8: Connecting the Ridges
Step 9: Final Solar Envelope

4.0.1.2 Profile angle method:

The angle that any surface of the solar envelope subtends with the horizontal surface is called *profile angle* and can easily be read form the sun chart by using a profile angle protractor. Such angles once defined become the input for the solar envelope. Profile angle for the above example is: Winter 9.00 - 20°(W), 18°(N) -15.00 - 20°(E), 18°(N) and Summer 9.00 - 26° (W), 70°(S) -15.00 - 20° (E), 18°(S). The process is shown in figure 6.

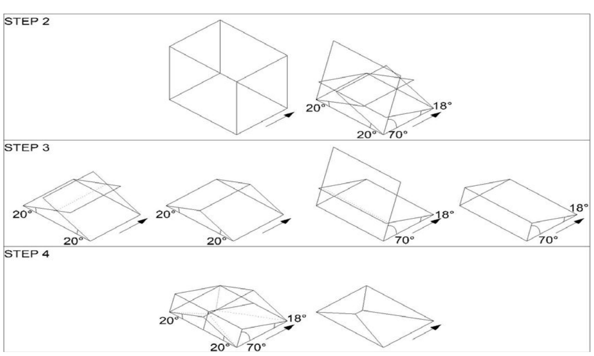
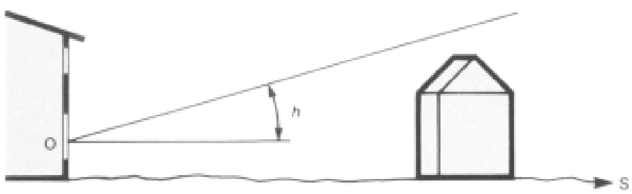


Figure 6:
Solar envelope generation with profile angle method (Topaloğlu B.2003)

Step 1: Decide profile angle
Step 2: Create inclined facades
Step 3: Intersection of inclined facades
Step 4: Indication and elimination of the Redundancies

Profile angle method has been adopted by Building Research Establishment (BRE) for design guidance in UK (Littlefair PJ 2002) where a 25° limiting angle of obstruction measured at 2 m above ground level of a building is suggested for general daylight access. The guidance also describes recommended latitude specific profile angles for passive solar design. For example, if solar gain were required all year at a site in London (52° N) then the maximum obstruction angle *h* in Figure 7 would be 65° - 52° = 13°. In this guidance the cut-off is defined by "*at least one quarter of annual probable sunlight hours, including at least 5% of annual probable sunlight hours during the winter months*" i.e. between 21 September and 21 March. *ibid*



Period of year	London	Manchester	Edinburgh	Other location
All year	13°	11°	9°	65° minus latitude
21 Jan –21 Nov	17°	15°	12°	68° minus latitude
6 Feb –6 Nov	21°	19°	16°	72° minus latitude
21 Feb –21 Oct	27°	25°	22°	78° minus latitude

Figure 7: (Left) The Limiting obstruction angle h to guarantee at least three hours possible sunlight per day in specific period. (Right) Chart showing relation of choice of solar radiation cut-off time period as a function of latitude. (Source: Littlefair PJ 2002)

4.0.2 The performance method

In the performance approach the required amount of solar radiation for each orientation, urban location and climatic zone is defined by the guidance which the planner/designer should ensure through his design. This process allows the planner more freedom to decide the cut off and thus the solar volume as long as the volume meets the desired insolation levels. Ratti and Morello (Ratti et al 2008) has developed a computational process through a DEM(Digital Elevation Model) to generate a solar envelope for required radiation levels (Figure 8). However since this process requires elaborate computation, despite being very flexible and accurate, it would not be intuitive enough to lend itself as a design guideline. More work has to be done on this system to introduce it at the design guideline level.

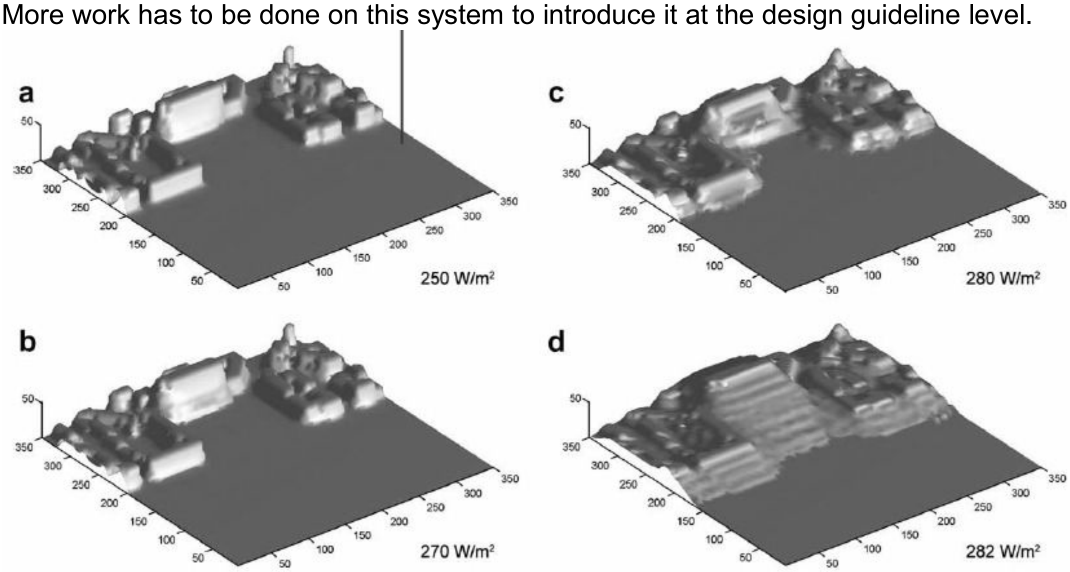


Figure 8. Iso-solar collector surfaces (CSE) developed on site in Milan; the chosen surfaces collect, respectively, (a) 250, (b) 270, (c) 280, and (d) 282 W/m2. Their height increases with increasing irradiation levels and any built form can be used according to the required photovoltaic potential. (Source: Ratti et al,2008)

4.0.3 The descriptive/performance method

A method developed by Shaviv (G.Capeluto et al, 2006) uses *solar section lines* as a simple tool for solar rights design. These section lines ensure the solar rights of the surrounding buildings and open spaces according to predefined cut-off values of solar radiation. A simple nomogram can be generated based on the cut-off values for different typical city locations depending on the context, built density, land use etc. The section lines shown in the figure 9 below represent critical (lowest) sun angle for the time period on all facades of a building shown for two districts in Tel Aviv.

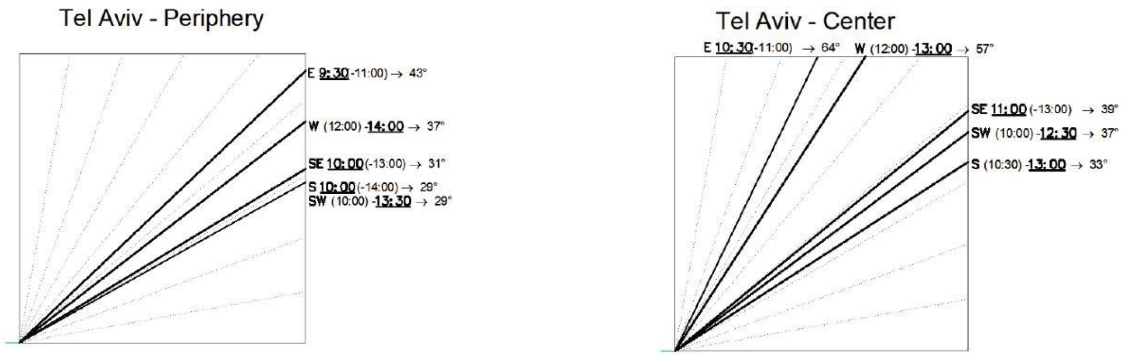


Figure 9: Section lines for Tel Aviv, central and peripheral locations. The hours of insolation required are mentioned next to each line. The critical hours are underlined. (G.Capeluto et al ,2006)

Based on these section lines the following solar envelope sections guaranteeing solar access to buildings, streets and open spaces are generated (Figure 10 and Figure 11).

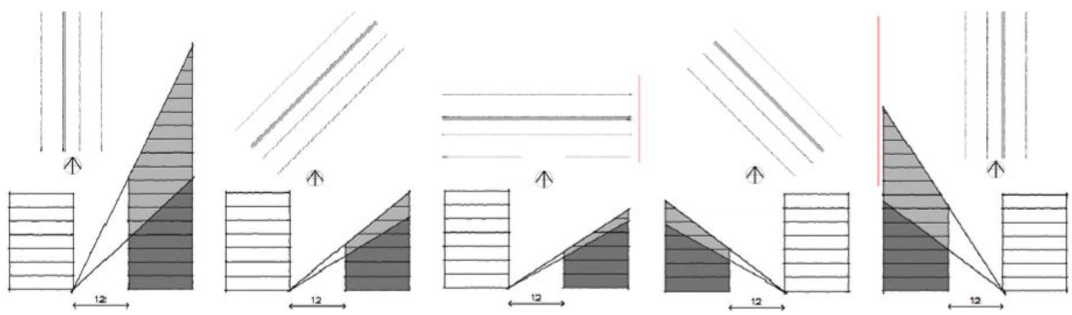


Figure 10: Solar envelope for different orientation respecting solar access of adjacent buildings. The distance between buildings is 12m. If the solar envelope calculation starts from 2m above the ground floor higher densities can be achieved. The dark shade represents peripheral areas and the light shade the central areas. (G.Capeluto et al, 2006)

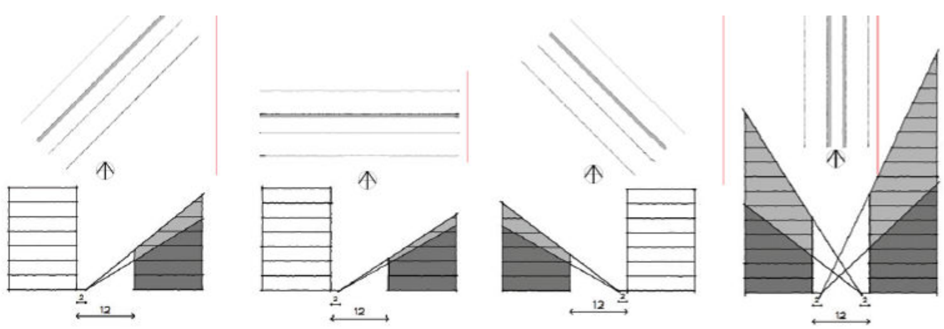


Figure 11: Same figure as above respecting solar access of a 2m sidewalk. The dark shade represents peripheral areas and the light shade the central areas. The volume generated would be higher than the previous figure. *(G.Capeluto et al, 2006)*

The rules of envelope generation through solar section lines discussed above have been employed to generate the solar envelope for a housing block in central Tel Aviv (Figure 12 below) *ibid*. The typical urban fabric has 20m and 12 m street width with 30mx67m plot size. The solar access condition allows sunlight to the first floor of neighbouring blocks and 1m width of sidewalks for the predefined cut-off period. 30 % area of the common open space between the buildings will also receive solar radiation throughout the year. The results show that an FSI of 1.9 to 3.8 could be achieved depending on the orientation as against a standard FSI of 2.0. A higher FSI could be achieved in the suburbs where higher solar angles are permitted.
The solar envelope ensures access to solar energy even at higher densities which would otherwise be violated with standard design guidance. Such guidance system would be beneficial for an urban block where density is an important criterion. However it is to be noted that FSI is a function of the latitude of a place and in high latitudes it is difficult to achieve very high FSI unless the level of solar access is more moderate. In lower latitudes much higher FSI is possible but it would not be advisable to design for extensive solar envelopes due to the high radiation levels in such latitudes. In fact project guidance for solar access in lower latitudes should be limited by the actual demand for photovoltaic potential and the in general the project should look for self shading urban forms, especially for buildings which require daytime occupation.

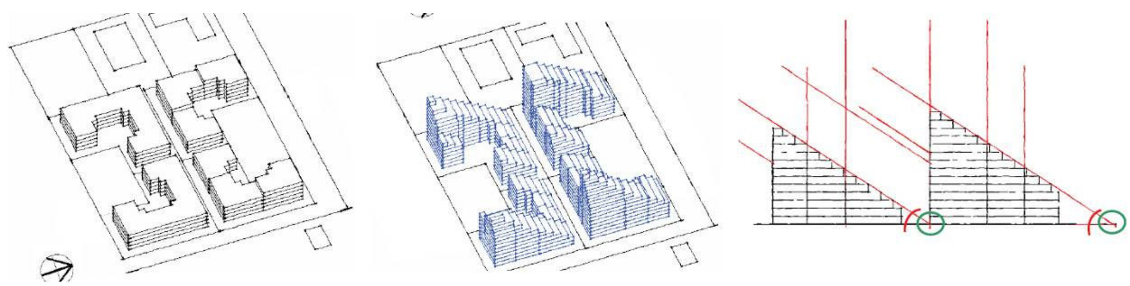


Figure.12: (Left) Standard design guidance FSI 1.9. (Middle)Solar envelope allows higher FSI of 3.8 and improved solar potential (Right) The basis of solar envelope guidance. (G.Capeluto et al ,2006)

5.0 Case study: Urban design for a Business district in Tel Aviv

A demonstrative example of using solar envelope as design guidance has been illustrated by Shaviv in Tel Aviv, Israel (Shaviv E.et al, 2003). The case under consideration is a business district *of* 250,000 m² area surrounded by high density residential neighbourhoods (Figure13). The FSI was to be increased from 2.0 to 4.5. A proposal for a commercial development of the urban block prepared by the Tel Aviv City Planning Department was examined against solar access guidance. The solar section lines (figure9) for Central Tel Aviv were adopted and a programme SustArc (which follows the process of solar envelope generation discussed in the section 2.0.1) was used to develop the solar envelope.

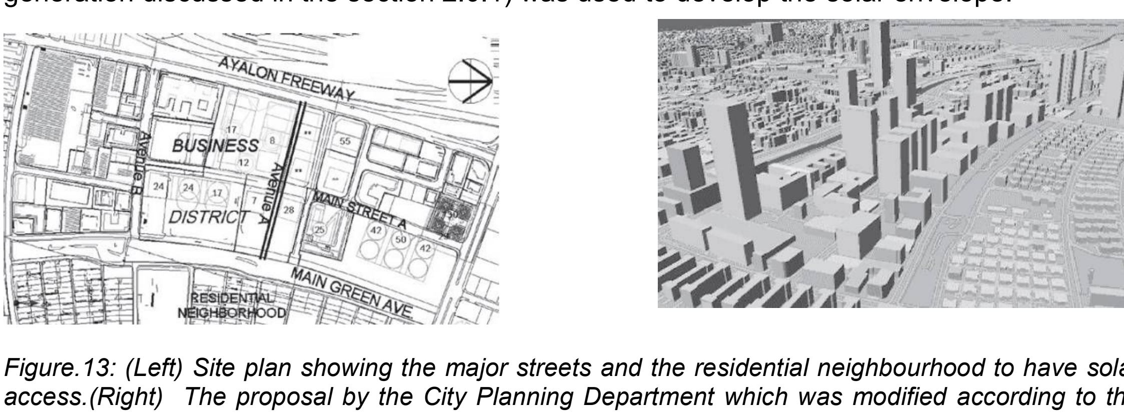


Figure.13: (Left) Site plan showing the major streets and the residential neighbourhood to have solar access.(Right) The proposal by the City Planning Department which was modified according to the solar envelope guidance.(Shaviv E.et al, 2003)

The guidance used both descriptive and performance approach to best suit the site conditions. Desired solar access for neighbouring residential districts between 8.00-15.00 hrs in winter was the primary criteria. Another additional criterion was solar access to two major east-west avenues during the same time and solar access to a major greenway at lunchtime. No summer time solar access was desirable due to extreme solar radiation in summer. In fact deciduous trees were planted for shading streets and open spaces in summer. However active shading of the buildings was not desired due to the mandatory requirements of solar panels for domestic hot water supply.

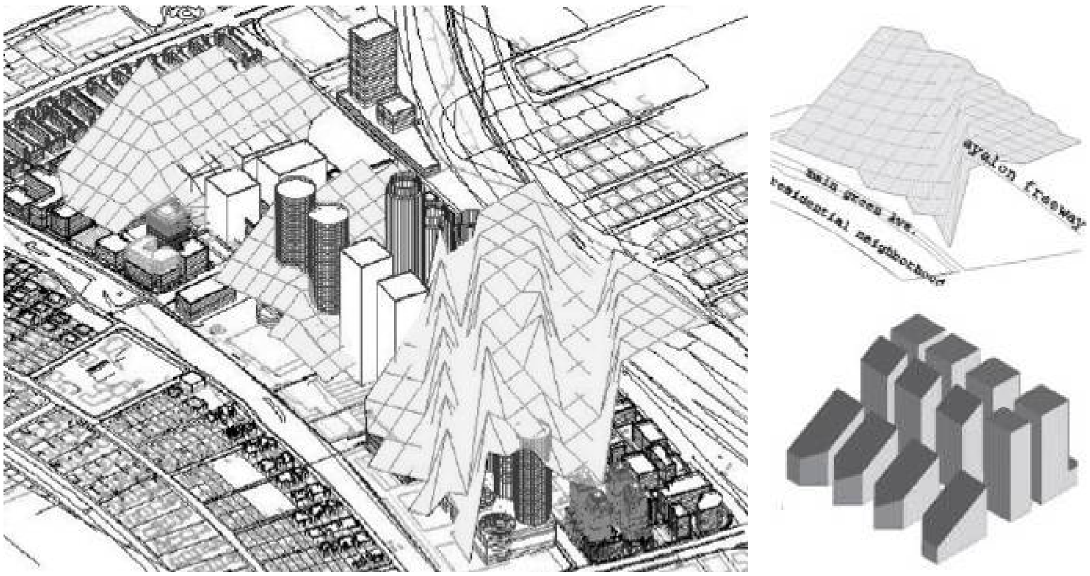


Figure14.(Left)The solar envelope superimposed on the urban design scheme showing tower blocks that will overshadow the existing residential neighbourhoods as well as in the main avenues and streets.(Right) Part of the solar envelope to ensure winter solar access in the existing residential neighbourhood as well as in the main streets and green open spaces .(Shaviv E.et al, 2003)

The solar envelope was accepted by the Tel Aviv City planning department for design guidance and the original urban design scheme is being modified by relocating the tall buildings (Fig 14).*ibid*

6.0 Solar envelope: Energetic benefits for Urban from

The primary intention of solar envelopes is to improve the photovoltaic potential of urban form. While this translates directly into an energetic advantage, there are various other benefits of solar envelopes like better day lighting and passive solar gains which help reduce space heating demands. In case an urban district is planned with such design guidance the overall urban form would have substantial improvement in both demand and supply potential of urban energy consumption. However more work is required to quantify this advantage and a direction has been indicated by Compagnon (Compagnon R. 2004).The improved photovoltaic potential of a solar envelope can be tested to quantify the potential of facades and roofs located in urban areas for active and passive solar heating, photovoltaic electricity production and day lighting (Figure 15). By specifying threshold values for systems mounted on facades and roofs, the potential for the corresponding solar techniques can be simulated under a sky dome using data from METEONORM software. If the designer combines this process with Ratti's algorithm referred to in section 4.0.2 ,(Ratti et al 2008) it is in fact possible to devise suitable urban built from for a region depending on the dominant solar radiation pattern and the specific choice of systems to be used (Passive thermal heating, Photovoltaic systems , Daylighting systems or Solar thermal collectors).

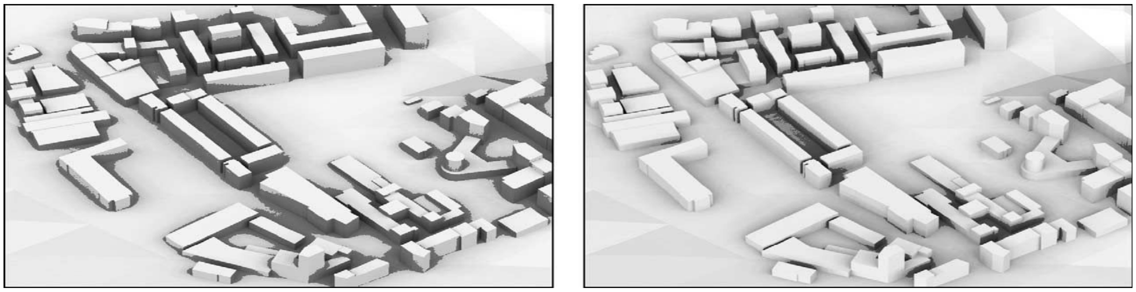


Figure 15. (Left) Test of the photovoltaic potential of urban form: All areas with annual irradiation below the relevant threshold value (800 kWhm−2) are shaded in grey. (Right) Test of facades suitable for passive solar systems: all areas with heating season irradiation below the relevant threshold value (216 kWhm−2) are shaded in grey. (Compagnon R. 2004)

7.0 Discussion:

The paper discusses solar envelope as a design guidance system for low energy urban block. It is generally agreed that a low energy urban structure would require an exploration of the solar irradiation of urban from as a primary source of energy. The photovoltaic potential of urban form can be greatly enhanced through solar envelopes. The Various processes of constructing a solar envelope are the core content of this paper. While it is noted that any of these processes are suitable for formulating a guidance system, the guidance itself would be extremely specific to an urban district .The various determinants of the guidance system are further indentified and discussed to illustrate the opportunities of improving photovoltaic potential of an urban block. The paper indicates various other benefits of the solar envelope like day lighting and solar access of streets and public spaces which can contribute tremendously to the liveability of a city. Certain limitations of this guidance system like FSI are also identified while indicating directions for their mitigation.
The concept is essentially a morphological one and addresses a gap between architecture and urban planning. It operates in the sphere of urban design and would be most successful if implemented at an urban block level. The concept is too limited to be applied to a whole sector of the city as it does not address various aspects like transportation or land use which are more important determinants of energy consumption at an urban level. The concept is too limited to be applied to small individual architectural projects as well due to its overwhelming dependence on existing built context. The solar envelop is most suitable for describing a low energy morphology essentially at a block level and should be conceptualised as a unitary constituent of a larger low energy urbanism.

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