The solar envelope
Its meaning for urban growth and form

RALPH L. KNOWLES

School of Architecture, University of Southern California (USC)
University Park - WAH 204, Los Angeles, CA 90089-0291
E-mail: rknowles@usc.edu/ Fax: 00-1-323-666-8182

Abstract

The solar envelope, first conceived and tested by the author at the USC School of Architecture, regulates development within imaginary boundaries derived from the sun's relative motion. Buildings within this container will not overshadow their surroundings during critical periods of solar access for passive and low-energy architecture. Twenty years of design research show that, if generally applied as an instrument of zoning, the solar envelope will not only allow potential growth but will open new aesthetic possibilities for architecture and urban design.

SOLAR ACCESS

A 50-story office tower in Los Angeles casts a shadow 1,000 feet long between 1pm and 2pm in December. By 3 P.M., that building's shadow is 1,800 feet long, with an area equivalent to two city blocks. Its leading edge cuts across the swimming pool of a popular downtown hotel, isolating a few sunbathers in a narrow strip of warm sunlight. The rest of the pool area is shadowed, cold and empty.

This actual picture, while perhaps a trivial case, raises ethical and legal issues of solar access. While I may choose to stand in shadow, I resist a developer's mandating it. And if I occupy a space or a building in the wake of that tower's shadow, I will resist that violation of my right to the sun's light and heat. It is this desire for sunrights, as well as our need to develop a sustainable architecture, that argues powerfully for legally protected solar access [1].

A continuing debate over the best way to guarantee solar access has left the consequences for urban form naively or inadequately addressed. The notion that solar access is antiurban and antiproperty rights has gained currency without a full exploration of its implications for the design and growth of cities. To say that solar access will destroy cities because it won't allow a tall building to be erected amidst low ones is hardly an argument for urban quality.

Solar access, when achieved by using the solar envelope, does not automatically result in the elimination of tall buildings nor does it mandate suburban densities (Figure 1). Extensive research has shown that floor area ratios (FAR's) as high as 7.5 and housing densities in excess of 100 dwelling units per acre (du/a) can be achieved. This far exceeds suburban densities and would be consistent with the densities of most urban areas in the U.S. with the exception of such high-rise centers as Manhattan.

The solar envelope does not abolish tall buildings but rather has a scaling impact on urban growth. Density can increase over time, according to public values, but violent disruptions of city scale are avoided. Where high-rise development already exists, the solar envelope can be used to protect rooftops and upper-floor solar access. New construction is shaped and proportioned with reference to the old.

Figure 1. The Bunker Hill Project: The solar envelope, viewed from the south, varies in height from 100' to 500' and contains a huge development potential, FAR = 20 (left); an exemplary design (FAR = 7.5) trades off development potential of the envelope for solar access to buildings and spaces within project boundaries (right). Designer, Randall Hong.

The solar envelope carries an implied moral obligation to use the sun and to relate to it formally. The designer is encouraged to differentiate building and urban form in graphic response to orientation. One side of a building will not look like another and one side of a street will not look like another. Development will tend to be lower on the south side of a street than on the north where a major southern exposure is thus preserved. Streets take on a directional character where orientation is clearly recognized.

The solar envelope calls for a design strategy based on natural rhythms. Sunlight is assured within the envelope's boundaries, hence designers can make use of the changing directions and properties of light without fear that a taller building will one day cancel their ideas. The potential exists to conceive of architecture in other than static terms of form and space. It is this insinuation of a new aesthetic, plus the need to understand how the solar envelope limits development, that has motivated research in USC's Solar Studio.

Legal Background

Solar access has, over the past twenty-five years, come into focus as a topic of discussion in the United States. Beginning in the 1970's, communities looked at the sun primarily as a source of energy, a replacement for uncertain supplies of fossil fuel. Then, during the 1980's, interest in solar access generally abated as oil supplies became more
reliable. But most recently, even though oil is now plentiful and cheap, environmental concerns are causing a renewed interest in sun rights as a condition of sustainable growth and life quality. Solar access thus remains today a legitimate area of public policy in which the aim is to regulate how and when neighbors may shadow one another.

The most commonly cited law outside the United States is the 19th-century English Doctrine of Ancient Lights but there are problems with its application. Roughly, the doctrine states that if in living memory no one has overshadowed your property, they cannot now do so. However, this doctrine has been repeatedly disavowed in U.S. courts [2].

Some legal experts have suggested that American water law, especially the Doctrine of Prior Appropriation, may offer a more useful precedent for sun rights [3]. Both sunlight and water are used rather than captured and sold; both may be consumed, but both are renewable. In addition, there is an equivalence between upstream and downstream in water law and the geometry of solar shadowing. But, like the Doctrine of Ancient Lights, there are problems with the application of water law.

The Doctrine of Prior Appropriation is a formalizing of the general practice among early western settlers of appropriating available water according to who first put it to beneficial use. Simply put, "He who gets there first, gets the most." It was the American frontier’s answer to the exigencies of pioneer settlement.

Prior appropriation is not likely to be applied to solar allocation in any simple way. Future access would not be assured for structures without present energy-conversion systems. Several permits acting on different, adjacent properties (as well as those on distant sites) may conceivably act to stop development completely on one of them. This point has been made abundantly clear in the writings of legal experts who point out serious weaknesses in any attempt to move directly from water law to solar law.

The difficulties in applying water law have led to arguments for straightforward zoning as a more appropriate approach to the problem [4]. First, it offers the possibility of local administration of rules affecting the allocation of sunlight. Second, zoning is traditionally applied to all properties in a district thus assuring future access and bypassing the problems of preference based on prior use. Finally, existing zoning limiting heights and setbacks is already based on the concept of an envelope of buildable volume. These reasons have been found compelling and have led to development of the solar envelope.

**Space-Time Construct**

The solar envelope is a construct of space and time: the physical boundaries of surrounding properties and the period of their assured access to sunshine. The way these measures are set decides the envelope’s final size and shape.

First, the solar envelope avoids unacceptable shadows above designated boundaries along neighboring property lines; these boundaries have been called shadow fences [5]. The height of shadow fences can be set in response to any number of different surrounding elements such as privacy fences, windows, or party walls. Their height may also be set by adjacent land-uses with, for example, housing demanding lower shadow fences than commercial or industrial uses. Different heights of shadow fence will effect the shape and size of the solar envelope (Figure 2-left).

Second, the envelope provides the largest volume within time constraints, called cut-off times [6]. The envelope accomplishes this by defining the largest theoretical container of space that would not cast shadows off-site between specified times of the day. Greater periods of assured solar access will be more constraining on the solar envelope. Cut-off times that are specified very early in the morning and late in the afternoon will result in smaller volumes than would result from later times in the morning and earlier times in the afternoon (Figure 2-right).

**Street Patterns**

The solar envelope’s size and shape are greatly influenced by the street patterns of urban settlement [7]. In the United States, those patterns are usually comprised of orderly subdivisions of the U.S. Land Ordinance of 1785 that has geometrized much of the land between Ohio and the Pacific Ocean. Typically, throughout the Midwest and the west, streets run with the cardinal points so that rectangular blocks extend in the east-west and north-south directions. But in Los Angeles, where most of the solar-envelope research has been done, there are two street grids: The US Land Ordinance and the much older diagonal grid of the original Spanish settlement, El Pueblo de la Reina de Los Angeles (Figure 3).

The solar envelope, and hence development potential, varies with street orientation. Generally, more envelope height is attainable at either of the two possible block orientations within the US grid while less volume is possible within the Spanish grid. This has made downtown Los Angeles an especially challenging problem.

The shape of the solar envelope also varies with street orientation thus enhancing legibility. Kevin Lynch said, “To become completely lost is perhaps a rather rare experience ... but let the mishap of disorientation once occur, and the sense of anxiety and even terror that accompanies it reveals to us how closely it is linked to our sense of balance and well-being” [8]. Pathways, districts, and directions take on clear perceptual meaning when the solar envelope becomes a framework for urban design.
Figure 3. Three different block orientations demonstrate the effect on size and shape of solar envelopes. Solar envelopes over E-W blocks have the most volume and the highest ridge, generally located near the south boundary (top). N-S blocks produce less volume and a lower ridge running length-wise down the middle (middle). Diagonal blocks produce the least volume and a ridge along the south-east boundary (bottom).

DEVELOPMENT POTENTIAL

A 10-year housing study conducted in the USC School of Architecture's Solar Studio has tested the possibilities for growth under the solar envelope. The study concludes that buildings of 3-7 stories generally represent the best size range for urban dwellings in Los Angeles. These figures can vary among cities but the underlying suppositions of solar-access policy and design are broadly applicable to places of density everywhere.

Each test comprising the study typically embraces 16 - 18 separate but contiguous land parcels, one for each member of a design class. This approach not only helps architecture students to see urban-design issues beyond a parcel by itself but also has the effect of advancing research. More parcel variety provides greater statistical reliability for understanding development potential (Figure 4).

Figure 4. Southpark housing, viewed from the east, shows a typical test project comprised of multiple land parcels: solar envelopes (left); design studies (right).

Each test proceeds in two major steps. First, is the generation of solar envelopes to match the actual land-uses and economics of diverse settings throughout Los Angeles. Second, once the envelopes are in place, the building-design process begins with each student being required to follow municipal codes as well as practical strategies for passive and low-energy architecture. A test-project on the Spanish grid near Downtown Los Angeles shows the transition from solar envelope to building design that characterizes all projects in the 10-year study.

Los Angeles Zoning as a Study Reference

Los Angeles zoning provides the urban housing reference for this study. First, the dwelling classifications are the actual ones used in the design studio. Second, they show in which density range the greatest variety of types is officially recognized by LA planners. Finally, each part of the range symbolizes not only different dwelling classifications, but a separate grouping of possibilities for designers, developers, and users. The study initially compares for reference two critical measures of Los Angeles housing types: V/S compared to Density (Figure 5).

Figure 5. A plot of V/S (volume-to-surface) against Density (dwelling units per acre) for all dwelling classifications covered by Los Angeles Zoning Regulations from 1 du/a (A2) to 200 du/a (R5). (Two separate V/S values at 150 du/a and again at 200 du/a signify that building and lot configurations can vary significantly without changing density.)

Volume/Surface (V/S) is measured on the vertical axis of the graph. Calculations for Volume (cubic ft) include only the space within dwelling units, not support facilities. Calculations for Surface (square ft) include exposed portions of the lot as well as the building's faces.

V/S acts both as an energy-related descriptor of form and an expression of design choices. The low V/S of a small building means that energy must be expended mainly to overcome surface or “skin” loads; it also implies a strong architectural bond to sunshine, fresh air, and view. On the other hand, the high V/S of a large building means that more energy must be expended to handle the internal stresses of overheating; it also means less potential for the architect to design with nature.
Density (dwelling-units / acre), on the horizontal axis of the graph, varies with housing classification. One-family dwellings are spread out compared with multiple dwellings, thus providing more space outside in the yards. Also, one-family houses tend to have more floor space than a unit within an apartment building.

Density, an indicator of land values, also expresses development options. High densities correspond with inflated land values; units, and even whole buildings, become compact and essentially repetitive. Low densities coincide with smaller land costs; developers concentrate on one-family houses multiplied over enormous tracts. But for urban housing on restricted sites in Los Angeles, developers usually try for the highest densities the market and zoning will support.

**Exemplary Housing Projects**

Four projects, covering a range of settings and densities, are shown as exemplary of the housing study as a whole (Figures 7 - 10). The design program calls for solar access and cross-ventilation to all dwelling units contained within the solar envelope. As density increases and buildings become larger, solar access and cross-ventilation to individual dwelling units becomes progressively harder to achieve. Projects 1 and 2 are comprised of individual houses with low V/S and plenty of opportunities to design with nature. But for Projects 3 and 4, two European prototypes have been adapted to solve the problem of solar access and cross-ventilation in high V/S apartment buildings (Figure 6).

The research protocol for solar envelopes is progressively adjusted to increase volume while maintaining solar access to all land parcels. First, shadow fences are successively raised at neighboring property lines; Projects 1 and 2 permit shadows only up to 8 ft at property lines while Projects 3 and 4 permit shadows up to 10 ft at residences and 20 ft at commercial properties where they exist in the surround. Additionally, cut-off times are adjusted to shorten the period of solar access; Projects 1 and 2 call for guaranteeing 6 hrs of solar access on a winter day while Projects 3 and 4 shorten the period to only 4 hrs, the minimum generally recommended for passive design in the “Mediterranean” climate of Los Angeles. The added density resulting from increased envelope volume corresponds with higher land values in some local settings.

Additional variations of envelope protocol conform as much with street aspect and wind direction as with solar access and density. For example, unlimited shadowing at property sidelines allows development of a continuous street facade in Projects 1, 2, and 4; however, shadow fences act at side property lines as well as front and back in Project 3 thus generating a street facade that systematically rises and falls. Such differences acknowledge the local character of streets; they also signal opportune adaptations of building mass to ease the free flow of cooling summer breezes through the city.

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Study Findings

A composite graph, representing all 150 student designs, falls short of the full range of LA zoning but for two different and opposing reasons (Figure 11). The lowest density of the study (7du/a) was deliberate, the result of an initial decision to exclude from investigation one-family dwellings on very big lots as inappropriate for urban housing. On the other hand, the high end of the study's density range (128du/a) was not deliberate but rather the chance result of a step-by-step disclosure over the ten years of testing. Between these values, the study found a remarkable variety of ways to live in the city within a height range of 3-7 stories. The conclusion of the study is that many opportunities do exist in this size range to provide both energy conservation and life quality without overly limiting development options for urban growth.

Figure 11. The graph shows round symbols representing all 150 student housing designs clustering in a density range of 7-128 du/a corresponding to a V/S range of 2.5-10.5. (Square symbols represent the extent of LA Zoning range.) In general, all round symbols can be seen to level off at a V/S of 10.0 corresponding to a maximum density of about 100 du/a. The few exceptions that rise fractionally above this plateau symbolize unusually tall buildings resulting from special site conditions such as the adjacent park in Project 4.

Symbols on the graph can be seen to level off at a plateau signaling the most important finding of the study. The consistent effort to achieve both energy efficiency and life quality, while striving for higher densities, yields a critical cut-off value of V/S = 10.0 corresponding to a maximum density of about 100 du/a. A few special circumstances, as a park or wide boulevard where longer shadows could be cast without harming a neighboring property, result in taller buildings with fractionally higher V/S values. Otherwise, for good solar access and cross-ventilation in a compact and continuous urban fabric, the rule holds. Designers who break it lose the choice of architectural means to sustain building comfort and must depend on energy-intensive mechanical systems.

The cut-off value of V/S = 10.0 provides a simple but powerful design tool. Architects don't have to wait until a project is far advanced to evaluate its passive-design potential. Even at very early stages of planning, a simple calculation, performed on alternative massing schemes, provides an unequivocal basis for comparing the eventual character of their energy usage. If V/S is less than 10.0, designing with nature is a good option. On the other hand, if V/S rises above 10.0, reliance on energy-intensive systems is inevitable.

DESIGN POTENTIAL

The solar envelope forestalls shadowing of neighboring properties, but the designer working within the envelope must settle important issues such as how to develop the aesthetic potential of sunshine. To study this subject, the USC Solar Studio has undertaken the design of a library. The actual list of programmatic requirements comes from the Los Angeles library planners, but the spirit of the work is taken more from a comment by Louis Kahn about his own design for the Exeter Library: "You get a book and move toward the light." He thus implies a conception of architectural space that is both rhythmic and ceremonial.

The Mama Plane

The architectural link between rhythm and ritual is introduced in the library study by asking students to imagine a wall with a gateway through it. An east-west facing wall accentuates a daily rhythm; shadows will be cast first to the west and then to the east, regardless of season. A north-south facing wall, on the other hand, will emphasize a seasonal rhythm; the shadow extends much farther northward in winter than in summer. Finally, if the wall faces diagonally to the cardinal points, the accents will be complex and contrapuntal. In each case, a person seeking either sunlight or shadow must repeatedly move through the gateway at regular intervals --- a rudimentary rite of passage.

The imagined wall gains architectural relevance when circumscribed by the solar envelope. If strategically placed, following specific ridges, the wall can act over time and seasons to fill the empty space of the envelope with overlapping shadows. It can thus act as a generator, an allusion to invisible form. When the form is brought into concrete existence, sunlight replays a series of rhythmic connections that can influence perceptions and actions. The generating wall has been dubbed the mama plane [9]. Its application in the Solar Studio is sometimes quite direct.

Figure 12. Library designs generated from the Mama Plane: Using a light-penetrating strategy - designer, Anthony Reiter (left); using a shadow-casting strategy - designer, Gustavo Koo (right).

One design for a library develops a literal interpretation of the wall and gateway (Figure 12-left). Beginning with the mama plane, a gateway opening through it allows sunshine to penetrate to a second plane where the lighted area is removed. After a prescribed interval of time, sunshine passes through both gateways to a third plane where the lighted area is again removed. The designer continues this process
throughout the course of a simulated day, interval by interval, until the final design embraces the entire set of planes. The designer's intention is that this arrangement of gateways will not only generate a system of transverse spaces but, on all future days, will act in sunlight to recite the original sequence of connections with seasonal variations.

A second design for a library uses shadows cast from edges of the mama plane to create both the building and a garden (Figure 12-right). The mama plane, with a diagonal orientation to the cardinal points, has been given thickness by the designer and serves as book storage, service, and circulation. To the south-west of the plane, morning shadows moving at intervals across the ground have been used to outline the terraces of a garden with parking below. To the north-east, afternoon shadows are used to define the shapes of floor plates: one set is generated on a winter day, alternate plates on a summer day. And as with the previous design, the creative process will be recited over time.

Technique of Study

The USC Solar Studio has depended mainly on physical models for design. Computers have recently added virtual models to expand our tool kit. Still, the physical model, either on the heliodon, outside under the sun, or under some controlled and movable lighting in the studio, continues to provide a powerful study method offering tactile as well as visual cues to design.

Figure 13. Large-scale model showing spatial transformations generated by daily shadow migrations within a library: morning, midday, afternoon. Designer, Jacky Yung.

The scale of physical models is systematically changed as work progresses. Initial investigations rely on models only a few inches across, analyzed on the heliodon. Then, step-by-step, the scale of study increases to include final models several feet high, large enough to examine transmutations of space within the building (Figure 13). Sometimes, as in the design shown, the space is transfigured by shifting shadows; in other designs, sunlight channels through different layers of stained glass, blending colors according to time and season. In all cases, the rhythm of transformation depends on orientation of the initiating mama plane.

Purpose of Study

The intention of the library study is to examine rhythm as a medium of design. Rhythm is the way our bodies and emotions respond to the passage of time. It is therefore a universal means of affecting experience and conveying meaning in our lives.

Creative possibilities can be amplified by linking rhythm and ritual in the places we occupy. Close analysis of the way traditional societies have identified with their environments suggests the value of such a linkage for modern design. This is not to say that we should all return to primitive shelters. Nor should we simply aim to describe solar phenomena by architectural means. The problem is more involved than that.

The places we occupy do need to reduce stress on our minds and bodies, but there is a real question of means. Does architecture have to hide from us every small variation that might repeatedly summon us to action? Something reassuring comes from the consonance of our actions with the motions of nature. The something may remain forever unknown. Perhaps it is nothing more than the cyclical re-proportioning of our bodily fluids. But more likely, it is a reaffirmation of our own existence --- a continuously repeating call for recreation. Our universal need for this call should not be underestimated nor its basis be trivialized by design.

By examining the influence of natural rhythms on form and space, the USC Solar Studio aims to reintroduce rhythm as a mysterious fact of aesthetic experience. The solar envelope expresses and affirms that possibility.

CONCLUSIONS

Without access to the sun, we cannot use it. The solar envelope is proposed as a zoning device to achieve solar access by regulating development within limits derived from the sun's relative motion. Buildings within its boundaries will not shadow surrounding properties during critical periods of the day and year. Assured solar access thus offers the chance to replace unreliable energy sources and to enhance the quality of urban life. Assured sunlight also suggests rhythm as a novel strategy for zoning policy and design: a way to bring us closer to a sense of nature in our buildings and urban spaces.

REFERENCES