On Being the Right Size[1]

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"Nothing is either too great or too small other than by comparison." *Gulliver's Travels* by Jonathan Swift

1. INTRODUCTION

The right size, and notably the right size of a building, is relative. It is associated with the measurable costs of construction and of maintenance. It is also connected with the more illusory standards of livability and of choice. In order to make sense of this complex picture, a 10-year housing study has been made in the Solar Studio of the USC School of Architecture comparing a range of sizes with reference to energy conservation and life quality. It turns out that the best choices of dwelling types for Los Angeles, and by inference for places of density everywhere, are in a size range that is neither too great nor too small.

1.1. Pedagogical Objectives

The educational purpose of the work is to prepare architecture students to deal with the complexities of urban housing. Low-density projects direct attention to the many problems attending hillside development. Mid-density projects look at the unsettled questions of mixed housing types. Finally, high-density projects focus on scale and open space. One or another of these design subjects is continually in dispute somewhere in metropolitan regions where most of the students plan to practice after graduation.

Students in the Solar Studio are encouraged to explore formal ideas that interest them, but a few definite obligations are established at the outset. This has meant being able to answer very precise questions: are solar access and cross-ventilation provided; are the codes for fire-safety followed ; is the required market-mix of dwellings included? The particular manner in which these obligations are met is the essence of personal style and perhaps difficult to judge; but whether or not they are managed is easily understood, and data based on the answers can be reliably used for research.

1.2. Research Objectives

The research purpose of the work is to test the notion that a public policy of solar-envelope zoning will not inhibit but instead enhance development and design opportunities for housing in an urban context.[2] The solar envelope as conceived in this work regulates development within a container whose shape is derived from the sun. Development within this container will not shadow its surround during critical periods of the day. The research protocol for generating solar envelopes is therefore defined by the passage of time as well as by the constraints of property.

Long-term explorations have been pursued with limited but very useful data coming systematically out of the design process. At the beginning of each semester's work, students are advised that they will be responsible for generating the highest densities possible without losing access to sunshine or cross-ventilation for energy-conservation and life quality. Periodically throughout the semester, they are asked for a count of dwelling units in their designs. Early figures tend to be unrealistically high or low; then, as the semester progresses and the designs become more refined, the counts settle down to reasonable numbers. [3]

1.3. Significant Conclusions

Data accumulated in the Solar Studio are used to relate *Density* (a count of dwelling units per acre) to *S/V* (surface-to-volume ratio, an energy-related measure of building form and space). This relationship is taken as the basis for concluding 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 concepts of solar policy and design are broadly applicable to sustainable development everywhere.

2. LOS ANGELES ZONING

Los Angeles zoning regulations provide the urban housing reference for both teaching and research in the Solar Studio. First, the dwelling classifications they contain are the actual ones used in the studio. Second, they show in which density range the greatest variety of dwelling types is officially recognized by L.A. planners. Finally, a novel way of displaying the relationship between dwelling categories reveals three distinct ranges of size that correspond with habits of energy consumption and styles of living.

2.1. Three Ranges of Size

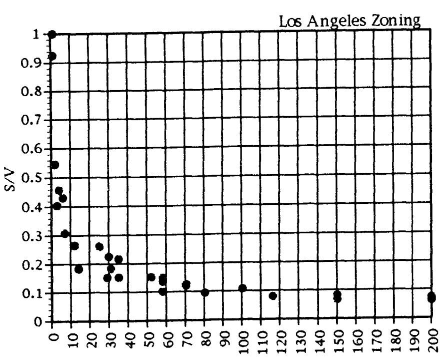
Graph 1 can be explained in three basic parts. The thin vertical part of the curve describes small buildings up to 3 stories. The similarly thin horizontal part describes big buildings of unlimited height. The broader "elbow" of the curve describes a range of mid-size buildings. Each part of the curve represents not only different dwelling classifications, but a separate grouping of possibilities for designers, developers, and users. To evaluate these possibilities, it is useful to establish the meaning and the method of calculating *S/V* and *Density.*

2.2. Surface/Volume

S/V (surface/volume), measured on the vertical axis of Graph 1, varies inversely with building size. The classic example often used to explain this ratio is a hypothetical unit cube resting on one face (S/V=5.0). Since area increases by the power of 2 while volume increases by the power of 3, doubling the cube's edge dimensions halves the ratio between exposed surface and contained volume (S/V=2.5).

S/V is an important energy-related descriptor of building form, but it also expresses design choices. The high S/V 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. The low S/V 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.

Calculations for Surface include exposed areas of the lot as well as the building's outer faces; the combination is used for three reasons. First, zoning codes usually list minimum yard and lot sizes together with building dimensions as a combined basis for classification. Second, energy is expended to maintain the lot as well as the building; and when the lot is an acre or more, the proportion used for lawns and gardens can be enormous. Finally, when assuring solar access for winter heating and access to summer winds for cooling, the lot and the building must be seen as an integral set.



Graph 1. A plot of *S/V* (surface-to-volume) 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). The shape of the curve, and the way points representing housing types are scattered along it, reveal three important groupings of choices for urban development.

Calculations for Volume include only the space within dwelling units. This is consistent with the research protocol that excludes from a guarantee of sunshine all commercial space and shops below housing as well as major parking facilities either above or below grade . This method of calculating building volume also conforms with the design program that emphasizes natural light for housing.4

2.3. Density

Density (dwelling units/acre), measured on the horizontal axis of the graph, varies directly with building size; there are two reasons for this. One-family dwellings are generally 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, 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.

Calculation for Density are based on net acreage only, the land within lot lines. It does not, for example include streets, parkways, or even shopping centers as do some density calculations for planned unit developments. While such density calculations based on gross acreage are commonly used, net acreage is here taken to be more consistent with the S/V calculations.

3. EXEMPLARY PROJECTS

Four exemplars represent twelve multiple-dwelling projects completed by students in the USC Solar Studio over the past ten years. Each exemplar can be recognized by some distinguishing characteristic of site while, at the same time, fairly representing the other projects in a particular density range. The design program for all projects calls for solar access and cross-ventilation to all dwelling units. The research protocol for solar envelopes has been systematically adjusted in successive exemplars to provide shorter periods of solar access and greater shadowing impact on neighboring properties. A graph accompanying each exemplar displays the consequences for greater Density and lower S/V when compared to Graph 1. (Note scale changes among graphs.)

3.1. Low-Density Hillside Housing

The first project, sited on the north-south ridge of a low hill, is under pressure to develop both higher densities and larger houses. To meet this challenge, the design program calls for replacing nearly all existing one-family dwellings with multiple dwellings. Individual units are in the 2-4 bedroom range or about 1350-2500 sq.ft.

The rules for generating solar envelopes include generous time and space constraints. Six hours of sunshine must be provided on a winter day and progressively more toward summer (10 hrs) for outdoor recreation and for gardening. Shadowing is allowed at any time below 8 ft at front and rear property lines, but is unlimited at side property lines and on all public rights-of-way. Finally, a building-line setback of 5 ft from the front property line is required, but there are no obligatory setbacks at side or back property lines.

Graph 2 shows only three points scattered in the density range of 5-10 du/a; otherwise, the majority group between 12-20 du/a. This means that on three of the lots, multiple dwellings could not be sited because of slope and envelope constraints. But on all the rest, at least two dwellings are built with solar access and cross-ventilation. S/V is relatively high, dropping below 0.20 on only one design.

A view toward the northeast shows several lots surrounding an intersection, each with a somewhat different condition of slope and solar access (Photo 1-left). Solar envelopes are high enough along the ridge to accommodate two- and three-story houses with ample south exposure. But on downhill slopes, the solar envelopes more usually allow only terraced, one-story houses. The results typically accentuate the natural topography of the hill: high on the ridge, low on the slopes where the solar access of houses further downhill must also be protected.

A detailed view of the western slope shows two different siting strategies (Photo 1-right). One lot contains two small houses separated by a stair for access to the rear of the lot. An adjacent lot holds only one large house. Unlike the taller houses on the ridge, these on the slope must press harder against the solar envelope to channel sunlight either into atria or down stairways into spaces below.

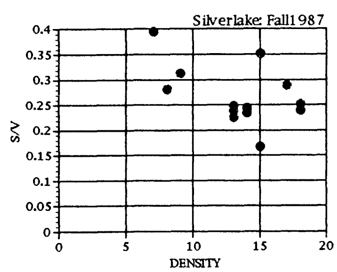
Both views show great architectural diversity with roofs, windows, terraces, and gardens all varying from one unit to another. Partly this is the result of different site conditions that affect the size and shape of the solar envelopes. But even within a parcel, the combination of low Density and high S/V provides designers with especially rich possibilities for identifying separate units.

3.2. Low-Mid Density Housing

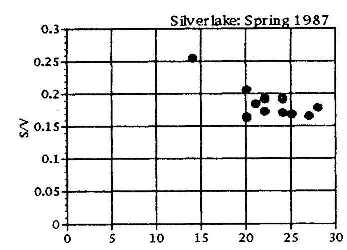
The second exemplar is sited on a more gentle eastern slope of the same hill. All programmatic requirements for dwelling types, and also the solar envelope rules, are the same as for the first project. But here, as the hill flattens, densities rise markedly over what is achieved on the higher slopes.

Graph 3 shows only one point in the 10-15 du/a range, corresponding to a two-family dwelling; all the rest cluster nearer to 20-30 du/a. And in this denser range, S/V drops to just above 0.15 meaning that houses are here crowding closer together than in the first project.

A view northward shows characteristics similar to those seen earlier on the west side of the hill (Photo 2-left). The



Graph 2. Exemplar #1 has a density range of 7-18 du/a (L.A. zoning designations R1 and R2) and a corresponding S/V range of 0.3942-0.1670.



Graph 3. Exemplar #2 has a density range of 14-28 du/a (L.A. zoning designations R2 and R3) and a corresponding S/V range of 0.2547-0.1625.

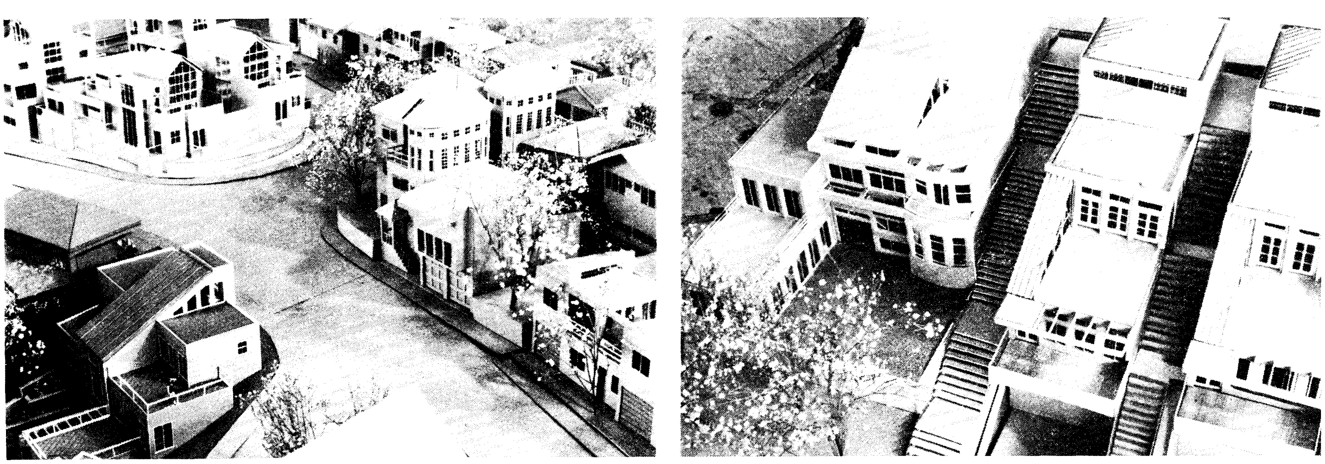
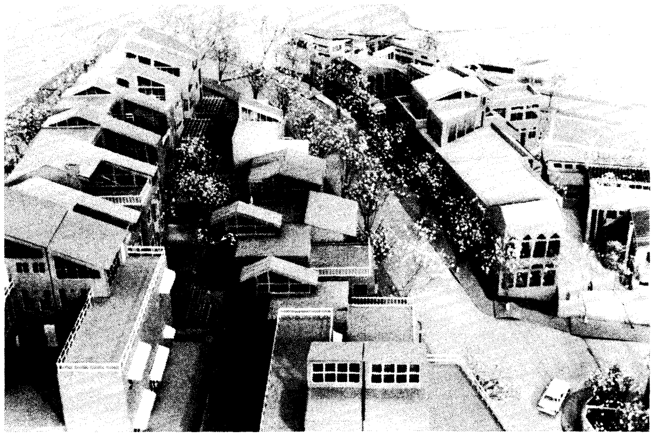


Photo 1



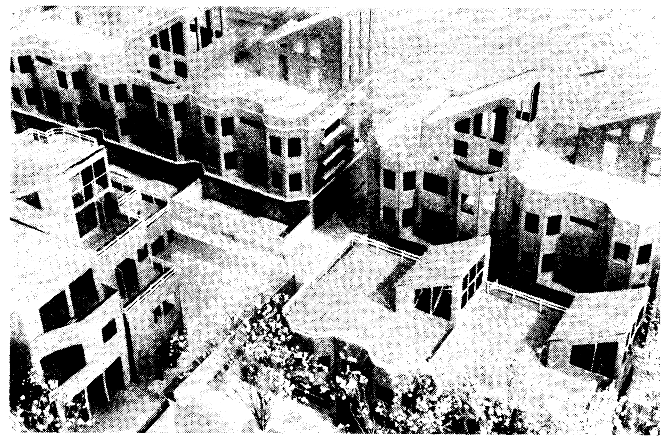


Photo 2

impact of the solar envelope can clearly be seen accentuating the downward tilt of the natural topography. And portions of otherwise buildable volume must be cut away and clerestories installed over stairwells to capture south light for daylighting and winter heating.

Downhill, and onto the flatter portion of the site, houses become taller and their shapes are less impacted by the solar envelope. A view toward the northeast shows fairly typical three-story row houses lined up along a very deep lot with gardens and access along one edge (Photo 2-right). Each house is centered by a very tall clerestory that provides light and air to an atrium or inside garden.

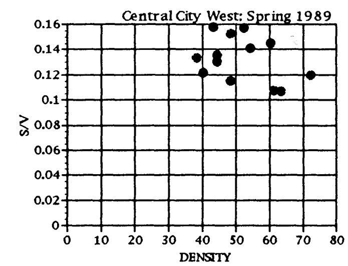
These views show somewhat less architectural diversity than was seen in the first project. Windows tend to be more of a size and shape. Terraces and gardens are smaller and less visible. This is not the result of less desire on the students' part for creative self-expression, but is almost entirely the result of increased Density and decreased S/V that together lower the possibilities for identifying separate units.

3.3. Mid-High Density Housing

The third exemplary project is on a gently sloping site near downtown Los Angeles, just west of the Harbor-Hollywood Interchange. Laid out on the old Spanish grid at about 26 degrees off true north, the area presently contains dilapidated one-family dwellings and a few, two- and three-story apartments. The design program here calls for replacing the one-family dwellings, but not the multiple dwellings, with a market mix of units averaging 1000 sq. ft. Parking is below grade on some lots, but is naturally ventilated.

The rules for solar envelopes meet less generous time and space constraints here than for the first two projects. While the earlier protocol guaranteed 6 hours of direct sunshine, the rules here guarantee only 4 hours - the minimum generally recommended for passive design in this "Mediterranean" climate. Shadowing is allowed at any time below 10 ft on residences and below 20 ft on commercial properties where they exist in the surround. All residential frontages are set back 5-15 ft depending on context.

Graph 4 shows most points clustering in the 40-70 du/a



Graph 4. Exemplar #3 shows a density range of 38-72 du/a (L.A. zoning designations R3 and R4) and a corresponding S/V range of 0.1574-0.1069.

range. Apartments served by stairs and elevators are now joined on the same lot with houses that have their own front doors. This combination drives S/V downward, making solar access and cross-ventilation to all units more difficult to achieve. But unconventional building sections are adapted to allow denser packing of units while still preserving design choices for energy conservation and livability.

3.3.1. Solar Studio Adaptations of European Prototypes

Two western European prototypes have been adapted in the Solar Studio to solve the problem of solar access and cross-ventilation in apartment buildings (Figure 1). At densities in the range of this project, multiple dwellings in American cities invariably depend on "double-loaded" corridors and mechanical systems. But in these European designs, hallways systematically skip some floors allowing units to pass freely both over and under for access to light and air in opposite directions. And because units typically have multiple levels, there is spatial variety beyond what is possible in flats.

The Solar Studio has applied the two European prototypes directly where site conditions suggest an east-west exposure, but adjustments have been made where the exposure is north-south (Figure 2). Winter sunshine enters only the south-facing rooms, leaving those on the north relatively darker and colder. Since every unit must have a south exposure, the north-south building section becomes asymmetrical in its spatial organization.

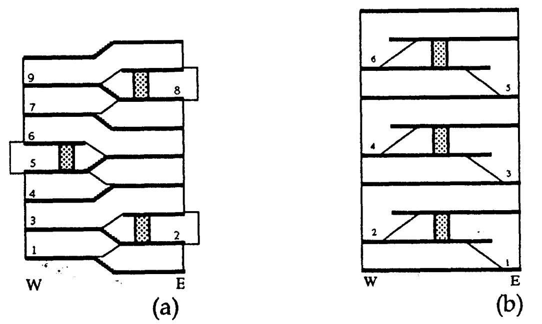


Figure 1. Housing sections developed in Western Europe for east-west exposures. Section "a", developed by the Dutch architect Jacob Bakema, connects three units to the corridor; an "efficiency" unit, entered directly off the corridor, has a bay window for better light and ventilation; Section "b", developed by the French architect Le Corbusier, connects only two units to the corridor as in the Marseilles housing block.

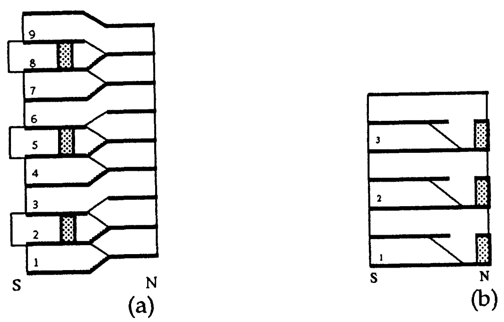


Figure 2. Housing sections adapted for north-south exposures. Section "a", an adaptation of the Bakema scheme, still connects three units to each corridor; however section "b", an adaptation of Le Corbusier's design, is less efficient because units must be two stories high to rise up and over the corridor for cross-ventilation without losing privacy.

The Solar Studio has made other adjustments at the top and bottom of the European sections. For example, a corridor at the top of the building can be double loaded because units connecting to it uniquely have their roofs exposed as well as one side for both solar access and cross ventilation. And adjustments have also been made at the bottom of the sections to accommodate either street-front shops or townhouses with entry off either the street or the courtyard.

3.3.2. The Right Size for a Building Section

The size of these building sections depends on orientation. For example, the Solar Studio has discovered that a depth of 40'-45' is about right for north-south exposures.5 This is based on extensive heliodon studies that attempt to channel low winter sun deep into south-facing rooms and especially into stairways where adjacent spaces can borrow some of the welcome light and warmth. Then in summer, the heat and glare are easily controlled with a shallow overhang because the sun is so high in the southern sky. The qualities of space thus vary naturally with the changing seasons: bright and warm in winter, darker and cooler in summer.

The section depth for an east-west exposure can average about 10 ft greater than for north-south exposures. The sun enters from two directions instead of only one, east in the morning and west in the afternoon. This introduces special sun-control problems in summer that are generally solved in the Solar Studio with porches or screens. But there is a wintertime advantage. The low morning sun enters from the east for 2-3 hours of useful light and heat, then it alternates. In the afternoon, another 2-3 hours of sunshine can be captured from the west. Rhythmically, over the course of a day, this alternating exposure enlivens most of the space inside the unit.

3.3.3. Site Applications

The use of these kinds of sections, along with relaxed envelope rules, lends a totally different aspect to the third exemplar from that seen in the previous two. A view toward the northeast, for example, shows more height variation within a given land parcel (Photo 3-left). Along the tree-lined street where the solar envelope is high, apartments can now rise 5-7 stories. Along the alley, where the envelope slopes downward, rows of 2-3 story townhouses reflect more the scale of the first two projects. Existing structures appear in the photo as simple blocks, 3-5 stories high and typically sited no more that 5 ft from the lot line.

A detail-view toward the southeast shows two different techniques for using communal open space to capture south light (Photo 3-right). A broad south exposure allows one design to use a generous, plaza-like courtyard with no shadow-casting obstructions. But another design, because of its narrow lot shape and the 26 degree orientation of the Spanish grid, splits open along a true N-S axis for the midday winter sun to enter a street-like court.

Both views show more repetition, and thus less choice, than was seen in either of the first two projects. Still, for the higher densities involved, there is remarkable design variety among parcels and unit diversity within any one lot.

3.4. High Density Housing

The 4th exemplar is on a vacant site with spectacular views toward the Los Angeles Civic Center and the new Disney Music Hall. Originally an area of one-family dwellings, the site was ten years ago cleared for high-rise office buildings. But a recession in Southern California has so far left the site undeveloped. The irregular topography and street layout is not appropriate for very large commercial structures, but ideal for needed housing close to downtown. Programmatic requirements for unit size and parking are the same as for Exemplar 3, and the building sections diagrammed there are used here as well.

The solar-envelope rules for time constraints are the same as for Exemplar 3, but the space constraints have been altered to provide still more volume. There are no setbacks, and neighboring parcels are allowed to share space across side-lines; in addition, overshadowing is allowed on a north-

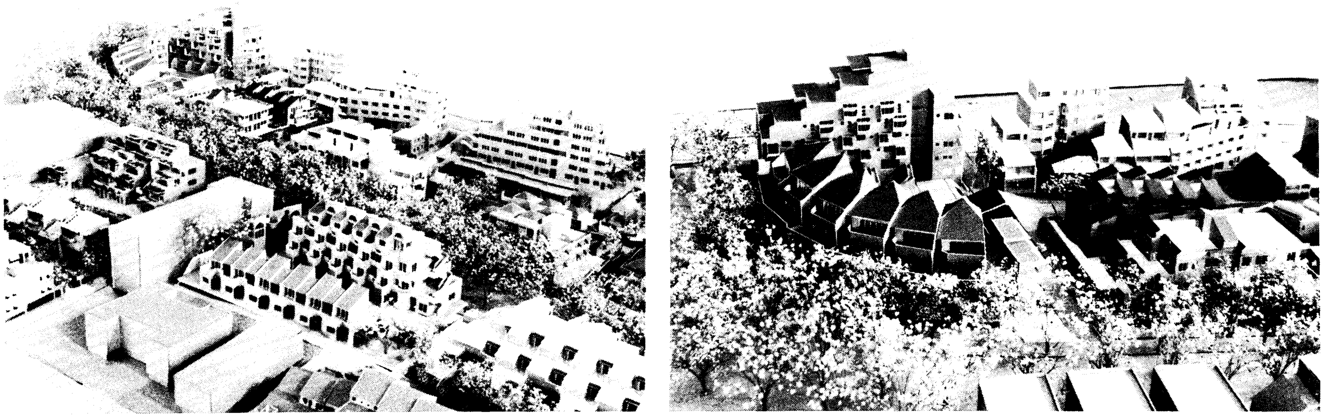
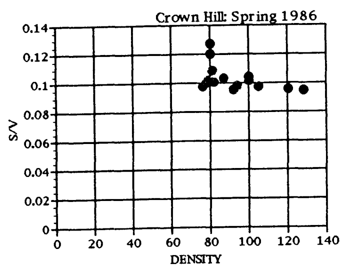


Photo 3



Graph 5. Exemplar #4 shows a density range of 76-128 du/a (L.A. zoning designations R4 and R5) and a corresponding S/V range of 0.1272-0.0954.

facing slope that has been left open as a park.

Graph 5 shows most points clustering around 80 du/a with a few scattered above that value; and as expected, S/V drops again, this time clustering around 0.1. The six points that fall slightly below that value symbolize the unique condition of parcels overshadowing the park. Obviously the result is periodic loss of winter sunshine on sections of the park; but there is also extra building height with spectacular views for many dwellings units.

A view northward shows that, because the solar envelopes do not drop at sidelines as they do in Exemplar #3, separate designs merge from lot to lot (Photo 4-left). In the foreground are actually three separate but continuous designs. The closest one is L-shaped. The middle one, very tall and with a low building in the front yard, extends an undulating roof line that copies the solar envelope. The third and last design in the row breaks from the envelope boundary but holds the line of a shared south facade.

A view toward the southeast and across the park again shows designs merging under shared solar envelopes. (Photo 4-right) In the background, across the park, are two separate designs that divide one envelope; but in the foreground are two other designs that take the division a step further by coalescing into a single, dynamic composition.

This last exemplar not only has the highest density of the four shown, but it extends the density range to the highest value attained in any of the twelve projects that comprise this work. The complete findings for all projects, including conclusions about the specific limits of size, are discussed next in the final section.

4. RESEARCH FINDINGS

Graph 6 contains data collected over 10 years from 12 studio

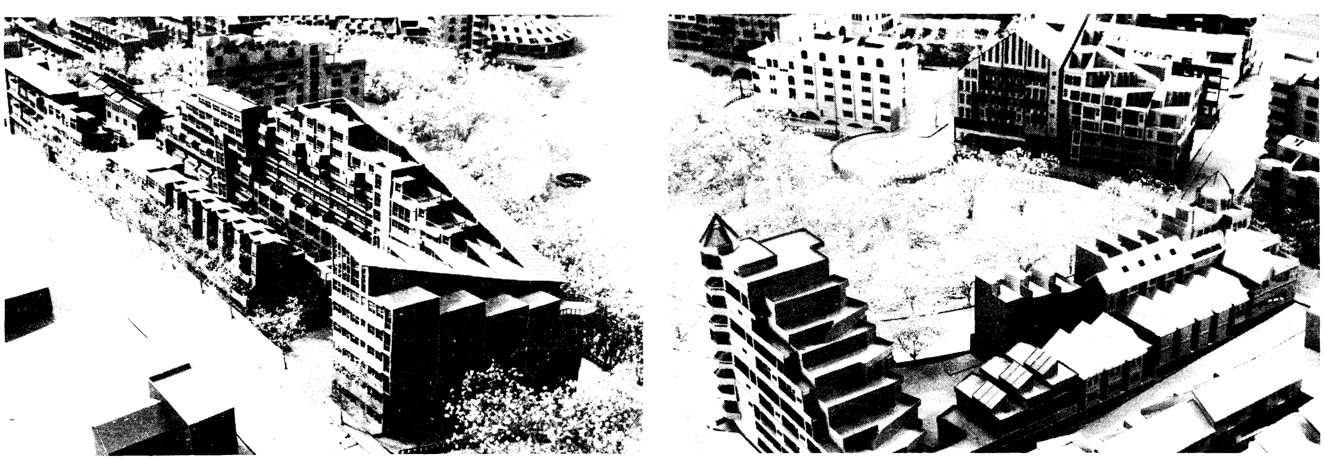


Photo 4

projects and 150 individual housing schemes. The information shows that while the full range of densities contained in L.A. zoning is not represented, a considerable part of that range has been achieved under the solar envelope. But the high and low values on the graph have emerged from quite different circumstances in the research: One, deliberate; the other, chance.

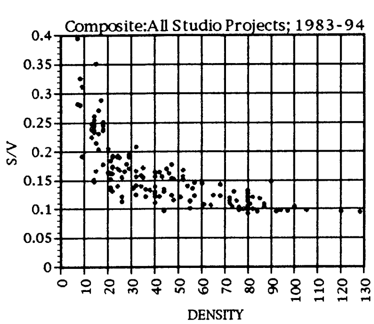
An initial decision was made to exclude from investigation one-family houses on big lots. Such dwellings are recognized at the very low-density end of L.A. zoning but are clearly inappropriate for urban development; nor do they adequately challenge students with the problems of solar-access policy and design to which the studio is dedicated. So the lowest densities investigated in the studio are one- and two-family dwellings on small hillside lots, the sort of dwellings that are typically found in the foothills surrounding the L.A. basin.

The high-density figure, on the other hand, is not deliberate but the chance result of a step-by-step disclosure over the years of testing. The studio found that solar access and cross-ventilation are easily provided through exposed walls and roofs up to 35-40 du/a. But as density is further increased, siting options for good orientation are reduced; walls and roofs begin to disappear as means of connection to the outdoors, and the "skip-stop" sections described earlier become necessary.

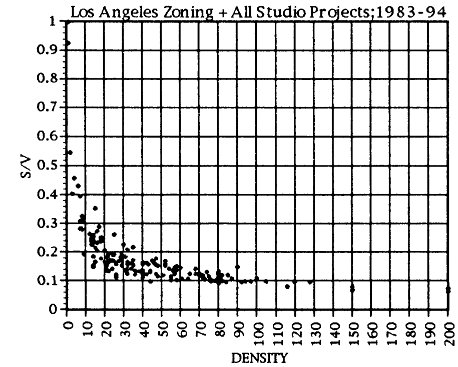
4.1. The Cut-Off Value for S/V

The consistent effort in the Solar Studio to achieve both energy efficiency and higher densities has produced a cut-off value of S/V = 0.1. Above this value, solar-access and cross-ventilation can be made available to every dwelling unit on a land parcel. Below that value, units begin to lose free access to light and air. The result is an energy-based limit on building form and hence on density.

Latitude affects the cut-off for S/V. Los Angeles is at 34 N. At higher latitudes, where the sun is lower in the winter sky, buildings must be either shorter or spaced further apart for solar access; the result is a higher cut-off value for S/V. Lower latitudes produce the opposite effect, in which buildings can be either taller or placed closer together without losing solar access. The result is a lower S/V cut-off. Other cities, especially at significantly different latitudes, need to be studied for corresponding limits.



Graph 6. The graph plots a separate point for each of 150 student housing designs completed under the solar envelope in the USC Solar Studio. The Density range is 7-128 du/a (L.A. zoning designations R1-R5); the corresponding S/V range is 0.3942-0.0954.



Graph 7. The graph overlays values for all 150 student housing designs on the values for Los Angeles dwelling classifications. The two curves agree completely in the density range 7-128 du/a where the solar envelope has been tested.

The few points on Graph 6 that fall below the cut-off value of S/V = 0.1 represent special circumstances and unusually high densities as earlier described. Otherwise, for good solar access and cross-ventilation in a compact and continuous urban fabric, an upper density limit of 80-100 du/a has emerged out of the student work at USC. Above this range, designers lose the choice of architectural means to maintain building comfort and must depend on energy-intensive mechanical systems.

4.2. The Fit With Los Angeles Zoning

Finally, Graph 7 shows that points representing all student designs cluster within the broad elbow of Graph 1 for L.A. zoning. This part of the curve includes a remarkable variety of ways to live in the city within a height range of 3-7 stories. It is therefore the conclusion of this work that ample opportunities do exist in this range to provide both energy conservation and life quality without overly limiting either design or development options for urban growth.

NOTES

1. This concept, applied here to buildings, has occupied an important place in biological literature, notably in Sir D'Arcy Wentworth Thompson's classic work, *On Growth and Form*, and in a very short but much published essay by J.B.S.Haldane from which this paper borrows its title.
2. Ralph L. Knowles, *Sun Rhythm Form* (Cambridge, Mass. and London: MIT Press, 1981), p.7.
3. Dwelling counts constitute the students' only direct involvement in the research process; otherwise, they progress in their own rhythms to make the best designs they can.
4. Other design studies in the USC Solar Studio have focused exclusively on office buildings with different rules for daylighting and thus for the Solar Envelope.
5. A floor-to-floor height of 10 ft has been consistently maintained in adapting these sections for different orientations. This has meant one less variable to deal with in the research, and it also seems to produce quite a good agreement between solar design and dense packing of units.