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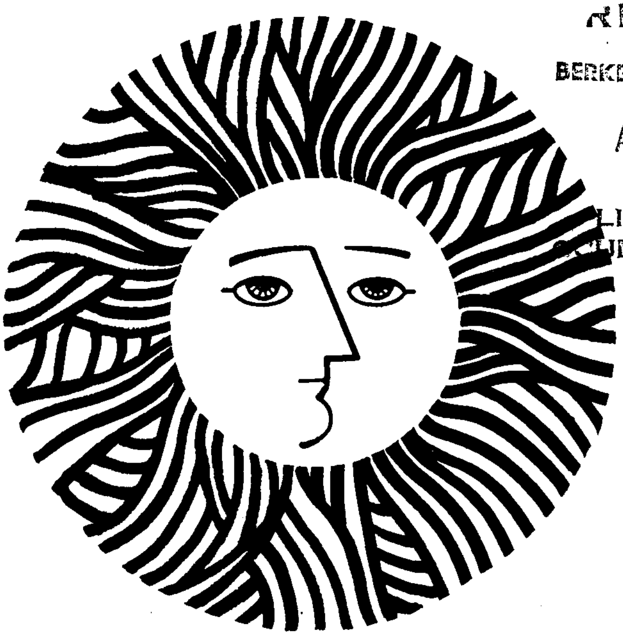
Patricia L. Smith and Scott T. McCreary

February 1980



Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

# A METHODOLOGY FOR EVALUATING PHYSICAL CONSTRAINTS ON RESIDENTIAL SOLAR ENERGY USE

Patricia L. Smith

Scott T. McCreary

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Thanks to Peter Pollock, who helped conceptualize the project; Professor Robert Twiss, advisor; Professor Thomas Dickert for his early critique of the methodology; Allan Gatzke, whose ideas worked their way into this paper; Peter Kreps and staff at the Lawrence Berkeley Laboratory Computer Center; Heather Clendenin, Tom Gravel, and Roger Herrera, who collected and coded data.

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## 1. Introduction

The paper prepared as part of Distributed Energy Systems in California's Future (Lawrence Berkeley Laboratory, 1978), "Land Use Implications of a Dispersed Energy System" (Twiss, Smith, Pollock) raised a series of issues about the land use requirements of decentralized alternative energy sources and their planning implications. (This paper will examine several of those issues in detail: the extent to which physical requirements limit the use of direct solar energy in existing urban residential communities; methods for assessing those limitations, and the use of such assessments in planning for solar energy use at the local level.)

Projections of practical levels of utilization of solar technologies for the near future are based upon technology assessments and market penetration analyses.* While market penetration analyses do consider physical requirements of the technologies, as one of the determinants of feasibility, those considerations remain generalized and hypothetical. General Electric estimates, for example, that only 65 percent of existing residential units can be retrofitted with solar space and/or water heating systems. Their reports states:

> "The 35% difference between feasiblity and maximum potential is the result of problems caused by the shading of the roof area for solar collectors as well as poor orientation of the slope of the roofs of many single family units" (Hirshberg, Alan and E.S. Davis, 1977).

How these national aggregated proportions might be applied to planning and implementing solar technologies in an individual community is a question that has only been addressed to a limited extent.

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*See, for example, the series of reports prepared by Westinghouse, General Electric, Rand, SRI International and the MITRE Corporation for ERDA's Solar Heating and Cooling of Buildings (SHACOB) Demonstration Project.

Similarly, the protection of "solar rights" i.e., the assurance of unobstructed insolation onto active or passive solar collectors, does not exist in most states. (National Solar Heating and Cooling Information Center, 1978.) The lack of solar rights protection is consistently identified as a barrier to the implementation of solar heating and cooling of buildings in the literature (Miller, 1977).

Only a few communities have begun to deal with these concerns. With the help of the design and planning firm of Living Systems, the small city of Davis, California, is developing techniques for ensuring that the physical requirements of solar technologies can be met in new developments.*

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* In most communities, however, it is left to architects or engineers working on a single project to deal with the physical requirements of the technologies and the constraints imposed by the site and its surroundings.

This situation is but one example of the gap between policy planning and implementation at the site level.

This paper attempts to bridge that gap. It sets forth a procedure for assessing physical constraints on solar energy use at the site scale and for computerizing findings as a data base for analysis at the community, sub-community and individual parcel scales.* First, background information regarding the development of the project is presented. Next, the solar technologies being considered, their requirements for optimal performance, and physical constraints on the achievement of those requirements are described.

This theoretical discussion is followed by a description of its application to a case study community. A discussion of the types of analyses in which the computerized data can be used is followed by a discussion of the way in which these analyses can be used at various points in governmental and private planning and decision-making processes.

## 2. Background: Carroll and Nathans' Hypothetical Community

This study was initiated partly in response to the ideas put forward by Carroll and Nathans, in "Land Use Configuration and the Utilization of Distributed Technologies" (Lawrence Berkeley Laboratory, 1978). Their paper represents one of the first efforts to evaluate the relationship between land use and decentralized solar energy use that has been undertaken to date.

Carroll and Nathans (1978) analyzed the land use requirements of a hypothetical "self-contained" community designed to rely on renewable energy

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*See paper by Edward L. Vine, prepared for the Distributed Energy Systems Study Group entitled, "Planning for an Energy-Conserving Society: the Davis Experience".

systems for all its energy needs except transportation. Assuming conventional community design standards and current land use proportions, they characterized a community of 10,000 people with a range of primary land use types and activities. The study concluded that to supply 100% of the energy demand of all homes, businesses and industrial plants using integrated solar thermal electric technology on an individual basis approaches gross acreage for most land use types, except the single family residential, and greatly exceeds gross acreage in the industrial sector.

The San Francisco/Bay Area community hypothesized by Carroll and Nathans (1978) contains 1800 single family units at a density of four units per gross acre, or 450 acres of which 63 are developed. About one fifth of the total area or 91 acres are needed for the collectors required to supply the integrated solar system. This breaks down to 2202 square feet per dwelling unit, or 1.4 times the built-on area.

Obviously, reliance on systems located _entirely_ within the community and on individual sites imposes unrealistically high spatial requirements. Application of the concept of end use matching (Lovins, 1977) would suggest a mix of technologies, each appropriate to the end use requirements. In the near future, flat plate collectors might be used to provide space heating and cooling and hot water with back-up provided by renewable (e.g., biomass derived) or nonrenewable fuels converted to heat either on-site or at a centralized source. In an urban setting, electricity would probably continue to be provided through the utility grid, allowing for flexibility in siting renewable energy conversion facilitis such as wind machines. In the most distant future, arrays of photovoltaic cells located on rooftops could produce electricity to be stored and use on-site with space and water heating as byproducts.

In considering immediately feasible applications, the ERDA Pacific Solar Handbook estimates that roughly 400 square feet of collector area would be required to provide 75 percent of the space heating and water needs of a 1500 square foot single family dwelling with 19 ceiling insulation, R-11 wall insulation and 20 percent window area (glazing) in a temperate California climate. This is less than one fifth the collector area assumed by Carroll and Nathans.

Although their findings may exaggerate realistic land use requirements, the study by Carroll & Nathans (1978) nevertheless points out the importance of considering land use requirements in planning for reliance on renewable energy sources. The study concludes that:

> "It is clear that local physical conditions will affect the amount of solar and energy input both on a local and seasonal basis. It will also determine the extent to which building settings and architectural designs can be utilized to take advantage of passive solar systems. Moreover, in the case of community energy systems, the ability to distribute energy on an economical basis will also be affected by the local terrain. Finally, if there are a scattering of existing structures already present, they may preclude obtaining sufficient acreage to dedicate to community energy facilities."

Between 1978 and 2000, there will be a considerable amount of new residential development beyond the urban fringe on land that has not yet been subdivided. In that context it will be relatively easy to accomodate solar technologies. However, a great deal of new construction will occur within the context of the existing urban pattern in filling of vacant parcels in already developed areas. Furthermore, as the availability, the high cost of expanding the urban infrastructure (i.e., roads, utilities, sewage), concern that deterioration of cities will accelerate and indications that urban sprawl will continue to pre-empt prime agricultural land and result in high transportation energy costs and deteriorated air quality, several factors led the State of California Office of Planning and Research (OPR) to develop an urban policy that emphasizes infilling of existing urban areas. The policy identifies three priorities for future urban development:

1. Renew and maintain existing urban areas--both cities and suburbs.
2. Develop vacant land that is within existing urban areas and presently served by streets, water, sewer and other public services.
3. Where it is necessary to develop land outside existing urban areas, only develop land that is immediately adjacent to the existing areas.*

As the availability of resources declines and the costs of contruction increase, the trend toward renovation rather than removal of older dwelling units will intensify. Consequently, in planning for the possibility of wide-spread reliance on decentralized solar techniques, it is necessary to evaluate that possibility within existing urban settings.

## 3. Solar Technologies Available for Community Applications

In this section three typical solar systems are described.

1. On-site passive design;
2. On-site active collectors;
3. Shared systems at the neighborhood or community wide scale.

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* For a complete discussion of the proposed California policy see Office of Planning and Research, State of California, An Urban Development Strategy for California, 1977.

### 3.1 On-Site Passive

Houses can act as selective collectors of solar energy, thereby achieving a decreased dependence upon mechanical climate control systems. For space heating, this can be accomplished "passively" by adjusting and orienting the building envelope to include an expanse of south facing windows and providing internal thermal mass.

In Figure 1, System I, Sun/Space, takes advantage of the seasonal differences in the path of the sun through the use of an overhang. During winter months, the sun, lower on the horizon, shines directly through a large expanse of south facing windows; its heat is stored in material with a high thermal mass built into the house. Moveable insulation helps to trap this heat inside during the night time. In the summer, insolation at a higher sun angle is reflected off and away by the overhang.

Figure 2 shows a further refinement, System II, Sun/Mass/Space, which utilizes the same principles of thermal storage. In the top drawing, sunlight is absorbed in roof-mounted water containers during the day. After moveable insulation covers the water,.heat is conducted from the water through the steel beams supporting the rooftop system into the house. The process is simply reversed to achieve nocturnal cooling. The lower drawing illustrates a construction method by which solar energy passing through southerly-oriented glazing is absorbed and stores in masses of concrete or water.

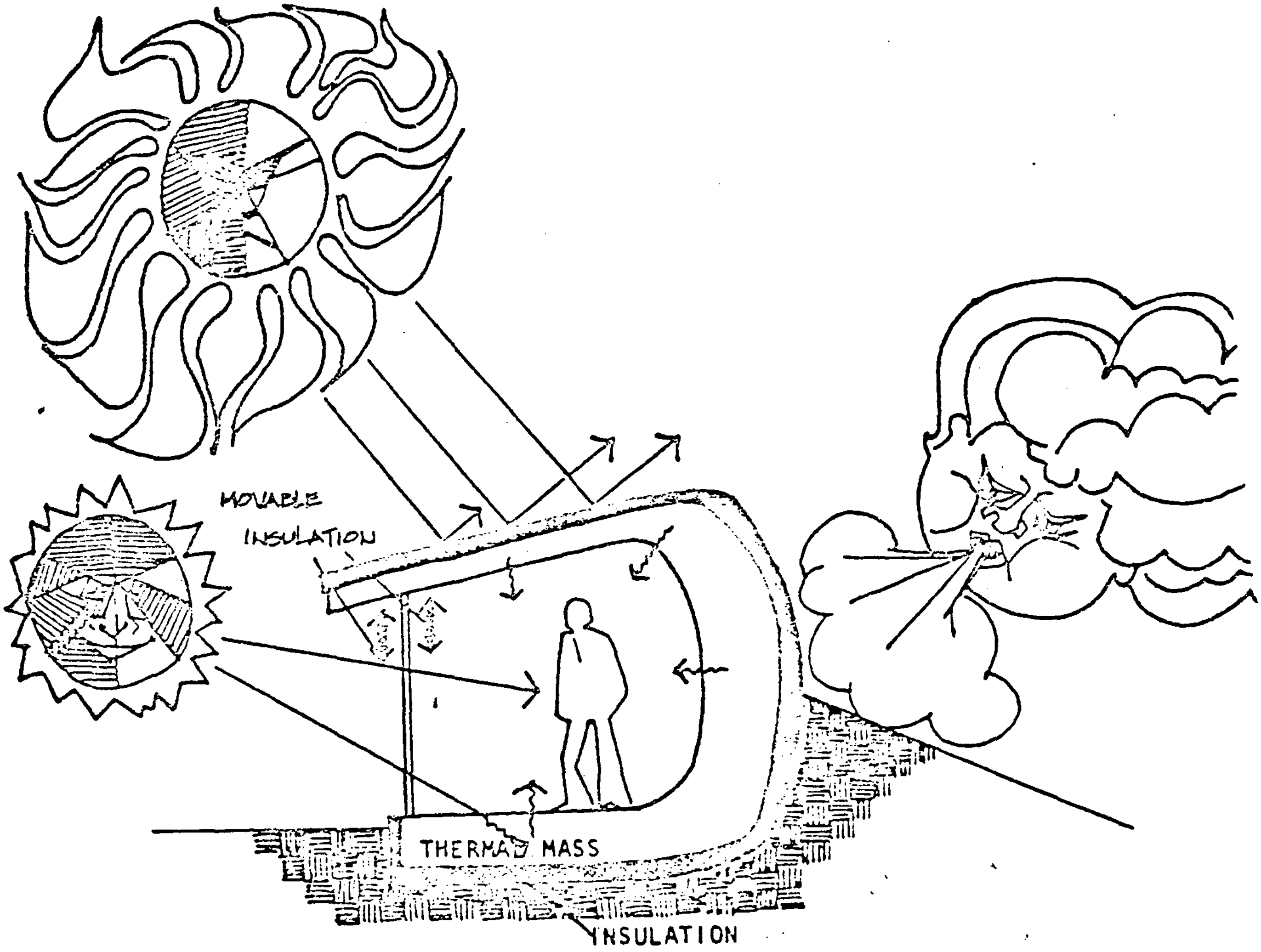
## On-Site Active

By adding flat-plate collectors and a storage and distribution system, solar energy can be "actively" utilized for space and water heating. In Figure 3, System III, Sun/Collector/Storage Space, the flat plate collector and active distribution system is shown. Either water or air can be circulated through the system. The collector is not an integral part of the storage medium. Thus, this design offers the greatest amount of flexibility, especially for renovating existing structures.

The system described above could be built on or integrated into the roof of a structure at the time of construction or added to already existing structures (retrofitted). Collectors can be placed on the roofs of dwelling units, garages, or carports. If roofs cannot be adapted to solar collector mounting, ground level collectors or independent support structures with other uses (e.g., patio covers) could be used.

It is impossible to derive a single, generalized specification of collector area required for a particular location. The heat load of structures of the same dimensions vary due to construction specifications, energy use patterns of residents, etc. Examples of existing active solar systems demonstrate a variation by a factor of two in the amount of collector area required to provide a given amount of the heat load in a house of the same size, in a given geographical area. Nonetheless, reasonable estimates for typical units have been made, and are essential to the analysis presented in this paper.

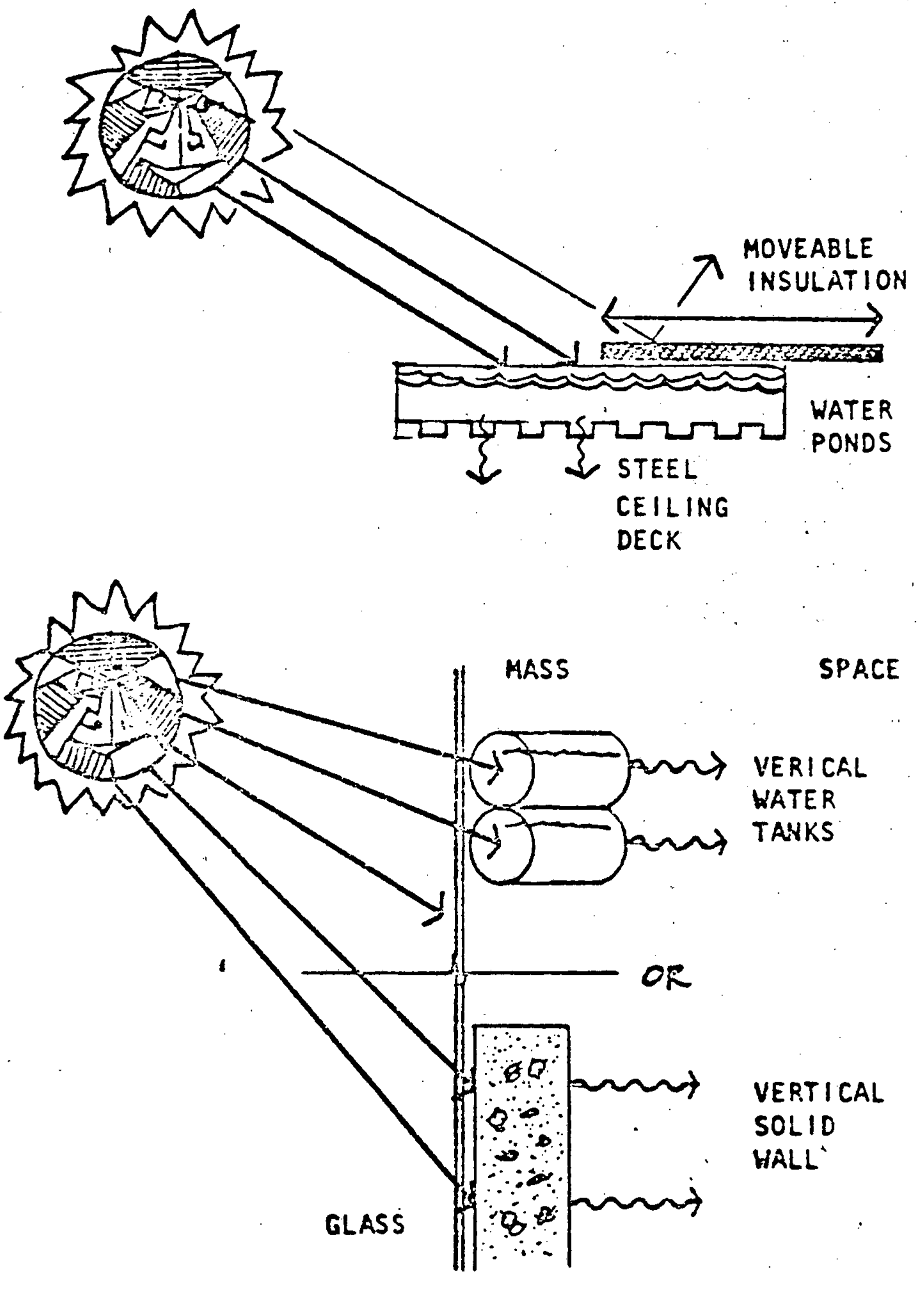
As mentioned earlier, the ERDA Pacific Regional Solar Handbook estimates that 400 square feet of collector area are needed to provide 75 percent of space heating and hot water needs of a typical California home in an average climate.



SYSTEM I SUN → SPACE

Figure 1 Passive Solar Design with Direct Heat Gain and Floor Storage

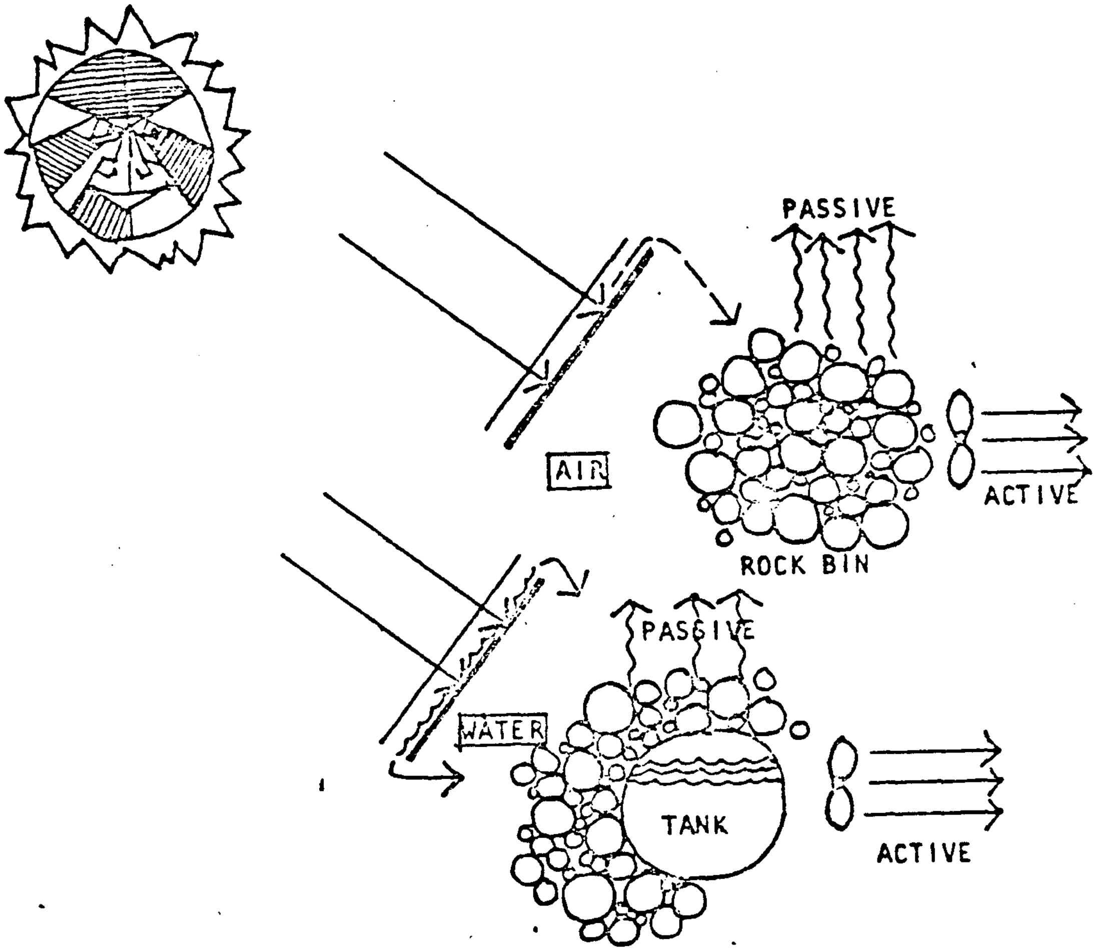
Source: AIA 1975



SYSTEM II SUN -> MASS -> SPACE

Figure 2 Passive Solar Design with Roof or South Wall Storage

Source: AIA 1975



SYSTEM III

SUN → COLLECTOR → STORAGE → SPACE

Figure 3 Active Solar Systems with Rock Bin Storage/ Air Circulation or Water Storage and Circulation

Source: AIA 1975

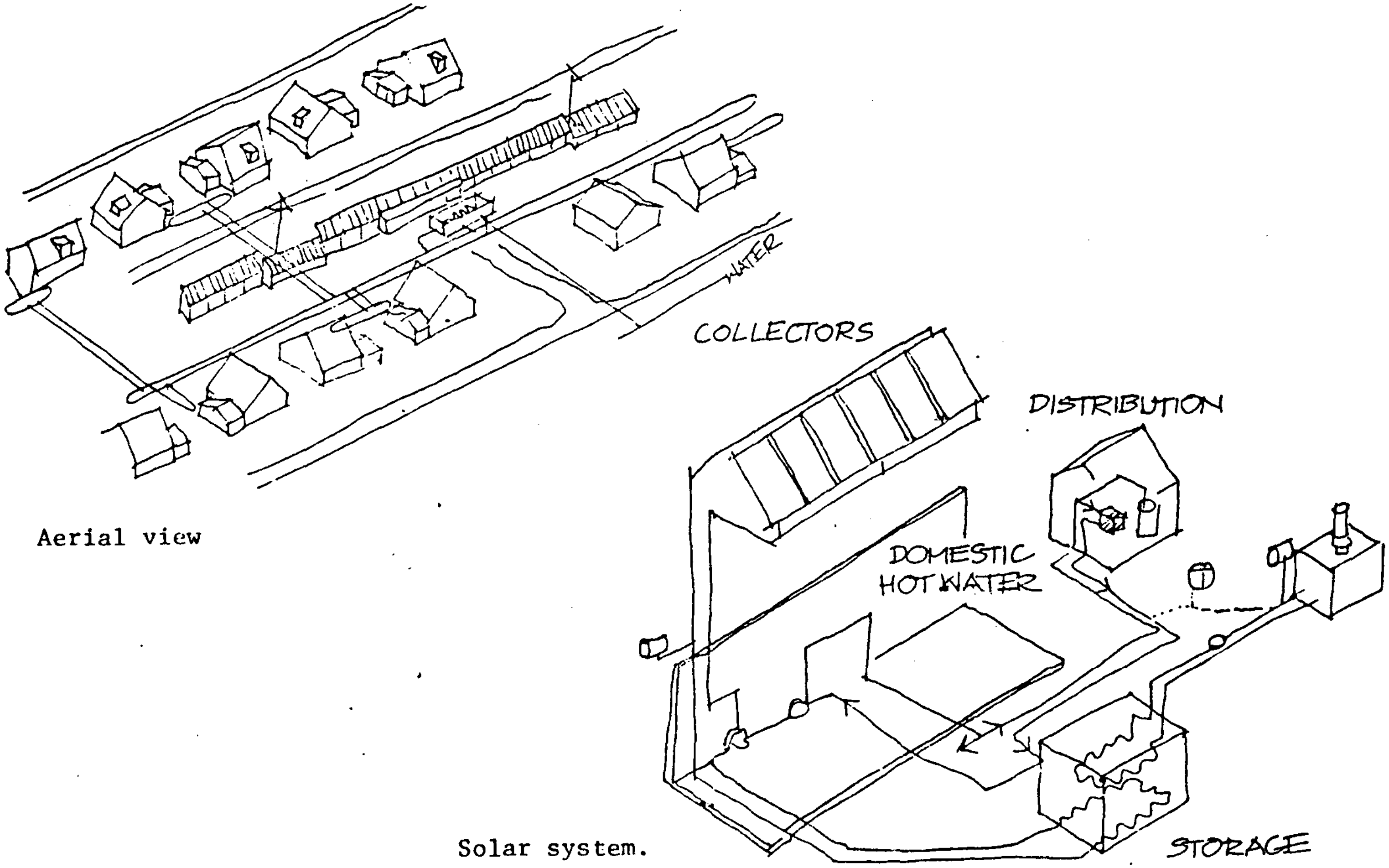
## 3.3 Neighborhood and Community Solar Energy Systems

Shared solar systems combine the individual contributions of roof and/or ground mounted collectors, utilize common storage facilities and distribute heat via conventional district heat via conventional district heating systems. The scale of such systems can range from a single block to an entire community. The block scale, roof and ground area on residential parcels and/or undeveloped lots and public land could be used for collector surfaces. The storage system might be located in the basement of a community facility, e.g., library, school or recreation center; on public land or a vacant lot, park or street intersection.

Examples of small scale shared systems are depicted in Figures 4 and 5. Figure 4 illustrates a shared system that was constructed during the renovation of ten small single family houses by the San Bernardino Community Development Corporation. Figure 5 depicts the new development of Grassy Brook Village in Brookline, Vermont, designed by People/Space Company and engineered by Dublin-Mindell-Bloome Associates. The 20 unit development was being built in 1976. The solar system serving houses consists of 4500 sq. ft. of collector area facing south at a tilt of 57° and 15,000 gallons of storage in the form of water-glycol solution. A heat pump and an oil-fired boiler provide back-up system heat; wood burning stoves provide individual back-up heat (Anderson, 1976).

Community scale hot water/space heating systems are used in several northern European countries. The source of heat is general fossil fuels or waste heat from industrial or electrical generator processes (Larson, 1976).

Figure 4. Neighborhood solar system installed by the San Bernadino Community Development Corporation.



Aerial view

Solar system.

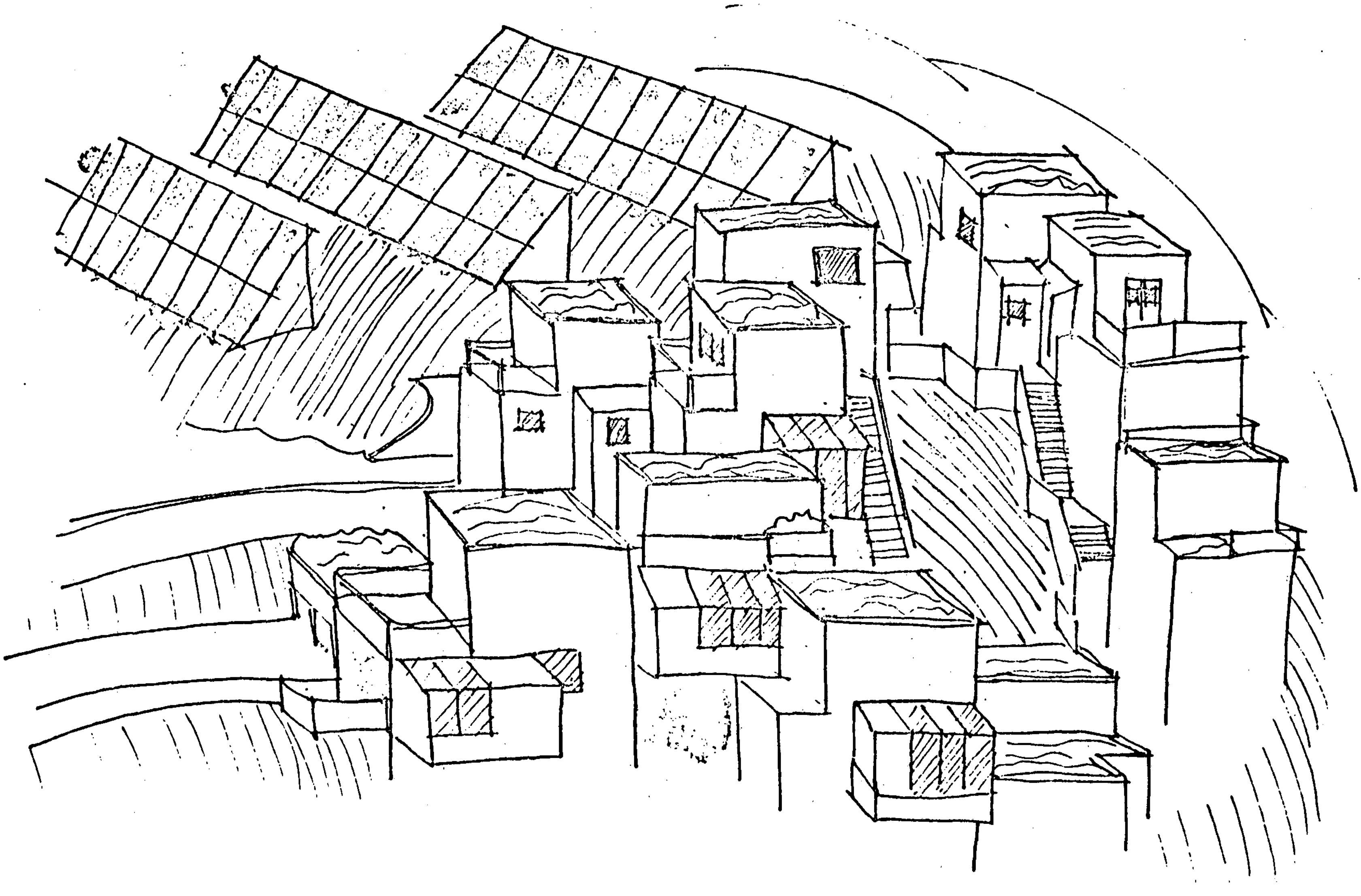


Figure 5. Grassy Brook Village--a community solar system.

Lawrence Berkeley Laboratory estimated that from 50,000 to 80,000 $ft^2$ of collector area, utilizing three to five acres of land or roof area, would be necessary to provide commercial and residential space and water heating for 1,000 people. This assumes five days storage for water and one day for space heat at a density of 1000 people per 40 acres (a situation similar to San Francisco) (Lawrence Berkeley Laboratory, 1978). In a lecture at U.C. Berkeley campus, Amory Lovins (1977) estimated that one acre of collector area would be needed for 100 single family dwellings. He assumed "well-insulated" homes and a heat loss from storage of 5 percent per year. At a density of 3 persons per dwelling unit, this figure yields a land requirement of a little more than 3 acres per 1,000 people, consistent with LBL's estimate.

All of the above technologies share the two basic components of collector and storage. The location of those components varies among them.

There are two essential physical requirements that must be met on a site if it is to serve as a solar system location. These are:

(1) Enough south-facing area to collect and store the required amount of energy; and

(2) Unrestricted insolation onto that area for the number of hours per day assumed in the design of the system. This unrestricted insolation is commonly referred to as "solar access".

Whether or not these requirements can be met is influenced by the characteristics of the natural and built environment. The following discussion will first address the basic physical requirements and then the constraints imposed on achieving them by the environment.

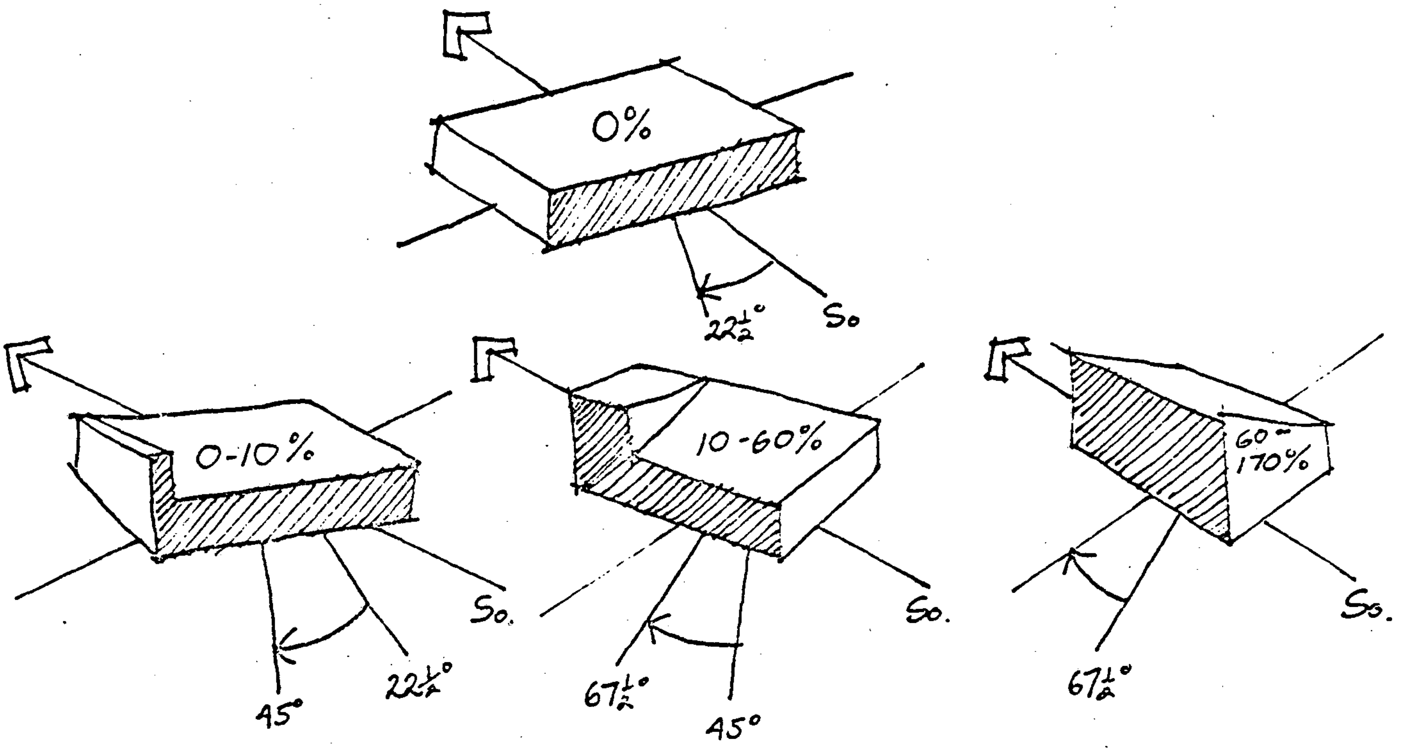


Figure 6. Increase in vertical collector area with deviation from due south orientation.

## 4. Basic Site-Dependent Requirements for Performance

### 4.1 South-Facing Area as a Requirement

For active solar systems, the required size of the collector area and the period of unrestricted insolation onto that area depends, in part, on the specifications of the system and the heating and cooling load of the structure. For a system with a given conversion efficiency (typically 50 percent), a collector orientation and angle of tilt ideally suited to its geographical location would be (latitude + 15° for heating and latitude + 0° for cooling). Local climatic conditions such as consistent morning fog or overcast might suggest that collectors should be oriented toward afternoon sun (i.e., slightly west of south). The rate of insolation as well as the building heat load will determine the size of the collector area needed to transfer a given amount of heat to the thermal storage mass. If 400 $ft^2$ of collector area is required to provide 75 percent of a San Francisco heat load, 800 $ft^2$ may be required for an identical structure in Minneapolis when the insolation rate is lower and heating demand is higher.

If optimal orientation and tilt are not possible, performance efficiency drops and the area of the collector surface must be increased in order to achieve the same amount of space and water heating. Total Environmental Action, an environmental design group, has quantified the amount of compensation required, based on research by Larch. Their findings for mid-latitude regions (40°) are shown in Figure 6 adopted from Department of Housing & Urban Development, 1975. In the case of passive solar design, the collector/thermal storage mass is part of the house.* The collector component of the

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* For example, glazing plus Trombe wall, roof top pond, or glazing plus concrete floor.

structure must be oriented south.

## 4.2 Solar Access

When an active or passive solar system is designed, a certain number of hours per day of insolation are assumed to be available. In order to operate at its design capacity, insolation must not be blocked during that period of the day. For space heating systems, the most critical day is generally assumed to be December 21. Although the heat load is slightly higher the following month, the amount of insolation reaching the earth is least on December 21 and the length of shadows is greatest so that insolation is most likely to be blocked on that day. This is due to the fact that the path of the sun is closer to the horizon on December 21 than on any other day of the year.

A reasonable period during which the sun should not be obstructed on that day has been defined for legislative purposes by several sources. Living Systems defines the period of protected solar access as 10:00 a.m. to 2:00 p.m. (Living Systems, 1976). A report prepared by the American Bar Foundation identifies a period of time in its definition of "solar skyspace" as:

> "that three-dimensional space extending from a collector to the location of the sun between 9:00 a.m. (8:00 a.m. for cooling) and 3:00 p.m. (4:00 p.m. for cooling) solar time; and where a solar energy system is utilized for heating, to all locations of the sun between September 22 and March 22; where a solar system is utilized for cooling, to the location of the sun between March 22 and September 22; and where a solar energy system is used for heating and cooling or for hot water uses to the location of the sun throughout the year." Miller, 1977).

Figure 7 depicts the concept of solar skyspace.

## 5. Constraints on Optimal Siting

Whether or not optimal conditions can be met is influenced by the form of the natural and built context in which the technology is implemented.

### 5.1 Natural Environment Constraints

#### 5.1.1 Topography

Topography affects solar feasibility in two ways: by restricting building/collector orientation and by direct blocking insolation. If solar collectors are placed on structures or independently on a slope greater than 15°, the orientation of the collectors is likely to be restricted by that of the slope. As shown in Figure 8, buildings on slopes are generally oriented with the slope, (parallel to the topographic lines). Consequently, if the slope if facing south, the house will face south; if the slope faces north, so does the house. For passively designed structures, this is a significant limitation. If the slope is oriented more than 20° or 30° east or west or south, it may be difficult to construct large south facing window and thermal mass areas. Figure 9 illustrates that while it is possible to orient the structure south on a slope that is oriented east or west, it is likely to be considerably more costly due to the increased amount of grading and/or design adaptations of the building.

Topography can also affect solar potential by obstructing insolation in the same way a tree or structure would. This constraint is most severe on north facing slopes and in canyons running east-west (having north and south-facing slopes)(see Figure 10).

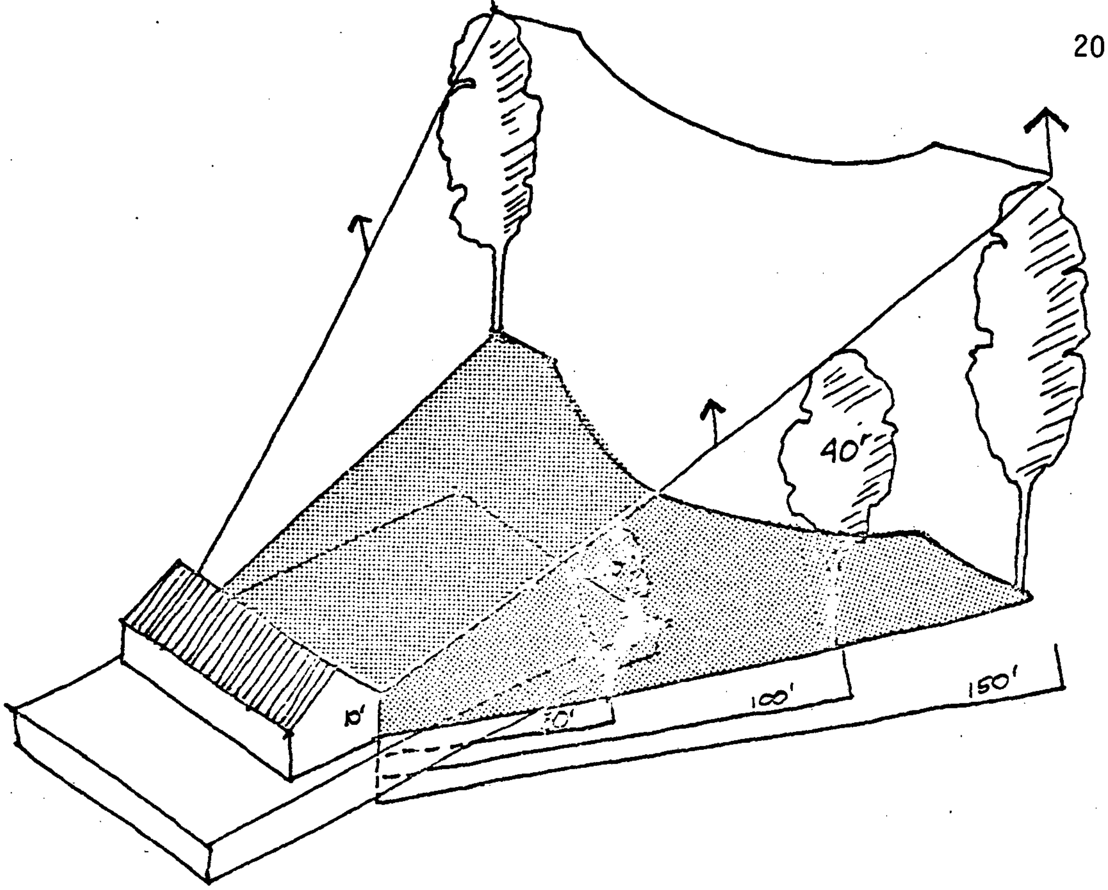

Figure 7. Solar skyspace 37° latitude, December 21, 10 a.m. to 2 p.m.

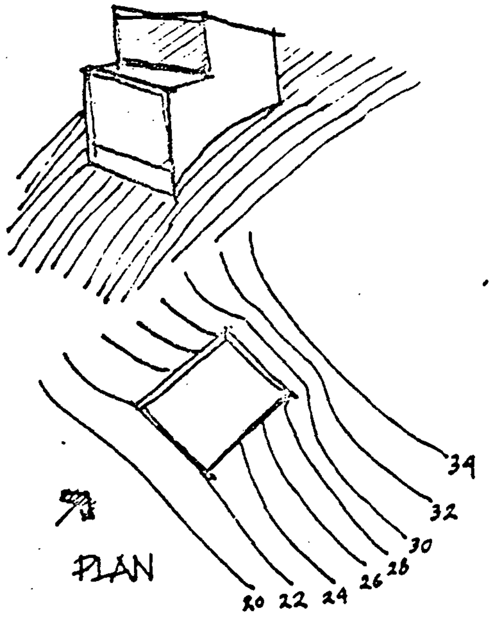

Figure 8. Building oriented <u>with</u> slope.

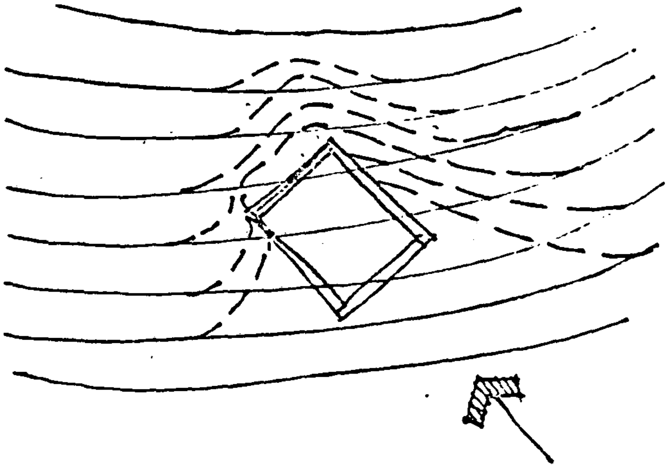

Figure 9. Grading a west-facing slope for a south-facing pad.

Active solar systems are less likely to be constrained by slope aspect. Even if the house is abutted against a north facing slope, a portion of its roof can still be oriented south. Only if the slope above the house is steep enough to cast a shadow on the roof top will the solar potential be affected. However, trees on the slope above the house will be more likely to block insolation onto the collector surface than a tree of the same height on level ground.

### 5.1.2 Vegetation

Vegetation can reduce solar potential by blocking insolation onto the site and/or structure. This is a difficult problem for the homeowner since trees unquestionably constitute an amenity and serve as significant energy conservers. They can serve as windbreaks to reduce heat loss from buildings and provide shade during the summer months. While deciduous trees only partially obstruct insolation in the winter when it is needed for heating, they could still present a problem. Depending on the branching structure of the species, a deciduous tree without foliage will reduce insolation 40 to 60 percent (Reifsnyder, 1965).

Even if deciduous trees are used to allow for winter insolation, they will obstruct summer insolation. This is a beneficial passive design technique. However, it does eliminate the opportunity to use solar energy as a source of energy for air conditioning. A quantitative comparison of heat load reduction and consequent conventional fuel savings due to shading versus fuel savings due to use of solar air conditioning is needed to assess the trade-offs between these two techniques.*

Similarly, more research is required to provide a quantitative basis for evaluating trade-offs between energy savings from windbreaks and solar air conditioning. If wind from the south has to be buffered, the windbreak trees may cast shadows on the site.

Vegetation constraints on solar energy use can be evaluated in terms of the period of time during which it obstructs the solar skyspace. The constraint is most severe if insolation is obstructed throughout the entire period during which solar skyspace must be protected, defined as 10:00 a.m. to 2:00 p.m. on December 21. During that four hour period at 40° latitude (mid-United States), a total of 1104 Btu's per square foot fall upon a surface oriented south at an angle of 60° from horizontal. From 10:00 a.m. to 11:00 a.m. there is a total of 242 Btu's; from 11:00 a.m. to noon and 1:00 p.m. to 2:00 p.m. 283 Btu's; and from noon to 1:00 p.m. 296 Btu's. If a single hour of insolation is obstructed, the consequence is obviously less severe. It is easier to mitigate the vegetation constraint either by increasing collector area or by modifying fewer trees. If the tree(s) to be modified is not the center of the solar skyspace zone (i.e., if it is in the 10:00

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*The study cited above indicates that a forest of conifers or hardwoods will reduce the monthly maximum air temperature in the summer by about 10°F below that in the open. At the same time, temperatures are higher in urban areas than in the surrounding countryside due in part to the relative absence of vegetation and consequent lack of evaporative cooling. "Mean monthly temperature differences between city and county in summer are about 2° F (Dratzer, 1956). However, much greater difference occur in hot calm weather...

Kratzer (1956) showed diurnal temperature variations for three locations in Vienna: an avenue with trees, a large square without trees and a narrow streets(surrounded by tall buildings) Figure 2 shows his findings in graph form. A study of San Francisco on March 26, 1952 showed that Golden Gate Park was 15° cooler than the surrounding city (Federed, 1971).

a.m. to 11:00 a.m. or the 1:00 p.m. to 2:00 p.m. zone) it is more likely that the collector area could be located by moving the array the opposite direction.

### 5.2 Built Environment Constraints

Constraints imposed by the man-made environment vary with the extent of existing development on and around the site. A large parcel of land which has not been subdivided provides maximum flexibility. On the other hand, constraints are severe for an existing structure on a typical street, surrounded by other structures.

### 5.2.1 Subdivision Patterns

Current land use patterns are established by the original subdivision of the land and reflected in street and utility alignment. These determine the orientation of parcels and the relationship of structures to one another.

If a parcel of land is zoned for construction of a planned unit development (P.U.D.) or for clustered residential development,* energy conservation and reliance on solar energy can be optimized through site planning and design. Structures can be oriented to maximize insolation, attached and/or clustered to minimize heat loss, or sited in a configuration that minimizes the obstruction of solar access. Zoning for detached single family develop-

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*A cluster development is one in which a number of dwelling units are grouped, leaving some land undivided for common use. It may mean grouping the same number of units in a given area on smaller than usual lots. The cluster approach increases design flexibility. The total project is evaluated and approved by the local permitting agency rather than requiring compliance with zoning or subdivision regulations. Planned Unit Developments are similar to cluster development but at a larger scale and include commercial and industrial as well as residential land use (DeChiara, 1975).

ments defines relatively inflexible relationships between structures by establishing setback restrictions. Subsequent subdivision mapping establishes the orientation and dimensions of parcels which are characteristic of many suburban communities. Construction of streets and utilities finalizes that form. At this late stage of the development process, maximization of energy conservation and solar energy use would be more difficult.

In situations other than PUD's, structures must be sited independently. The probability that they can be oriented to optimize collection of insolation is limited by several factors: lot orientation, lot dimensions and zoning restrictions.

First and most obvious is the orientation of the lot. Most single family houses, especially those in subdivision tracts, are aligned parallel to lot lines (Figure 13). As was illustrated in Figure 6, insolation onto a vertical surface (passive solar window and wall) or a tilted surface (active solar collector panel) drops off as orientation deviates from due south.

To maximize efficiency and minimize cost, collectors or passive walls should be oriented as close to due south as possible. If the parcel is oriented to north, south, east or west ± 22-1/2°, the house will probably be well oriented for solar utilization, even if solar orientation was not a planning or design consideration.

The potential for adjusting the orientation of a home away from that of the lot is limited by the dimensions of the lot and by zoning restrictions. New subdivision parcels in California are typically at a density of 6-8 dwelling units (d.u.) per acre and have dimensions of 50' x 80' to 50' x 100'. In older urban areas, lots are frequently smaller, ranging

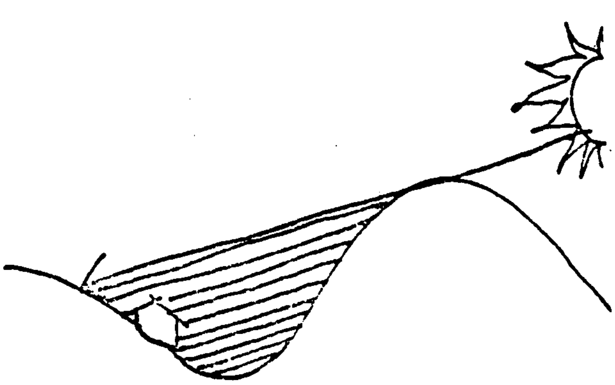


Figure 10. Landform shading structure.

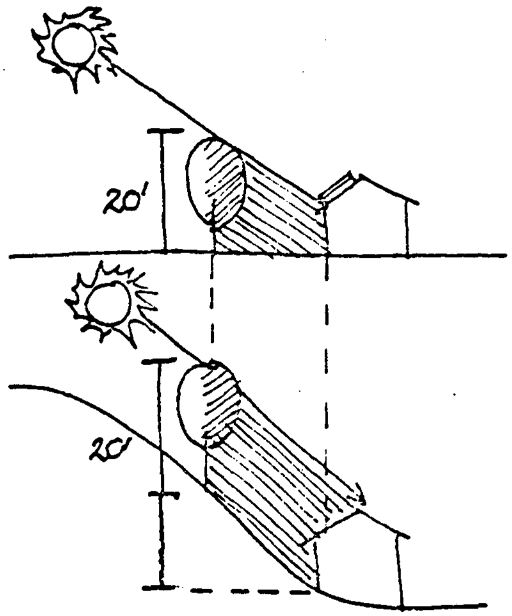
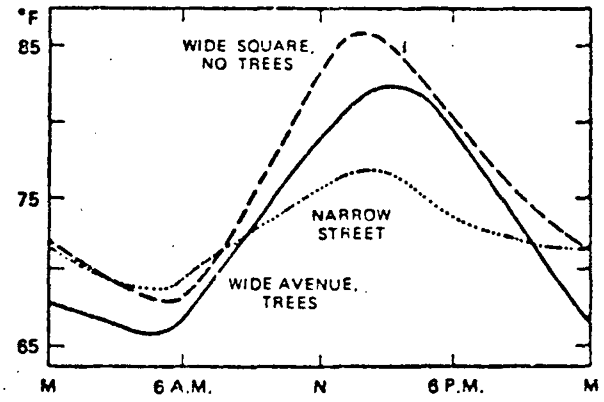


Figure 11. Tree shading on a flat surface versus tree shading on slope.



Diurnal temperature variation in Vienna on 4-5 August 1931 for a wide square with no trees, a wide avenue with trees, and a narrow street (from Kratzer, 1956).

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Figure 12. Ambient temperature variations with street trees and street width variations.

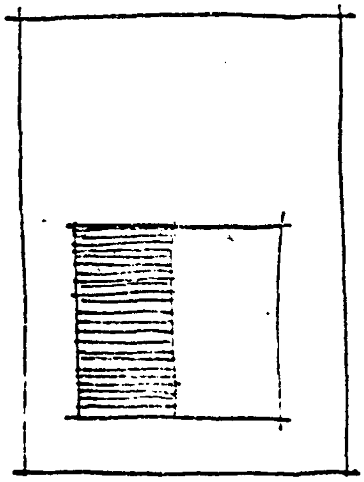

Figure 13. Structure aligned with parcel lines.

from 8 d.u./acre to 14 d.u./acre. A density of 14 d.u./acre results in parcels with dimensions of about 30' x 70'. Parcels in outlying areas are frequently larger, ranging from one to four dwelling units per acre.

Common combined sideyard setback restrictions on a 6-8 d.u./acre parcels are 15 feet, with a minimum of 5 feet on either side. On a 50' wide lot, this leaves a width of 35' for one dimension of the house. The addition of an attached garage and a frontyard setback of 15 or 20 feet provides little flexibility for reorienting a typical ranch style tract house. A specially designed house could be adapted to achieve optimal orientation, even on a 50' x 100' parcel, particularly if it were a two-story structure. In generaly, flexibility increases as lot size increases.

For new construction, constraints imposed by narrow lot width are more relevant to passive than to active design. If the entire structure cannot be oriented south, banks of collectors could be mounted on a flat portion of the roof. Not all passive "systems" are dependent on south-facing walls.*

Urban tracts subdivided subsequent to the United States land survey and prior to the 1950's largely consist of parcels oriented north-south or east-west. These lots and the houses on them are ideally oriented to take advantage of solar energy. With the advent of curvilinear street designs in the late 1950's and its continued use to the present, the large number of single family units that were constructed during that period have no "typical orientation". Consequently, most new tracts of single

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*See for example, Harold Hay's rooftop pond and Jonathan Hammond's rooftop collector "cones". (Living Systems, 1976).

family detached units consist of houses oriented in a range of directions. The suitability of retrofitting such tracts is therefore reduced by the poor orientation of many of the houses.

It is important to emphasize that although orientation does affect the amount of collector area required to collect a given amount of heat, poor orientation does not prohibit use of solar technology. Rather, it increases the collector area needed, and therefore, the cost of achieving a desired level of solar reliance.

### 5.2.2 Characteristics of the Structure

Characteristics of the structure itself impose direct constraints on the use of solar technologies. This is particularly true for passive design since structure and technology are one and the same. The characteristics discussed thus far directly influence the feasibility of installing solar technologies in new developments. Once a structure is built without incorporating conservation or solar energy use as a design consideration, it has to be retrofitted with solar technologies. At that point in time, its established form and orientation determine the extent to which it can be retrofitted and the cost of doing so.

Retrofit with passive elements would be fairly costly, at least for those techniques currently used, unless substantial renovation is being undertaken. Retrofit of active solar systems is more common and less complicated. Generally, the easiest place to locate a set of collectors is on a rooftop. Therefore, the suitability of an existing structure for retrofit is constrained by the adaptability of the roof: its orientation, area and slope.

Roofs typically have one primary division, forming two major areas (Figure 14). This primary division may run parallel or perpendicular to the front of the lot (Figure 15). If a single family detached dwelling unit has 1600 square feet of floor area, a gabled roof would result in somewhat more than 800 square feet of area oriented in each direction. A hipped roof would have roughly 500 square feet in each section. Some roofs are flat, although this is less common for single family detached units than for any other building type. If a house with a flat roof were oriented in any of the cardinal directions plus or minus 22-1/2°, fully 100 percent of its roof area would be available as a site for collector banks. Only about 50 percent of that area is available as collector surface since the banks must be spaced apart to prevent shadowing of one another (Figure 16).

On divided roofs, one of the two primary sections is always oriented within 90° of south and can therefore serve as a location for collection panels.

## 5.3 Multiple Variables Posing Constraints

As discussed in the previous section, several site characteristics influence the feasibility of implementing solar technologies. The presence of some of these characteristics by themselves may pose constraints, while in other situations it is the coincidence of characteristics that may make the use of solar technologies difficult. For example, shadows cast on a site either by trees or by topographic forms always constrain solar feasibility. However, poor slope aspect is only a problem where lot

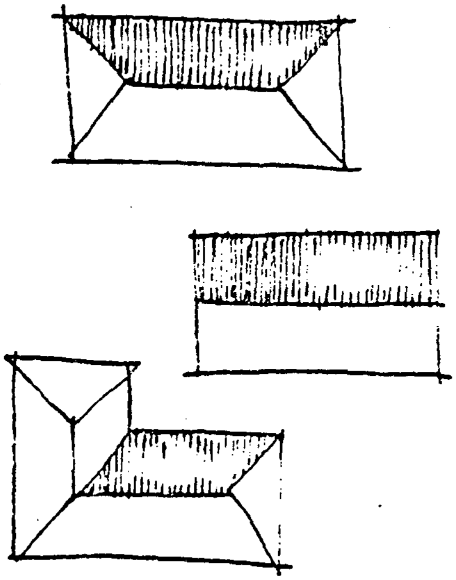


Figure 14. Most roofs have one primary roof division.

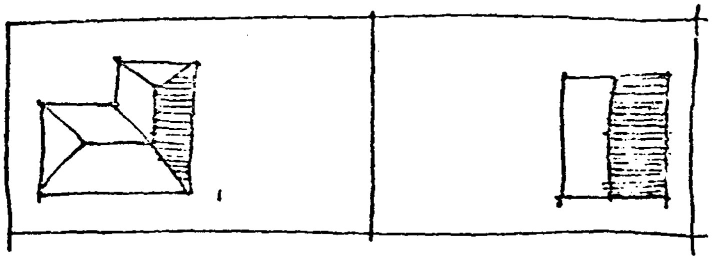


Figure 15. The primary roof division is either parallel with lot depth or lot width.

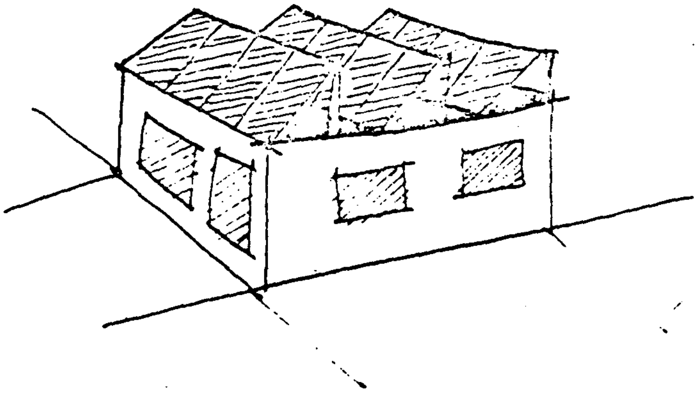
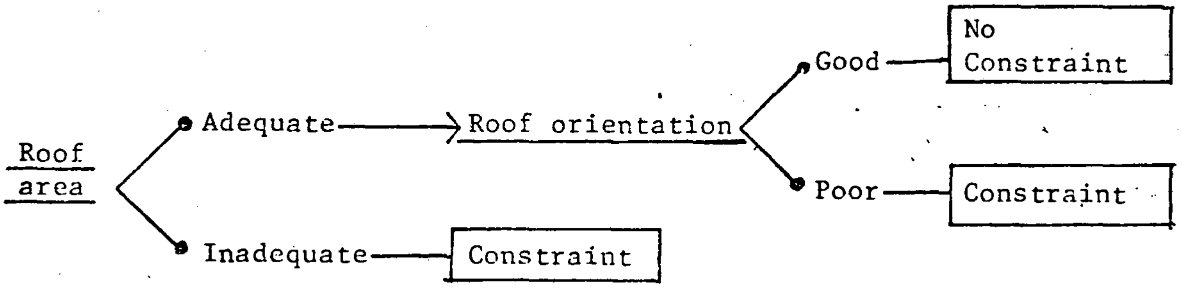


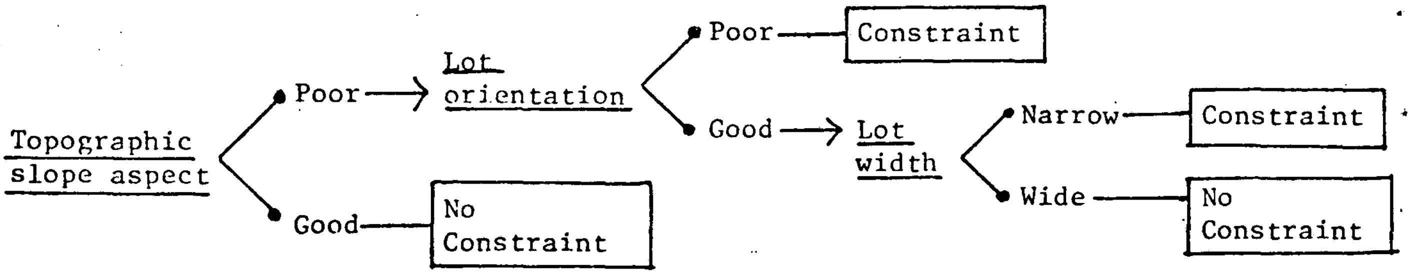
Figure 16. Collector banks on a flat roof.

orientation is also less than optimal or where lots are narrow, it may be particularly difficult to shift the structure from parallel alignment with the lot lines and still maintain sideyard setbacks required by zoning regulations. Combined sideyard setbacks are commonly 15 feet and not less than 5 feet on either side in single-family neighborhoods. On a typical 50 foot wide lot, a structure 35 feet wide has no flexibility or orientation. For example, Figure 17 identifies the constraints on implementing on-site active or passive technologies on already subdivided sites being in-filled. Shading from trees and topographic shadows creates difficulties if solar devices are to be sited on either roofs or yards. The constraints posed by a combination of slope aspect, lot orientation, and lot width apply only to rooftop solar panels.

Figure 17. Constraints on the suitability of rooftops for flat plate collectors:



Constraints on the suitability of sites for conventional single-family structures with active or passive solar technologies:



## 6. Scaling of Constraints to Measure Severity

To assess the influence of these characteristics on the suitability of a site or group of sites as solar collector locations, each variable must first be scaled in order to measure the extent to which it poses a constraint on collector siting. The table in Figure 18 indicates which of the natural and built-environment characteristics constrain the various technology/collector location combinations being considered.

Figure 18

Relationship of Constraints to Solar Systems

| | ON SITE | | | | NEIGHBORHOOD | | CENTRAL |
|---|---|---|---|---|---|---|---|
| | Retrofit (active) | | New (active or passive) | | | | |
| VARIABLE | Roof | Yard | Roof | Yard | On Sites | Single Site | |
| o slope aspect | x | x | x | x | x | x | x |
| o landform shadow | x | x | x | x | x | x | x |
| o structure shadow | x | x | x | x | x | x | |
| o tree shadow | x | x | x | x | x | x | x |
| o lot orientation/ lot width | | | x | x | | | |
| o roof area/roof orientation | x | | x | | x | | |
| o roof slope | x | | x | | x | | |

The table in Figure 19 ranks each variable in terms of whether it presents an opportunity for, a constraint on, or a major constraint on solar technology siting. This ranking is based on the factors identified in the discussion in Section 5.

Figure 19. Ranking of Potential Constraints

| VARIABLE | OPPORTUNITY | CONSTRAINT | MAJOR CONSTRAINT |
|---|---|---|---|
| Landform shadow | Absent | | Present |
| Slope aspect | South ± 45° | East or west ± 45° | North ± 45° |
| Lot orientation | South ± 22½° | South ± 22½ - 67½° | South ± 67½ - 90° |
| Lot width | Greater than 50 feet | 50 feet | Less than 50 feet |
| Roof area | Greater than or equal to collector area* | 50-100% of collector area | Less than 50% of collector area |
| Roof orientation | South ± 22½° | South ± 22½ - 67½° | South ± 67½ - 90° |
| Structure shadow | None from 10 a.m. - 2 p.m. Dec. 21 | 10 - 11 a.m. OR 1 - 2 p.m. only | Any other time period from 10 a.m. - 2 p.m. Dec. 21 |
| Tree shadow | None from 10 a.m. - 2 p.m. Dec. 21 | 10 - 11 a.m. OR 1 - 2 p.m. only | Any other time period from 10 a.m. 2 p.m. Dec. 21 |

## 7. Matching Information Requirements to Applications

Information concerning the extent to which these constraints limit use of solar technology in a community can be applied in several ways. If it were sufficiently detailed at the site scale, it could be used by homeowners as a basis for determining whether their homes could be retrofitted to rely on solar systems. At the subdivision or neighborhood scale, it can be used to determine which technology is most appropriate (i.e., most efficient and cost-effective). At the community scale, information about physical constraints on implementation of solar could be used to inform policy making. A community wanting to "push" solar energy would benefit from understanding how much solar reliance is physically possible. Local governments, builders and homeowners would also be interested in an assessment of the physical problems and opportunities that would be encountered in implementing a pro-solar policy, and in the comparative ease of installing various technologies. Furthermore, policies based on an adequate data base could better reflect variations between neighborhood communities.

Ideally, the detail of the data collected to assess community solar potential would be determined based on the purpose of the analysis. Data mapped or compiled at a fine grain would provide maximum flexibility for community energy planning and could be used by designers, homeowners and developers as well. However, accurate fine-grained data collection is probably more time consuming and, therefore, more costly than data collection at a coarser scale. A community with limited resources might choose to concentrate solely on the planning applications.

The choice of the "grain" of analysis is influenced by the informational resources and analytic tools already available, especially when monetary resources are limited. If the community possesses a set of high resolution aerial photographs taken when sun angle is low, it may be possible to extract all of the information needed for a fine-grained analysis from these maps. This would reduce labor costs significantly from those required to conduct a field survey of the community. If aerial photographs are available at a poor resolution, planners have the choice of either supplementing photographs with field surveys or settling for a less fine-grained analytic capability.

Without computer capabilities, it would be tedious and time consuming to aggregate site-specific data in order to apply it to a community-wide analysis.

## 8. Computer-Based Information Systems

Computer based information systems are now being applied in a range of information synthesis and land use planning activities. Many cities and counties in the United States maintain computerized assessor's files containing data on ownership, land use, and structure dimensions. A review of the assessors records in California coastal counties conducted by a Sea Grant sponsored project revealed that fourteen of the fifteen counties have computer-based files. Of these, about half include land use type and acreage data and are potentially applicable to land use planning tasks (Dickert, 1979).

A project sponsored by the Department of Energy identified land use data bases for several major United States cities. Denver, Minneapolis, Baltimore, Honolulu and Atlanta all maintain computerized systems. Denver's system is used extensively by its planning department and includes dimensions of both building and parcels (Twiss, 1979).

Although assessors files generally contain only ownership and parcel information, computerized information systems have been applied to environmental planning activities in forested areas, urbanizing regions and the coastal zone. Some of these systems have used proceudres that overlay maps of natural resource characteristics to identify constraints on development. In other cases information systems have been used to generate revised land use plans, develop land use controls and identify impacts of proposed developments (McCreary, et. al., 1979).

The Sea Grant project at U.C. Berkeley has constructed an information system based on assessors' records for use in coastal zone planning using a case study in San Mateo County, California. Resource protection policies contained in the California Coastal Act of 1976 were used as a guide in compiling and mapping data on a common 1:9,600 base sheet for twenty variables including prime agricultural land, geologic hazards, and habitats of endangered species. This mapped information was scaled and coded for each parcel in the study area which included portions of the communities of El Granada, Princeton and Montara. Using assessors parcel numbers as a common reference, the resources data base was merged with the assessors computer files. The latter contained ownership, parcel and land use information.

Several kinds of manipulations were performed with the data base using the program known as INGRES (see discussion in the following section). These included:

- An inventory of parcel characteristics;
- Cross-tabulation of parcel characteristics which involved summing the number of parcels and the number of acres in each class, (e.g., how many acres in class I agricultural land;
- Identification of similarly situated parcels so that land use controls can be consistently applied (e.g., which parcels have a high erosion potential and are less than five acres in size);
- Identification of conflicts between present zoning of parcels and Coastal Act policies (e.g., which parcels contain prime agricultural land, geologic hazards, or habitat areas and are zoned for development).

All of the manipulations involved summing, counting or aggregating information contained in the large table of data organized by parcel number.

## 9. The INGRES Computer Program

The computerized data retreival system developed by Sea Grant involved the application of an existing relational data base software system known as INGRES.* This program is designed to allow large amounts of tabular information to be manipulated by simple commands typed into an interactive

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*The INGRES program was written by Professor Michael Stonebraker of the Department of Electrical Engineering, U.C. Berkeley. The operating system known as UNIX was originally designed by Bell Laboratories.

Cathode Ray Tube (CRT) Terminal. The data manipulation language supported by INGRES is QUAL (QUEry Language), a simple language that requires no previous training in programming. The higher level operating system, UNIX, includes a text editing capability which can be used to delete or enter data and to correct keyboard entry errors.

Data files in INGRES are structured hierarchically. An overall data file is called a relation; it is simply a table containing rows and columns. The columns or "tuples" are spaces set aside for the storage of information about a given variable. Each tuple is allocated a certain amount of space which determines its column width when represented on a printout. The columns are given headings of attribute names.

Commands for the retrieval of information from a relation (called queries) consist of three parts: the range statement, the retrieve command, and the qualifier. The range statement is essentially a marker that identifies which relation is being manipulated. Retrieve commands specify which information is to be retrieved. The qualifier restricts the information which is printed out to data with a prescribed combination of characters. In the case of the Montara-El Granada Information System, the retrieve commands specify which parcel characteristics are to be printed out, while the qualifier restricts the data retrived to parcels with certain characteristics. For example, the following command--"Retrieve i.page, i.block, i.parcel where i.toposhadow = y."--means "print out a listing of all parcels which are shaded by landforms".

## 10. The El Granada Solar Case Study

The Sea Grant Information Retrieval System was accessible to this research group through the Department of Landscape Architecture and was therefore a logical case study in which to test the usefulness of parcel-linked data on constraints to solar energy use.

Information about the physical constraints described above was gathered from San Mateo County orthophoto maps of aerial photographs at a scale of 1:400 and U.S. Geologic Survey topographic maps. Resolution of the orthophoto maps was poor. Moreover, the photographs were taken at mid-day so that shadows are minimal. Consequently, it is impossible to discern roof lines on most structures and, therefore, to directly record roof orientation.*

Since roof orientation could not be derived directly from the orthophoto maps, the amount of roof area available on each house could not be calculated using that data source. However, orientation can be estimated for aggregation of houses. A survey of all houses in the study area showed that they were consistently aligned parallel to lot lines. A field survey of three blocks (approximately 60 houses) revealed that about 50 percent of the houses have their primary roof division parallel to the lot width and 50 percent parallel to lot length. Thus, for an aggregation of all lots of a given orientation, it can be estimated that half have rooftops with primary sections oriented in that direction and half have rooftops with primary sections oriented 90° from that direction.

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*On maps at the same scale for the city of Houston roof lines can be discerned because they were photographed when the sun angle was low.

Appendix A contains the rules used to record data on each constraint. These rules are, for the most part, self-explanatory. The process used to determine tree shading requires additional explanation.

A template of the zone south of a rooftop which must be free from obstruction from 10:00 a.m. to 2:00 p.m. on December 21 was drawn on a sheet of transparent acetate. Figure 20 depicts the template and Figure 21 a cross-section of the zone it represents. These demonstrate how the zone expands as tree height increases.*

The template shown in Figure 20 corresponds to a relatively flat surface. The form of the zone will change on slopes, depending on steepness and orientation. Templates for various orientation/steepness combinations are shown in Figure 22.

Tree height should be determined before encoding shadow constraint data. If it cannot be determined by measuring shadow length on the aerial photos, a field survey should be conducted.

In this case study data was encoded prior to the field survey. Tree masses in all zones (20 foot to 80 heights) were recorded. Therefore, identification of tree heights have to be included at the time the data is retrieved. For example, if the mature tree height of the dominant species is 40 feet then only the presence of trees in zones shadow 20 and shadow 40 needs to be recalled to identify constraints imposed by those trees even though trees in the other zones have been recorded.

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*The template can be used in reverse to identify shadows cast by objects of various heights, e.g., trees. For example, the environmental design firm of Living Systems has, independent of this project, developed a design procedure for site planning of new neighborhoods which entails the use of such a template (Landscape Architecture, Nov. 1978).

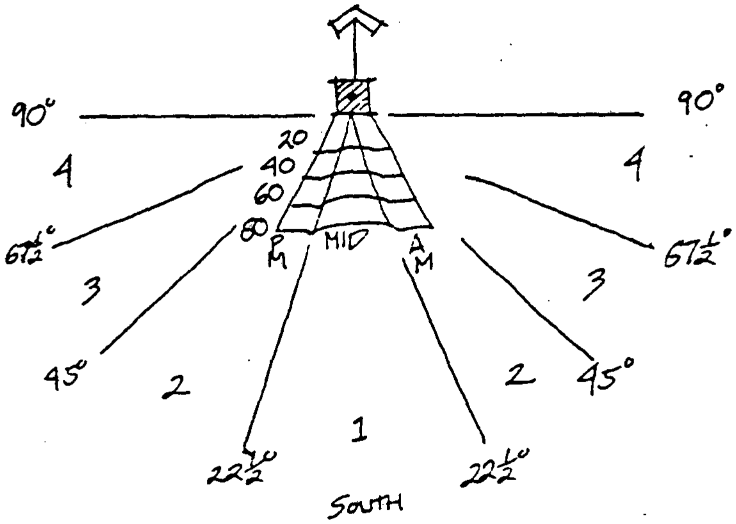


Figure 20. Template for 0 percent slope.

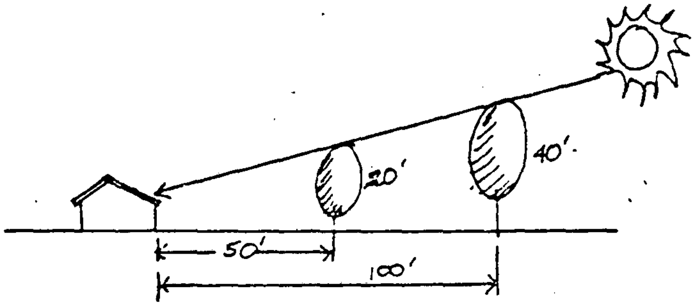


Figure 21. Cross-section of solar skyspace.

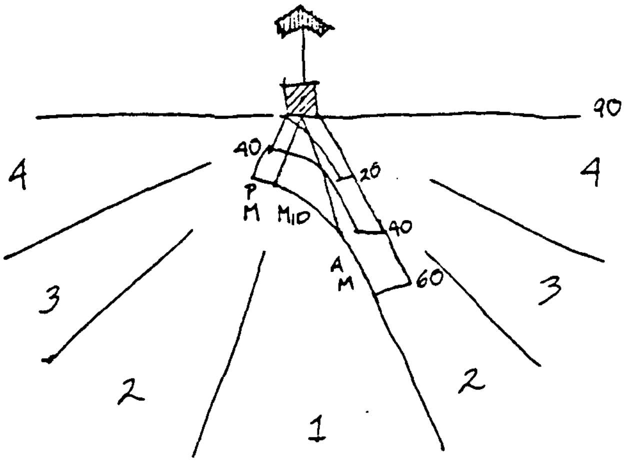


Figure 22A. Templates for shadows on 30 percent east-facing slope.

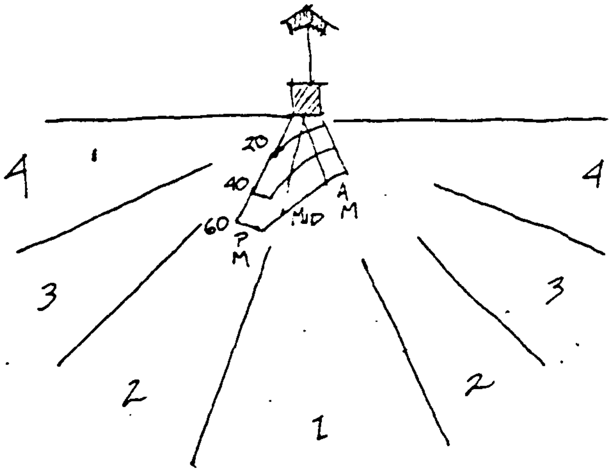


Figure 22B. Templates for shadows on 15 percent west-facing slope.

The additional information about tree height which was obtained in the field survey can still be included in the data base using the INGRES editor function. Then the retrieval procedure can be simplified.

Appendix B contains a sample of the form onto which data was recorded. This form organizes the data so that it can be key-punched quickly. In practice the data would be recorded into the existing data base for the Half Moon Bay area. Then, assessment of solar constraints could be integrated with existing assessments of natural hazards and environmental conditions. However, for the purposes of this study, it was easier to establish an independent data base in a computer system at the Lawrence Berkeley Laboratory. The data was key-entered directly into a 1134 computer from a user terminal.

A section of the Half Moon Bay area with a mix of constraint conditions was selected as the case study. These included:

- topographic variety: slopes of various orientation, flat land, and canyons
- vegetation variety: dense stands of Eucalyptus species, scattered street and yard trees, and carefully planted street trees in tract developments; and
- variety in the form of the built environment: lots of different sizes, gridded and curvilinear streets, fully developed tracts and blocks with a large proportion of vacant parcels.

## 10.1 Specific Natural Environment Constraints in the Study Area

A field survey of the El Granada area revealed a spatial pattern of tree types or heights. When recalling data from the computer base on shading constraints in each area, occurence of trees within the solar skyspace zones can be requested in terms of appropriate tree heights. For example, in the area in which Pinus radiata (Monterey Pine) dominates, obstruction of shadow zones 20, 40, 60 and 80 must be specified in the queries, since these conifers reach a height of 80 feet. In the recently developed areas where Pittosporum eugenoides (Victorian Box) have been planted, obstruction of zones 20 and 40 only must be requested since the maximum mature height of that species is 40 feet.

## 10.2 Specific Built Environment Constraints in the Study Area

The majority of lots in the El Granada area are 50' x 100+' feet (5,000 sq. ft.); the remainder is divided between lots less than 50 feet wide (usually 25' x 100' +), and lots greater than 50 feet wide. The proposed Community Plan sets forth regulations pertaining to lot coverage and building setbacks to be applied in single family residential districts. On 5,000 sq. ft. lots, the combined sideyard setback is designated as 15 feet with a minimum setback on either side of 5 feet; maximum total coverage is set at 35% of the building site. On 7,500 sq. ft. lots, the combined sideyard setback is 20 feet with a minimum on any side of 7.5 feet; maximum total coverage is 30% of the building site.

A sample measurement of 115 lots in the El Granada area (two per block) was taken from a 1:400 orthophoto to determine the mean roof area of existing single family dwellings. The mean roof area was found to be

1655 sq. ft. with a standard deviation of 314 sq. ft. The proposed Community Plan sets lot coverage limitations of 1750 sq. ft. on 5,000 sq. ft. lots and 2,250 sq. ft. on 7,500 sq. ft. lots. It would seem, therefore, reasonable to assume 1600 sq. ft. as a measure of roof area in assessing the suitability of rooftops as collector locations.

On that basis, gabled roofs of a single division would have 800 sq. ft. of roof area oriented south ± 90°. This is sufficient to accomodate collector area for 75 percent of space heating and hot water needs regardless of orientation, although costs would increase along with collector area. Since the majority of houses observed in the field survey and on the maps have more than one primary division, roof area is likely to become a limiting factor on feasibility of rooftops as collector locations.

Parcel area is never a limiting factor on feasibility of yards as collector locations due to the size of the parcels. Since collectors can be located on independent or attached structures nearly the same height as the house, e.g., patio covers, shading by structures is rarely a constraint. Shading by trees becomes the primary constraint in that case.

Utilization of passive solar design will be limited by the amount of window area which can be oriented properly. The prototype Odeillo solar house designed by Trombe contained a 58' x 15' south facing window to collect sunlight (AIA, 1975). For a lot 50 feet or less in width, such an expanse of window is only possible if the house is oriented lengthwise. Development on a 7,500 square foot lot or larger would not entail such problems.

### 10.3 Data Analysis

The following types of analyses can be made using the computerized data base:

1. Inventory of constraints present on a given parcel.
2. Identification of the number of parcels on which a constraint occurs for the entire study area or for a subarea such as a block.
3. Calculation of the frequency of occurence of each constraint, i.e., the ratio of the number of parcels with specific constraints to the total number of parcels in the area of subarea.
4. Ranking the subareas (blocks or otherwise defined "neighborhoods") in terms of frequency of occurrence of a specific constraint.
5. Assigning suitability ranking to parcels for a given technology implementation scenario based on ease of mitigation of constraints.
6. Calculating suitability score for a subarea. This can be obtained by summing the individual rankings and dividing by the number of parcels.
7. Rank blocks in terms of their suitability for solar energy development.

In order to make these analyses more useful to policy making and implementation they can be linked to different technology implementation scenarios. Figure 23 identifies six on-site implementation scenarios based on combinations of which alter the relative importance of the constraints. The "independent variables" or influences are: location of solar technology, time of application within the development process, and characteristics of the system installer/operator.

| Installer/ operator of system | Location/time of application of technology | | |
|---|---|---|---|
| | Roof/retrofit | roof/new | yard/ new or retrofit |
| Individual property owner | A | C | E |
| Cooperative, municipality or utility | B | D | F |

Figure 23. Implementation scenarios.

An additional scenario (H) consists of application of a neighborhood system operated by a cooperative of homeowners, a municipality or a utility company.

Figure 24 ranks the constraints and combinations of constraints in terms of the facility with which they can be mitigated in each scenario. A ranking of "1" identifies a site as most suitable, i.e., having no physical constraints. As the numerical value increases, suitability decreases. A site with a land form shadow is always the least suitable since that constraint is the most difficult to mitigate. Constraints whose importance varies as the situation varies are roof orientation. lot orientation and the shading of the site by trees and structures.

Where the system is being located on the roof of a new house, lot orientation as it restricts house orientation is important. Where the system is being retrofitted onto an existing structure roof orientation is the important consideration. For the individual homeowner, shadows which may be cast by trees located on a neighbor's property are more difficult to mitigate than onsite problems such as poor roof orientation. The latter can be accomodated by altering the form of the roof. For a utility having the legal authority to modify trees which interfere with the utility network, it would be easier to prune the offending trees.

As one progresses from scenario A to G, the physical constraints themselves decrease in severity. There is more flexibility in dealing with constraints in new development relative to retrofitting existing homes. Similarly, as the legal authority of the solar system installer and operator increases, the ease with which constraints can be overcome increases. A site with a suitability ranking of 5 in situation F is less constrained than is the same ranking in situation E, since the utility, municipality or

| | | |
|---|---|---|
| **A** INDIVIDUAL OPERATOR<br>ROOF/RETROFIT<br>1. No constraints.<br>2. Roof orientation.<br>3. Shading - trees in a.m. or p.m.<br>4. Shading - trees, other times.<br>5. Shading - structures.<br>6. Shading - trees a.m. or p.m. and structures.<br>7. Shading - trees at other times and structures.<br>8. Shading - landform. | **C** INDIVIDUAL OPERATOR<br>ROOF/NEW<br>1. No constraints.<br>2. Lot orientation/width.<br>3. Shading - trees a.m. or p.m.<br>4. Shading - trees, other times.<br>5. Shading - structures.<br>6. Shading - trees a.m. or p.m. and structures.<br>7. Shading - trees at other times and structures.<br>8. Shading - landform. | **E** INDIVIDUAL OPERATOR<br>YARD/NEW OR RETROFIT<br>1. No constraints.<br>2. Shading - trees a.m. or p.m.<br>3. Shading - trees, other times.<br>4. Shading - structures.<br>5. Shading - trees a.m. or p.m. and structures.<br>6. Shading - trees at other times and structures.<br>7. Roof orientation.<br>8. Shading - landform. |
| **B** ORGANIZATION OPERATOR<br>ROOF/RETROFIT<br>1. No constraints.<br>2. Shading - trees in a.m. or p.m.<br>3. Shading - trees, other times.<br>4. Shading - structure.<br>5. Shading - trees a.m. or p.m. and structures.<br>6. Shading - trees at other times and structures.<br>7. Roof orientation.<br>8. Shading - landform. | **D** ORGANIZATION OPERATOR<br>ROOF/NEW<br>1. No constraints.<br>2. Shading - trees a.m. or p.m.<br>3. Shading - trees, other times.<br>4. Shading - structures.<br>5. Shading - trees a.m. or p.m. and structures.<br>6. Shading - trees at other times and structures.<br>7. Lot orientation/width.<br>8. Shading - landform. | **F** ORGANIZATION OPERATOR<br>YARD/NEW OR RETROFIT<br>1. No constraints.<br>2. Shading - trees a.m. or p.m.<br>3. Shading - trees, other times.<br>4. Shading - structures.<br>5. Shading - trees a.m. or p.m. and structures.<br>6. Shading - trees at other times and structures.<br>7. Roof orientation.<br>8. Shading - landform. |

Figure 24. Ranking of constraints in terms of mitigability within each implementation scenario.

cooperative has the legal authority to modify interfering trees. At the neighborhood system scale, the operator would have to be an organization such as a homeowner's cooperative. Collectors could be located either on individual sites--on roofs or yards--or on one or two vacant parcels or on public land.

Suitability for neighborhood systems is a function of the suitability of individual parcels combined with the availability of vacant parcels. A block's suitability can be viewed as increasing as its choices for collector location increase. Block suitability for on-site locations can be obtained by adding suitability scores for scenarios B and F or D and F for each parcel (depending on whether the parcel is developed or vacant) and summing the totals for the block. Suitability of vacant parcels for location of collectors can be measured using the ranking for scenarios E and F, i.e., yard location.

The following section describes how the results of these analyses can be used by various individuals and organizations involved in energy and land use planning, regulation and development.

Figures 25 through 27 contain excerpts from the aerial photographs for which roof divisions were determined from a field survey. The scale has been increased to 1:200. These areas reflect the variety of development types present in the study area.

Figure 25 is a sparsely developed and sparsely vegetated area. Several observations can be made:

- Of the 18 parcels in the center block, only 11 have been built on. The trees are a mix of introduced species with an average mature height of 40 feet. To identify the suitability for passive and active technologies in new construction, the presence of constraining lot orientations/lot widths, landform shadows and tree shadows on vacant lots is needed.
- Tree shadows prove to be a constraint on five of the nine undeveloped parcels.
- Lot orientation/lot width is not a constraint since all lots are oriented within 22-1/2° of south. If they were located between 22-1/2° and 67-1/2° of south, the 50 foot lot width would limit the extent to which conventional single-family houses could be constructed with optimal orientation for passive or active systems.
- Landform shadow imposes no constraint nor do structure shadows since all buildings are approximately the same height.
- Tree shadows constrain yard location in four cases: Suitability rankings of each vacant parcel are reordered along the top of the map, first the rooftop collectors/passive design by property owner (Scenario C), then for rooftop collectors by a cooperative or a utility (scenario D), and finally for yard location of collectors by either installer (scenarios E and F).

Of the 11 houses in the block, for seven roof orientation provides an opportunity for solar collector location <u>and</u> roof area is sufficient for 75 percent solar reliance. In one case a portion of the roof is optimally oriented but the area is inadequate, i.e., less than 25 percent of 1600 square feet or less than 400 square feet are available.

Tree shadows present a constraint for rooftop orientation in only two cases and for yard location in the same two cases. Again, landform and structure shadows present no constraint.

Suitability rankings for existing structures are recorded at the bottom of the map by scenario.

Suitability for a block system can be characterized in the following way: 10 existing homes and three new houses (currently vacant parcels) can achieve 75 percent reliance onsite, leaving five for which trees must be modified to accomodate collectors. Two of the vacant lots are completely unconstrained. These lots are 50' x 100' or 5,000 square feet in size. The area available on one parcel is sufficient to provide 75 percent reliance for 12 units. Due to the reduced heat loss from shared storage, a neighborhood system might provide more than 75 percent self-sufficiency for space and hot water heating with the same collector area.

Figure 26 depicts an area relatively densely vegetated by Monterey Pines and with a slightly higher proportion of developed parcels than the previous area. Its suitability rankings are recorded as in the previous figure.

Figure 27 is a new tract development with curvilinear streets. Each parcel has a single Victoria Box tree (maximum height 40 feet) in its front

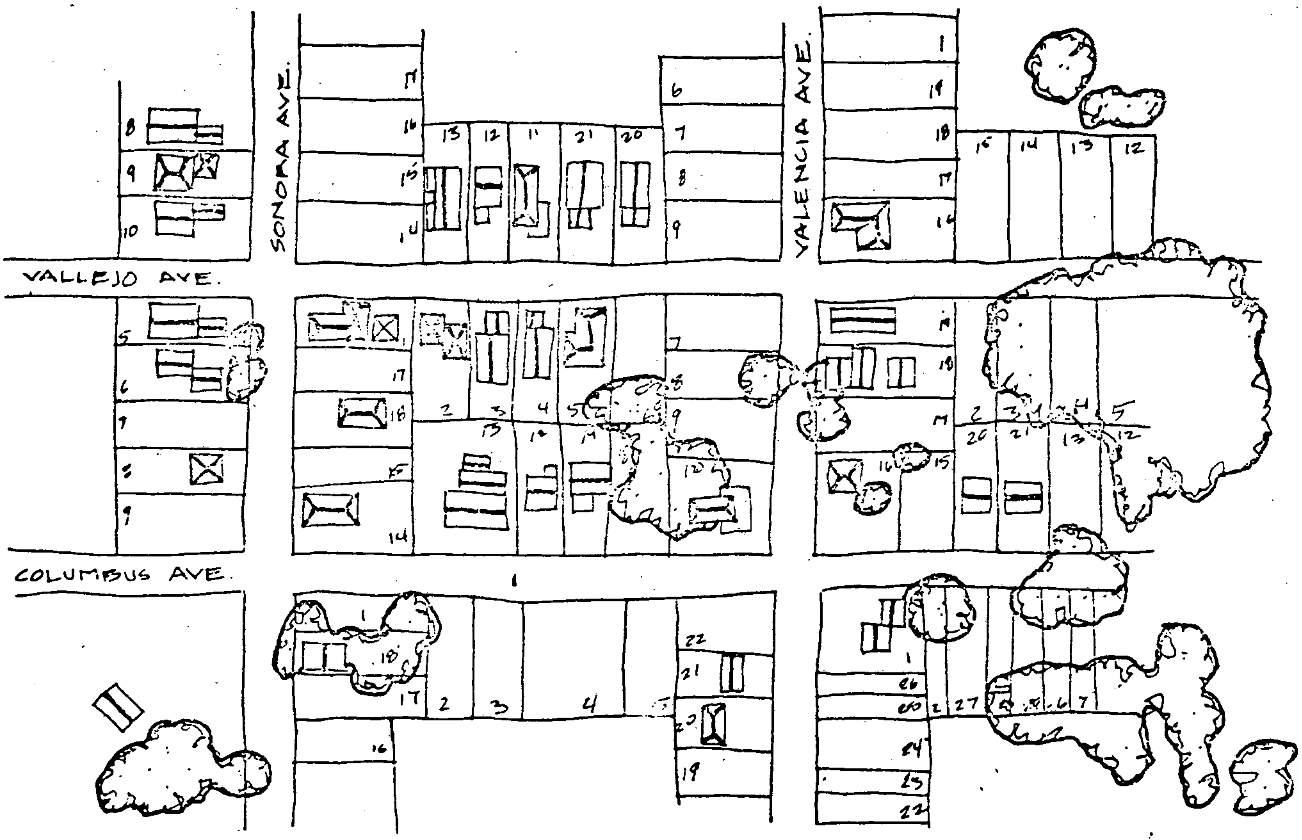
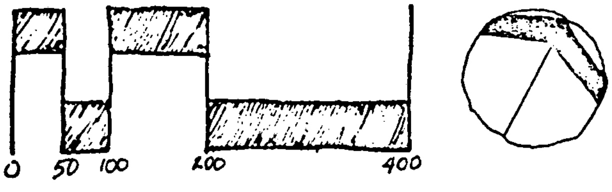
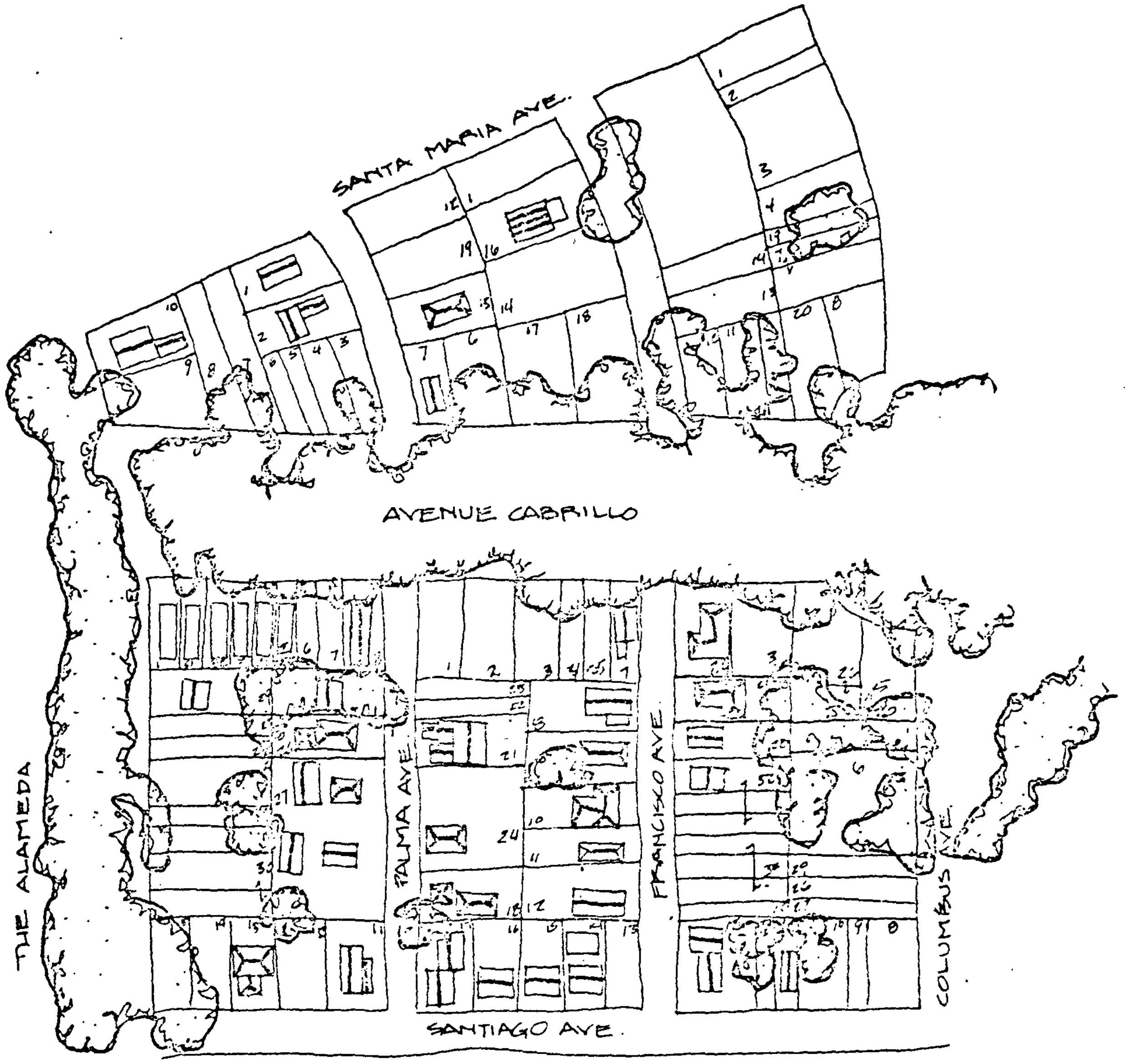
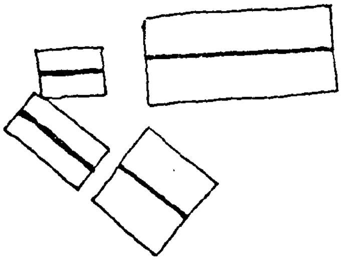


Figure 25. A sparsely developed and sparsely vegetated area.







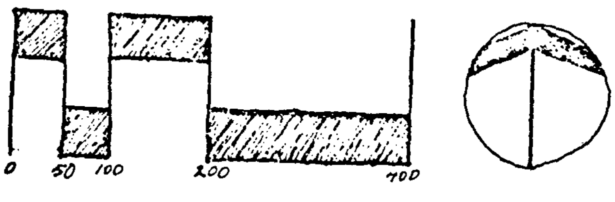


Figure 26. A heavily vegetated area with moderate build out.

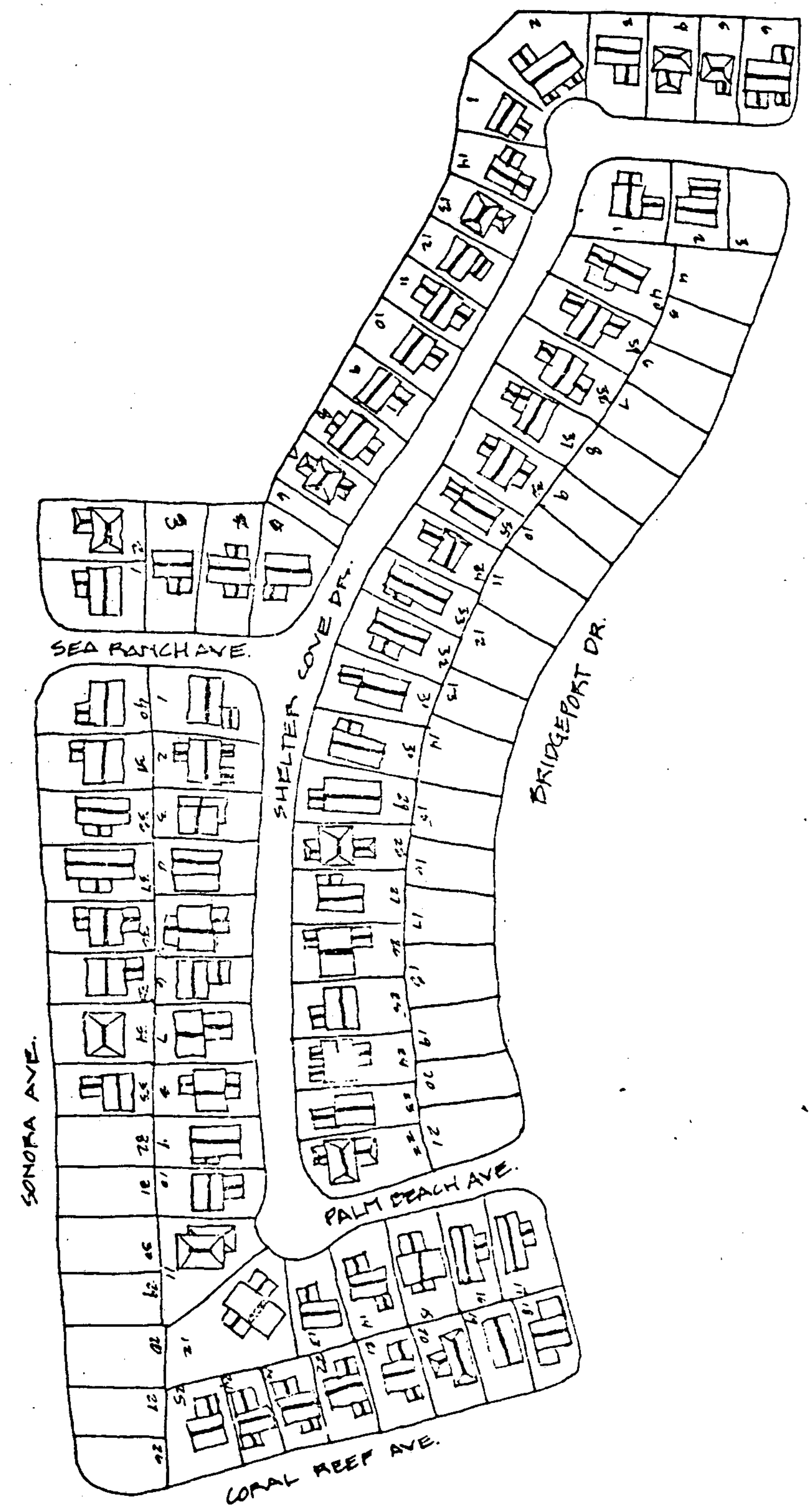
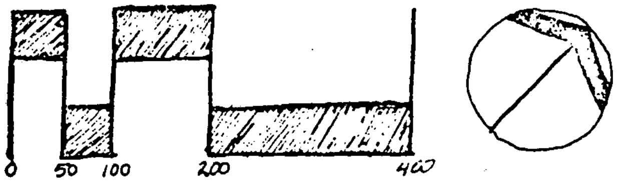


Figure 27. A new tract development with curvilinear streets.



yard. Every parcel is developed, leaving no opportunity for neighborhood systems located on a single parcel.

## 11. Applications of the Analyses

As stated in the introductory discussion, this assessment and analytic process is intended to provide useful information planning in the context of policy-making and implementation of regulatory controls. The following disucssion of some applications of the analyses is organized according to types of users. Figure 29 sets forth a matrix of types of users and kinds of analyses as a framework for disucssion.

| | ENERGY PLANNERS | LAND USE PLANNERS (policy development and implementation) | LAND DEVELOPERS AND DESIGNERS | TECHNOLOGY DEVELOPERS AND DESIGNERS |
|---|---|---|---|---|
| 1. Constraint inventory. | | | | ○ |
| 2. Number of parcels with each constraint. | ○ | ○ | | |
| 3. Frequency of occurance of each constraint. | | ○ | | ○ |
| 4. Ranking of subareas according to occurance of constraints. | | ○ | ○ | |
| 5. Suitability ranking of parcels. | ○ | ○ | ○ | |
| 6. Suitability scores of subareas. | ○ | ○ | ○ | |
| 7. Ranking of subareas. | ○ | ○ | ○ | |

Figure 28. Users of solar constraint analyses.

## 11.1 Energy Planners

Identification of the frequency with which different constraints occur provides a quantitative basis for ranking the importance of various barriers to solar energy use and for developing policies to overcome such barriers. For example, a planner or policy maker can identify the number of cases in which solar access is a problem and in which legislation to ensure solar rights would eliminate that obstacle. In California the recently enacted solar rights legislation applies only to situations in which solar technologies are in place before a tree is planted. This analysis can identify the extent to which such legislation would not eliminate solar access problem.

By relating constraints to specific technologies in terms of constraint mitigability, policy implications regarding the most appropriate type of technology can be derived. For example, where solar access is consistently a problem due to heavy vegetation, shared neighborhood systems may appear to be a reasonable alternative to onsite systems. Solar access to only one or two parcels would have to be assured. The analysis could indicate whether any vacant lots are available and whether they are suitable collector locations.

Similarly, the constraint/technology relationship can be used to identify the extent to which a barrier is "system-specific". For example, guaranteed solar access is a critical concern if individuals are responsible for their own solar energy systems onsite. If systems were to be installed and/or maintained by a cooperative or a utility, solar rights could be incorporated as a responsibility of that organization. The need for implementation of complex solar access laws would be minimized.

Rating and ranking areas according to their suitability for a given technology provides a basis for selecting sites for demonstration projects or for sequencing installations (i.e., the easiest would logically be addressed first).

## 11.2 Local Planners

Information concerning frequency of occurrence of constraints can be used in local land use planning for policy development much the same as in the context of energy planning. However, at this level energy related concerns are viewed much more as only one of many variables to be considered in making a decision. The readily accessible computerized storage of solar constraint data together with other environmental data facilitates the integration of concerns regarding solar energy use with other environmental planning goals such as avoidance of geologic hazards, protection of habitat areas, and maintenance of land in agricultural production.

In the implementation and regulatory aspects of local planning, constraint information can be used as a basis for directing development to those areas best suited for solar energy use. Solar suitability can be used as a criteria for project approval. The concept of establishing criteria for project approval is being adopted in various localities as a growth control measure.[*] An additional application of this analytic capability is in identifying parcels for public acquisition in order to provide sites for

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[*] See the previously referenced report by E. Vine on Davis, California.)

neighborhood solar collector installations.

Assessment of the comparative feasibility of different scales/ locations of the solar technologies can assist planners in their determination of the most appropriate system for a given situation.

## 11.3 Land Developers and Designers

Site suitability is a central concept in the design process. In the "ideal" situation the designer assesses the opportunities and constraints present on a site. These considerations are then integrated into the development of the design package to maximize the use of opportunities and to minimize impacts from constraints. If solar energy use is perceived of as a design goal (usually as a result of policy decisions to which the designer responds), then the availability of information regarding constraints simplifies the designer's task. It provides her/him with a basic set of data which can be expanded upon as greater specifity is required.

In an even more desirable process, the developer uses site suitability as criteria for selection of the site to be developed. This concept is expressed in the California Environmental Quality Act's guidelines which require that alternative sites to the one selected be assessed.. As the impact assessment process is gradually assimilated into the overall development process, developers are beginning to take environmental suitability into account when they select a site for development. If solar energy use is adopted by the local regulatory agency as a criteria for project approval, experience with SEQA suggests that it will be incorporated into the developer's site selection process. A computerized data base containing information on constraints will facilitate the developer's search process and would make possible several iterations of design. He/she can request a list of those sites most suitable for a particular solar technology.

In many cases, especially when the site is a small one, the developer already owns the land. Then, the ability to compare the constraints on various systems is useful to the developer who wants to install or facilitate later installation of the most appropriate solar technology.

### 11.4 Technology Developers and Designers

Those individuals involved in developing the technologies themselves can use the results of constraint assessment as a means of identifying physical barriers which need to be overcome to facilitate "market penetration" of the technologies. There may be modifications of the technologies or their infrastructures which overcome certain barriers. For example, the problems involved in retrofitting roof tops with collectors could be avoided by developing simple structures on which to locate collectors which function as outdoor area covers as well.

# APPENDIX

This appendix describes coding rules for each of the ten variables interpreted from maps or photographs. The second part of the appendix outlines the procedure used to develop the topographic shadow map for use in coding the "toposhadow" variable.

## 1. Lot Width

Source: San Mateo County Assessor's parcel book.

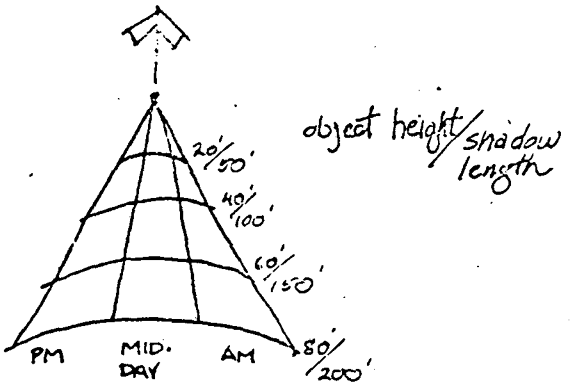
Lot Width: Narrower dimension of the lot.

Coding: Record a Y in Column 13 if lot width is less than 50 feet.

Record an N in Column 13 if lot width is greater than or equal to 50 feet.

For parcel separated by dotted lines (indicating "paper" lots) add individual lot widths.

Figure A-1. One Point Shadow Template



ONE-POINT SHADOW TEMPLATE
0% SLOPE
37°N. Latitude NOT TO SCALE

Rationale: Lot widths greater than or equal to 50 feet provide flexibility for siting structures.

## 2. Lot Orientation

Source: Interpretation from San Mateo County orthophoto base map.

Scale: 1" = 400"

Lot Orient: Orientation measured in increments of 10 degrees eastward from due north.

Coding: Plate template A (Figure A-1) on the orthophoto base map with the dot aligned over the center of the parcel and the north arrow oriented north. Read orientation by zone for the width of the lot.

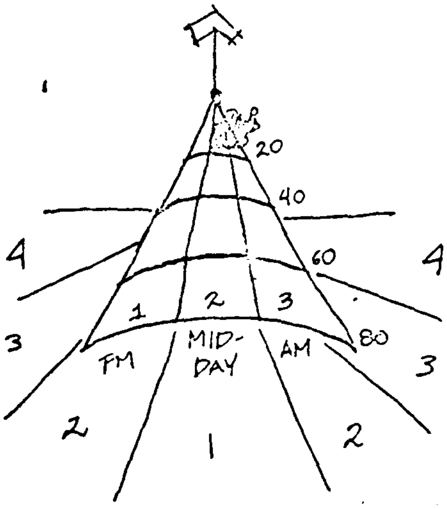


Figure A-2. Use of Shadow Template.

Bands 1 through 3 divide the zone according to orientation. A tree in band 1 obstructs incoming insolation from 1:00 p.m. to 2:30 p.m. on December 21. This date is chosen because on December 21st the sun is in its lowest position in the sky and therefore casts the longest shadow (i.e., worst case). A tree situated in band 2 obstructs insolation from 11:00 a.m. to 1:00 p.m.; in band 3 from 9:30 a.m. to 11:30 a.m.

These 3 intervals allow for evaluation of the severity of solar obstruction. Since it is frequently foggy in the morning in the study area, obstruction of morning insolation (band 3) is less critical than obstruction of mid-day and afternoon sun.

Place template A on the orthophoto map with the dot aligned over the center of the parcel and the north arrow pointing north.

Coding: For vegetation masses within a 50 foot concentric ring to the south, record the number representing the appropriate band in Column 19. For multiple vegetation masses, the coding is as follows:

| Bands containing vegetation | Code in Column 19 |
|---|---|
| 1 and 2 | 4 |
| 2 and 3 | 5 |
| 1, 2 and 3 | 6 |
| 1 and 3 | 7 |

For example, in Figure A-2, a tree mass occurs within the 20 foot tree height zone during the morning and mid-day. Record "5" in Column 19.

Rationale: Shadows cast by trees on adjacent parcels are a major constraint on installation of solar collectors.

In Figure A-2 orientation is between south and 22-1/2° east of south, i.e., zone 1, Record "1" in Column 14.

Rationale: Optimum collector orientation and building orientation is due south, with collector area increasing as orientation changes. Anderson, The Solar Home Book (1976) p. 175.

3. Slope Orientation

Source: Interpretation from San Mateo County orthophoto base map.

Scale: 1" - 400'

Slope Orient: Orientation of the slope on which the parcel is situated expressed as cardinal points plus or minus 45°.

Coding: Place template "B" on orthophoto map with dot aligned over the center of the parcel or grid and the arrow oriented north. Read orientation as north (N), south (S), east (E), or west (W).

Record the appropriate letter in Column 17.

Rationale: Optimum collector orientation is due south (Anderson, The Solar Home Book, 1976, p. 175) lots facing south will afford greatest solar exposure, while lots facing north will be shaded during much of the day. South-facing slopes are the best locations for solar designed homes and large banks of collectors.

4. Shadow Site

Source: Interpretation from San Mateo County orthophoto base map.

Scale: 1" = 400'

Shadow Site: This variable is an expression of the presence of one or more vegetation masses on the parcel itself. Vegetation is a major constraint on siting solar collections due to the shadows cast by bush and tree masses.

Coding: If a vegetation mass is present within a parcel, or if a vegetation mass occupies greater than 50% of a grid, record a Y in Column 18.

If no vegetation mass is present within a parcel, or if it occupies less than 50% of a grid, record an N in Column 18.

5. Shadow 20

(Note: This variable has the same data sources, coding rule and rationale as the variables "Shadow 40", "Shadow 60" and "Shadow 80". Therefore, only the definition and coding rules are included for these other variables.)

Source: Interpretation from San Mateo County orthophoto base map.

Scale: 1" = 400'

Shadow 20: This variable is an expression of the presence of one or more vegetation masses greater than or equal to 20 feet tall within a 50 foot concentric zone to the south of the panel boundary.

6. Shadow 40

Shadow 40: This variable is an expression of the presence of one or more vegetation masses between 51 and 100 feet from the parcel boundary.

Coding: Bands apply as for "Shadow 20"; record the appropriate number in Column 20. In this zone, a tree 40 feet in height or taller will block insolation into the parcel.

7. Shadow 60

Shadow 60: This variable is an expression of the presence of one or more vegetation masses between 101 and 150 feet from the parcel boundary.

Bands apply as for "Shadow 20"; record the appropriate number in Column 21. In this zone, a tree 60 feet in height or taller will block insolation into the parcel.

8. Shadow 80

Shadow 80: This variable is an expression of the presence of one or more vegetation masses between 151 and 200 feet from the parcel boundary. In this zone, a tree 80 feet in height or taller will block insolation into the parcel.

Coding: Bands apply as for "Shadow 20"; record the appropriate number in Column 22.

9. Toposhadow

Source: Interpretation from U.S.G.S. Montara Mountain quadrangle. The procedure for identifying topographic shadows is described in Figure A-3.

Scale: 1:9600 (1" = 800')

Toposhadow: This variable is an expression of shadows cast by topographic features.

Coding: If a topographic shadow falls on any portion of the parcel or grid, record a Y in Column 23.

If no topographic shadow falls on any portion of the parcel record an N in Column 23.

Rationale: In hilly areas, topographic shadows are a significant constraint on the installation of solar collectors.

10. Structures and Vacant Land

Source: Interpretation from San Mateo County orthophoto map and San Mateo County assessor's maps.

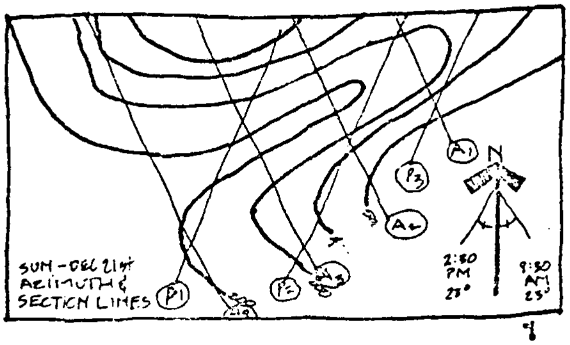
Scale: 1:400 and 1:200 - 1:500, respectively

Vacant Land: This variable identified locations that could potentially be used as locations for banks of collectors

Coding: By referring to both the orthophoto map and assessor's map, code a "Y" where there is a structure and an "N" if the parcel is vacant.

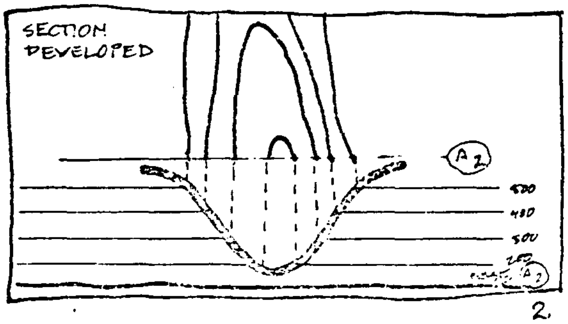
Figure A-3

# PROCEDURE USED TO DEVELOP TOPOGRAPHIC SHADOW MAP



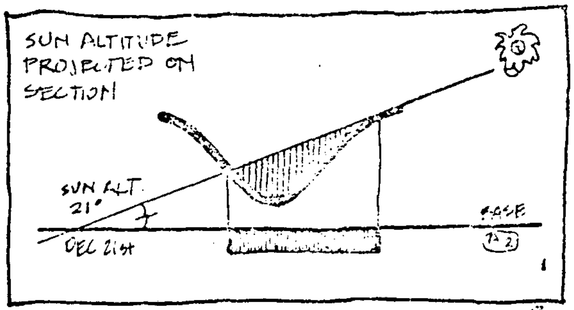
1

Using the sun azimuths for December 21st, in this case 23° F from South for 9:30 AM and 23° W for 2:30 PM, develop a series of section lines through the topography parallel to the azimuths Fig. 1



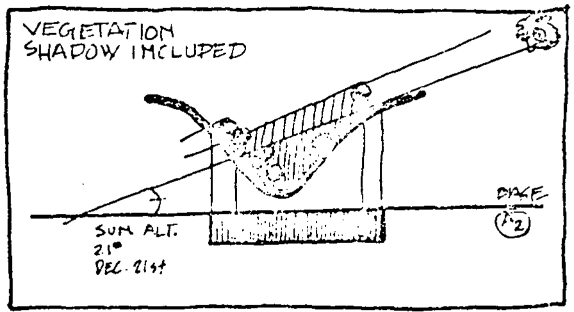
2.

Develop a vertical section along each of the lines making sure to retain the same orientation for each line and section. Fig. 2.



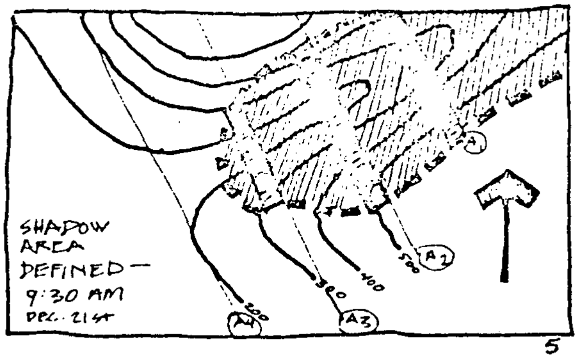
3

Project the sun altitude for the same time and place, in this case 21° at 9:30 AM and 2:30 PM onto the sections. The areas that fall into shadow will become apparent. Fig. 3.



4

In the case of extensive vegetative cover approximate the height of the cover, here 60-80 ft, and add it to the section with its corresponding shadow. Project the shadow length down onto the base/section line, A2 in this case. Fig. 4.



5

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Transfer the shadow lengths back to the original section lines and interpolate between lines to show area of shadow. The greater number of sections taken and the more frequent intervals taken the more accurate the picture becomes. Fig. 5.

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