FACTORS AFFECTING SOLAR ACCESS IN THE PORTLAND-VANCOUVER METROPOLITAN AREA

by

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ABSTRACT: This study examines the relationships among variables influencing solar access in the Portland-Vancouver Metropolitan Area. The analysis is based on a random sample of approximately 400 single-family homes in 21 local jurisdictions outside the city limits of Portland. Relationships between percentage of available sunlight and selected variables were examined by using t-tests, correlation analysis and regression analysis. Findings indicate that homes elongated along the east-west axis, located on east-west streets, and with north-south lot orientation have significantly greater solar access. These and other results will be helpful in developing ordinances to provide and protect solar access in local Oregon communities.

Introduction

The energy crisis, which began in 1973 with the Organization of Petroleum Exporting Countries' (OPEC) oil embargo, raised concern among Americans about future costs of petroleum-based products. Vulnerability to OPEC oil policy prompted many to examine alternative energy sources.

In Oregon during the 1970's, the cost of energy began to rise substantially. Construction plans for new hydroelectric facilities were scrutinized due to strong environmental concerns. Furthermore, alternatives such as coal and nuclear thermal generating plants produced energy at 5 times the cost of existing dams (Kaufman, 1981).

Oregon State Law requires that land development be managed so as to maximize energy conservation. Within the past several years, numerous city and county governments in Oregon have passed legislation in the form of solar access ordinances (SAO's) designed to protect the home owner's right to sunlight (Figure 1). Recently, 21 local governments in the Portland-Vancouver Metropolitan Area received a grant from the Bonneville Power Administration for a joint project to develop a consistent set of standards to protect solar access (Figure 2). This is the largest solar access project anywhere in the nation, encompassing an entire metropolitan area (Kaufman, 1987). The project is being administered by the Oregon Department of Energy (ODOE) on behalf of the local governments.

Proper planning for solar access today increases the potential for utilizing solar energy tomorrow. A number of factors, however, can reduce the amount of sunlight available to the property owner. For example, street and lot orientation, slope aspect, vegetation, setback length, etc. can all influence the availability of sunlight. Site planning and regulations affecting building design may enhance or reduce solar access, consequently having a significant effect on residential energy consumption.

Purpose and Objectives

The purpose of this study is to present research findings which will assist in the development of a consistent set of ordinances designed to provide and protect solar access in each of the 21 communities.

Specific objectives of this study are to:

1. provide background on how site planning decisions can influence

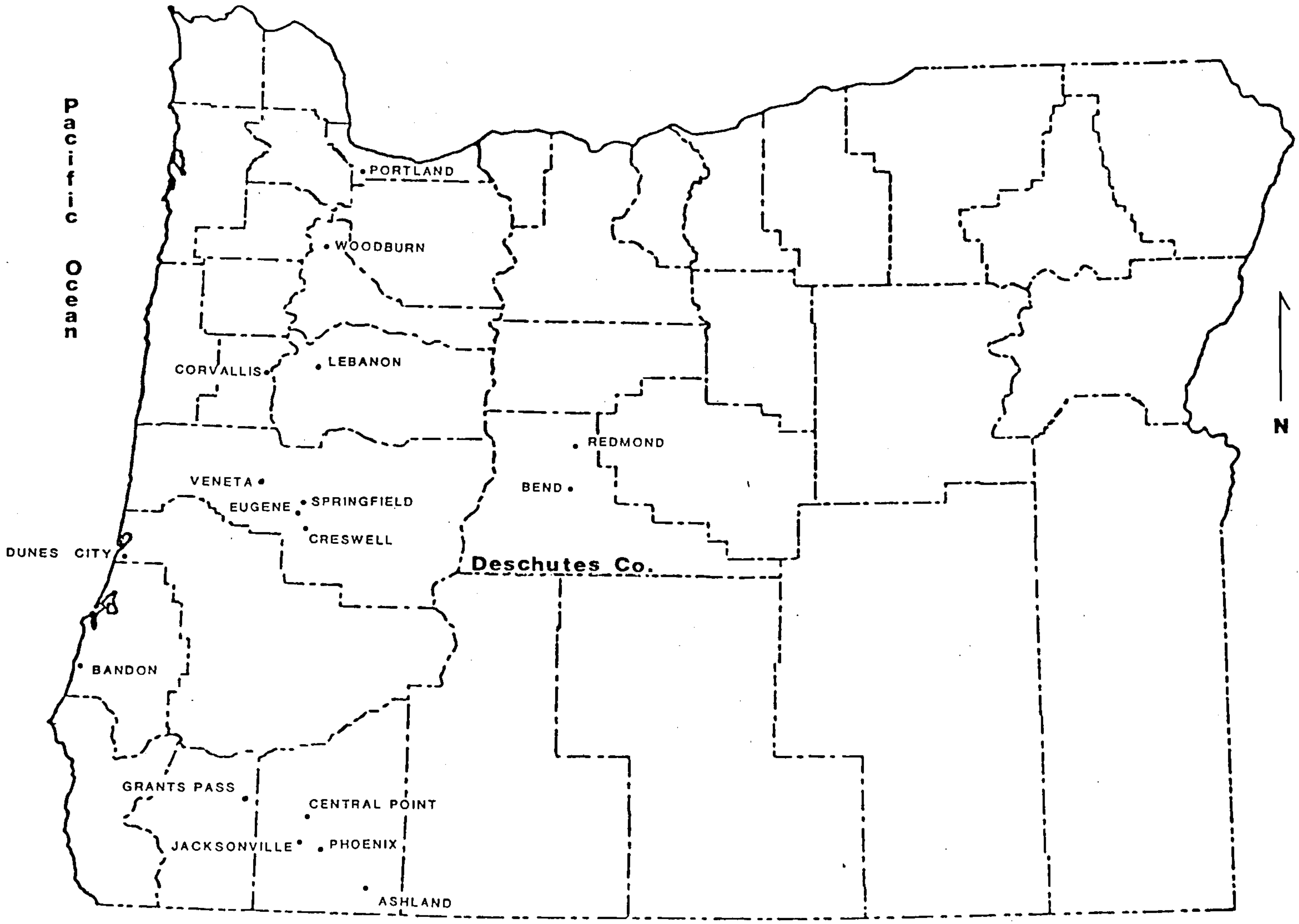

Figure 1. Oregon Cities and counties with solar access ordinances. (Source: Kaufman 1987)

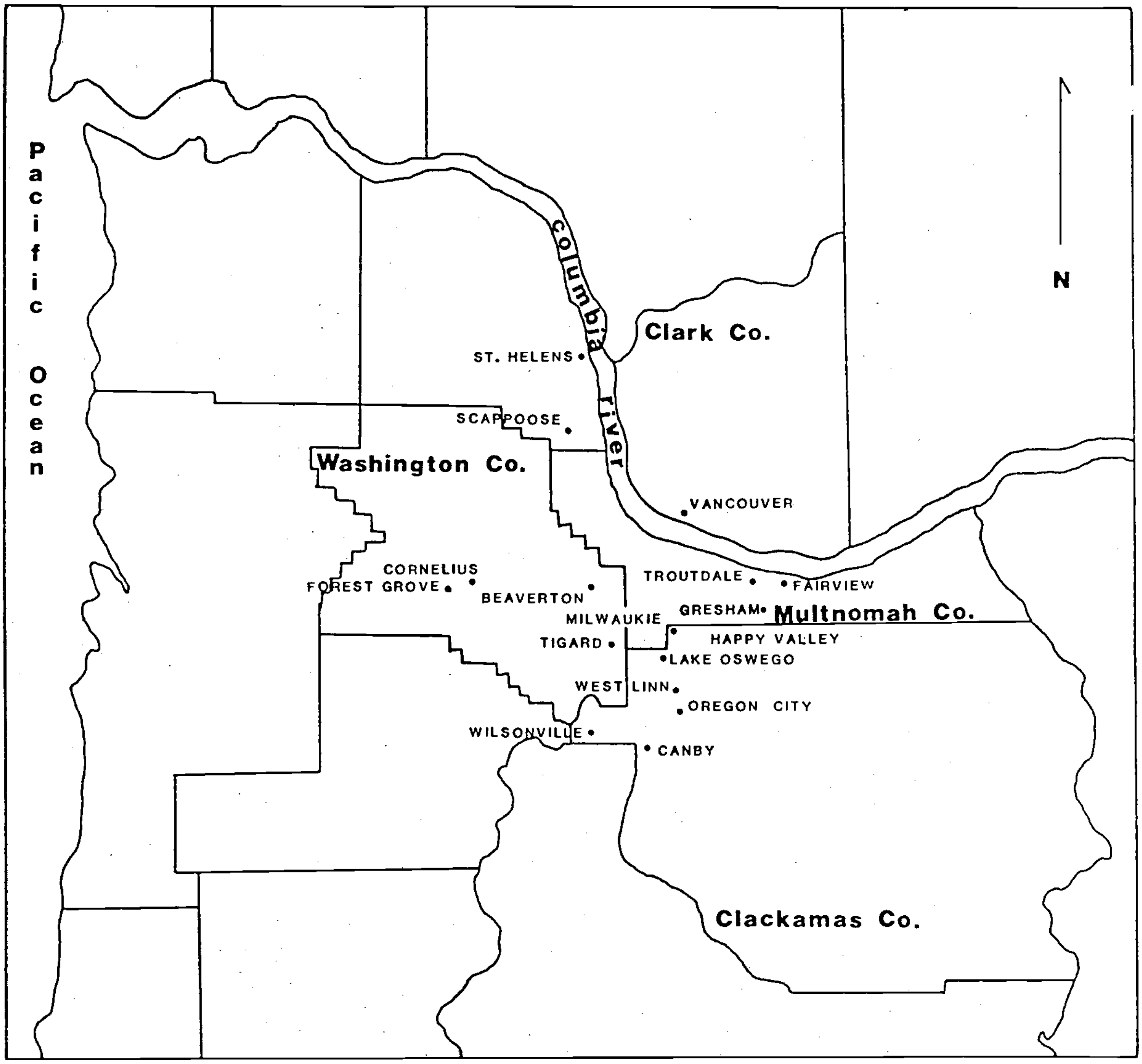

Figure 2. Local governments in the Portland-Vancouver Metropolitan Area which are developing solar access ordinances. (Source: Kaufman 1986)

the availability of sunlight to the home owner;

2. examine changes in the mean percentage of available sunlight (solar access) on the basis of associated site characteristics;

3. identify relationships between the percentage of available sunlight and setback length, separation between houses, lot size, height of house, etc; and

4. analyze the influence of surrounding trees and buildings on solar access.

Background

Solar Access in Oregon

Major barriers to the use of solar energy are the concerns that structures or trees located on property under the control of others may shade solar energy systems, and that existing land use regulations are inadequate to provide the degree of protection needed (Markus 1983). A number of counties and cities throughout Oregon have adopted solar access ordinances intended to insure sunlight by reasonably regulating the interests of property owners. For instance, in June, 1983, Deschutes County, Bend and Redmond, Oregon adopted a comprehensive set of amendments to their zoning and subdivision ordinances (McKeever and Connell 1983). The package of ordinances addressed new large developments, such as subdivisions, in-fill development and the addition of solar features to existing houses. A performance standard was added to the subdivision ordinance to provide and protect access in new developments. New setback and height requirements ensured that new dwellings on existing lots would not obstruct solar access to adjacent neighbors. Lastly, home owners could apply for a permit which would legally protect their solar collectors from being shaded.

In 1984, the City of Portland conducted a feasibility analysis to determine the extent and causes of shading (Kaufman 1985). Findings revealed that approximately half the shading problem was caused by buildings and half by trees. Close to half or more of the shading from trees was from on-site trees. Recommendations included educational efforts geared toward homeowners and the adoption of a solar-conscious street tree planting policy for the City itself.

Factors Influencing Solar Access

Butti and Perlin (1980, 37) point out in their history of solar architecture that the Greeks were among the earliest passive solar designers. Their concern for solar energy had a significant effect on community development patterns. Most local buildings were oriented south for winter heating, while the walls consisted of adobe or stone to keep out summer heat.

In the 1980s, street, lot, and building orientation; topography; vegetation; as well as many additional factors influence solar access in residential areas. Crowley and Zimmerman (1984, 41) maintain that orientation, specifically of streets, lots and buildings, is the single most important design strategy in solar access planning.

Proper building orientation is achieved when the home is sited with its longest wall facing south. This allows for the maximum amount of solar radiation to be received during the winter season, thus reducing heating requirements and permitting better cooling in the summer (Mazria 1979, 79). Olgyay (1963, 226) asserts that a square home is not the optimum form in any location. Furthermore, buildings elongated along the north/south axis are even less efficient than square houses in terms of heating and cooling. They have less south-facing wall area exposed to the sun's rays, and because the sun is relatively higher in the sky during the summer, the broader east/west exterior walls receive increased amounts of solar radiation which may cause the house to overheat.

Correct building orientation depends upon lot orientation. Lot orientation dictates where a building may be located and which direction it faces. Lots elongated north-south and situated on east-west streets provide the best conditions for solar access (Bryenton, Cooper and Mattock 1979, 239). Elongated north-south lots permit greater distances between buildings from north to south. Consequently, these lots can accommodate longer north shadows, thereby reducing the amount of shading to solar collectors. Although buildings oriented east-west have the greatest degree of solar exposure, if a garage occupies a considerable portion of the house's south-facing side, then potential solar radiation is reduced. This maybe a problem with passive solar heating strategies which require large amounts of south-facing window area (Adams, 1976).

Existing setback requirements in many communities can prevent solar access to the buildable area of lots. Conventional setback practices allow the street or lot line to be staggered in order to meet minimum yard requirements. However, uneven setback lengths among neighboring lots may cause adjacent buildings to shade each other during morning and afternoon hours (Figure 3). By aligning neighbors' south walls, the chance of adjacent buildings being shaded is reduced. Zanetto (1979) proposes some additional setback requirements designed to improve solar access in residential areas. First, reducing front and rear yard setback requirements for lots on east-west streets allows houses to be located at the north end of their lots. Second, implementing north zero lot siting increases the size of the south yard under the control of the property owner (Figure 4). This allows the home owner to regulate shading from on-site trees and buildings.

In many developments, streets and lots may not be laid out so that buildings will have good solar orientation if they are sited under conventional yard and setback requirements. Flexibility in siting of buildings may allow good solar orientation despite poor lot or street orientation (Figure 5). Finally, increasing sideyard setback length on north-south streets provides a buffer area between adjacent homes. This enables longer shadow lengths to be accommodated, thus increasing solar access potential (Jaffe and Duncan 1979a).

Surrounding vegetation affects solar access and, due to its capacity as a windbreak and shading source, influences a home's energy efficiency. The extent to which various trees cast shadows depends upon variations in twig density (Figure 6). For example, Holzberlein (1979, 477) determined that the bare winter branches of a deciduous tree may block up to 80 percent of the available solar energy. In addition, trees and shrubs can

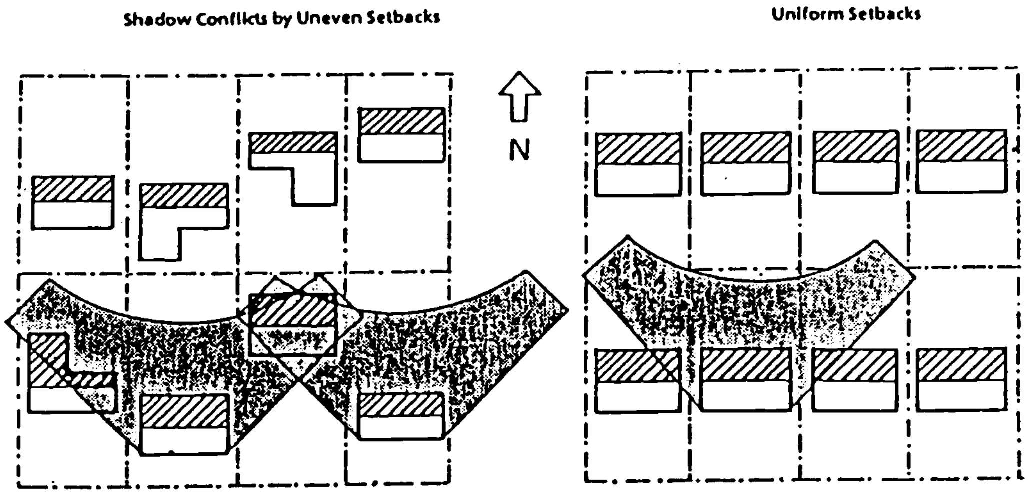

Figure 3. Shading resulting from uneven setbacks. (after Jaffe and Duncan 1979b, 59).

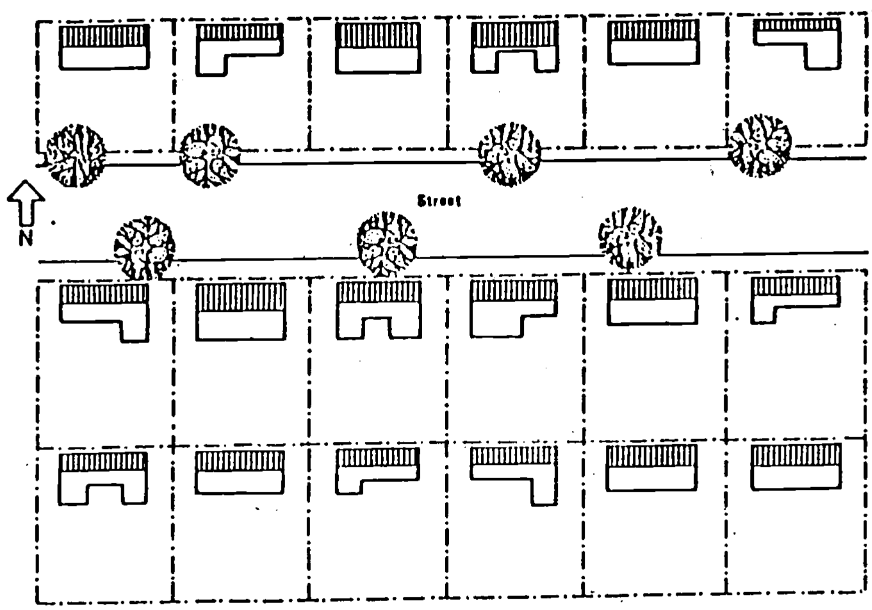

Figure 4. North zero lot line siting protects solar access by increrasing the distance from trees and buildings on adjacent lots. (after Crowley and Zimmerman 1984, 53).

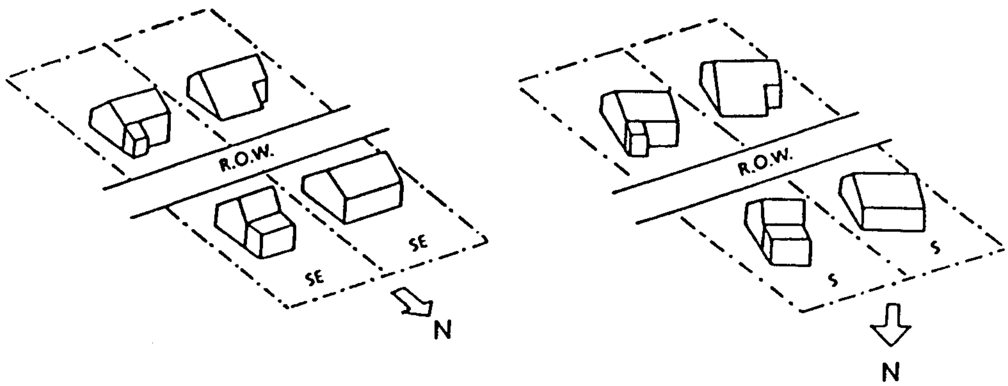

Figure 5. Flexible siting allows good solar orientation despite poor lot or street orientation. (after Jaffe and Duncan 1979b, 72).

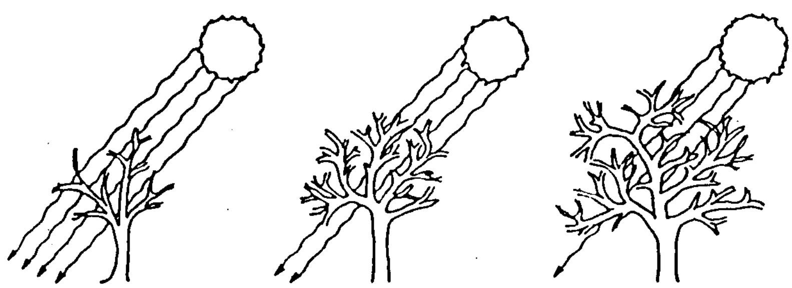

Figure 6. Variations in bare twig density give variations in penetration of winter sunlight. (after Crowley and Zimmerman 1984, 57).

be used as a windbreak to block cold winter winds or to reduce cooling costs by providing shade in the summer. Buffington and Black (1984, 795) estimated life-cycle costs of landscaping designs involving vegetation as a means of energy conservation. Their findings indicated that effective annual returns on landscaping investments (e.g., trees, shrubs, etc.) could be realized for residential buildings.

As the aspect and slope of the earth's surface changes, so does the angle at which the sun's rays strike the ground (Becker 1979, 15). Analyzing topographic features is an important facet in determining solar access potential in residential areas. On south-facing slopes, shadows are shorter than on north-facing slopes and the intensity of solar radiation is greater. Shorter shadow lengths enable dwellings to be located closer to one another without blocking neighbors' sunlight (Conservation Management Services, 1983). Because of changes in the sun's altitude, east and west slopes receive more solar radiation in the summer and less in the winter than do south slopes. Finally, north slopes generate long shadows; hence they are least ideal for solar access. Increases in slope gradient accentuate each of the described above situations; i.e., greater south slope gradients produce shorter shadows while greater north slope gradients create longer shadows.

Window orientation is a major factor in the thermal performance of a building. In estimating the impacts of window orientation on space heating loads in Seattle, Washington, Palmiter and Straub (1979, 252) determined that buildings with all south glass had a 52 percent reduction in heating load compared to buildings with all northern glass. They concluded that orientation of principal window areas should be towards the southeast, south or southwest to ensure maximum wintertime heating.

Because of the lower solar altitude in the winter, the southside of a building receives 3 times the amount of solar radiation than any other side. Consequently, allocating a large portion of the south exterior wall area to windows serves as an effective direct-gain solar collection system. Mazria (1979, 119) recommended that in temperate climates, .11 to .25 square feet of south facing glass should be provided for each square foot of floor space.

Another study (Lawrence Berkeley Laboratory 1982), used computer simulations to examine the effect of window orientation on annual heating and cooling energy costs. Results indicated that in temperate climates with the major window area facing east or west instead of south, the home consumed 24 to 74 percent more heating and cooling energy. Likewise, when the major window area faced north rather than south, home energy consumption for heating and cooling increased 12 to 45 percent.

Hypotheses

Site design strategies affect the amount of sunlight available to a residence. The following hypotheses concerning the influence of residential site planning on solar access will be tested:

1. The percentage of available sunlight is greater for houses elongated along the east-west axis than for houses elongated along the north-south axis.

2. The percentage of available sunlight is greater for houses located on east-west oriented streets than for houses located on north-south oriented streets.

3. The percentage of available sunlight is greater for homes with a north/south orientation than for homes with an east-west lot orientation.

4. The percentage of available sunlight is greater for homes located on south-facing slopes than for homes on north facing slopes.

5. The percentage of available sunlight is greater for houses with yards oriented to the south than for houses with yards oriented to the north.

6. The percentage of available sunlight is greater for houses with a south neighbor's house height equal to one story than for houses with a south neighbor's house height greater than one story.

7. The percentage of available sunlight is positively related to setback length (measured from south property line).

8. The percentage of available sunlight is positively related to distance between homes (measured north-south).

9. The percentage of available sunlight is positively related to lot size.

Surrounding trees and buildings create the majority of shade, thus indirectly influencing the amount of sunlight available to the home owner. The following hypotheses have been formulated to assess shading by on-site and off-site trees and buildings.

10. More shading occurs from off-site trees and buildings than from on-site trees and buildings.

11. Houses located on north-south streets receive more shade from off-site trees and buildings than do houses on east-west streets.

12. Houses located on north-south streets receive less shade from on-site trees and buildings than do houses on east-west streets.

13. Houses located on east-west oriented lots receive less shade from on-site trees and buildings than do houses on north-south lots.

14. Houses located on east-west oriented lots receive more shade from off-site trees and buildings than do houses on north-south lots.

15. Houses with yards oriented to the south receive more shade from off-site trees and buildings than do houses with yards to the north.

Procedures

Several statistical techniques have been selected to examine and test the aforementioned hypotheses. Procedures for collecting and analyzing data are summarized below.

Data Collection

1. The Oregon Department of Energy obtained a list of single-family urban tax lots. Approximately 400 homes were randomly sampled. Sample sizes for each county were proportional to the total population within urban growth boundaries, based on the 1980 census for urbanized areas (Clark 84, Clackamas 82, Washington 108, Multnomah 119, cities of St. Helens and Scappoose 7, Total 400).
2. The Oregon Department of Energy was responsible for all data gathering. At each of the 400 study sites, a sunchart photograph was taken at a position along the center of each home's south wall. The photograph depicts the position of the sun during different hours and seasons of the year and any obstructions to solar access from trees and buildings. Total solar radiation for each month was adjusted due to the effects of shading which were determined from the sunchart photo. The adjusted value was divided by total solar radiation (monthly) to determine the percentage of available sunlight. Also, additional information on 20 other variables that could affect solar access was collected on a separate data sheet.

Data Analysis

1. The t-test was used to compare sample means. A test statistic was

computed to determine if the differences between sample means was significant ($p < .05$).

a. The percentage of available sunlight (PCTSUN) for houses was compared on the basis of street, lot, house, and yard orientation; height of the house directly south; and slope aspect.

b. The percentage of obstructed sunlight (shading) from trees and buildings is represented by the variables ONTRE (on-site trees), ONBLD (on-site buildings), OFFTRE (off-site trees), and OFFBLD (off-site buildings. Sample means were compared. Also, each was compared individually on the basis of street, lot and yard orientation; and slope aspect.

2. Correlation coefficients and linear regression were employed to determine relationship between variables.

a. Correlation coefficients were computed to measure the strength of the relationship between percentage of available sunlight (dependent variable-PCTSUN) and the following independent variables: setback length (SB), total separation between houses (TSB), north/south lot dimension (NSLOT), lot size (SIZE) and the angle from the horizontal to the highest point on the house directly south (ANGLE).

b. Linear regression was used to show the degree of change in PCTSUN due to variation in one of the independent variables.

c. Multiple regression was employed to establish the relative importance of the independent variables in the model.

Table 1. Variable list

VARIABLE DESCRIPTION	NAME	UNITS
1. Percent available sunlight	PCTSUN	percent
2. House orientation	HOUSE	dimensionless
3. Street orientation	ST	dimensionless
4. Lot orientation	LOT	dimensionless
5. Slope Aspect	SLOPE	dimensionless
6. Yard orientation	YARD	dimensionless
7. Setback length	SB	feet
8. Total separation between houses	TSB	feet
9. Lot size	SIZE	square feet
10. Angle from the horizontal to the highest point on the house directly south	ANGLE	degrees
11. Percent sunlight obstructed by on-site trees	ONTRE	percent
12. Percent sunlight obstructed by off-site trees	OFFTRE	percent
13. Percent sunlight obstructed by on-site buildings	ONBLD	percent
14. Percent sunlight obstructed by off-site buildings	OFFBLD	percent
15. North-south lot dimension	NSLOT	feet

Results

T-Test Results

House, street and lot orientation.

The mean percentage of available sunlight for houses elongated along the north-south axis was compared to the mean percentage of available sunlight for houses elongated along the east-west axis (Table 2). The result is highly significant, indicating that houses oriented east-west have significantly better solar access than those houses oriented north-south.

The same procedure was followed to examine the effects of street orientation on solar access. A p-value of .000 is again highly significant, maintaining that houses located on east-west streets have significantly greater solar access than those found on north-south streets (Table 2).

In most residential areas the long axis of the building lot is perpendicular to the street, while the elongated side of the house is parallel to the street. Sample means of percentage of available sunlight for houses with different lot orientations were compared to see if they differed significantly. Findings reveal that houses with north-south lot orientation have greater solar access than houses with east-west lot orientation (Table 2).

Slope aspect.

South-facing slopes are naturally oriented for good solar exposure, whereas north slopes have longer shadow lengths, thereby increasing the likelihood of residences being shaded. The availability of sunlight for houses located on south-facing slopes was compared with the availability of sunlight for houses on north-facing slopes. The derived t-statistic (Table 2) is highly significant, supporting the hypothesis that houses situated on south-facing slopes have significantly greater solar access than houses on north-facing slopes.

Yard orientation.

Orienting yards to the southside of a dwelling creates a buffer between neighbors which may reduce shading caused by off-site trees and buildings. For each study site, yard orientation was noted (YARD). Sample means were compared to examine the difference in the amount of available sunlight for houses with north yard orientation and houses with south yard orientation. Table 2 shows that houses with yards oriented to the south have better solar access than houses with yards oriented to the north.

South neighbor's house height.

It is logical to assume that a two story residence would obstruct more sunlight from its northern neighbor than would a single story dwelling. The amount of available sunlight was compared for houses with the south neighbor's house comprised of one story and houses with the south neighbor's house comprised of more than one story. Table 2 reveals that the availability of sunlight is significantly greater for houses with a south neighbor's height no greater than one story.

Table 2. T-test results comparing the percentage of available sunlight based on different site characteristics.

	Mean	T-value	P-value
Percent available sunlight for houses oriented north-south	.66	-3.92	.000
Percent available sunlight for houses oriented east-west	.74		
Percent available sunlight for houses on north-south streets	.64	-6.19	.000
Percent available sunlight for houses on east-west streets	.75		
Percent available sunlight for houses with north-south lot orientation	.74	5.23	.000
Percent available sunlight for houses with east-west lot orientation	.64		
Percent available sunlight for houses on south-facing slopes	.71	3.59	.000
Percent available sunlight for houses on north-facing slopes	.63		
Percent available sunlight for houses with south yard orientation	.78	-3.03	.003
Percent available sunlight for houses with north yard orientation	.71		
Percent available sunlight for houses with a south neighbor's house height of 1 story	.70	2.75	.008
Percent available sunlight for houses with a south neighbor's house height greater than 1 story	.64		

On-site and off-site trees and buildings.

By examining the mean percentage of obstructed sunlight for each of the four shading sources, it is apparent that trees located off-site are responsible for the greatest amount of shading (11.0 percent). Obstructed sunlight from off-site buildings and on-site trees averaged 9.5 and 9.0 percent, respectively, while on-site buildings caused minimal shading (2 percent).

Property owners have control over on-site trees and buildings which can directly influence their solar access. Therefore, it can be assumed that off-site trees and buildings would pose the greatest threat to solar access. Table 3 reveals that no significant differences exist between the amount of shading from on-site trees (ONTRE) and off-site trees (OFFTRE), and off-site buildings (OFFBLD).

Variations in street, lot, and yard orientation as well as slope were examined to assess their influence on shading by on-site and off-site trees and buildings. Shading resulting from each of the four sources was compared on the basis of street orientation. Differences between the means for all pairings are indeed significant (Table 3). Houses located on east-west streets have more sunlight obstructed by on-site trees and buildings than houses on north-south streets. Houses on north-south streets, however, have more sunlight obstructed by off-site trees and buildings than houses on east-west streets.

Similarly, each shading source were compared on the basis of lot orientation. Table 3 reveals that on-site trees and buildings obstruct

Table 3. T-test results comparing the percentage of obstructed sunlight due to on-site and off-site trees and buildings.

	Mean	T-value	P-value
A.			
Percent sunlight obstructed by on-site trees	.09	-1.64	.103
Percent sunlight obstructed by off-site trees	.11		
Percent sunlight obstructed by on-site trees	.09	-.38	.705
Percent sunlight obstructed by off-site buildings	.09		
Percent sunlight obstructed by off-site trees	.11	1.14	.257
Percent sunlight obstructed by off-site buildings	.09		
B.			
Percent sunlight obstructed by on-site trees on N-S streets	.07	-3.59	.000
Percent sunlight obstructed by on-site trees on E-W streets	.12		
Percent sunlight obstructed by off-site trees on N-S streets	.13	2.05	.041
Percent sunlight obstructed by off-site trees on E-W streets	.09		
Percent sunlight obstructed by on-site buildings on N-S streets	.01	-3.65	.000
Percent sunlight obstructed by on-site buildings on E-W streets	.03		
Percent sunlight obstructed by off-site buildings on N-S streets	.17	10.41	.000
Percent sunlight obstructed by off-site buildings on E-W streets	.01		
C.			
Percent sunlight obstructed by on-site trees on N-S lots	.13	4.58	.008
Percent sunlight obstructed by on-site trees on E-W lots	.06		

Table 3 continued

	Mean	T-value	P-value
Percent sunlight obstructed by off-site trees on N-S lots	.09	-1.90	.04
Percent sunlight obstructed by off-site trees on E-W lots	.12		
Percent sunlight obstructed by on-site buildings on N-S lots	.03	3.22	.001
Percent sunlight obstructed by on-site buildings on E-W lots	.01		
Percent sunlight obstructed by off-site buildings on N-S lots	.02	-9.62	.000
Percent sunlight obstructed by off-site buildings on E-W lots	.17		
D.			
Percent sunlight obstructed by off-site trees for houses with yards oriented to the north	.13	3.01	.003
Percent sunlight obstructed by off-site trees for houses with yards oriented to the south	.06		
E.			
Percent sunlight obstructed by off-site buildings for houses on north-facing slopes	.07	-3.77	.000
Percent sunlight obstructed by off-site buildings for houses on south-facing slopes	.16		

more sunlight from houses on north-south lots than from houses on east-west lots. Because north-south lots are prevalent on east-west streets, this supports previous results regarding street orientation. These findings also indicate that houses on east-west oriented lots, a characteristic of north-south streets, have more shading caused by buildings located off-site than houses on north-south lots.

Yard orientation may affect the extent to which on-site and off-site trees and buildings shade the southside of a house. Yard areas can create a buffer between adjacent houses from north-south, helping to minimize the effects of shadows. Test results indicate that houses with yards oriented to the south have significantly less shading resulting from off-site trees than houses with yards oriented to the north (Table 3).

Finally, the effects of slope orientation on the four shading sources was examined. Table 3 points out that houses located on north-facing slopes have more sunlight obstructed due to off-site buildings than houses on south-facing slopes.

Correlation and Regression Analysis

Correlation coefficients were computed to examine relationships between the percentage of available sunlight and selected independent variables (Table 4). The r-value of .22 for setback length is highly significant. Figure 7 shows a scatter plot of the relationship along with the regression equation. Based on the derived model, a 10 foot

	PCTSUN	SB	TSB	SIZE	ANGLE	NSLOT
PCTSUN	1.0000	.1314*	.2222**	-.1418*	-.3856**	.0466
SB	.1314*	1.0000	.7530**	.3047**	-.4721**	.6934**
TSB	.2222**	.7530**	1.0000	.1819**	-.5563**	.5681**
SIZE	-.1418*	.3047**	.1819**	1.0000	-.1389*	.6877**
ANGLE	-.3856**	-.4721**	-.5563**	-.1389*	1.0000	-.3810**
NSLOT	.0466	.6934**	.5681**	.6877**	-.3810**	1.0000

* - SIGNIF. LE .01   ** - SIGNIF. LE .001

Table 4. Correlation Matrix for Variables in the Solar Access Analysis

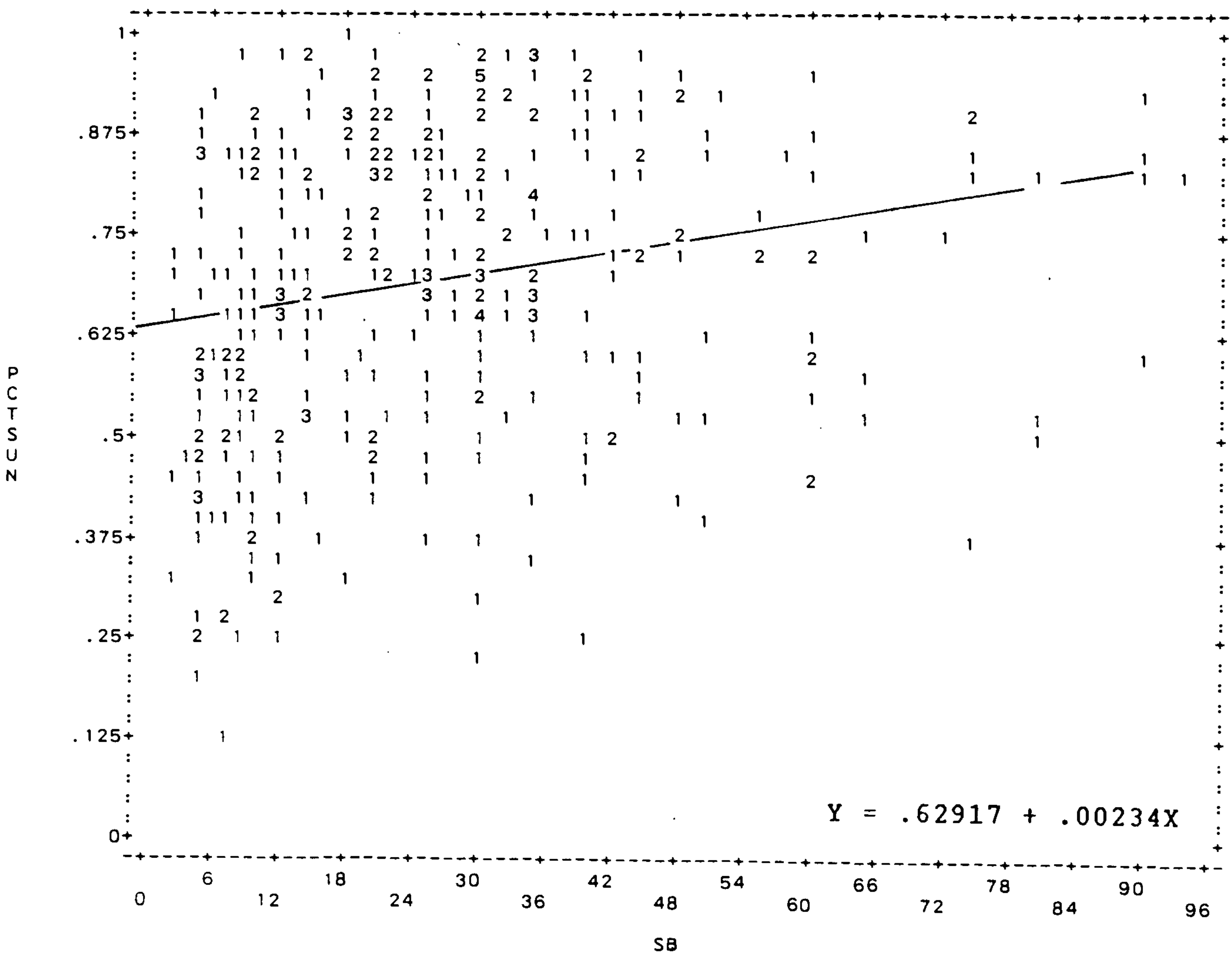

Figure 7. Scatter Plot - Percent Available Sunlight vs. Setback Length.

increase in setback length could conceivably increase the amount of available sunlight by 2 percent.

A correlation coefficient of 0.22 implies that a very similar relationship exists between percentage of available sunlight and the total separation between houses (TSB). By examining the regression coefficients for both of the equations (Figures 7 and 8), it is apparent that more of the variation in available sunlight can be explained by setback length than by the total separation between houses.

Table 4 shows that an inverse relationship exists between lot size (SIZE) and the percentage of available sunlight. This result contradicts the assumption that larger lot sizes may have better solar access by allowing for greater distances between the south property line and the south wall of the dwelling. A scatter plot and accompanying regression equation are shown in Figure 9.

The south neighbor's house height can affect the availability of sunlight to neighbors located to the north. At each study site, an angle from the horizontal to the highest point on the house directly south was measured (ANGLE). A correlation coefficient of -0.39 (Table 4) is highly significant and supports the assumption that an inverse relationship exists between the south neighbor's house height and the percentage of available sunlight. By utilizing the regression equation (Figure 10), a 6 percent decrease in percent available sunlight can be predicted by a 10 degree increase in ANGLE.

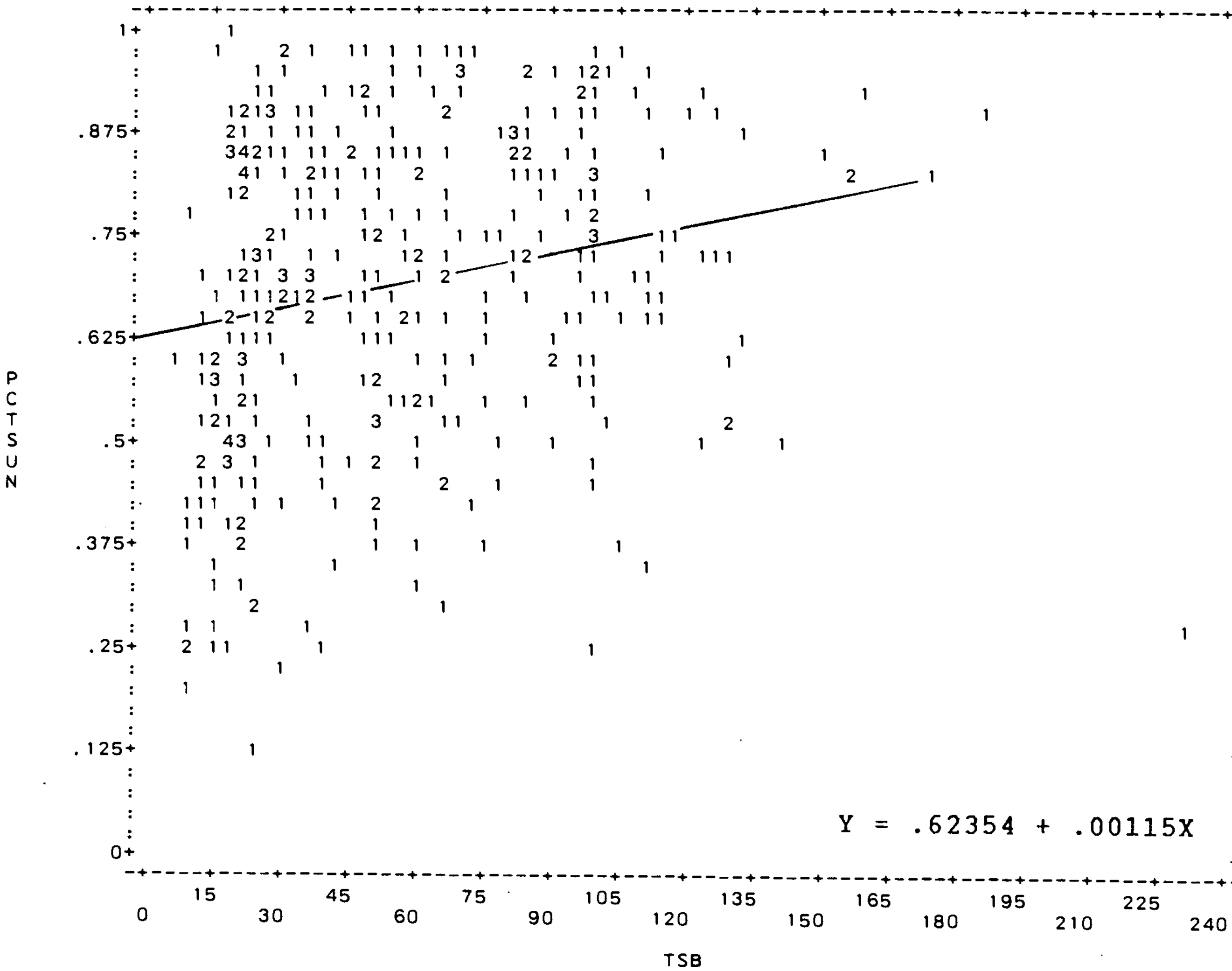

Figure 8. Scatter Plot - Percent Available Sunlight vs. Total Separation Between Houses

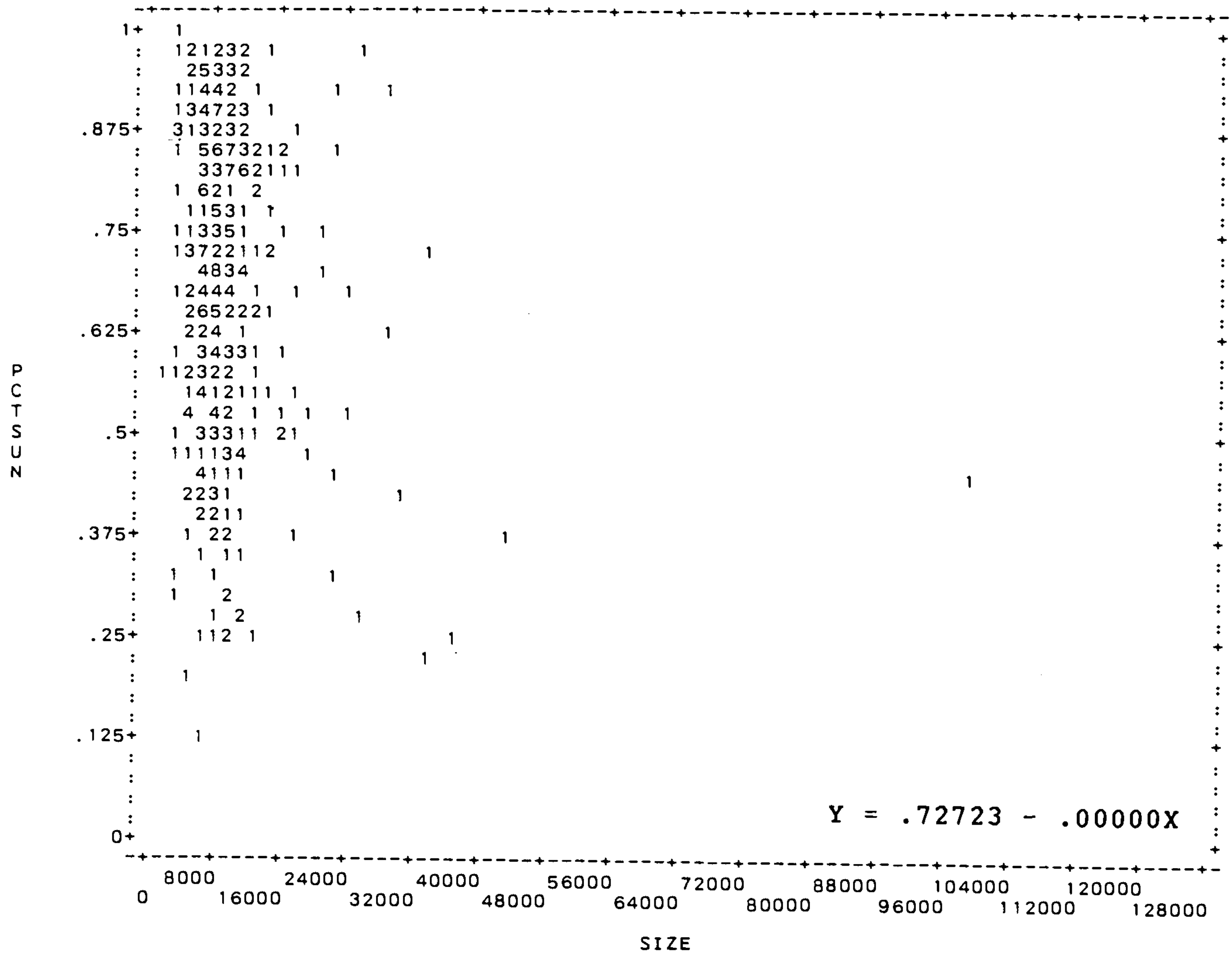

Figure 9. Scatter Plot - Percent Available Sunlight vs. Lot Size

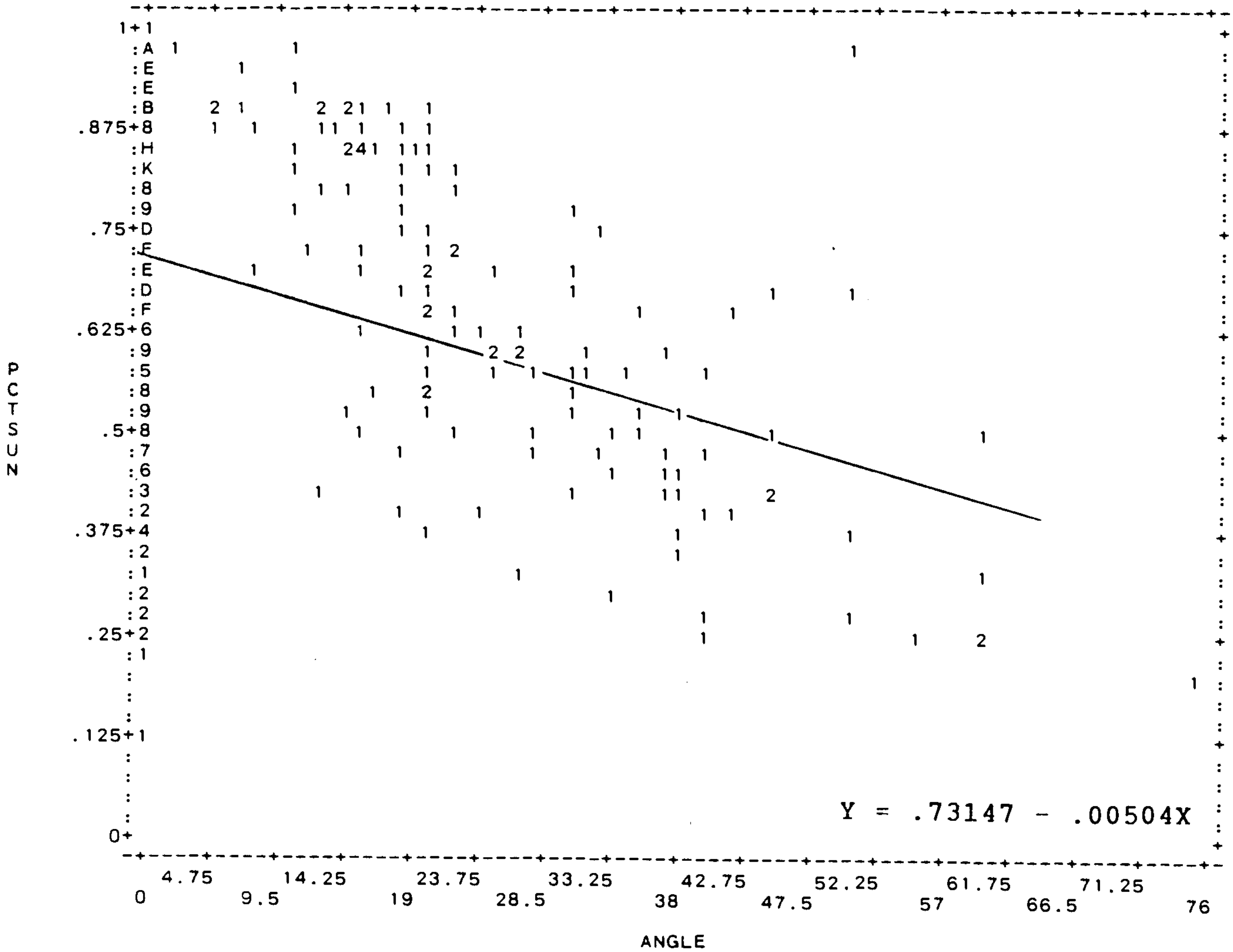

Figure 10. Scatter Plot - Percent Available Sunlight vs. South Neighbor's House Height (measured in degrees from the horizontal to highest point on the house)

Multiple regression

Multiple regression was used to explain variation in the percentage of available sunlight via variations in the independent variables. The resulting multiple regression equation expressing available sunlight in percent is:

$$Y = .755546 - .00082X_1 + .00035X_2 - .00001X_3 - .0051X_4 + .00046X_5$$

where X1 is setback length (feet), X2 is total separation between houses (feet), X3 is lot size (sq. feet), X4 is the angle from the horizontal to the highest point on the house directly south (degrees) and X5 is north-south lot dimension (feet). The computed F ratio of 18.1 is significant (p-value = .000) and indicates that the model is a valid expression of the dependent variable's behavior.

The above conclusion is undeniably useful, but it gives no understanding of the relative importance of the five selected variables. Table 5 shows the precise statistical significance of each variable in the model. It is evident that south neighbor's house height and north-south lot dimension are the only significant entries.

Stepwise regression.

Using stepwise regression, independent variables were re-examined at each stage to identify any that had become unnecessary following the introduction of other variables, or to permit use of previously rejected variables. In doing so, stepwise regression pays particular attention to the problems of multicollinearity (Shaw and Wheeler 1985, 245). The following regression equation was produced using stepwise regression:

$$Y = .78830 - .0054X_1 - .00001X_2$$

where X1 is the angle from the horizontal to the highest point on the house directly south and X2 is lot size. Table 6 shows the statistical significance for variables in the equation and for those not in the equation.

Discussion

A review of literature pertaining to solar access planning suggests that orientation, primarily of streets, lots and homes, is the most critical design strategy (Crowley and Zimmerman 1984; Jaffe and Erley 1979; and Mazria 1979). The findings of this study support aforementioned hypotheses concerning the influence of orientation on solar access. Within the Portland-Vancouver Metropolitan Area, solar access is significantly greater for houses elongated along the east-west axis, located on east-west streets and with a north-south lot orientation. Aligning streets and houses east-west allows for optimum orientation to the sun's daily path, while north-south lot orientation provides greater distances between dwellings from north-south.

Basic assumptions concerning slope and yard orientation were also supported. Houses on south slopes had better solar access than those located on north slopes. Shadow lengths are shorter on south slopes than on north slopes, consequently, homes can be located closer to one another while still ensuring adequate solar access. Also, orienting yards to the

VARIABLE	B	T	SIG T
NSLOT	.00046	.997	.3192
ANGLE	-.00511	-7.080	.0000
TSB	.00035	.889	.3747
SIZE	-.00001	-3.561	.0004
SB	-.00082	-1.144	.2532
(CONSTANT)	.75546	24.171	.0000

Table 5. Statistical Significance of Variables in the Regression Model Using Forced Entry.

VARIABLES IN THE EQUATION

VARIABLE	B	T	SIG T
ANGLE	-.00540	-8.980	.0000
SIZE	-.00001	-4.328	.0000
(CONSTANT)	.78830	47.671	.0000

VARIABLES NOT IN THE EQUATION

VARIABLE	BETA IN	T	SIG T
SB	-.00419	-.078	.9380
TSB	.04193	.758	.4490
NSLOT	.05876	.859	.3911

Table 6. Statistical Significance of Variables in the Regression Model Using the Stepwise Method

south creates greater distances between the dwelling's south wall and shadows resulting from off-site trees and buildings.

The results from correlation and regression analysis were similar. The height of the neighbor's house directly south (ANGLE) had the greatest effect on the solar access of its northern neighbor ($r = -.39$). In addition, five independent variables were regressed against percent available sunlight using the stepwise procedure. The variables ANGLE and SIZE (lot size) had the greatest statistical significance and were retained in the final regression equation. The adverse effect which neighboring building heights can have on others' solar access is obvious. However, the influence of lot size on the availability of sunlight is difficult to interpret. An examination of the data base, however, revealed that several large lots had a substantial amount of shading caused by on-site trees.

Houses located on the northside of an east-west street commonly have yards which are oriented to the north. The results showed that houses with north yard orientation received more shading from off-site trees than houses with yards located to the south. Therefore, a significant portion of shading caused by off-site trees may come from city-owned street trees. City and county governments have the ability to minimize this problem through the adoption of street tree ordinances.

The City of Portland's solar access study revealed that approximately half the shading problem was caused by buildings and half by trees. In the Portland-Vancouver Metropolitan Area, however, approximately one-third of the shading is caused by buildings and twothirds by trees. Shading from off-site trees and buildings was most severe on streets oriented north-south, while on-site trees caused the greatest shading problem on east-west streets. Flexible setback requirements may improve solar access on north-south streets by permitting houses to be sited closer to the north property line. Also, a significant portion of the shading problem caused by on-site trees can be addressed by providing homeowners with information on solar-conscious landscaping practices.

References

Adams, A. 1976. Your energy efficient home. Charlotte, VT: Garden Way Publishing.

Becker, C. F. 1979. Solar radiation availability on surfaces in the United States as Affected by season, altitude and cloudiness. Arno Press. New York: New York.

Bryenton, R., Cooper, K., and Mattock, C. 1979. Community and site planning for solar developments. Proceedings of Solar 79 Northwest. Seattle, Washington.

Buffington, D. E. and Black, R. J. 1984. Plant materials for residential energy conservation--life cycle costing. Proceedings, Third Annual PLEA Conference.

Butti, K. and Perlin, J. A. 1980. A golden thread: 2000 years of solar architecture and technology. New York: Van Nostrand Reinhold.

Conservation Management Services, 1983. Solar access design manual: A guide for providing and protecting solar access in new developments. Unpublished paper.

Crowley, J. S. and Zimmerman, L. Z. 1984. Practical Passive Solar Design. New York: McGraw-Hill Book Company.

Holzberlein, T. M. 1979. Don't let the trees make a monkey out of you. Proceedings of 4th National Passive Solar Conference 4:417-420.

Jaffe, M. and Duncan, E. 1979a. Site planning for solar access: A guidebook for residential developers and site planners. Washington, D. C.: U.S. Government Printing Office.

Jaffe, M. and Duncan, E. 1979b. Protecting solar access for residential development: A guidebook for planning officials. Washington, D.C.: U.S. Government Printing Office.

Kaufman, J. 1981. The Portland, Oregon Energy Policy. Unpublished paper. Salem: Oregon Department of Energy.

Kaufman, J. 1985. Portland solar access analysis. Unpublished paper. Salem: Oregon Department of Energy.

Kaufman, J. 1986. Portland-Vancouver metropolitan area solar access project. Unpublished paper. Salem: Oregon Department of Energy.

Kaufman, J. 1987. Personal communication.

Lawrence Berkeley Laboratories, 1982. The importance of residential building orientation. Washington D.C.

Markus, H. 1983. Model solar access land use regulations. Unpublished paper. Salem: Oregon Department of Energy.

Mazria, E. 1979. The passive solar energy book. Emmaus: PA: Rodale Press.

McKeever, M. R. and Connell, C. W. 1983. Deschutes County, Oregon: A unique solar access program. Proceedings for 8th Passive Solar Conference, Portland 1983.

Olgyay, V. V. 1963. Design with climate. Princeton: Princeton University Press.

Palmiter, L. and Straub, D. 1979. Window performance and the Seattle energy code. Proceedings of Solar 79 Northwest. Seattle, Washington.

Shaw, G. and Wheeler, D. 1985. Statistical techniques in geographical analysis. New York: John Wiley & Sons.

Solar Energy Research Institute. 1980. Solar envelope zoning: Application to the city planning process. 5641.20. Springfield, Virginia: Department of Commerce.

Zanetto, J. 1978. The location and selection of trees for solar neighborhoods. Landscape Architecture, vol. 7, 514-520.

Zanetto, J. 1979. Planning solar neighborhoods. Proceedings of the National Passive Solar Conference, Kansas City, Missouri.