Sunspace Performance
in the
Willamette Valley

by

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Abstract

The Los Alamos Solar Design Methodology is used to predict the performance of three hypothetical solar homes situated in the Willamette Valley. The three homes all used a sunspace for supplemental heating and differed only in their level of heat loss. Results obtained indicate that a sunspace can contibute up to 60% of a super-insulated home's heating demand, 40% of a moderately-insulated home's heating demand, and 20% of a poorly-insulated home's heating demand. Yearly savings and payback period for the homes are estimated using a variety of alternative fuel sources. Yearly savings ranged from $19.00 to $459.00. Payback periods ranged from 2 years to 324 years. Information on solar access ordinances adopted by Willamette Valley communities is also discussed.

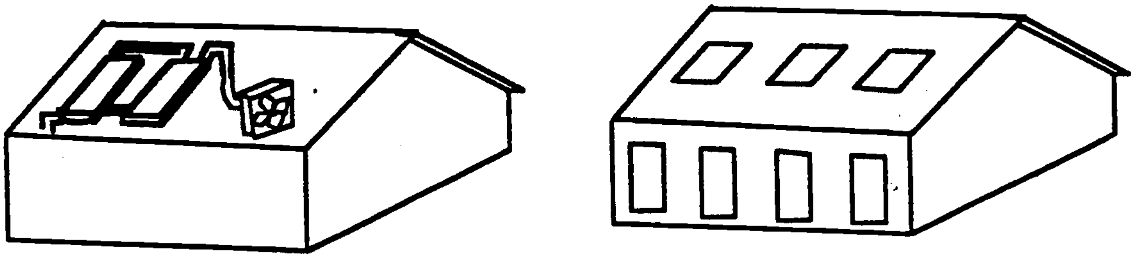
I INTRODUCTION

Solar energy has been used to help heat homes for thousands of years. One of the earliest recorded references to the use of solar energy was Socrates, circa 400 B.C. :

Now in houses with a south aspect the sun's rays penetrate into the porticoes in the winter, but in the summer the path of the sun is right over our heads and above the roof, so that there is shade. If, then, this is the best arrangement, we should build the south side loftier to get the winter sun, and the north side lower to keep out the cold winds. (Kaufmann, 1985.)

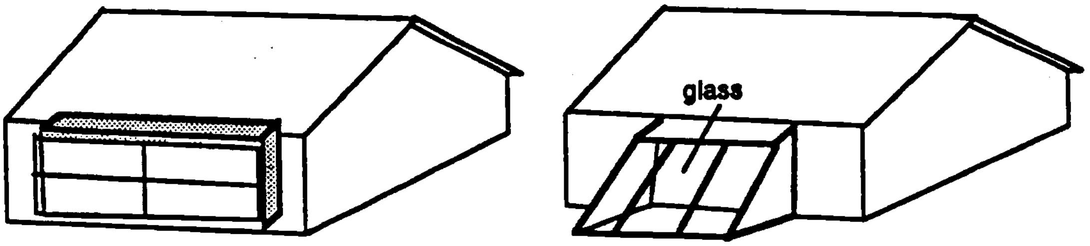
While the value of solar energy was recognized long ago, there are a variety of geographic variables that affect the performance and utility of solar energy in particular areas. The most important of these is climate, but other factors such as fuel prices, social values, and legal provisions also influence the decision to utilize solar energy to help heat a home. It is obvious from the orientation, landscaping, and placement of glazing that the majority of contemporary homes have not been designed to utilize solar energy effectively. This does not mean, however, that the opportunity to capture more of the sun's energy is limited to builders of new homes. A variety of options, commonly called solar retrofits, are available to the existing homeowner, including active solar collectors, adding south-facing windows, a Trombe Wall, and solar room additions (Figure 1).

Figure 1 - Common Solar Designs



Active Solar Collectors
Use a fluid to transfer heat from collectors to interior space

South-facing Windows
The addition of more south glazing increases solar direct gain



Trombe Wall
A large wall of masonry or water which absorbs solar energy and releases it slowly

Sunspace
A solar collector that also provides useful living spac

Source: Carter, J. 1981, pp. iv-v

All of these designs share the objective of decreasing a home owner's dependence on conventional fuel and have been successfully used to retrofit existing homes. This paper, however, will focus on the use of sunspaces as a solar retrofit option. Sunspaces are relatively easy to add to an existing home and have the advantage of providing high-quality living space for both plants and people. Sunspaces are very popular with builders and homeowners. Between 33,000 to 39,000 prefabricated sunspaces were sold in 1986, with approximately 80% of these being used in remodeling projects rather than new construction (Gray 1987, p9). There is no reliable estimate available for the total number of sunspaces that were retrofitted to existing homes. Due to the relatively high cost of prefabricated units, many people build the sunspaces themselves or in conjunction with a local contractor.

Several researchers have documented the fact that many people enjoy living in passive solar structures such as sunspaces (Balcomb 1983; Davis & Davis 1979; Hogue 1984). One interesting theory why people enjoy living in passive solar homes was proposed by Herwage and Heerwagen (1983). They suggested a relationship between the evolution of humans on the African savannah and the satisfaction of living in a solar home. By living for millions of years in savannah-type environments, humans may have developed psychological and physiological systems that function best when people live and work in environments that contain the fundamental features of a savannah, including semi-tropical temperatures, open spaces, sunshine, green plants, and expansive views of the landscape. If this theory is true, it might help explain why people enjoy sunny days so much, particularly residents in rainy, cloudy climates like the Willamette Valley. If people respond well to increased levels of light , plants, space, etc., one way to provide these elements would be to add a sunspace to their home. But how well does solar space heating, and in particular, the sunspace, function within the particular geographic conditions of the Willamette Valley?

The purpose of this paper is to answer that question by analyzing the thermal design, economic, and regulatory factors that affect sunspaces in the Willamette Valley. Specific objectives are to: 1) examine the affect of the Willamette Valley climate on sunspace thermal performance, 2) summarize the extent to which solar access ordinances have been adopted within the Valley, and 3) estimate annual savings and payback periods based on average local fuel prices.

II REVIEW OF RELEVANT LITERATURE

There are several well-documented cases of successful solar energy designs in Western Oregon. Gray and Baker (1976) described ten solar buildings in the Northwest. Four of these were in Western Oregon, including: Portland, Gladstone, Stayton, and Coos Bay. The researchers involved in the survey estimated that these solar designs contributed from 53 to 85 percent of the homes' heating supply. A study by Portland General Electric of eleven solar installations in the Portland area found that solar could contribute as much as 70% of the energy requirements of a home (Boleyn 1979). Both of these studies focused primarily on solar designs that were incorporated at the time of building construction rather than added on later. Also, none of the installations studied relied exclusively on sunspaces. However, the studies do serve to document the potential of solar energy in the Willamette Valley.

The Oregon Department of Energy (1980) prepared a manual for homeowners and builders who were interested in determining the economics of residential solar systems in Oregon. The report included a description of several solar system types and a general discussion of their performance. The report also provided techniques for estimating the performance of individual systems as well as rules of thumb for economic feasibility. While the performance of a variety of systems was analyzed in four geographic regions of the state (the coastal area, Willamette Valley, southwest, and southeastern region), there was no analysis of sunspace performance in the Willamette Valley. The methodology used was based on earlier work by Balcomb, et al (1983). Brandt and Wilson (1987) compiled a descriptive survey of passive solar homes in Oregon, and found that 76% of passive solar home owners were 'very satisfied' with their system's fuel savings and performance.

Evaluations of pasive solar performance in Washington were completed by Straub (1981); and McDonald and Tsongas (1981). The Straub study looked at optimum mixes of conservation and passive solar in eastern and western Washington, and concluded that thermal mass and southern glazing were the two most cost effective passive features when compared to conservation. McDonald and Tsongas compared the energy savings and cost effectivenesss of a wide variety of conservation and passive solar features.

Recommendations included the sizing of south glazing at about 15 percent to 18 percent of floor area, and the provision of thermal mass sufficient to supply 15 to 20 Btu per square foot of south facing glass. The example homes in this paper have south glazing proportions within this range (16%), but the amount of thermal mass provided is substantially higher than recommended by McDonald and Tsongas (about 30 Btu per square foot of south glazing). This is possibly a result of the emphasis by McDonald and Tsongas on cost effectiveness, whereas the design methodology used in this paper emphasizes thermal performance.

Kale (1989) completed an assessment of solar access ordinances in the Pacific Northwest. This study highlighted the potential electricity savings associated with the implementation of solar access ordinances. Procedures for analyzing the economics of individual systems were developed by Knapp (1979) and McDonald (1979). Knapp described a method for predicting the return on investment of solar heating systems, using a residence located in Corvallis as an example. McDonald developed a lifecycle cost model and prototype house designs for Northwest locations west of the Cascades. McDonald concluded that energy costs in an energy conserving house are insufficient to justify much investment in solar design strategies. These findings are supported by economic analysis of sunspace performance in this paper. Neither Knapp or McDonald provided in-depth modeling procedures for sunspaces, but their methods are useful in determining an optimum design mix of solar and conservation.

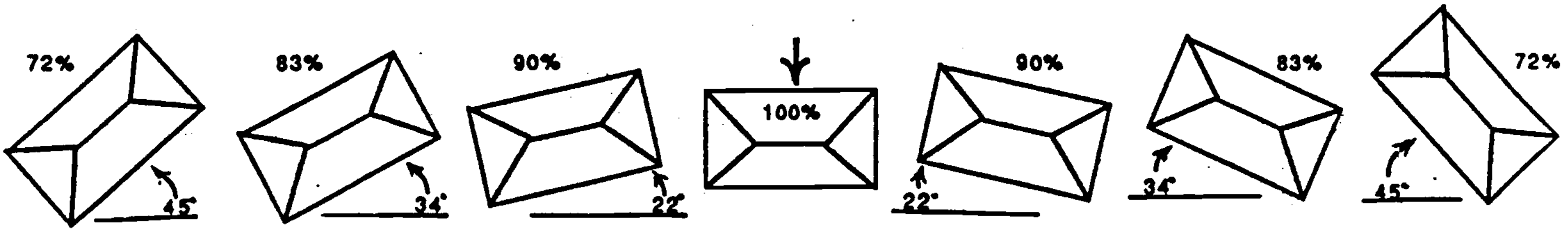
III SOLAR HEATING - GENERAL PRINCIPLES

A great variety of solar designs and devices are available to help heat homes. Despite this variety, nearly all of these products share some basic characteristics. The most universal of these is the use of some type of glazing to trap infrared energy inside the collector or living area. Since glazing readily transmits direct solar energy but is relatively opaque to longer wave, reradiated infrared, heat energy builds up inside the solar collector. This phenomenon is called the 'greenhouse effect.'

Another basic characteristic that most solar designs share is the use of thermal mass to store heat energy. Typically, this involves the use of concrete, brick, or water in containers to help store the heat energy that is trapped inside the solar collector. If there is inadequate thermal mass, the collector will tend to overheat during the day, and cool off too rapidly at night, resulting in uncomfortable temperature swings.

Solar designers are also very concerned with the orientation of the collector. Orientation refers to the direction the collector faces relative to true south. The more the collector faces away from south, the less energy is collected. As Figure 2 illustrates, losses are not substantial until the collector faces more than 45 degrees from true south (Carter 1979).

Figure 2 - The Effect of Orientation on Net Solar Energy Gain



Source: Carter 1981, p9

IV SUNSPACES IN THE WILLAMETTE VALLEY

A. Description of Area - The Willamette Valley is a broad alluvial plain about 100 miles long and up to 40 miles wide. It is bounded to the west by the Coast Range and to the east by the Cascades. The northern and southern terminuses are approximately marked by the cities of Portland and Eugene. Topographical variation within the valley is minor, though the Salem, Eola, and Chehalem hills, as well as many buttes, rise as much as 300 feet above the Valley floor. The Valley is a relatively homogenous climatological unit. In a 30-year comparison of heating degree-days for 13 locations in the Valley, there was a 17% difference between the station with the highest number of degree days (Bull Run Watershed - 5163 dd), and the station with the lowest (Oregon City - 4415). If Portland and Oregon City are excluded from analysis, the range is only about 7.5% (NOAA 1983).

Seasonal insolation data are not readily available for a variety of representative sites across the Valley, but the State Climatologist estimates that variation probably does not exceed 15 percent (Redmond 1988).

B. The Los Alamos Design Methodology-The analytical procedure that will be used in this paper to analyze sunspace design and perfomance in the Willamette Valley was developed by the Los Alamos National Laboratory. This method is commonly referred to as the Balcomb Method after the editor and co-author of the volumes outlining the procedure. The Balcomb Method was used since it provides the most comprehensive data and procedural reference currently available. First presented in 1978 at the Second National Passive Solar Conference in Philadelphia, the Balcomb Method has become a popular solar design methodology in the United States. The method is based on computer simulation of the performance of 28 sunspace systems under a variety of climatic and design conditions (Table 1).

Table 1 - Description of 28 Sunspace Designs Used in the Balcomb Method

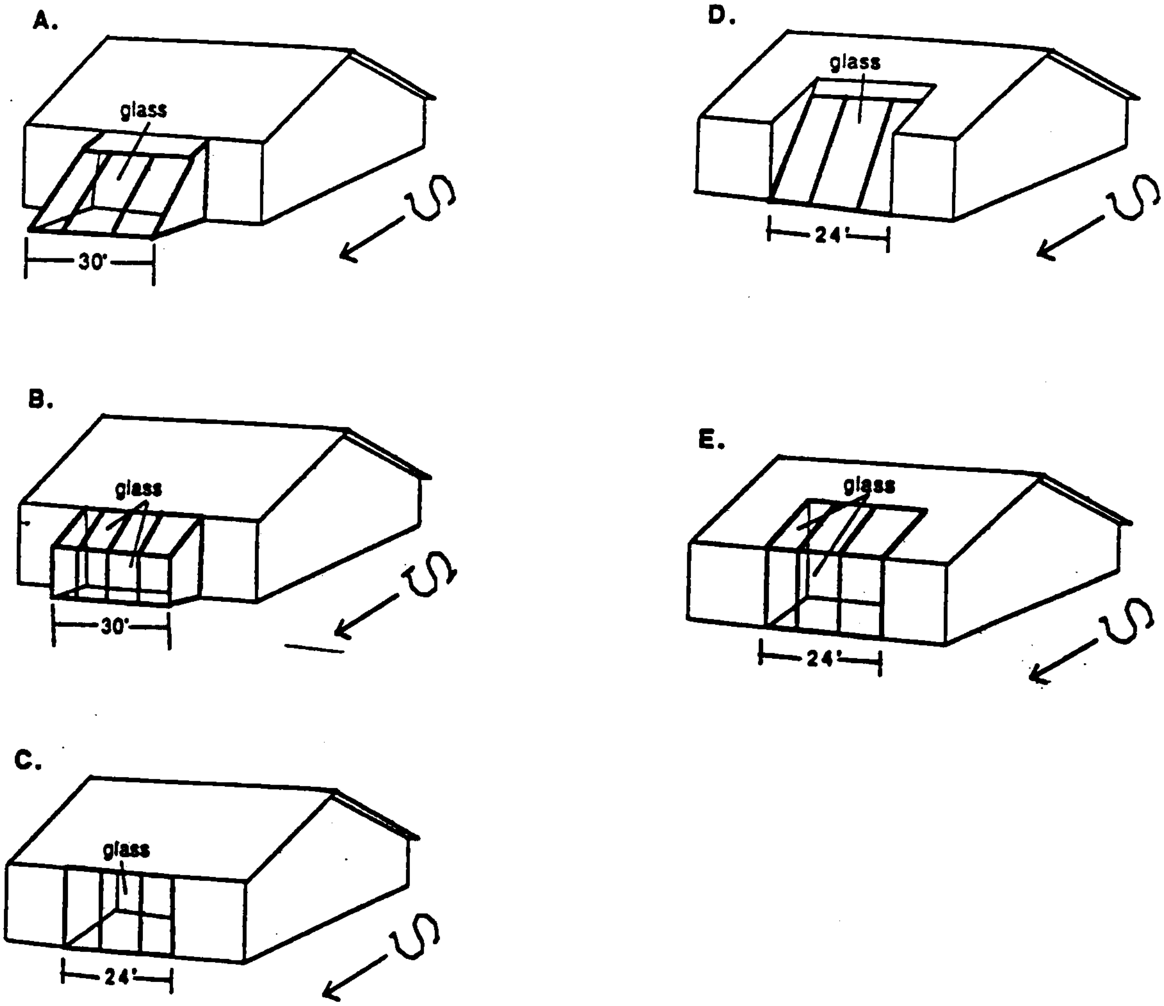
Geometry Designation	Type	Glazing Tilt (degrees)	Common Wall	End Walls	Night Insulation (R7)
A1	attached	50	masonry	opaque	no
A2	attached	50	masonry	opaque	yes
A3	attached	50	masonry	glazed	no
A4	attached	50	masonry	glazed	yes
A5	attached	50	insulated	opaque	no
A6	attached	50	insulated	opaque	yes
A7	attached	50	insulated	glazed	no
A8	attached	50	insulated	glazed	yes
B1	attached	90/30	masonry	opaque	no
B2	attached	90/30	masonry	opaque	yes
B3	attached	90/30	masonry	glazed	no
B4	attached	90/30	masonry	glazed	yes
B5	attached	90/30	insulated	opaque	no
B6	attached	90/30	insulated	opaque	yes
B7	attached	90/30	insulated	glazed	no
B8	attached	90/30	insulated	glazed	yes

C1	semi-enclosed	90	masonry	common	no
C2	semi-enclosed	90	masonry	common	yes
C3	semi-enclosed	90	insulated	common	no
C4	semi-enclosed	90	insulated	common	yes
D1	semi-enclosed	50	masonry	common	no
D2	semi-enclosed	50	masonry	common	yes
D3	semi-enclosed	50	insulated	common	no
D4	semi-enclosed	50	insulated	common	yes
E1	semi-enclosed	90/30	masonry	common	no
E2	semi-enclosed	90/30	masonry	common	yes
E3	semi-enclosed	90/30	insulated	common	no
E4	semi-enclosed	90/30	insulated	common	yes

Source: Balcomb 1983, p 237

The 28 systems differ from each other in one or more of the design characteristics (i.e. - type, glazing tilt, composition of common and end walls, and presence of night insulation. These five design characteristics were chosen due to their importance to sunspace performance and to represent a wide variety of common sunspaces. Note that the designations A1 thru E4 refer to variations of the five basic geometries pictured in Figure 3. These sunspaces share a number of design features which are outlined in detail in Appendix A. Two of the basic design geometries are attached (share only one common wall), while the other three are semi-enclosed. It is much easier and less expensive to add an attached sunspace to a home, though it is possible to add a semi-enclosed sunspace. A semi-enclosed sunspace may be the only alternative in situations where site constraints (setback regulations, slope, etc.) rule out attached sunspaces.

Figure 3 - Reference Design Geometries



Source: Balcomb 1983, p 88

Table 2 summarizes the results of computer simulation for these 28 designs. The table is for Salem, Oregon, and considering the relative uniformity of the Willamette Valley climate, the results should be fairly applicable to the remainder of the Valley. The table indicates the load-to-collector ratio (LCR) necessary to attain a desired solar savings fraction (SSF) for the various reference designs. For example, in order to achieve a solar savings fraction of 60% for Sunspace System C4, a load-to-collector ratio of 11 would be needed. This means that the building's heat loss (in Btu/dd) can only be eleven times the area of sunspace glazing. In reality, this is an unreasonably low LCR for anything but a super-insulated building, and most of the homes in the Willamette Valley are not that well insulated. As many as 35% have no insulation at all (Coleman,1988).

Table 2 Load-to-Collector Ratios for Salem, OR

SSF =	.10	.20	.30	.40	.50	.60	.70	.80	.90
A1	402	106	48	26	14	7	3	-	-
A2	364	141	75	46	29	19	13	-	-
A3	385	92	39	19	13	8	4	-	-
A4	371	139	73	43	27	18	11	7	4
A5	683	106	42	20	10	-	-	-	-
A6	360	138	73	44	28	18	12	7	4
A7	773	87	30	11	-	-	-	-	-
A8	371	135	70	41	25	16	10	6	3
B1	268	78	36	19	10	5	-	-	-
B2	283	114	62	38	25	17	11	7	4
B3	244	68	30	15	6	-	-	-	-
B4	278	110	59	36	23	15	10	6	3
B5	352	69	28	13	6	-	-	-	-
B6	265	108	59	36	23	15	10	6	3
B7	309	55	21	7	-	-	-	-	-
B8	257	102	55	33	21	14	9	5	3
C1	149	58	30	17	9	-	-	-	-
C2	168	80	47	30	20	14	9	5	3
C3	162	48	22	12	6	-	-	-	-
C4	169	73	41	26	17	11	7	4	2
D1	357	124	61	34	20	11	5	2	-
D2	311	150	88	57	38	26	17	11	6
D3	465	119	54	28	16	8	3	-	-
D4	321	148	85	54	36	24	16	10	6
E1	256	91	44	24	12	-	-	-	-
E2	251	120	69	44	29	19	13	8	4
E3	324	81	35	18	8	-	-	-	-
E4	264	114	63	39	25	17	11	6	3

Source: Balcomb 1983, p 463

Note that there is substantial variation in potential solar savings between the various designs. For example, according to Table 2 a 50% solar savings is not possible with

Designs A7 and B7. The combination of glazed end walls and no night insulation is the primary reason for this (Table 1).

Table 3 highlights the relationship of LCR to home insulation levels that are typical of a \`super' - insulated home, an \`average' - insulated home, and a \`poorly' - insulated home. These terms are based on Carter's (1981) classification, where heat losses and weatherization levels were divided into the following groups: 1) < 5 Btu/ft^2/dd = super-insulated, 2) 5-10 Btu/ft^2/dd = average-insulation, and 3) >10 Btu/ft^2/dd = poorly-insulated. The examples assume an average sunspace glazing area of 243 sq ft (the average of the 28 reference designs), and a home size of 1500 sq ft. The LCR figures are means derived from Table 2. The way the calculations were performed is as follows: 1) LCR means were derived for the 60%, 40%, and 20% SSF columns; 2) these means were multiplied by the average sunspace glazing area (243 square feet) to determine the Building Load Coefficient (BLC); 3) the BLC was used as a basis for determining weatherization measures necessary to achieve that heat loss standard. It is apparent from Table 3 that sunspaces will not provide much more than 60% of a building's heating requirements without very high conservation levels. The heat loss shown for the super-insulated home is already at the bottom end of Carter's scale. However, moderate contributions (approx. 40%), are possible with average insulation levels, and even homes with little insulation can receive a modest 'solar subsidy' by adding on a sunspace.

Table 3 - Relationship of Load-to-Collector Ratio, Solar Savings, and Insulation Levels

Maximum	LCR	Heat Loss		R-Value			
Savings	X	BLC(Btu/DD)	Btu/ft^2/dd	Wall	Ceiling	# glazings	Air changes/hr
60%	11	2,551	1.7	50	77	triple	.187
40%	30	7,290	4.9	12	20	double	1.25
20%	102	24,786	16.5	2	12	single	2

Source: calculated by author

It is important to note that since solar savings depend on the load-to-collector ratio, the maximum savings can be increased by lowering the building's heat loss or by increasing the collector area. However, it is usually far too expensive to build a collector large enough to compensate for very low levels of insulation. For example, it is possible to achieve a load-to-collector ratio of 11 (and a solar savings of 60%) by intensive weatherization or by having a poorly-insulated house and a collector about 9 times larger than the 243 square foot average used in Table 3. Besides the design difficulties involved in building a collector this large, the cost would be inordinate. The impact on solar savings of varying the sunspace size is graphically presented in an appendix of the Balcomb Design Manual (pp. 220-240). In addition, the effect of varying 15 other design variables is also presented in `sensitivity' graphs. These graphs are a valuable reference for researchers who are interested in designs which vary from the designs presented in this paper.

C. SOLAR ACCESS ORDINANCES

Obviously, a homeowner who has invested a good deal of time and money adding a sunspace to his home is likely to be very frustrated if a neighbor adds a second floor to their home and shades the sunspace. This loss of solar access can come about in a variety of ways. For instance, a homeowner in Salem asked the City to trim some trees which were shading his solar collector. The City refused and the homeowner learned the hard way that a collector which is unshaded during installation in summer may be almost completely shaded in winter when the sun is low in the southern horizon. The solar access that he assumed would be there when he built the collector was in fact not guaranteed at all.

In another case, the construction of a new home blocked solar access to an existing solar home, resulting in a series of lawsuits as well as hard feelings between neighbors (Kaufman 1985). In cases like this, contractors, realtors, neighbors, or the City may be liable for loss of solar access. Another incentive to protect rights to sunlight has been the realization that greater solar access will reduce energy bills. A study in Eugene-Springfield found that approximately 22% of all residential energy needs in the area could be provided by solar energy. This includes 23% of all space heating, 33% of all water heating, and 13% of all lights and electric appliances (O.A.T. 1982). To ensure that these potential savings are not irrevocably lost, the study recommended implementation of solar access ordinances. A study in Portland reached similar conclusions and also noted that a conventional home in the sun, with windows evenly distributed, uses 20% less energy for heating than if it were totally shaded (Levi 1984). Kale (1989) estimated that achievable savings in the Pacific Northwest from solar access protection ranged from 18 to 36 megawatts over the next 20 years.

Potential energy savings and strong public support for the protection of solar access (Levi 1984; Berg 1984) have led a number of Oregon jurisdictions to adopt solar access ordinances. These ordinances can be divided into three categories, and are discussed below.

- Deed covenants are typically placed on lots within new subdivisions. They guarantee solar access to neighboring lots and may restrict the placement of buildings, trees or both.

- Zoning standards involve the revision of standard height and setback requirements to protect solar access on neighboring lots.

- Solar access permits extend protection only when a homeowner applies to the local planning department. Once approved, the permit will provide legal protection of solar access.

As of September, 1988, 27 Oregon jurisdictions, including 16 in the Willamette Valley, have enacted one or more of these forms of solar access protection (Table 4). Much of the credit for adoption of these ordinances must go to the Solar Conservation Task Force who were resposible for research and development of model ordinances in 1979. The results of their work are summarized in the Final Report to Oregon Alternate Energy Development Commission (1980).

Table 4 - Oregon Jurisdictions with Solar Access Ordinances as of September, 1988

Willamette Valley	Ordinance Type		
Jurisdictions	Cov.	Zon.	Per.
Portland	X	X	X
Eugene	X	X	X
Springfield	X	X	X
Corvallis	X		X
Beaverton	X	X	X
Gresham	X	X	
Lake Oswego	X	X	X
Multnomah Co.	X	X	X
Cornelius	X	X	X
Troutdale	X	X	X
Fairview	X	X	X
Veneta		X	
Creswell	X	X	
Scappoose	X	X	X
Lebanon	X	X	
Woodburn			X

Other Oregon	Ordinance Type		
Jurisdicitons	Cov.	Zon.	Per.
Ashland	X	X	X
Grants Pass	X	X	X
Klamath Falls	X	X	X
Redmond	X	X	X
Bend	X	X	X
Deshcutes Co.	X	X	X
Bandon	X	X	
Jacksonville	X	X	
Talent	X	X	
Phoenix	X	X	
Dune City	X	X	X

Source: Oregon Department of Energy 1988

Solar access ordinances illustrate how planning regulations can protect and encourage development, thus providing an incentive for a homeowner considering the addition of a sunspace. On the other hand, planning regulations can also restrict or prevent a homeowner from adding a sunspace. The most common example of this is setback requirements. If the sideyard setback is 8 feet, for example, and the home is currently 10 feet from the property line, there will not be sufficient clearance to add an attached sunspace. In this case the homeowner can apply for a variance or consider a semi-enclosed sunspace instead. Since building a semi-enclosed sunspace is often prohibitively expensive, trying for a variance is probably a good first move and worth the cost of the application fee. On the other hand, building a sunspace close to the property line increases the risk of solar access loss due to development on adjacent property. This highlights the need for securing solar access rights before building a sunspace.

D. FINANCIAL ANALYSIS

Sunspace Cost - The cost of building a sunspace will vary considerably, depending on the source and type of materials, the size and design of the sunspace, and the amount of work a homeowner is willing to do himself. The easiest, but most expensive option is to purchase a pre-fabricated unit from a manufacturer. A 1985 market survey revealed that the prices of pre-fabricated sunspaces varied from $28.00 to $90.00 per square foot (Germer 1985, p24). At 1989 prices, an average cost for a 156 square foot sunspace (similar to Design B on page 7) would be about $8,200. This is a marked comparison to an owner-built model which could be constructed for as little as $1,500.00.

Fuel Savings - The range of fuel savings for three example homes with differing amounts of insulation is shown in Table 5.

Table 5 - Heat Loss Associated with Various Insulation Levels

	Degree of Weatherization[1]	Heat Loss (Btu/DD)	Annual[2] Heat Loss
Home #1	super-insulated	2,551	12.5 MBtu
Home #2	average-insulation	7,290	35.7 MBtu
Home #3	poorly-insulated	24,786	121.7 MBtu

Source: Calculated by author
Climate data derived from NOAA 1983

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[1] Specific information on R-values is given in Table 3

[2] A value of 4,909 DD was used. This is a 30-year average for 13 cities in the Willamette Valley.

The heat loss of these homes can be balanced by using a variety of heating systems. Typical fuels and their average costs are listed below. Note that these figures correspond to the heat losses in Tables 3 and 5, and assume an average system efficiency of 98% for electric, 60% for oil and wood, and 70% for gas (U.S. Department of Energy ______).

Table 6 - Fuel Costs Associated with Various Insulation Levels

	FUEL SOURCE AND COST (Quantity/Price)			
	Wood	Electric	Oil	Gas
Super-insulated	1/2 cord $45	3,578 Kwh $139	147 gals $42	150 ccf $95
Average-insul.	2 1/2 cords $200	17,315 Kwh $675	706 gals $200	728 ccf $462
Poorly-insulated	9 cords $720	58,874 Kwh $2,296	2,400 gals $680	2,476 ccf $1,572

Source: U.S. Department of Energy (for system efficiencies)
Northwest Natural Gas, Craig Oil, Inc., and Pacific Power & Light (for 1989 fuel prices)

Given the fuel costs and the cost of building the sunspace, it's possible to get an approximate idea of how cost-effective the sunspace is by determining the simple payback period. The simple payback period does not reflect the potential effects of fuel cost escalation, interest rates, or income tax rates (real payback period). Simple payback was used because present economic and political trends make projections difficult. For example, the federal government may substantially revise the repayment schedule for federally subsidized utilities (NPPC 1988). Recent price increases as a result of the Alaskan oil spill are another example of how fuel costs may fluctuate unpredictably. A table is provided in the appendix which relates simple payback to real payback under a number of fuel cost and interest rate scenarios (Appendix C).

For the purposes of payback calculations an assumption will be made that solar savings of 20%, 40%, and 60% will be realized based on the load-to-collector ratios of the corresponding example homes. The resulting annual savings and payback periods are listed in Table 7.

Table 7 - Yearly Savings and Simple Payback Period

		Super-insulated	Average-insulation	Poorly-insulated
		SSF = .6	SSF = .4	SSF = .2
Wood	Annual Savings	$27	$80	$144
	Payback Period			
	Pre-Fab.	302 yrs	102 yrs	56 yrs
	Owner-Built	54 yrs	17 yrs	9 yrs
Electric	Annual Savings	$83	$270	$459
	Payback Period			
	Pre-Fab.	98 yrs	29 yrs	17 yrs
	Owner-Built	17 yrs	4 yrs	2 yrs
Oil	Annual Savings	$25	$80	$136
	Payback Period			
	Pre-Fab.	324 yrs	101 yrs	60 yrs
	Owner-Built	58 yrs	17 yrs	10 yrs
Gas	Annual Savings	$57	$161	$275
	Payback Period			
	Pre-Fab.	143 yrs	50 yrs	29 yrs
	Owner-Built	25 yrs	8 yrs	4 yrs

Source: Calculated by author

The figures in Table 7 include an Oregon tax credit which is equal to the first year fuel savings. It is evident from Table 7 that the more highly insulated a home is, the longer the payback period will be. This is the case even though the relative heating contribution of the sunspace is so much higher in better insulated homes. The reason for this is evident if one looks at the differences in heat loss between the three homes. For example, the poorly-insulated home is loosing about 10 times as much heat as the super-insulated home.

It is also obvious from Table 7 that the payback periods for pre-fabricated sunspaces are far too long to justify their purchase based solely on financial considerations. On the other hand, owner-built sunspaces exhibit shorter payback periods under a number of insulation and fuel scenarios.

V CONCLUSION

Large numbers of sunspaces are added to existing homes each year, providing high quality living space as well as reducing heating costs. Some researchers have suggested that the use of sunspaces may have positive physiological and psychological effects. Further research is needed to determine whether these effects vary between different geographic regions. Perhaps residents in cloudy, rainy areas such as the Willamette Valley may be particularly sensitive to these effects.

The proportion of heating demand a sunspace is able to provide depends on the insulation level of the home and the design of the sunspace. Even in an area with a long, cloudy winter, such as the Willamette Valley, sunspaces can provide significant portions of a home's heating demands. Sunspaces with design characteristics similar to those in this study can contribute as much as 60% of a super-insulated home's heating demand. On the other hand, the same sunspace will contribute only 20% or less of a poorly-insulated home's heating demand. These findings are similar to that of other passive solar research done in the region by Gray and Baker (1970); and Boleyn (1979).

Sunspaces added to poorly-insulated homes have far shorter payback periods due to the extremely high heating costs of these homes. Several researchers have documented that investments in conservation are generally more cost effective than investments in passive solar. Consequently, from an economic standpoint it is better to weatherize before adding passive design features. Depending on the cost of building the sunspace, and heating costs, payback periods can range from 2 years to 324 years. The most dramatic increase in payback period results from the decision to purchase a pre-fabricated unit, since these units average about six-times the cost of an owner-built model. Of the payback periods presented in Table 7 for pre-fabricated units, only one scenario resulted in a payback of less than 20 years.

These conclusions assume that the sunspace design is identical to that of the reference designs used in this paper (Table 1 and Appendix A). If any of the design characteristics vary from these reference conditions, the relative solar savings will change. Researchers interested in using Balcomb's Method to predict the performance of designs substantially different from those in this paper should use the 'sensitivity' graphs described on page 12.

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APPENDIX A

Reference Design Characteristics

Thermal Storage Capacity	
masonry common wall, per square foot of common wall area	30.0 Btu/F ft^2
water containers, per square foot of common wall area	62.4 Btu/F ft^2
floor, per square foot of floor area	15.0 Btu/F ft^2
Masonry Properties	
thermal conductivity, wall	1.0 Btu/h ft F
density	150 lb/ft^3
specific heat	0.2 Btu/lb F
infrared emittance of surface	0.9
Glazing Properties	diffuse
infrared emittance of surface	0.9
Control Range	
sunspace, heating thermostat setpoint	45 F
sunspace, cooling thermostat setpoint	95 F
room dead band, difference between heating and cooling thermostat setpoints	10 F
Thermocirculation Vents	
vent area/projected area	0.06
height between vents	8 ft
reverse flow	none
Lightweight absorption factor	0.2
simulates effect of solar radiation absorption on lightweight objects by transferring given fraction back to sunspace air	
Additional assumptions	
sunspace solar absorptances:	
common wall, lightweight	0.7
common wall, masonry	0.8
water containers	0.9
floor	0.8
other surfaces	0.3
ground reflectance	0.3
internal heat generation	0
room lower thermostat setpoint	65 F
sunspace opaque wall thermal resistance	R20
sunspace infiltration rate	0.5 ac/hr
sunspace glazing properties:	
orientation	due south
shading	none
number of panes	2
index of refraction	1.526
extinction coefficient	0.5 $in.^{-1}$
thickness of each pane	1/8 in.
air gap between panes	0.5 in.
night insulation thermal resistance, when used	R9

Source: Balcomb 1983, p 91

APPENDIX B

DEFINITIONS

Building Load Coefficient (BLC) - The total building heat loss (minus the solar wall) per degree day. The units are Btu/DD.

Degree Day - The sum of the differences between a fixed base temperature (typically 55 F) and the daily mean outside temperature; usually reported on an annual basis.

Load-to-Collector ratio (LCR) - The building load coefficient divided by the projected area. The units are Btu/dd/ft^2

Projected Area (A_p) - The solar wall projected on a vertical plane. For vertical glazing, this is simply the projected area. The unit is ft^2.

Solar Savings Fraction (SSF) - The extent to which the solar design has reduced the auxiliary heating requirements of the solar building relative to a reference building.

Solar Wall - Any south facing glazing which contributes to the building's energy gain.

Sunspace - A room that serves as a solar collector and also provides useful living space.

Thermal Mass - Any material with a high heat capacity (typically water, brick, or concrete) that stores incident solar energy and releases it slowly.

APPENDIX C

Relationship of Simple Payback Period to Real Payback Period

Real Payback Time (years)

NIR (%)	FER (%)	SIMPLE PAYBACK TIME (years)								
		5	10	15	20	25	30	35	40	45
2.5	2.5	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
2.5	5.0	4.7	8.9	12.7	16.2	19.4	22.4	25.2	27.8	30.2
2.5	7.5	4.4	8.0	11.1	13.8	16.2	18.3	20.3	22.1	23.7
2.5	10.0	4.2	7.4	10.0	12.2	14.1	15.8	17.3	18.6	19.9
2.5	12.5	4.0	6.8	9.1	11.0	12.6	14.0	15.2	16.3	17.3
2.5	15.0	3.8	6.4	8.4	10.0	11.4	12.6	13.6	14.6	15.4
5.0	2.5	5.4	11.6	18.9	27.8	39.0	54.6	79.8	154.1	***
5.0	5.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
5.0	7.5	4.7	8.9	12.7	16.2	19.5	22.5	25.3	27.9	30.4
5.0	10.0	4.4	8.1	11.2	13.9	16.3	18.5	20.5	22.3	23.9
5.0	12.5	4.2	7.4	10.0	12.3	14.2	15.9	17.5	18.8	20.1
5.0	15.0	4.0	6.9	9.2	11.1	12.7	14.1	15.4	16.5	17.5
7.5	2.5	5.9	14.0	27.6	78.0	***	***	***	***	***
7.5	5.0	5.4	11.6	18.8	27.5	38.4	53.2	76.1	129.4	***
7.5	7.5	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
7.5	10.0	4.7	8.9	12.8	16.3	19.6	22.6	25.5	28.1	30.6
7.5	12.5	4.4	8.1	11.2	14.0	16.4	18.6	20.6	22.5	24.2
7.5	15.0	4.2	7.4	10.1	12.4	14.3	16.1	17.6	19.0	20.3
10	2.5	6.4	18.6	***	***	***	***	***	***	***
10	5.0	5.8	13.9	26.9	65.4	***	***	***	***	***
10	7.5	5.4	11.5	18.7	27.2	37.9	52.0	73.2	115.8	***
10	10.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
10	12.5	4.7	8.9	12.8	16.4	19.7	22.7	25.6	28.3	30.8
10	15.0	4.4	8.1	11.3	14.1	16.6	18.8	20.8	22.7	24.4
12.5	2.5	7.2	39.9	***	***	***	***	***	***	***
12.5	5.0	6.4	18.2	***	***	***	***	***	***	***
12.5	7.5	5.8	13.8	26.3	58.6	***	***	***	***	***
12.5	10.0	5.4	11.5	18.6	27.0	37.4	51.0	70.6	106.7	***
12.5	12.5	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0
12.5	15.0	4.7	8.9	12.8	16.4	19.7	22.8	25.7	28.5	31.0
15.0	2.5	8.2	***	***	***	***	***	***	***	***
15.0	5.0	7.1	33.5	***	***	***	***	***	***	***
15.0	7.5	6.4	17.7	***	***	***	***	***	***	***
15.0	10.0	5.8	13.6	25.8	53.9	***	***	***	***	***
15.0	12.5	5.4	11.4	18.4	26.7	36.9	50.0	68.4	100.0	***
15.0	15.0	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0

FER = Annual fuel escalation rate
NIR = Net annual interest rate after taxes
*** Means that real payback cannot be achieved

Source: Jones, R.W. and McFarland, R.D. 1984, p89