VALUE OF LONG-TERM SOLAR RADIATION DATA

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ABSTRACT

The value of collecting solar radiation data over long time periods (up to 30 years) is examined by analyzing high quality monthly averaged direct normal beam data gathered at two sites of the University of Oregon Solar Monitoring Network over a 15-year period. The main conclusions of this study are:

- A 5-year long data set is useful for estimating the long-term monthly average insolation.
- A 15-year long data set demonstrates the variations experienced from year to year. This data set can also be to used to demonstrate or test possible relationships between the availability of the solar resource and other renewable resources.
- A 30-year long data set will begin to show any changes in climate and can establish possible relationships with other renewable resources to a higher statistical level of confidence.

At the same two sites, comparisons are also made with 15 previous years of monthly averaged beam values generated for the National Solar Radiation Data Base.

1. INTRODUCTION

High quality, 30-year long solar radiation data sets obtained through continuous monitoring are desired to comprehensively describe the trends and variability of the solar resource. However, gathering high quality solar radiation data over extended periods involves a dedicated effort. The focus of this study is on how well the monthly average solar resource is characterized by 5-, 15-, and 30-year long data sets.

Direct normal beam radiation is utilized because beam measurements are usually more precise than global measurements and typically the beam component characterizes the solar energy resource potential better than the global horizontal values. The high quality beam data comes from 13 years of beam measurements at Burns, Oregon and 15 years of data from Eugene, Oregon. Both sites are part of the University of Oregon (UO) Solar Monitoring Network. Beam values from 1961 through 1977 or 1978 come from the National Solar Radiation Data Base (NATSOL) generated by the National Renewable Energy Laboratory. NATSOL included the measured global and beam data from Eugene and Burns in the data base and also used these data to help estimate model parameters for those sites.

1.1 Rationale for 30-Year Data Sets

Before examining the data, it is useful to review why 30-year data sets are considered desirable. From a pragmatic perspective, solar electric facilities are expected to operate longer than 30 years. Since it is difficult to predict weather and hence the solar resource in the future, designers and investors must look at past records in order to assess the resource availability.

From a meteorological perspective, climatologists and the National Weather Service use 30-year data sets to characterize norms for meteorological parameters such as temperature and rainfall. Since solar radiation can be considered another weather variable, there is no reason why it should take less time to characterized the solar resource. In fact, the length of the NATSOL data base was chosen to be 30 years so that solar radiation could be treated in the same manner as other weather variables.

Many factors affect the length of time necessary to fully characterize the solar resource and other meteorological parameters. The eleven year sunspot cycle and the approximately 4-year cycle of El Niño influence both climate and the amount of solar radiation. Data must be collected over several cycles in order to properly determine both long-term averages and variability. Once the effect of weather cycles is characterized, other effects such as local climate change can be deduced. The time needed to gather representative data sets can be lengthened by unusual events such at the eruption of El Chichón in 1982, and Mt. Pinatubo in 1991.

1.2 Organization

First, the solar resource is characterized using only 5-year data sets. This is followed by a similar examination of data collected over a time period of 15 years. Data collected over 15 years by the UO group is then compared to values tabulated in the NATSOL data base. Finally, conclusions drawn from this study are presented and discussed.

2. 5 YEAR DATA SETS

The required length of a solar radiation data set depends on the accuracy and the degree of detail desired. If one wants to obtain the average monthly solar radiation, clearly one year of data does not supply enough information. The standard deviation of the monthly average solar radiation can range anywhere from 10 to 50% for sites in Oregon with the largest variations occurring during the winter heating season.

As one would expect, 5 years of data enable a much better estimate of the monthly average insolation. In this section 5 year averages of monthly beam radiation at Eugene and Burns, Oregon are examined. The sites represent two different climate zones with Eugene located in the verdant Willamette valley while Burns is located on the high desert plateau in eastern Oregon. Three months were chosen to use as examples because they represent different weather conditions. July is typically the sunniest month, during October the weather changes from mostly sunny to mostly cloudy, and December is cloudy and wet.

An appreciation of how well any 5-year period is able to approximate the monthly average beam radiation averaged over 15 years can be obtained by studying Tables 1- 6. In Table 1, 10 different 5-year periods were used to calculate the average July beam radiation for Eugene, Oregon. For the 14 years for which beam data are available, the average July beam radiation is 6.94 kWh/m^2/day and the standard deviation of each year's monthly beam radiation is approximately 20%. This means that approximately 65% of the time, the measured July beam radiation will be within 20% of the average July value, and 35% of the time, the measure July beam radiation will be more than 20% different from the average July value.

The July beam radiation averaged over 5-years provides a better estimate of the long-term average. All 5-year average July values are within ±8% of the average July value and the standard deviation of the 5-year averaged July values from the 14 year average of 6.94 kWh/m^2/day is about 5%. This means that most of the time, the average of 5 years of July beam data is within 5% of the actual average July beam radiation.

In Burns, the July weather is almost always sunny and the standard deviation of the 5-year averaged July beam data from the 13-year average of 8.82 kWh/m^2 per day is only 2%. All 5-year averages are within 4% of the 13 year average July beam value. The 2% standard deviation for July might be artificially low because there is a repeated 5 year cycle in the first 10 years of the data set.

In October, when the proportion of sunny to cloudy days is more random, the variance of the yearly and 5-year averages is larger. The standard deviation for one year of data drops from approximately 30% for Eugene and 20% for Burns of the long term average to 13% for the 5-year data sets for both Eugene and Burns.

In December, which is mostly cloudy, the yearly variance is about 50% for Eugene and 30% for Burns. The standard deviation for the 5 year averages is 18% for both Eugene and Burns.

In summary, 5 years of data provides an estimate of the long term monthly average beam radiation to an accuracy ranging from 5 to 20%, with the best estimates for months that are typically very sunny. This is an improvement of 2 to 3 over estimates of the long-term monthly average radiation based on only 1 year of data.

Table 1. 5-Year Monthly Averaged July Beam Data from Eugene, Oregon

Years in Average	Monthly kWh/m^2/day	Δ(Avg-6.94) kWh/m^2/day
1978-82	6.97	0.03
1979-83	6.39	-0.55
1980-84	6.63	-0.31
1981-85	6.95	0.01
1982-86	6.85	-0.09
1983-87	6.61	-0.33
1984-88	7.51	0.57
1985-89	6.83	-0.11
1986-90	6.47	-0.47
1987-91	6.79	-0.15
Average	6.80	SD=0.35

Table 2. 5-Year Monthly Averaged October Beam Data from Eugene, Oregon

Years in Average	Monthly kWh/m^2/day	Δ(Avg-3.34) kWh/m^2/day
1978-82	3.37	0.03
1979-83	2.97	-0.37
1980-84	2.76	-0.58
1981-85	2.64	-0.70
1982-86	2.76	-0.58
1983-87	3.20	-0.14
1984-88	3.30	-0.04
1985-89	3.68	0.34
1986-90	3.63	0.29
1987-91	3.72	0.38
Average	3.20	SD=0.43

Table 3. 5-Year Monthly Averaged December Beam Data from Eugene, Oregon.

Years in Average	Monthly $kWh/m^2/day$	Δ(Avg-1.07) $kWh/m^2/day$
1977-81	0.86	-0.21
1978-82	0.99	-0.08
1979-83	0.87	-0.20
1980-84	0.90	-0.17
1981-85	1.13	0.06
1982-86	1.26	0.19
1983-87	1.18	0.11
1984-88	1.38	0.31
1985-89	1.34	0.27
1986-90	1.32	0.25
1987-91	1.10	0.03
Average	1.12	SD=0.20

Table 4. 5-Year Monthly Averaged July Beam Data from Burns, Oregon

Years in Average	Monthly $kWh/m^2/day$	Δ(Avg-8.82) $kWh/m^2/day$
1979-83	8.60	-0.22
1980-84	8.65	-0.17
1981-85	8.64	-0.18
1982-86	8.46	-0.36
1983-87	8.51	-0.31
1984-88	8.86	0.04
1985-89	8.89	0.07
1986-90	8.90	0.08
1987-91	9.02	0.20
Average	8.73	SD=0.22

Table 5. 5-Year Monthly Averaged October Beam Data from Burns, Oregon

Years in Average	Monthly $kWh/m^2/day$	Δ(Avg-5.02) $kWh/m^2/day$
1979-83	4.44	-0.58
1980-84	4.32	-0.70
1981-85	4.19	-0.83
1982-86	4.65	-0.37
1983-87	5.00	-0.02
1984-88	5.41	0.39
1985-89	5.85	0.83
1986-90	5.82	0.80
1987-91	5.70	0.68
Average	5.04	SD=0.67

Table 6. 5-Year Monthly Averaged December Beam Data from Burns, Oregon.

Years in Average	Monthly $kWh/m^2/day$	Δ(Avg-2.33) $kWh/m^2/day$
1979-83	1.70	-0.63
1980-84	1.92	-0.41
1981-85	2.06	-0.27
1982-86	2.12	-0.21
1983-87	2.18	-0.15
1984-88	2.59	0.26
1985-89	2.77	0.44
1986-90	2.77	0.44
1987-91	2.79	0.46
Average	2.32	SD=0.41

3. <u>15-Year Data Sets</u>

15 years of data can obviously determine the average monthly beam radiation better than just 5 years. The question is how much better. Since the beam data from the UO Solar Monitoring Network covers only about 15 years, it is necessary to use the 30 year long NATSOL data base to address this question.

For Eugene and Burns, the NATSOL data base incorporated the UO Solar Monitoring Network data and used the meteorological statistical model (METSTAT) to estimate solar radiation from 1961 through 1977 and later when no measurements were available. Most of the site specific parameters in the METSTAT model were derived from measured data for the Burns and Eugene sites. While the beam values calculated by the METSTAT model mostly depend on 3 hour cloud cover observations, the fact that some site specific model parameters were derived from actual data at each site, should help improve the accuracy of the modeled values for the Burns and Eugene sites.

The NATSOL data base was used to obtain 15-year average monthly beam values given in Table 7 for Burns in October. The month of October was chosen because the NATSOL and the UO Solar Monitoring Network data have similar long-term averages and cover the same range of averages.

The standard deviation of the 15-year data sets from the 30 year average is only 3%. While there is considerable overlap between the 15-year data sets that probably reduces the standard deviation, the largest difference between the estimate of the long-term monthly average beam radiation is only ±6%. Therefore the 15-year data set improves the estimate of October's beam radiation by a factor of 2 to 4 over the 5-year long data set.

Table 7. 15-Year Monthly Averaged October Beam Data from Burns, Oregon.

Years in Average	Monthly $kWh/m^2/day$	Δ(Avg-4.97) $kWh/m^2/day$
1961-75	4.64	-0.30
1962-76	4.76	-0.18
1963-77	4.82	-0.12
1964-78	5.03	0.09
1965-79	4.94	0.00
1966-80	4.95	0.01
1967-81	4.86	-0.08
1968-82	4.89	-0.05
1969-83	4.88	-0.06
1970-84	4.82	-0.12
1971-85	4.78	-0.16
1972-86	4.91	-0.03
1973-87	4.99	0.05
1974-88	5.13	0.19
1975-89	5.14	0.20
1976-90	5.23	0.29
1977-91	5.19	0.25
Average	4.94	SD=0.16

3.1 Variability of Monthly Average Beam Values

The reliability of the solar resource, adequate sizing of the solar system, proper design of storage or backup systems, and interfacing the solar system with other sources of energy require knowledge of the variability of monthly radiation. One needs to know the minimum and maximum solar radiation one can receive during a given month and the percentage of time one has a given solar radiation level.

The frequency distributions for approximately 15 years of monthly averaged beam data for Eugene and Burns are shown in Figs. 1-6 for July, October, and December. About fifteen data points seems to be a minimal for describing the frequency distribution. A comparison of 5-year verses 15-year distributions is shown in Fig. 5 that has been divided into 3 different time intervals. None of the shorter time intervals show the distribution as clearly as when all 13 years of data are used.

From 15 years of data, a good determination of the minimum and maximum amount of monthly average beam radiation can be made. Examination of the previous 15 years of beam values contained in the NATSOL data base shows that, with a few exceptions, the range of monthly averaged beam radiation is encompassed by the 15 year UO Solar Monitoring Network data set.

With 15 years of data, other important questions can also be addressed. For example, how well does the availability of the solar resource correlate with the availability of hydroelectricity. This is an extremely important question in the Pacific Northwest where the hydroelectric capacity of the Columbia River can be used to some extent as a giant battery for solar electric plants. Another important question concerns the correlation between the demand for air conditioning and the available solar intensity. Fig. 4 illustrates this correlation during the hot summer month of July.

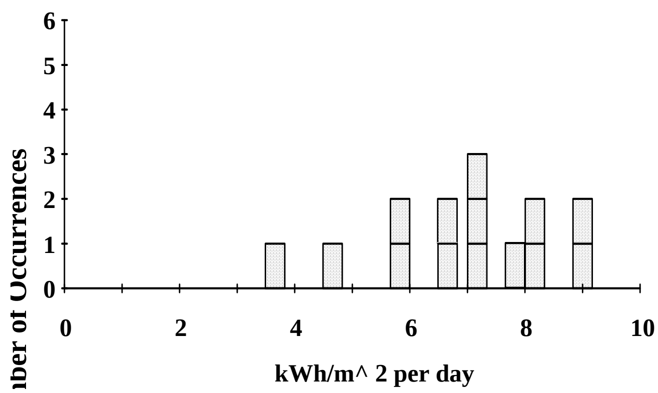

Fig. 1. Monthly Average July Beam Insolation for Eugene, Oregon from 1978 - 1991.

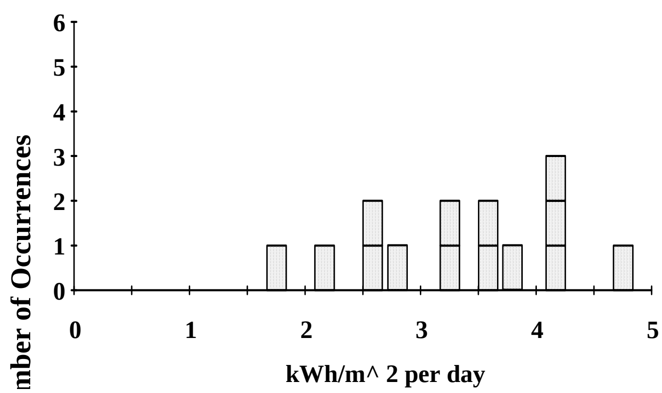

Fig. 2. Monthly Average October Beam Insolation for Eugene, Oregon from 1978 - 1991.

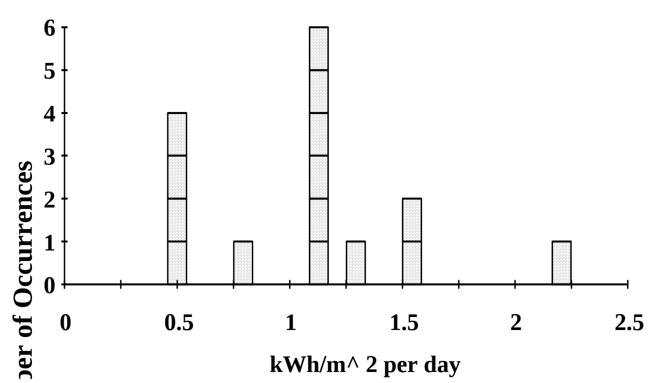

Fig. 3. Monthly Average December Beam Insolation for Eugene, Oregon from 1977-1991.

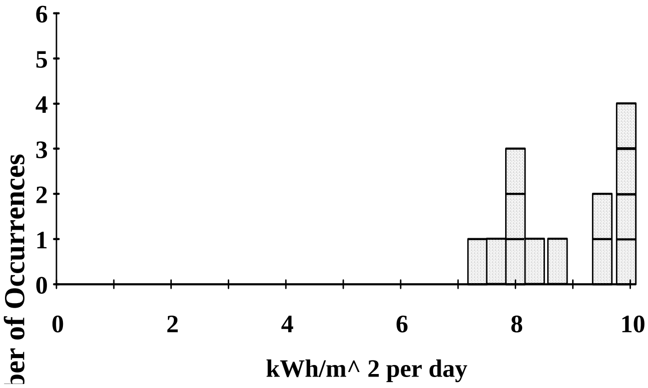

Fig. 4. Monthly Average July Beam Insolation for Burns, Oregon from 1979 - 1990.

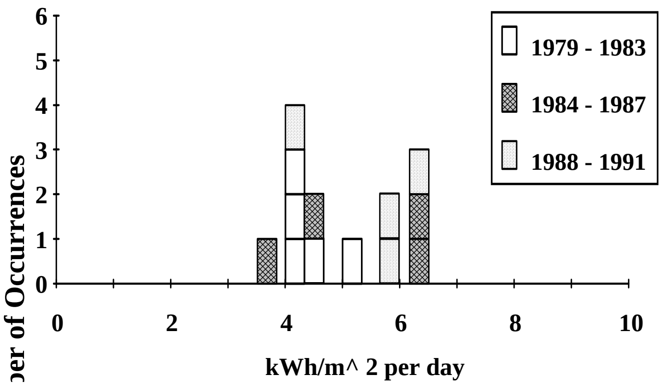

Fig. 5. Monthly Average October Beam Insolation for Burns, Oregon from 1979 - 1991.

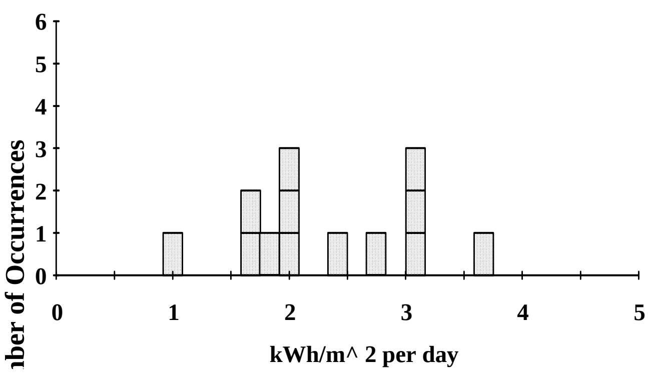

Fig. 6. Monthly Average December Beam Insolation for Burns, Oregon from 1979 - 1991.

4. <u>Need for 30-Year Data Sets</u>

While 15 years of data provide a very good estimate of monthly average beam intensity and enable preliminary conclusions to be drawn on how well solar energy technologies can fulfill existing energy needs, data sets over longer periods are needed to confirm the statistical conclusions drawn from smaller data sets and to provide the ability to forecast both the available solar energy and its fluctuations in a reliable manner.

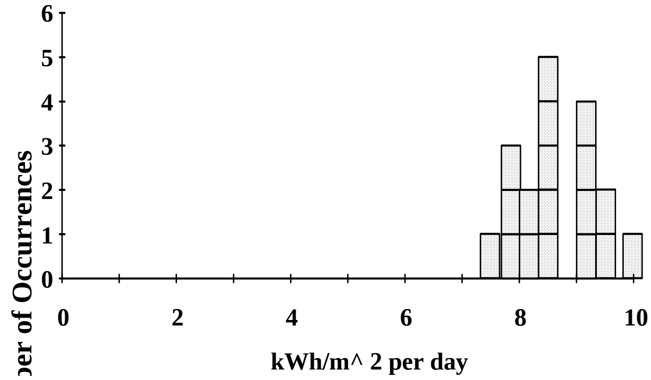

Fig. 7. Monthly Average July Beam values for Burns, Oregon from 1961- 1978.

Few of the distributions of monthly averaged beam intensities obtained from 15 years of data appear to be truly normally distributed. The beam radiation for July at Burns, shown in Fig. 4, seems to have a bimodal distribution. If the distribution is truly bimodal, chances of being able to forecast the July radiation would improve. Of course, with only 13 data points, the distribution shown in Fig. 4 could be misleading. Fig. 7 shows 18 years of previous beam values from the NATSOL data base. While the accuracy of the NATSOL data base has yet to be established, the values appear to indicate a more normal distribution.

The distribution of NATSOL monthly average beam values generally appear normally distributed as opposed to the data from the UO Solar Monitoring Network. Whether this apparent difference is do the small number of measured monthly average values in the UO data set or is an artifact of the METSTAT modeling statistics is difficult to answer.

Long-term data sets are also required to differentiate climate change from fluctuations in the solar resource. Measured monthly average beam values between 1986 and 1991 are often among the highest values over the past 15 years in the UO Solar Monitoring Network data. Examina-tion of the 30-year NATSOL values shows that the there has been a trend towards sunnier skies during the winter months but results for the summer months do not indicate a similar a trend. Table 8 compares the measured monthly averages for Eugene and Burns with those obtained over the 1961-1977 time period from the NATSOL data base.

More data is needed before any credible statements about climate change can be made, especially with two volcanic eruptions and 3 El Niño events that affected the weather over the past decade. Other periodic events may also affect the weather such as the 11-year sun spot cycle. Without a much longer data set it is difficult to separate normal variation of the monthly average beam radiation from long-term climate change.

Table 8. Long Term Average Beam Radiation for Burns and Eugene during July, October, and December

Site	Month	Time Period	Average Beam Insolation $kWh/m^2/day$	Ratio
Eugene	July	1978-1991 1961-1977	6.94 7.06	0.98
Eugene	October	1978-1991 1961-1977	3.34 2.85	1.17
Eugene	December	1977-1991 1961-1976	1.07 0.70	1.53
Burns	July	1979-1991 1961-1978	8.82 8.61	1.02
Burns	October	1979-1991 1961-1978	5.02 4.93	1.02
Burns	December	1979-1991 1961-1978	2.33 1.96	1.19

December's monthly average beam data from Eugene is unusual for two reasons. First, comparison with the monthly values from the NATSOL data base seems to indicate that there has be a significant increase (50%) in beam radiation during December in Eugene. Second, the distribution of monthly averaged beam radiation is very peaked. Six times in the last 15 years the average December beam radiation for Eugene was between 1.04 and 1.17 $kWh/m^2/day$ and four times the beam radiation was between 0.49 and 0.54 $kWh/m^2/day$ (See Fig. 3). The NATSOL beam values would add one event to the 1.04-1.17 $kWh/m^2/day$ range and 4 occurrences to the 0.49-0.56 $kWh/m^2/day$ range. There are also 9 occurrences that fall in the 0.79-0.93 $kWh/m^2/day$ range that had occurred only once in the UO Solar Monitoring Network data set. Are these peaks caused by weather patterns that are repeatable year after year or are they just flukes of a normal statistical nature? The answer can only be found with a much longer data set.

5. Summary and Conclusion

Solar energy systems are still relatively new technologies and it is important to establish consumer confidence by delivering the amount of energy advertised. Since the performance of solar energy systems depends both on the amount of incident solar energy and its variability, reliable estimates of the energy delivered by the system require a comprehensive knowledge of the solar resource.

It takes time to acquire sufficient data to have a thorough knowledge of the solar resource. Because of the lack of solar data, systems are often designed and built with inadequate understanding of the solar resource. If the solar system does not perform as expected because the solar resource is over estimated, the credibility of solar technologies suffers. High quality solar radiation data is necessary for the sound development of solar technologies.

Since it takes time and effort to gather solar radiation data, it is important to know how long a data set is required to adequately characterize the solar resource. Put in another way, how well does any given data set characterize the solar resource. For many solar energy technologies, monthly average solar radiation is adequate to design reliable solar energy systems. However, for larger scale projects that contribute substantially to the total energy mix, knowledge of the variability of the solar resource and how the solar resource complements other resources is equally important.

In the present study, solar radiation data measured at two sites in the Pacific Northwest with very different climates have been carefully analyzed. While the variation in the solar resource will be different for other sites around the world, the general conclusions drawn from the two Oregon sites should give an idea of the uncertainties inherent in data sets of various lengths. With a 5-year solar data set, monthly average beam radiation can be estimated to an accuracy of 5 to 20%. The sunnier the weather, the more accurate is the estimate. However, a 5-year data set does not cover the whole range of solar intensities that are likely to occur from year to year.

A 15-year data set can reduce the uncertainties of the monthly average estimates by a factor of 2 to 4. In addition, with a 15-year data set, one can estimate the minimum and maximum performance of a solar energy system and define a typical performance year. Since the distribution of occurrences is fairly well defined, users of solar systems can then be told whether that year was a good or poor solar year and whether their system should have performed better or worse than normal. The 15-year data set can also be used to estimate how the solar energy system will match the load demands and uncover any possible relationship between the solar resource and other energy supplies or demands.

A 30-year data set determines the magnitude of the average insolation and it variability better. With a 30-year data set, short term (~5 years) deviations can be distinguished from long-term changes caused by climate change. The 30-year data set also improves confidence in any statistical relationship between the availability of the solar resource and other resources used to meet the energy demand. As stream flow data helps with planning of hydroelectric systems, long-term solar radiation data will enable planners to fully utilize the solar energy contribution.

6. Acknowledgments

We would like to acknowledge the Eugene Water and Electric Board and the Bonneville Power Authority for their long-term support of the UO Solar Monitoring Network without which this study would not have been possible.