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SOLAR AVAILABILITY FOR WINTER SPACE HEATING: AN ANALYSIS OF THE CALENDAR PERIOD 1953—1975

by

J. G. Asbury, C. Maslowski, and R. O. Mueller

MASTER

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April 1979

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ABSTRACT

Solar availability for space heating has been determined from an analysis of SOLMET data tapes for eight U.S. sites. The tapes contain hourly readings of insolation and ambient temperature for the period 1953-1975. Scatter-diagrams of insolation versus heating degree-days, compiled on a daily basis, indicate a wide variation in insolation levels, even during periods of coldest weather. For seven of the eight sites, the peak-day backup energy required by a solar space heating system exceeded 85% of the peak-day energy requirement of a conventional (nonsolar) heating system.

1 INTRODUCTION AND SUMMARY

The day-to-day variation in insolation observed at most locations in the United States is a serious problem facing designers of solar heating systems. In most solar energy applications, an auxiliary, or backup, system is required if the heating load is to be met reliably during extended periods of cloud cover. In space heating applications, this usually means the addition of a backup furnace capable of supplying the design-day heating load. Although the cost of the auxiliary system, by itself, is usually a relatively minor component of the total system's capital cost, the cost of supplying energy to the backup system can be high. In particular, if the backup energy is electricity, the demand component of the cost, including the electric utility's investment in "standby" generation and distribution capacity, can be substantial.*¹

The impact of space heating on the electric utility's capacity requirements depends upon whether the utility's peak load occurs during the winter or the summer. If the utility is summer-peaking, neither a solar nor conventional heating system will contribute to the utility's generation and transmission capacity requirements. On the other hand, if the utility is winter-peaking, its capacity expansion requirement will be largely determined by the peak space heating loads. In this case, the impact of a solar heating system may differ significantly from that of a conventional system, depending upon the level of insolation on the coldest winter days.²

Two recent studies examined solar availability on peak heating days. A study of the Philadelphia area concluded that a solar heating system's auxiliary power requirements were the same as the total requirements of a

*To a lesser extent, this is also a problem for the natural gas distribution system.

conventional furnace.³ Another study simulated the peak-period performance of both solar heating and solar cooling systems at several U.S. locations. At the two northern sites, in New England and Wisconsin, there was evidence of substantial solar availability on peak heating days.⁴ This led to speculation that, in certain climatic regions, there may be a correlation between high insolation levels and low outdoor temperatures. A more conclusive assessment of the solar availability question would require additional data from more sites, collected over longer periods of time.

The release of the SOLMET data tapes by the National Climatic Center in early 1978 provided an opportunity to examine insolation levels at a number of U.S. locations for a period of more than two decades, from 1953 to 1975.⁵ The results presented in this paper are based upon analyses of the SOLMET data for eight representative U.S. sites. Solar availability and daily heating requirements were examined on a seasonal and coldest-days basis. The data were displayed in two general formats.

First, SOLMET data for insolation and heating degree-days were compiled on a daily basis and the results for each site presented in scatter-diagrams. The plots encompass the full calendar period available in the SOLMET data and give a simple visual display of the relationship between daily insolation and daily average temperature. As these plots make clear, the correlation between daily insolation and daily average temperature is weak for all sites, over both the full heating season and the subset of coldest days. Second, a simple model of solar collector performance was used to calculate the daily output of a solar heating system. The daily backup requirements for solar energy systems and the daily power needs of conventional heating systems were then computed and the results presented in the form of load duration curves. Except for one site, in Albuquerque, the addition of solar space heating systems did not significantly reduce the electric utility's capacity requirement. The peak-day backup requirement of a solar energy system sized to supply 50% of the annual space heating load usually exceeded 85% of the peak-day electrical requirement of a nonsolar heating system.

2 DESCRIPTION OF SOLMET DATA

The SOLMET data are the product of an extensive "rehabilitation" of hourly solar radiation data by the National Climatic Center.⁵ Data tapes are now available from 26 weather stations across the United States. For most locations the period of record extends from July 1, 1952, to December 31, 1975.

The tapes contain hourly readings of global solar radiation incident on a horizontal surface and instantaneous measurements of certain surface-weather variables, including wind speed, atmospheric pressure, and ambient temperature. The recorded insolation is the total of direct and diffuse radiation received on a pyranometer, integrated over the hour.

In addition to the raw solar-radiation data, the SOLMET tapes contain two types of rehabilitated radiation data: "engineering-corrected" and "standard-year-corrected" data. The engineering-corrected data incorporate corrections for all recorded scale and calibration changes. Although more

accurate than the observed data, these data include unrecorded and undetected systematic errors.

To correct for long-term, undetected changes in sensor or recorder response, the Climatic Center constructed the standard-year-corrected data. By comparing the observed values of solar radiation on clear weather days with predicted values from a standard-year irradiance model, the Climatic Center calculated correction factors that were then used to normalize all of the hourly insolation readings. We calculated the root-mean-square values of the correction factors for hourly insolation over all years of data for each of the eight sites. The values ranged from 0.05 to 0.10.

Due to malfunctions of the sensors and recording instruments, the SOLMET tapes have gaps in observed insolation data for periods extending over days, weeks, and even months. To fill these gaps, the Climatic Center estimated hourly solar radiation levels from measurements and observations of opaque cloud cover, precipitation, and minutes of sunshine per hour. These estimates were added to the standard-year-corrected field to make it serially complete.

3 DATA ANALYSIS

The Climatic Center recommends the standard-year-corrected data as the most reliable of the data fields. Accordingly, the results presented in this paper are based on these data. A complete description of the raw data and the techniques and procedures used to construct the standard-year-corrected data are presented in the SOLMET manuals.⁶

Data from eight sites are presented here. These sites, selected to span the range of climatic and geographic conditions of locations with solar-space-heating potential in the United States, are:

- Albuquerque, New Mexico;
- Bismark, North Dakota;
- Boston, Massachusetts;
- Caribou, Maine;
- Columbia, Missouri;
- Madison, Wisconsin;
- Seattle, Washington; and
- Sterling, Virginia.

The only modification to the standard-year-corrected data was to adjust insolation to take collector tilt into account. Adjusted insolation values were computed using the standard Liu and Jordon relation for dividing the global insolation into diffuse and direct components. The diffuse component was assumed to be isotropic, and the direct component was estimated by simple cosine projection onto the collector surface.⁷

Plots of insolation on the collector surface versus heating degree-days are shown for individual days at each site in Fig. 1. The heating degree-day values are calculated relative to a 65°F reference temperature. The collector tilt angle for each site is set equal to the latitude of the site. The points in the scatter-diagrams correspond to all days within the 23-year period from January 1, 1953, through December 31, 1975.* In constructing the plots, we imposed somewhat arbitrary degree-day cutoffs of 10°F on the northern sites and 0°F on the more southern sites. The effect of a change in collector tilt to an angle equal to latitude plus 20° is shown in Fig. 2 for the Columbia, Missouri, site.

All the scatter-diagrams indicate a wide variation in insolation levels for each degree-day value. Even the subset of the 230 coldest days at each site includes a number of days with insolation levels less than 20% of the clear-day level for that site.

To obtain a quantitative measure of the correlation between solar availability and temperature on the coldest days, we performed a least-squares linear regression of daily insolation on daily degree-days for the coldest 230 days for each site. The calculated correlation coefficients ranged from -0.0044 for Bismark, North Dakota, to +0.189 for Seattle, Washington. When the data sample was not restricted to the coldest days, but was expanded to include all days with a space heating requirement, the correlation coefficients were found to be negative for all of the sites.

4 BACKUP REQUIREMENTS FOR SOLAR HEATING SYSTEMS

During cold periods, when the daily heating load exceeds solar collector output, most solar energy systems deliver available solar energy to the load with little or no day-to-day carryover of stored energy. To calculate the backup energy requirements for the coldest days, we adopted a simple model of solar collection that assumed no storage carryover.

This model is applicable to solar heating systems that incorporate storage with capacity approximately equal to one day's collector output. The analysis does not apply to solar energy systems with storage capacities capable of meeting heating loads during extended (multi-day) periods of cloudy weather. In particular, it does not apply to seasonal solar heating concepts, that is, those systems in which solar energy is collected during summer months and stored for use during the winter heating season.

Collector performance was modeled with the Hottel-Whillier equation. A standard hydronic flat-plate collector, with a heat loss of 17 kJ/m²-°C-hr and an absorptance transmittance product of 0.73, was used. On the coldest days, collected energy passes rapidly to the load, with storage temperature and collector-inlet temperature remaining at relatively low values, as determined by the minimum temperature requirements of the load. The constant value of 90°F selected here for the collector-inlet temperature is suitable for space heating and will yield an optimistic estimate of collected solar energy.

*For Boston, Massachusetts, the period is 16 years, from January 1, 1953, to December 31, 1968; for Sterling, Virginia, 22 years, from January 1, 1954, to December 31, 1975.

Fig. 1. Daily Insolation vs Heating Degree-Days

Fig. 1. Daily Insolation vs Heating Degree-Days (Cont'd)

Fig. 1. Daily Insolation vs Heating Degree-Days (Cont'd)

Fig. 1. Daily Insolation vs Heating Degree-Days (Cont'd)

Fig. 2. Daily Insolation vs Heating Degree-Days for Columbia, Missouri, at a Collector Tilt Angle Equal to Latitude plus 20°

At each location, collected solar energy was estimated on a daily basis for three array sizes. Table 1 gives the ratios of building heating requirements to collector areas for solar systems designed to supply 25%, 50%, and 75% of the annual heating load.⁸ By comparing the availability of solar energy with total heating requirements on a daily basis, we then computed the daily backup-energy requirements for the solar heating systems. The resulting load-duration curves (cumulative frequency distributions) of daily backup-energy requirements are shown for each site in Fig. 3. The curve labeled "0%" corresponds to conventional heating systems and the other three curves to solar heating systems sized to meet 25%, 50%, and 75% of the annual heating load.

As indicated in each figure the backup energy requirement is normalized to the maximum daily heating load observed over the SOLMET period of record (usually one day in 23 years). With this normalization, the solar system's backup requirement depends only on the ratio of the building heating requirement to the collector area. Along the horizontal axis, the number of occurrences is divided by the number of years of data to normalize to a one-year cycle. Because the calculation of solar output is based on the assumption of no day-to-day storage carryover, it is strictly accurate only for the subset of coldest days. The dashed portions of the curves show the results of continuing the same calculational procedure over all days with a positive heating load. The logarithmic scale along the horizontal axis provides greater detail over the period of coldest days.

Table 1. Ratio of Building Heating Requirement to Collector Area [(Btu/degree-day)/ft²]^a

Site	Solar Fraction of Annual Heating Load ^b		
	25%	50%	75%
Albuquerque	161	64	31
Bismark	78	29	14
Boston	86	33	16
Caribou	68	26	12
Columbia	102	38	18
Madison	76	28	13
Seattle	94	33	13
Sterling	111	43	21

^aSource: Ref. 8.

^bSolar fractions pertain to a collector with the characteristics described in the text. To obtain collector area (in ft²), divide heating requirement (in Btu/degree-day) by the ratio given in the table.

Except for the Albuquerque site, there is little reduction in backup requirements of the solar heating systems relative to the capacity requirements associated with conventional (nonsolar) heating systems. Even for solar heating systems sized to supply 75% of the annual space heating load, backup requirements usually exceed 85% of the peak-day requirement for the nonsolar system. For Albuquerque, the capacity reductions were approximately 10%, 18%, and 25% for solar heating systems sized to supply 25%, 50%, and 75% of the annual heating load, respectively.

5 RESULTS

Using recently-released SOLMET data tapes, we have examined solar availability for space heating at eight U.S. sites. Scatter-diagrams of insolation versus heating degree-days, compiled on a daily basis, indicate a wide variation of insolation levels. The correlation between daily insolation and daily average temperature is weak for all of the sites examined, over both the full heating season and the subset of coldest days.

A simple model of solar collector performance was used to compare solar heating system output with daily space heating loads to obtain the daily backup-energy requirements. Underlying the model is the assumption that no day-to-day storage carryover occurs during the coldest periods. This is appropriate for the large class of solar heating systems with storage capacities less than or equal to one day of solar collector output. Except in Albuquerque, the backup energy requirements of the solar heating systems were found to exceed 85% of the peak-day energy requirements of the conventional heating systems.

Fig. 3. Load Duration Curves of Daily Backup-Energy Requirements

Fig. 3. Load Duration Curves of Daily Backup-Energy Requirements (Cont'd)

Fig. 3. Load Duration Curves of Daily Backup-Energy Requirements (Cont'd)

Fig. 3. Load Duration Curves of Daily Backup-Energy Requirements (Cont'd)

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