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SOLAR INDEX GENERATION AND DELIVERY

By
Loren J. Lantz

MASTER

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Solar Environmental Engineering Co., Inc.
Fort Collins, Colorado

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Abstract

The Solar Index, or, more completely defined as the Service Hot Water Solar Index, was conceptualized during the spring of 1978 with direction from a U. S. Government interoffice agency committee, headed by the Department of Energy. *The purpose was to enhance public awareness to solar energy usability.* Basically, the Solar Index represents the percentage of energy that solar would provide in order to heat an 80 gallon service hot water load for a given location and day. The Index is computed by utilizing SOLCOST, a computer program, which also has applications to space heating, cooling, and heat pump systems and which supplies economic analyses for such solar energy systems. The Index is generated for approximately 68 geographic locations in the country on a daily basis. This paper describes the definition of the Index, how the project came to be, what it is at the present time and a plan for the future. Also presented are the models used for the generation of the Index, a discussion of the primary tool of implementation (the SOLCOST program) and future efforts.

Project Overview

The Solar Index is a number between 0 and 100 which represents the percentage of energy made available by a solar system that is used to

heat an 80 gallon per day service hot water load for a given geographic location and given day. For example, if the Solar Index is 70 for a given day, it means that a solar service hot water system could have provided 70 percent of the heat needed to boost 80 gallons from ground water temperature to 120°F. The Solar Index is much like the pollen count, wind chill factor and air quality index in that it can provide more useful information than can be provided by observations such as ambient temperature or carbon monoxide concentrations. A mathematical description follows in the paper. (See the appendices.)

The objective of the Solar Index[†] effort is to increase public awareness. Approximately two years ago it was decided within a U. S. interoffice committee that an index, general in nature, would increase public awareness of solar energy. Several indices were investigated and it was decided that the Index should provide an indication of what the sun can do for the individual rather than to simply state how much solar radiation is available. That is why the current definition of the Service Hot Water Solar Index has been adopted - because it does give an indication of what the sun is capable of doing for the individual. The solar service hot water system was decided upon as a base because it appears to be one of the most commercially viable and is the most easily defined and most frequently installed solar system in the country at the present time. Also, the average hot water usage for a service hot water heating system is fairly constant throughout the country.

In order to obtain the Index, a set of simplified and representative systems must be defined for computer modeling purposes. These

[†] Additional information, general in nature, can be obtained by writing to Solar Index, U. S. Department of Energy, Forrestal Building, Washington, D.C. 20585.

systems were defined in the following manner. They are to be representative of service hot water systems which would be designed for the specific city of interest. In the south, drain down systems with water being the collection fluid were modeled while in the northern climates heat exchangers were employed with an antifreeze agent in the collection loop. Furthermore, the systems were sized with the storage being sized approximately 1-1/2 gallons per square foot of collector as it has been determined that this is the most cost effective storage size. The collector area is determined so that the system will be capable of providing approximately 70-75% of the annual service hot water heating load for an 80 gallon per day consumption rate. Consequently, there is a different system size for each city. In the south the collector area may only be 40-50 square feet, while in the north the area may very well exceed 90 square feet.

In the beginning of the project, initiation of the Solar Index for any given city required that the media in that city must request the Solar Index.[†] At the present time, cities which are prime market areas are being added to the list whether or not the media have shown interest. Media interest, however, will increase the motivation for inclusion. Media requests usually come from T.V. and radio weather forecasters, and most recently, requests have been coming from newspapers. After

[†] Information kits for the news media are available by writing to Solar Group, 1424 K Street, N.W. - 3rd Floor, Washington, D.C. 20005. Also, those who would like to request the Index for their area should contact Andrea Brown at the same address, (202) 789-5366 or Erich Parker, Department of Energy, Forrestal Building, Washington, D.C. 20585, (202) 235-8108.

deciding to possibly include a site in the effort, the SOLCOST Service Center[†] then selects the appropriate solar system and determines the availability of weather information. Weather service information is essential.

Once it has been ascertained that all necessary information is available, the computer files required for generation of the daily Index are created. This is accomplished with SOLCOST, which is a computer program used to analyze prospective solar energy systems of various types on the basis of economics and thermal performance. It is basically a design tool which provides to the user the necessary information to facilitate decisions regarding a solar energy system. As pertaining to the Index, SOLCOST is used to size the system and then produce a performance Index on the basis of the current weather day. The inputs to the program are: location, orientation, size of specific components, the load and the weather. With these inputs the Index can be generated easily and quickly.

An alternative which has been employed recently, has been to create a simplified data base with two input parameters once the system model and locale are selected. In essence, a transformation is made. The two inputs are average ambient temperature and percent sunshine with the output being the Solar Index. This may be accomplished either by tabular or graphical means. Both methods of analysis are easily implemented. More on this will be given later. A trade-off is that a great deal of time must be spent during the creation of the data bases, while using the SOLCOST program

[†] Technical responsibility for the Solar Index is furnished by the SOLCOST Service Center, 2524 E. Vine Drive, Fort Collins, Colorado 80524. Specific technical questions not addressed by this paper should be addressed to Loren J. Lantz at the above address.

on a daily basis does not require that initial outlay of manpower but does require a high daily expenditure of time and money.

To generate the Index on a daily basis, hourly weather data is obtained from high speed weather wires. This data is reduced and used to create the Solar Index at the end of each day. For those sites where wire service data is not available, the National Weather service is contacted sometime after their local sundown and is asked for minutes of sunshine, percent of sunshine or daily total horizontal radiation; whichever is available. Also requested are the maximum and minimum temperatures for that day. These quantities are necessary for the generation of the Index; for the sites which supply wire service data these values are calculated.

The Solar Index process is two phased. The first phase is setting up and the second phase is execution. Involved in setting up is the media request and then following up to determine if weather service information is available, and finally, creation of all the necessary computer files for execution of the Index procedure on a daily basis. Execution of the Index on a daily basis requires utilization of computer files, which have already been defined in the initialization phase. Figure 6 depicts the current procedure.

As the Solar Index project currently stands, the Department of Energy, Conservation and Solar Applications, provides direction for the overall project. There are three prime contractors who provide support to the Department of Energy (see Figure 1). They are:

Figure 1. Solar Index Organizational Relationship

1) SOLCOST Service Center, 2524 East Vine Drive, Fort Collins, Colorado 80524; 2) National Solar Heating and Cooling Information Center, 20th and Race Streets, Philadelphia, Pennsylvania 19103; and 3) the Solar Group, 1424 K Street, N.W., 3rd Floor, Washington, D.C. 20005.

The SOLCOST Service Center provides technical direction for the project. Its personnel are responsible for determining availability of weather information and setting up computer files for execution of the Solar Index on a daily basis. They are also responsible for delivering the Solar Index in an automatic fashion to the news wire services, which is done at the present time by direct computer ties.

The National Solar Heating and Cooling Information Center in Philadelphia is responsible for delivering the Solar Index to those interested parties who do not subscribe to one of the news wire services. They are delivered each evening by telephone call. Individuals at the SOLCOST Service Center phone the Index numbers to the National Solar Heating and Cooling Information Center each evening for dissemination to those people who wish to receive the number by phone call. They are also responsible for tabulating monthly summaries, keeping records and dissemination of media information to interested parties.

The Solar Group provides direct administrative support to the Department of Energy. They assist in designating market areas for further expansion of the Index effort and preparation of informational materials which are mailed to interested individuals. All of the contractors interact freely among themselves and with each other under the Department of Energy's direction.

There are two other agencies here which are very important. They are the United Press International, which at the current time is disseminating the Solar Index daily through its wire services, and the other one is a computer service agency located in Massachusetts which collects the weather data each hour from the prime weather wires, including those generated by National Weather Service, National Oceanographic and Atmospheric Administration and the Federal Aviation Administration. The latter is the one that is used primarily in the generation of the Index. More will be given later about how this weather data is transformed into a Solar Index for a given city.

At the present time, approximately 68 areas (Table 1) are being serviced by the Solar Index effort. The Index is supplied on weekdays only. Figure 2 gives the Index for Washington, D.C. and Denver, Colorado for one month each. There is every reason to believe that this effort will continue to grow as media interest increases. The Department of Energy is constantly striving to inform the media of this new service, especially in the prime solar commercial market areas of the country.

Service Hot Water Model Description

A generic solar service hot water system model is chosen for each location and is selected to best represent what is commercially being installed in that particular locale. Service hot water systems are made up of many different basic designs. For purposes of the Index, two system types were decided upon; one for relatively non-freezing climates where the collector fluid was water and one for freezing climates where the

TABLE 1
City List by State*

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
ANNISTON, AL	NO	YES			
BIRMINGHAM, AL	NO	YES	1		
DOTHAN, AL	NO	YES			
HUNTSVILLE, AL	YES	YES	2	60	INDIRECT
MUSCLE SHOALS, AL	NO	YES			
MOBILE/PENSICOLA, AL	NO	YES	2		
MONTGOMERY, AL	YES	YES	3	45	DIRECT
TUSCALOOSA, AL	NO	YES			
DOUGLAS, AZ	NO	YES			
EL DORADO, AZ	NO	YES			
FLAGSTAFF, AZ	NO	YES	3		
GRAND CANYON, AZ	NO	YES			
PAGE, AZ	NO	YES			
PAYSON, AZ	NO	YES			
PRESCOTT, AZ	NO	YES			
PHOENIX, AZ	YES	YES	1	30	DIRECT
TUSCON, AZ	NO	YES	2		
WINSLOW, AZ	NO	YES			
YUMA, AZ	NO	NO	3		
FORT SMITH, AR	NO	YES	3		
HARRISON, AR	NO	YES			
HOT SPRINGS, AR	NO	YES			
JONESBORO, AR	NO	YES			
LITTLE ROCK, AR	NO	YES	2		
TEXARKANA, AR	NO	YES			
ARCATA, CA	NO	YES			
BAKERSFIELD, CA	NO	YES			
BEAUMONT, CA	NO	YES			
BISHOP, CA	NO	YES			
BLUE CANYON, CA	NO	YES			

* This table indicates whether a city is currently being serviced by the effort. The weather wire column indicates if weather information is available for possible inclusion. The market type is the priority for inclusion. A one (1) designates that it is highly desirable to include the city in the project. The collector size and system type designate the collector size and solar system type when the city is being supplied with a Solar Index..

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
BLYTHE, CA	NO	YES			
BURBANK, CA	NO	YES			
BURNEY, CA	NO	YES			
CAMPO, CA	NO	YES			
CARLSBAD, CA	NO	YES			
CHICO, CA	NO	YES			
CRESCENT CITY, CA	NO	YES			
DAGGETT, CA	NO	YES			
EL MONTE-ESMU, CA	NO	YES			
FRESNO, CA	NO	YES	2		
FULLERTON, CA	NO	YES			
HAWARD, CA	NO	YES			
HAWTHORNE, CA	NO	YES			
IMPERIAL, CA	NO	YES			
LANCASTER, CA	NO	YES			
LOS ANGELES, CA	YES	YES	1	35	DIRECT
MARYSVILLE, CA	NO	YES			
MODESTO, CA	NO	YES			
MONTEREY, CA	NO	YES			
MT. WILSON, CA	NO	YES			
MT. SHASTA, CA	NO	YES			
NAPA, CA	NO	YES			
NEEDLES, CA	NO	YES			
OAKLAND, CA	NO	YES			
ONTARIO, CA	NO	YES			
OXNARD, CA	NO	YES			
PALM SPRINGS, CA	NO	YES			
PASO ROBLES, CA	NO	YES			
REDDING, CA	NO	YES			
RED BLUFF, CA	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
RIVERSIDE, CA	NO	YES			
SACRAMENTO, CA	NO	YES	1		
SAN DIEGO, CA	YES	YES	1	45	DIRECT
SAN FRANCISCO, CA	NO	YES	1		
SAN JOSE, CA	NO	YES			
SANDBERG, CA	NO	YES			
SANTA ANA, CA	NO	YES			
SANTA BARBARA, CA	NO	YES			
SANTA CATALINA, CA	NO	YES			
SANTA MARIA, CA	NO	YES			
SANTA MONICA, CA	NO	YES			
SANTA ROSA, CA	NO	YES			
SOUTH LAKE TAHOE, CA	NO	YES			
STOCKTON, CA	NO	YES			
SUSANVILLE, CA	NO	YES			
THERMAL, CA	NO	YES			
TORRANCE, CA	NO	YES			
UKIAH, CA	NO	YES			
VAN NUYS, CA	NO	YES			
VISALIA, CA	NO	YES			
AKRON, CO	NO	YES			
ALAMOSA, CO	NO	YES			
ASPEN, CO	NO	YES			
COLORADO SPRINGS, CO	NO	YES			
CORTEZ, CO	NO	YES			
DENVER, CO	YES	YES	1	55	INDIRECT
DURANGO, CO	NO	YES			
EAGLE, CO	NO	YES			
FT. COLLINS, CO	NO	YES			
GRAND JUNCTION, CO	NO	YES	3		

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
SARASOTA, FL	NO	YES			
TALLAHASSEE, FL	NO	NO	4		
TAMPA/ST. PETERSBURG, FL	YES	YES	1	40	DIRECT
VERO BEACH, FL	NO	YES			
WEST PALM BEACH, FL	NO	YES	2		
ALBANY, GA	NO	YES			
ALMA, GA	NO	YES			
ATHENS, GA	NO	YES			
ATLANTA, GA	YES	YES	1	50	DIRECT
AUGUSTA, GA	NO	YES	3		
BRUNSWICK, GA	NO	YES			
COLUMBUS, GA	NO	YES	3		
MACON, GA	NO	YES			
ROME, GA	NO	YES			
SAVANNAH, GA	NO	YES	3		
VALDOSTA, GA	NO	YES			
BOISE, ID	YES	YES	3	60	INDIRECT
BURLEY, ID	NO	YES			
GOODING, ID	NO	YES			
GRANGEVILLE, ID	NO	YES			
IDAHO FALLS/POCATELLO, ID	YES	YES	3	65	INDIRECT
LEWISTON, ID	NO	YES			
MALAD CITY, ID	NO	YES			
MULLAN, ID	NO	YES			
SALMON, ID	NO	YES			
CHICAGO, IL	YES	YES	1	80	INDIRECT
MARION, IL	NO	YES			
MARSEILLES, IL	NO	YES			
MOLINE, IL	YES	YES	3	70	INDIRECT
MOUNE, IL	NO	NO	2		

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
PEORIA, IL	NO	NO	2		
ROCKFORD, IL	NO	YES	2		
SPRINGFIELD, IL	NO	NO	2		
EVANSVILLE, IN	NO	NO	2		
FT. WAYNE, IN	YES	YES	2	75	INDIRECT
INDIANAPOLIS, IN	NO	NO	1		
SOUTH BEND, IN	NO	YES	4		
TERRE HAUTE, IN	NO	NO	3		
BURLINGTON, IA	NO	YES			
CEDAR RAPIDS, IA	NO	YES			
DES MOINES, IA	YES	YES	2	65	INDIRECT
DUBUQUE, IA	NO	YES	4		
FT. DODGE, IA	NO	YES			
LAMONI, IA	NO	YES			
MASON CITY, IA	NO	YES			
OTTUMWA, IA	NO	YES			
STOUX CITY, IA	NO	YES	3		
SPENCER, IA	NO	YES			
WATERLOO, IA	NO	YES			
CHANUTE, KS	NO	YES			
CONCORDIA, KS	NO	YES	4		
DODGE CITY, KS	NO	YES	4		
EMFORIA, KS	NO	YES			
GARDEN CITY, KS	NO	YES			
GOODLAND, KS	NO	YES			
HILL CITY, KS	NO	YES			
HUTCHINSON, KS	NO	YES			
MANHATTAN, KS	NO	YES			
MEDICINE LODGE, KS	NO	YES			
RUSSELL, KS	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
SCOTTISBLUFF, NE	NO	YES			
SIDNEY, NE	NO	YES			
VALENTINE, NE	NO	YES			
BATTLE MOUNTAIN, NV	NO	YES			
ELKO, NV	NO	YES			
ELY, NV	NO	YES			
LAS VEGAS, NV	NO	YES	3		
OWYHEE, NV	NO	YES			
RENO, NV	YES	YES	3	45	INDIRECT
TUNDUPAH, NV	NO	YES			
WINNEHUECA, NV	NO	YES			
CONCORD, NH	YES	YES	4	00	INDIRECT
KEENE, NH	NO	YES			
LACONIA, NH	NO	YES			
LEBANON, NH	NO	YES			
MANCHESTER, NH	NO	YES			
MT. WASHINGTON, NH	NO	YES			
ATLANTIC CITY, NJ	NO	YES	4		
MILLVILLE, NJ	NO	YES			
MORRISTOWN, NJ	NO	YES			
NEWARK, NJ	NO	YES			
TETERBORO, NJ	NO	YES			
TRENTON, NJ	YES	YES	4	65	INDIRECT
ALBUQUERQUE, NM	YES	YES	2	40	INDIRECT
CARLSBAD, NM	NO	YES			
CLAYTON, NM	NO	YES			
DEMING, NM	NO	YES			
FARMINGTON, NM	NO	YES			
GALLUP, NM	NO	YES			
HOBBS, NM	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
GUNNISON, CO	NO	YES			
HAYDEN, CO	NO	YES			
LA JUNTA, CO	NO	YES			
LAMAR, CO	NO	YES			
LEADVILLE, CO	NO	YES			
LIMON, CO	NO	YES			
MONTRUSE, CO	NO	YES			
PUEBLO, CO	NO	YES	3		
RIFLE, CO	NO	YES			
SALIDA, CO	NO	YES			
TRINIDAD, CO	NO	YES			
BRIDGEPORT, CT	NO	YES	4		
DANBURY, CT	NO	YES			
GROTON, CT	NO	YES			
HARTFORD, CT	NO	YES	1		
WASHINGTON, DC	YES	YES	1	70	INDIRECT
WILMINGTON, DE	NO	YES	4		
APALACHICOLA, FL	NO	YES			
CRESTVIEW, FL	NO	YES			
CROSS CITY, FL	NO	YES			
DAYTONA BEACH, FL	NO	YES	1		
FT. LAUDERDALE, FL	NO	YES			
FT. MEYERS, FL	NO	YES			
GAINESVILLE, FL	NO	YES			
JACKSONVILLE, FL	NO	YES	2		
KEY WEST, FL	NO	YES			
MELBOURNE, FL	NO	YES			
MIAMI, FL	YES	YES	1	40	DIRECT
ORLANDO, FL	NO	YES	1		
PENSACOLA, FL	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
SALINA, KS	NO	YES			
TOPEKA, KS	NO	YES	3		
WICHITA, KS	NO	YES	2		
LEXINGTON, KY	NO	NO	2		
LOUISVILLE, KY	YES	NO	1	65	INDIRECT
PADUCAH, KY	NO	YES	2		
PIKEVILLE, KY	NO	YES			
ALEXANDRIA, LA	NO	YES			
BATON ROUGE, LA	NO	YES	2		
BOOTHVILLE, LA	NO	YES			
FORT POLK, LA	NO	YES			
LAFAYETTE, LA	NO	YES			
LAKE CHARLES, LA	NO	YES	3		
MONROE, LA	NO	YES			
NEW ORLEANS, LA	YES	YES	1	45	DIRECT
SHREVEPORT, LA	NO	YES	2		
AUGUSTA, ME	NO	YES			
BANGOR, ME	NO	YES	3		
BAR HARBOR, ME	NO	YES			
CARIBOU, ME	NO	YES	4		
HOULTON, ME	NO	YES			
PORTLAND, ME	YES	YES	2	65	INDIRECT
BALTIMORE, MD	YES	NO	1	80	INDIRECT
HAGERSTOWN, MD	NO	YES			
MIDDLE RIVER, MD	NO	YES			
SALISBURY, MD	NO	YES			
REDFORD, MA	NO	YES			
BEVERLY, MA	NO	YES			
BOSTON, MA	YES	YES	1	70	INDIRECT
HYANNIS, MA	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
MARTHAS VINEYARD, MA	NO	YES			
NANTUCKET, MA	NO	YES			
NEW BEDFORD, MA	NO	YES			
NORWOOD, MA	NO	YES			
PITTSFIELD, MA	NO	YES			
SPRINGFIELD, MA	YES	NO	2	65	INDIRECT
WESTFIELD, MA	NO	YES			
WORCHESTER-LAWRS, MA	NO	NO	4		
ALPENA, MI	NO	YES			
BATTLE CREEK, MI	NO	YES			
DUNTON HARBOR, MI	NO	YES			
DETROIT, MI	NO	YES	1		
ESCANABA, MI	NO	YES			
FLINT, MI	NO	YES	2		
GRAND RAPIDS, MI	NO	YES	1		
HOUGHTON LAKE, MI	NO	YES			
IRONWOOD, MI	NO	YES			
IRON MOUNTAIN, MI	NO	YES			
JACKSON, MI	NO	YES			
KALAMAZOO, MI	NO	YES			
LANSING, MI	NO	YES	2		
MANISTEE, MI	NO	YES			
MARQUETTE, MI	NO	YES	3		
MENOMINEE, MI	NO	YES			
MUSKEGON, MI	NO	YES			
PELLSTON, MI	NO	YES			
PONTIAC, MI	NO	YES			
SAGINAW, MI	NO	YES			
SAULT STE. MARIE, MI	NO	YES	4		
TRAVERSE CITY, MI	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
ALEXANDRIA, MN	NO	YES			
DULUTH, MN	YES	NO	2	80	INDIRECT
EVELETH, MN	NO	YES			
INTERNATIONAL FALLS, MN	NO	NO	4		
MINNEAPOLIS/ST. PAUL, MN	YES	YES	1	80	INDIRECT
REDWOOD FALLS, MN	NO	YES			
ROCHESTER, MN	NO	YES	4		
ST. CLOUD, MN	NO	YES			
GREENVILLE, MS	NO	YES			
GREENWOOD, MS	NO	YES			
OSHTO, MS	NO	YES			
JACKSON, MS	NO	NO	2		
ACCOMB, MS	NO	YES			
MERIDIAN, MS	NO	YES	3		
NATCHEZ, MS	NO	YES			
CAPE GIRARDEAU, MO	NO	YES			
COLUMBIA/JEFFERSON CITY, MO	YES	YES	3	60	INDIRECT
JOPLIN, MO	NO	YES			
KANSAS CITY, MO	YES	YES	1	60	INDIRECT
KIRKSVILLE, MO	NO	YES			
SPRINGFIELD, MO	YES	YES	2	60	INDIRECT
ST. JOSEPH, MO	NO	YES			
ST. LOUIS, MO	YES	YES	1	65	INDIRECT
BILLINGS, MT	NO	YES	3		
BOZEHAN, MT	NO	YES			
BROADUS, MT	NO	YES			
BUTTE, MT	NO	YES			
CUTBANK, MT	NO	YES			
DILLON, MT	NO	YES			
DRUMMOND, MT	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
GLASGOW, MT	NO	YES			
GREAT FALLS, MT	YES	YES	3	80	INDIRECT
HARLOWTON, MT	NO	YES			
HAVER, MT	NO	YES			
HELENA, MT	NO	YES			
KALISPELL, MT	NO	YES			
LEWISTOWN, MT	NO	YES			
LIVINGSTON, MT	NO	YES			
MILES CITY, MT	NO	YES			
MISSOULA, MT	NO	YES	3		
SIDNEY, MT	NO	YES			
WEST YELLOWSTONE, MT	NO	YES			
WOLF POINT, MT	NO	YES			
AINSWORTH, NE	NO	YES			
ALLIANCE, NE	NO	YES			
BLATRICE, NE	NO	YES			
BROKEN BOW, NE	NO	YES			
BURWELL, NE	NO	YES			
CHADRON, NE	NO	YES			
COLUMBUS, NE	NO	YES			
GRAND ISLAND, NE	NO	YES	4		
HASTINGS, NE	NO	YES			
IMPERIAL, NE	NO	YES			
KEARNEY, NE	NO	YES			
LINCOLN, NE	YES	YES	1	60	INDIRECT
MCCOOK, NE	NO	YES			
MULLEN, NE	NO	YES			
NORFOLK, NE	NO	YES			
NORTH PLATTE, NE	NO	YES	4		
OMAHA, NE	YES	NO	1	60	INDIRECT

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
LAS VEGAS, NM	NO	YES			
ROSWELL, NM	NO	YES	3		
SANTA FE, NM	NO	YES			
SILVER CITY, NM	NO	YES			
TRUTH OR CONSEQUENCES, NM	NO	YES			
ALBANY, NY	NO	YES	1		
BINGHAMTON, NY	YES	YES	3	90	INDIRECT
BUFFALO, NY	NO	YES	1		
ELMICA, NY	NO	YES			
FARMINGDALE, NY	NO	YES			
GLENS FALLS, NY	NO	YES			
ISLIP, NY	NO	YES			
ITHACA, NY	NO	YES			
JAMESTOWN, NY	NO	YES			
LOVELOCK, NY	NO	YES			
MASSENA, NY	NO	YES			
MONTICELLO, NY	NO	YES			
NEWBURGH, NY	NO	YES			
NEW YORK, NY	NO	YES	1		
NIAGARA FALLS, NY	NO	YES			
POUGHKEEPSIE, NY	NO	YES			
ROCHESTER, NY	YES	YES	3	70	INDIRECT
SARANAC LAKE, NY	NO	YES			
SYRACUSE, NY	YES	YES	2	85	INDIRECT
UTICA, NY	NO	YES			
WATERTOWN, NY	NO	YES			
WHITE PLAINS, NY	NO	YES			
ASHVILLE, NC	NO	YES	4		
CAPE HATIERAS, NC	NO	YES			
CHARLOTTE, NC	NO	YES	1		

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
ELIZABETH CITY, NC	NO	YES			
FAYETTEVILLE, NC	NO	YES			
GREENSBORO/HIGH POINT/WINSTON-SALEM, NC	YES	YES	2	60	DIRECT
HICKORY, NC	NO	YES			
HOT SPRINGS, NC	NO	YES			
NEW BERN, NC	NO	YES			
RALEIGH/DURHAM, NC	YES	YES	1	45	DIRECT
ROCKY MOUNT/WILSON, NC	NO	YES			
WILMINGTON, NC	NO	YES	4		
RISHARCK, ND	YES	NO	3	75	INDIRECT
DEVILS LAKE, ND	NO	YES			
FARGO, ND	YES	NO	3	75	INDIRECT
AKRON, OH	NO	YES			
CINCINNATI, OH	NO	NO	1		
CLEVELAND, OH	NO	YES	1		
COLUMBUS, OH	YES	NO	1	75	INDIRECT
DAYTON, OH	NO	NO	1		
FINDLAY, OH	NO	YES			
TOLEDO, OH	NO	YES	2		
YOUNGSTOWN, OH	NO	YES	2		
ARDMORE, OK	NO	YES			
BARTLESVILLE, OK	NO	YES			
CLINTON/BURNS FLAT, OK	NO	YES			
GAGE, OK	NO	YES			
HOBART, OK	NO	YES			
MCALISTER, OK	NO	YES			
OKLAHOMA CITY, OK	YES	YES	1	55	INDIRECT
PONCA CITY, OK	NO	YES			
TULSA, OK	YES	YES	2	55	INDIRECT
ASTORIA, OR	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
BAKER, OR	NO	YES			
BURNS, OR	NO	NO			
EUGENE, OR	NO	YES	3		
KLAMATH FALLS, OR	NO	YES			
LAKEVIEW, OR	NO	YES			
HEACAM, OR	NO	YES			
MEDFORD, OR	NO	YES	3		
NORTH BEND, OR	NO	YES			
PENDLETON, OR	NO	YES			
PORTLAND, OR	YES	YES	1	70	DIRECT
REDMOND, OR	NO	YES			
SALEM, OR	NO	YES			
SEXTON-SUMMIT, OR	NO	YES			
THE DALLES, OR	NO	YES			
TROUTDALE, OR	NO	YES			
ALLENTOWN, PA	NO	YES			
ALTOONA, PA	NO	YES			
BRADFORD, PA	NO	YES			
DUBOIS, PA	NO	YES			
ERIE, PA	NO	YES	4		
FRANKLIN, PA	NO	YES			
HARRISBURG/YORK/LEBANON, PA	YES	YES	1	70	INDIRECT
JOHNSTOWN/ALTOONA, PA	NO	YES			
LANCASTER, PA	NO	YES			
LATROBE, PA	NO	YES			
MIDDLETOWN, PA	NO	YES			
PHILADELPHIA, PA	YES	YES	1	65	INDIRECT
PITTSBURG, PA	NO	YES	1		
TOBYHANNA, PA	NO	YES			
WILKS-BARRE-SCRANTON, PA	YES	YES		70	INDIRECT

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
WILLIAMSPORT, PA	NO	YES			
BLOCK ISLAND, RI	NO	YES			
PROVIDENCE, RI	YES	YES	1	70	INDIRECT
ANDERSON, SC	NO	YES			
CHARLESTON, SC	NO	YES	3		
COLUMBIA, SC	YES	YES	2	55	DIRECT
FLORENCE, SC	NO	YES			
GREENVILLE--SPRTNBO, SC	YES	YES	1	55	DIRECT
ABERDEEN, SD	NO	NO	4		
HURON, SD	NO	YES			
PHILIP, SD	NO	YES			
PIERRE, SD	NO	YES			
RAPID CITY, SD	YES	YES	3	65	INDIRECT
SIOUX FALLS, SD	NO	YES	2		
WATERTOWN, SD	NO	YES			
BRISTOL, TN	NO	YES	2		
CHATTANOOGA, TN	NO	NO	2		
KNOXVILLE, TN	NO	NO	2		
MEMPHIS, TN	YES	YES	1	65	INDIRECT
NASHVILLE, TN	NO	NO	1		
ABILENE/SWEETWATER, TX	YES	YES	3	35	DIRECT
ALICE, TX	NO	YES			
AMARILLO, TX	YES	YES	3	45	INDIRECT
AUSTIN, TX	NO	YES	2		
BROWNSVILLE, TX	NO	YES			
CHILDRESS, TX	NO	YES			
COLLEGE STATION, TX	NO	YES.			
CORPUS CHRISTI, TX	NO	YES			
COTULLA, TX	NO	YES			
DALHART, TX	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
DALLAS/FT. WORTH, TX	YES	YES	1	45	DIRECT
DEL RIO, TX	NO	YES			
EL PASO, TX	NO	YES			
GALVESTON, TX	NO	YES			
GUADALUPE PASS, TX	NO	YES			
HARLINGEN, TX	NO	YES			
HOUSTON, TX	YES	YES	1	45	DIRECT
JUNCTION, TX	NO	YES			
LAREDO, TX	NO	YES			
LONGVIEW, TX	NO	YES			
LUBBOCK, TX	YES	YES	3	45	DIRECT
LUFKIN, TX	NO	YES			
MARFA, TX	NO	YES			
MCALLEN, TX	NO	YES			
MIDLAND, TX	NO	YES			
MINERAL WELLS, TX	NO	YES			
PALACIOS, TX	NO	YES			
PARIS, TX	NO	YES			
PLAINVIEW, TX	NO	YES			
FORT ARTHUR, TX	NO	YES			
SAN ANGELO, TX	NO	YES			
SAN ANTONIO, TX	YES	YES	2	40	DIRECT
TEMPLE, TX	NO	YES			
TYLER, TX	NO	YES			
VICTORIA, TX	NO	YES			
WACO, TX	NO	YES	3		
WICHITA FALLS, TX	NO	YES			
WINK, TX	NO	YES			
DRYCE CANYON, UT	NO	YES			
CEDAR CITY, UT	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
DELTA, UT	NO	YES			
GREEN RIVER, UT	NO	YES			
HANKSVILLE, UT	NO	YES			
MILFORD, UT	NO	YES			
ODDEN, UT	NO	YES			
PRICE, UT	NO	YES			
SALT LAKE CITY, UT	YES	YES	1	50	INDIRECT
VERNAL, UT	NO	YES			
WENDOVER, UT	NO	YES			
BURLINGTON, VT/PLATTSBURG, NY	YES	YES	2	90	INDIRECT
MONTPELIER, VT	NO	YES			
RUTLAND, VT	NO	YES			
CHARLOTTESVILLE, VA	NO	YES			
DANVILLE, VA	NO	YES			
HOT SPRINGS, VA	NO	YES			
LYNCHBURG, VA	NO	YES	2		
NORFOLK/FORTSMOUTH/NET NEWS/HAMPTON, VA	YES	YES	1	60	DIRECT
RICHMOND, VA	NO	YES	2		
ROANOKE, VA	NO	YES	2		
STAUNTON, VA	NO	YES			
WALLOPS ISLAND, VA	NO	YES			
BELLINGHAM, WA	NO	YES			
COLVILLE, WA	NO	YES			
EPHRATA, WA	NO	YES			
EVERETT, WA	NO	YES			
HOQUIAM, WA	NO	YES			
MOSES LAKE, WA	NO	YES			
OLYMPIA, WA	NO	YES			
PULLMAN, WA	NO	YES			
OMAK, WA	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
QUILLAYUTE, WA	NO	YES			
SEATTLE/TACOMA, WA	YES	YES	1	90	INDIRECT
SPOKANE, WA	NO	YES	2		
STAMPEDE PASS, WA	NO	YES			
TOLEDO, WA	NO	YES			
TRI-CITIES, WA	YES	NO	4	90	INDIRECT
WALLA WALLA, WA	NO	YES			
WENATCHEE, WA	NO	YES			
YAKIMA, WA	NO	YES	3		
BECKLEY, WV	NO	YES	3		
BLUEFIELD, WV	NO	YES			
CHARLESTON, WV	NO	YES	1		
CLARKSBURG, WV	NO	YES			
ELKINS, WV	NO	YES			
HUNTINGTON, WV	NO	YES	4		
LEWISBURG, WV	NO	YES			
MARTINSBURG, WV	NO	YES			
MORGANTOWN, WV	NO	YES			
PARKERSBURG, WV	NO	YES			
WHEELING, WV	NO	YES	3		
APPLETON, WI	NO	YES			
EAU CLAIRE, WI	NO	YES			
GREEN BAY, WI	YES	YES	2	75	INDIRECT
JANESVILLE, WI	NO	YES			
LACROSSE, WI	NO	YES	3		
LONE ROCK, WI	NO	YES			
MADISON, WI	YES	YES	3	80	INDIRECT
MANITOWOC, WI	NO	YES			
MILWAUKEE, WI	NO	YES	1		
MOSINEE, WI	NO	YES			

TABLE 1 (cont.)

CITY	INDEX NOW	WEATHER WIRE	MARKET TYPE	COL. SIZE	SYSTEM TYPE
OSHKOSH, WI	NO	YES			
RHINELANDER, WI	NO	YES			
WAUSAU, WI	NO	YES			
BIG PINEY, WY	NO	YES			
CASPER, WY	NO	YES	4		
CHEYENNE, WY	NO	YES	4		
CODY, WY	NO	YES			
DOUGLAS, WY	NO	YES			
GILLETTE, WY	NO	YES			
LANDER, WY	YES	YES	4	55	INDIRECT
LARAMIE, WY	NO	YES			
RIVERTON, WY	NO	YES			
ROCK SPRINGS, WY	NO	YES			
SHERIDAN, WY	NO	YES	4		
WORLAND, WY	NO	YES			

Figure 2.

Washington, D.C. Solar Index for May, 1979

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Denver, CO Solar Index for January, 1979

collector fluid was antifreeze. These two systems are shown schematically in Figures 3 and 4. Generically, the only difference between the two systems is a device which is included to help prevent possible freezing of the collectors. These components are the heat exchanger and associated pumps and plumbing that are shown between the collector and the storage system in Figure 3.

The collectors were also chosen to represent the climate. In the model for non-freezing climates, the collector is a flat plate, one glass cover, flat black paint on a roll-bond absorber plate. For freezing climates, the collector is identical with the exception of the number of cover plates, which are two. The storage tank for both systems was sized to be a multiple of the collector area. The multiplication factor is 1.5 gallons per square foot of collector. For example, if the collector area were 40 ft², the storage tank would be sized at 60 gallons. A storage size of 97.5 gallons could result using this method, which may not be available commercially. The Index numbers are not highly sensitive to the storage size. In reality, a storage size other than 97.5 gallons would probably be installed. However, this would depend on local availability. If storage sizes of 90 or 100 gallons were used in the model, the final Solar Indices would not be appreciably influenced. The hot water heater in both cases was assumed to be a standard 42 gallon electric hot water heater and both systems are assumed to have a tempering valve set at 120°F where if the hot water heater temperature goes above 120°F, cold water is mixed with the outlet water. It is also assumed that the hot water heater

Figure 3.

INDIRECT ACTIVE SYSTEM WITH TWO TANKS AND HEAT EXCHANGER

Figure 4.

DIRECT ACTIVE SYSTEM WITH TWO TANKS

temperature control thermostat is set at 120°F. High temperature protection for the storage tanks in both models was set at 200°F. In other words, the storage tank temperature was never allowed to exceed 200°F.

Using the weather information for the city and a predetermined load of 80 gallons per day, and with the assumption that the ground water temperature is an average of 50°F throughout the year, the solar system was sized to where it gave an annual load fraction of 70 - 75%. Specific collector areas for the cities of interest are given in Table 1. It would be more accurate to use ground water temperatures on a monthly basis, which can be easily accomplished in the program, but this information is difficult to obtain and is generally only available for certain locations throughout the country. If this information becomes available, it will be incorporated in future models.

When the governing committee for the Solar Index project was originally formed, it was decided that the model used for generation of the individual solar indices should be representative of what is being installed. It was also desirable to have some comparative base so that the indices could be compared against each other across the country. As a result, it was decided that a solar fraction design point of 70 - 75% would be appropriate. In general, systems with this load fraction are cost effective as compared to electricity across the country except for possibly in the northwest where electricity is cheap. For certain situations, however, it might not be the most cost effective design or what is actually being installed in a local area. For example, load fractions of 50% are commonly seen in the northeast part of the United States and in certain parts of the country, for example, the southwest, load fractions may reach 90% or greater. Taking

all of these local variations in mind, it was decided that a good all around number to use as a sizing point was 70 - 75%. This particular decision may be reviewed later in the project and a new realization may take place. That is, lower the load fraction for the northeast so it is much more representative of what is actually being installed. In light of the new incentives, which are likely to be passed by congress in the very near future, this generally expected design point in the industry may change substantially; also if solar system sales begin to increase in the future, system costs may lower and again cause the representative system to appear much differently than it is today.

For the utilization pattern assumed in defining the individual systems for the Solar Index project, one would expect to require approximately 5 - 6,000 kilowatt hours of electricity on a yearly basis. If that electricity sells for 5 cents per kilowatt hour, this is equal to approximately \$250 - \$300 per year for heating hot water. The solar system described would be capable of saving approximately \$185 - \$225 of this amount per year. Of course, these savings will vary depending upon local fuel costs and utilization of the collected solar energy.

The model for each city can be executed daily to generate the Solar Index or it can be executed several times initially and the results reduced to a data base for daily usage. The latter method is currently used and a simplified representation of using this data base is presented in Figure 5. See Appendix D for more details.

SOLAR INDEX
Saint Louis, MO - January

If the PERCENT OF POSSIBLE SUNSHINE IS 70 and the AVERAGE TEMPERATURE is 30, the SOLAR INDEX is 65.

NOTE: Formulas: %SUNSHINE = percent of actual solar radiation received between clear and cloudy expected daily totals.

AVERAGE TEMPERATURE = sum of the maximum and minimum temperatures divided by 2

Figure 5. For a given location and month the Solar Index can be determined graphically as illustrated. This is usually the procedure used until the Index is automatically generated by computer.

Site Selection and Initialization

Several justifications can be used for adding a particular site to the Solar Index effort. The two most important ones are: 1) that the media in a particular location have shown a strong interest in being serviced in this endeavor; or 2) the city of interest is a prime market area. Table 1 lists the cities for which weather information is available and which are prime market areas. A "1" in the market area column indicates that the city is a prime site and will be added to the Solar Index effort sooner or later. A "2" indicates that it is of interest as well, but not with the same priority as the one before. The expansion will continue until a total of approximately 250 sites are included in the effort. At that time, a reevaluation will take place to see if possibly more can be included. The SOLCOST Service Center will work with the Department of Energy in deciding priorities for adding these cities to the effort. It is expected that this project will last for at least a total of three more years. See the future efforts section of this paper for more details.

Once it has been decided to add a city, several things need to be analyzed to determine whether or not such an effort can indeed be supported (see Figure 6). Weather services need to be researched to find out what weather information is available for any particular site. The SOLCOST Service Center receives daily and hourly information for most cities in the country which have a National Weather Service, National Oceanographic and Atmospheric Administration or Federal Aviation Administration observatory. These particular sites collect hourly cloud cover and surface observations and report this to data computers, which in turn dispatch it over several

Figure 6. Solar Index Setup Procedure

high speed wire services. The one of primary interest is the one maintained by the Federal Aviation Administration. A computer network in Concord, Massachusetts observes these wires and takes the information and stores it in computer mass storage each hour. Software is then executed to reduce this data to numbers which are suitable for generation of the Solar Index on a daily basis. More information on this is given in Appendix B. The data is reviewed to see, first of all, if data is recorded for the particular site of interest, and, secondly, whether there is enough data on an hourly basis to accomplish the transformation process and to generate the Solar Index number on a daily basis with acceptable reliability (see Figure 7). If the weather service agencies do not collect suitable weather information, then suitable alternatives may be researched if indeed this is a high priority station or site of interest. For certain selected locations, telephone calls are made at the end of each day to get indicators of sunshine, which are manually input into the computer for generation of the Solar Index. If no suitable alternatives are available, then the search is stopped and the appropriate agencies are informed. However, if suitable alternatives are found, then the next step is to set up the necessary computer files for the daily procedure. More information on this is given in Appendix D.

Coordination then takes place between all of the appropriate agencies. The media for the particular city are informed, and then the daily procedure begins as soon as all coordination and computer hookup requirements are accomplished.

Daily Procedure

The next process is the Solar Index daily procedure. The wire services are reviewed each hour at the computer facilities in Concord, Massachusetts,

Figure 7. Solar Index Daily Procedure

and data is stored and filed for subsequent processing and reduction into the necessary information used for the generation of the Solar Index. Data is received for hundreds of cities. However, this data needs to be sorted, for it contains special reports, general information that is not of interest, as well as the information for sites which are not included in the effort. Reduced files are created at Concord, Massachusetts and then shipped via telephone lines to a mini-computer at the SOLCOST Service Center for subsequent processing and retransmittal (see Appendix B). These particular files eventually end up in a high speed computer, utilized by the SOLCOST Service Center, which takes the cloud cover information, temperature and pressure data, and transforms it into total horizontal radiation for the hour for the cities of interest. This particular process goes on periodically throughout the day until sunset occurs at the local time for the various sites of interest. For example, sunset does not occur in Washington, D.C. exactly the same time as it does in Denver, Colorado.

As the sun sets in the various time zones, daily summaries are tabulated which include total horizontal radiation and the maximum and minimum temperatures for the day. The total horizontal radiation is transformed into percent sunshine. These values are the ones that are required for generation of the Solar Index by a table lookup procedure, which will be described later (see Appendix D). Not all weather information that is required is obtained through the wire services, as described above. Some special sites require telephone calls to the National Weather Service observatories to supplement the data. After the sun has set at a particular location, and after all of the weather service information that is available has been reduced into a suitable form, the Solar Indices are calculated for that particular location.

The city names and numbers are reduced to a file which is transferred from the high speed computer utilized by the SOLCOST Service Center through a computer-to-computer tie where the second computer is the one maintained by the United Press International. A mini-computer is located between the computer maintained by UPI and the high speed computer to the SOLCOST Service Center. This is required since the news services have special formatting requirements. Special editing characters are inserted to control paragraphing and margins.

The resultant news file is eventually shipped off to the United Press International for subsequent routing and disposal through their wire services. For the media who do not subscribe to the news wire, phone calls are made by the National Solar Heating and Cooling Information Center to provide the Solar Index on a daily basis. This service will decline in the future as other news wire services are possibly added to the effort. The final thing done for each location is to record all of the weather information and the resultant Indices for future reference. This particular procedure is executed once per location. It is possible that various things are going on simultaneously for each time zone. For example, weather data could still be coming in for the mountain time zone at the same time the Solar Index indices are being generated for the eastern time zone. Late in the day, execution and generation of the Solar Indices can become quite a hectic process, with several people scurrying around and completing the various tasks that are required to produce the final product and to maintain records.

Quality Assurance

Since the beginning of the Solar Index project there has been a great deal of concern about the quality of the number that is delivered to the media for dissemination. There have been two basic schools of thought surrounding the number. The first is that the number should be very accurate, sometimes to extremes. Other individuals have stated that the number need not be accurate at all. To understand the basic arguments, one must consider the foundation for constructing them. Those who insist upon extreme accuracy usually want to use the number for other purposes than the Index's primary objective which is, basically, to get the word out. Those who are not concerned about the accuracy insist that the number is not used in any way for design or analysis purposes. Consequently, the quality of the number need not be assured. In reality, the numbers' primary objective was to inform the public that solar energy can do something for them, but there is a small community of users who use the number for more far reaching purposes; such as judging solar system performance. Consequently, the quality assurance issue must be addressed. The accuracy of the Index numbers must be ascertained and published so that those people who are using it as a measure know exactly what they are getting. The Index was designed to be a qualitative but an exact predictor of solar system performance, specifically for the generic service hot water system as commonly seen in the industry today. That is why a simplistic approach for the generation of the Index was initially adopted.

Recent detailed simulation work has been done for the solar system model used in a Solar Index effort. The simplified approach which is

described in the last section of this document was compared with the detailed simulation results. Figure 9 shows the results for 40 days of simulation versus the numbers calculated for the Solar Index for those days. Real weather data was used and then was reduced to get percent of sunshine and average ambient temperature for those days. For the 40 days depicted in Figure 9, the average error was approximately 1% overprediction by the Index method and the standard deviation of that error was approximately 7%. If the errors were normally distributed, then approximately 2/3 of the time the Solar Index would be within simulation results, $\pm 7\%$, or within the simulation results, $\pm 14-15\%$, 95% of the time. As a tool for generation of the Solar Index, simulation would probably be the most accurate method. However, different simulation programs and different analysts will get different results using simulation tools. Frequently, the integration error alone, using detailed simulation techniques, is on the order of 5%. Approximately the same error magnitude is seen between the reduced simplified methodology and simulation as between different analysts and different simulation tools for the same problem. This argument leads the author to believe that this reduced methodology is as good as detailed simulation and that there is certainly no evidence to believe that detailed simulation would produce any better or more accurate results. The simulation strategy would be substantially more costly.

Many individuals, including people within the National Weather Service, have suggested that a service hot water system should be built and installed at each one of the Solar Index sites and monitored and then the results reduced automatically at the end of each day for

Figure 9. Comparison of Solar Index predictions versus detailed simulations for 40 days. The mean error was about 1% overprediction by the Solar Index method. The error standard deviation was about 7%.

dissemination to the media. This particular methodology has a certain amount of charm in that it can be used quite effectively as a public interest tool because those generally interested can go out and see and lay their hands upon the real system. An analysis or design tool is very hard to touch. Associated instrumentation accuracy is questionable, however; the author of this report has looked at many different sets of performance data and has found errors to usually be on the order of 10-20% on a daily schedule and sometimes as large as 50%. The error of interest here is the unaccounted energy quantities that somehow escaped from the instrumentation. Probably the most important reason for not installing real systems is the cost. It would probably require constant manpower requirements in each city and then several thousand dollars for installation and setup. This may be a real alternative later on when regional solar energy centers come in to much more prominent view and energy extension type of offices become evident in most metropolitan cities.

Another primary area of concern has been the type of weather data used. Many individuals would rather see total horizontal radiation used instead of percent of sunshine. Utilization of radiation values would possibly result in more accurate Solar Index numbers. The National Weather Service to date has approximately 20-30 pyranometers stationed around the country in certain metropolitan locations. At the current time, and at most stations, the National Weather Service monitors the pyranometers only with cassette recorders. They do not look at the data points on an hourly basis, but simply mail the cassettes in at the end of each month. This makes obtaining hourly radiation data in real time almost impossible.

An alternative to get around installing a real service hot water system in each city and to present the solar system costs could be to install real time weather instruments in each city; that would not be directly tied to the National Weather Service, but would be for the sole purpose of generating the Solar Index. Again, the manpower requirements would probably be prohibitive and the cost would be astronomical; especially when adding up the numbers that would be needed to cover each metropolitan area of the country.

The current procedure uses a computer model to estimate solar radiation levels. To provide an indication of the radiation model's prediction accuracy, the Solar Index was calculated using measured global radiation, minutes of sunshine and the predicted radiation. Of six SOLMET[†] locations (all but Sterling, Virginia are listed in Table 2) observed, only three reported both global radiation and minutes of sun. Of these three, two, Albuquerque, New Mexico and Boston, Massachusetts, recorded observations every hour. Figure 10 illustrates the Solar Index estimated using both minutes and synthesized radiation versus the Solar Index based on the reported global radiation for these two locations.

The values used to create Figure 10 were further broken out and the error was calculated against the Solar Index as produced using actual measured radiation. Figures 11 and 12 display these errors for the Solar Index calculated using minutes of sunshine. The Solar Index calculated using the cloud model exhibited a slightly wider spread, but did not display the systematic error seen when calculating it using minutes of sunshine. The Solar Index calculated using minutes of sunshine is particularly susceptible to error when the minutes of sunshine recorded is equal to 0. In these

[†] See Appendix C for more information.

situations, a great deal of radiation can actually be observed and collected by a solar system. This is true for real systems as well. Later in the paper real data will be presented for systems built and monitored by the National Bureau of Standards. They were able to show that even on completely overcast days the systems in general collected some energy. It takes a combination of dense cloudiness and cold temperature to completely turn a system off throughout the whole day.

Estimating the Solar Index with the measured global radiation as the basis of comparison, the prediction using minutes of sun was found to overpredict by 4.4% (Table 2). The Solar Index, based on the synthesized radiation, had a standard deviation 1% greater than that using minutes. To show the minimal increase in error, the mean percent error and standard deviation of the Solar Indices calculated with both minutes and synthesized radiation are tabulated in Table 2.

Figure 10. Solar Index calculated using measured total radiation versus the Solar Index escalated using estimated radiation and reported minutes of sunshine for Albuquerque, NM and Boston, MA.

SOLAR INDEX ESTIMATED USING THE RADIATION PREDICTION MODEL

Figure 11. The error observed when estimating the Solar Index using the radiation prediction models as compared to the Solar Index calculated using actual radiation.

SOLAR INDEX ESTIMATED USING MINUTES OF SUNSHINE.

Figure 12. The error observed when estimating the Solar Index using minutes of sunshine as compared to the Solar Index calculated using actual radiation.

TABLE 2.* MEAN ERROR ($\hat{\mu}$) AND STANDARD DEVIATION ($\hat{\sigma}$) ESTIMATES OF THE DIFFERENCES OBTAINED WHEN CALCULATING THE SOLAR INDEX IN TWO WAYS: 1) USING MEASURED RADIATIONS VERSUS ESTIMATED RADIATION, AND 2) USING MEASURED VERSUS MINUTES OF SUNSHINE.

Location	Month	Act. Rad. vs. Model		Act. Rad. vs. Min	
		$\hat{\mu}$	$\hat{\sigma}$	$\hat{\mu}$	$\hat{\sigma}$
Boston, MA	Jan	2.20	14.02	-9.27	14.39
	June	4.41	12.00	-3.59	13.01
	April	8.07	18.21	-7.66	11.75
	July	2.97	11.38	-2.63	9.77
	Oct	7.53	10.00	-7.07	11.31
Albuquerque, NM	Jan	5.62	6.11	-1.75	7.97
	April	3.20	5.20	0.83	5.29
	July	2.55	7.05	-1.07	5.51
	Sept	3.10	8.66	0.67	6.63
Nashville, TN	Jan	5.25	19.54	-4.33	8.25
	April	-2.24	16.30	-3.62	7.42
	June	0.03	11.22	-4.03	7.98
	July	2.80	13.34	-5.30	7.90
	Oct	3.21	12.58	-2.32	13.43
Santa Maria, CA	Jan	5.70	7.11		
	July	3.14	4.49		
Seattle, WA	Jan	8.20	18.40		
	July	0.34	11.35		

* Sterling, VA was not included because there were no recorded minutes of sunshine and the radiation data was only reported every three hours.

To investigate the radiation model's prediction-ability using observations reported every third hour, Nashville, Tennessee was analyzed. Figure 13 represents the Solar Index calculated with both minutes and synthesized radiation versus that calculated using the reported global radiation. In the winter months, since the days are extremely short, the synthesized radiation was based on three observations. This induced a significant amount of scatter since Nashville is particularly susceptible to days which are sporadically overcast and clear. The model is restricted to assuming the interim sky condition is a continuous function of the observations.

The comparison of the Solar Index estimated with the synthesized radiation to that calculated with minutes of sun showed the standard deviation to increase 5.6%. However, the Solar Index calculated with the synthesized radiation had a 1.8% mean error in contrast to a 3.9% mean error for that calculated with minutes of sun.

Figures 10 and 13 help demonstrate the difficulty in predicting radiation on overcast days. The sunshine switch* registers only when the radiation intensity is adequate to cast a shadow. However, the threshold for the solar switch is not necessarily the threshold for the solar system. This causes severe overprediction of the solar system's performance using minutes of sun when the cloud cover is extremely opaque and the radiation intensity is below the solar switch's threshold.

The next area of concern is the variation of weather in the metropolitan areas from where the weather is reported which is usually at airports. Figure 14 depicts the Solar Index as calculated and then recalculated with a certain amount of noise added to the percent of sunshine and ambient temperature data. This was done to display the

* A sunshine switch records minutes of sunshine which is transformed into percent sunshine.

Figure 13. Solar Index calculated using measured global radiation versus the Solar Index calculated using estimated radiation and reported minutes of sunshine for Nashville, TN.

Figure 14. Comparison of calculating the Solar Index and then adding random noise and then calculating the Solar Index again for 20 days for 4 cities. The mean error was about 1% with the noisy inputs producing an over prediction. The error standard deviation was about 8%. The inputs varied were percent of possible sunshine and average temperature.

randomization that would occur due to micro-climate variations. In other words, let's say a specific set of data were recorded for Denver, Colorado. The percent of sunshine and the ambient average temperature in the various metropolitan areas surrounding the area may be higher or lower. The random set of noise was created and added to these cities' data and then the Index number was recreated to reflect the possible randomization in data or even error in reporting data. The four cities for which this plot was created were Denver, Atlanta, Los Angeles and Washington, D.C. Standard deviation of the noise for percent of sunshine used was 15% and the standard deviation of the noise added to the average ambient temperature was 3°F. The resultant was the mean error of 1% overprediction and a standard deviation of approximately 8%. This particular plot is very important in that it affirms the fact of uncertainty. The numbers predicted by any design or analysis tool currently available for the solar systems are only estimates. The probability is close to zero that the user would ever realize that estimate exactly. The user's resultant load fraction, or any other system performance factor, lies somewhere in the neighborhood of the estimates. Individual user variation, difference in solar system installation and variation in off the shelf components causes much variation from system to system. Several supposedly exact systems can be installed simultaneously and monitored closely and the resultant performance would vary.

In an effort to compare the Solar Index methodology against real data the National Solar Data Network demonstration data sets have been reviewed along with descriptions of the systems involved; it was observed that very, very few of the systems closely resembled residential service hot water systems. Two systems resembled service hot water systems, but they were

large commercial installations; one was a laundry and one was a hotel. However, the data for the Aratex Laundry and Hogates Restaurant were reviewed and compared with the SOLCOST Program's monthly predictions for a reduced set of data points.[†] (See Figure 15.) The results were quite good in agreement. The results are inconclusive at best but add a small amount of confidence to the whole effort. More importantly, detailed instrumentation data was obtained from the National Bureau of Standards through Dr. Jim Hill and his associates Hunter Fanney and Stan Liu. One season's performance data was obtained for six different service hot water systems. Two of the systems were judged appropriate for the analysis and the data was reduced. After filtering to obtain data sets for days that could easily be compared with some amount of confidence, approximately 30 days of data were obtained. Reduction of the data turned out to be a major project. The data that came from the National Bureau of Standards was non-uniform and in a non-standard format which required a great deal of labor and computer time for reduction. The data has been reduced for as many days as seemed appropriate and was compared with SOLCOST Program projections; the results are quite encouraging and are shown in Figure 16. The annual load fraction of the systems monitored by the National Bureau of Standards is in the neighborhood of 60% on an annual basis, which is fairly close to the design point used for the Solar Index systems.

The mean error observed when comparing the Solar Index methodology versus the reduced measured data was about 1.5% with a standard deviation of about 8.7%. In an effort to see how significant this spread.

SOLCOST VALIDATION RESULTS - SERVICE WATER HEATING

Figure 15. SOLCOST Validation Results - Service Water Heating

Figure 16. Solar Index predictions as compared to a real system maintained by the National Bureau of Standards in Gaithersburg, MD. The Solar Index method predicted on the average a 1.5% over prediction. The standard deviation of the error was about 8.7%.

in data was, a sensitivity analysis was performed. This analysis indicated that an error spread of less than 10% was within the expected one standard error band that would be achieved due to uncertainty in the real systems specifications, such as the collector efficiency or the storage heat loss coefficient. The National Bureau of Standards recently published comparisons between measured monthly load fractions and SOLCOST Program predictions. The results of this comparison are shown in Figure 17.

One of the objectives of this project was to estimate the final overall expected error that might be observed over the long run. The long run mean error will be quite small. There is no reason to believe that it will not be close to zero. The spread about the mean error for daily predictions will not be near zero, however. The sources of any spread or daily error is the error seen when using estimated radiation and then the error produced by the SOLCOST Program itself. The resultant standard deviation of the daily error will be a combination of these two sources. Therefore, the daily error will be a function of the local climate. Simplifications can be made. For predominantly clear locations, the error observed caused by the radiation estimate modes had a standard deviation of about 7%. This error deviation was about 14% for areas that exhibited some daily cloudiness. The SOLCOST Program's errors, when using measured radiation, had a standard deviation of about 9%. The resulting error spread is:

	Solar Index Daily Error Standard Deviation
clear locations	$\sqrt{9^2 + 7^2} = 11\%$
cloudy locations	$\sqrt{9^2 + 14^2} = 17\%$

SOLCOST VALIDATION RESULTS - NBS DOMESTIC HOT WATER SYSTEMS

Figure 17. SOLCOST Validation Results - NBS Domestic Hot Water Systems

This implies that about two-thirds of the time the Solar Index estimate will lie within one standard deviation of a value that would be realized by a real solar system.

In concluding this section, a certain amount of uncertainty exists in the Solar Index number as compared to what a real system performance would be for that site. This is caused by two things: 1) the analysis and prediction tool that is used to create the Solar Index numbers has a certain number of uncertainty embedded within it; also, 2) no one knows for sure exactly how the real system would perform because several systems supposedly constructed in an equal manner have different results. If the Solar Index number is to be used for public awareness purposes only, and it is not to be used as an exact measure, it is certainly, in the authors' estimate, the best tool for doing that task. Also, there are many reasons to indicate that as far as an estimate of possible system performance, it is probably one of the best tools available. There is no indication to believe definitively that there are any that are a whole lot better. There are possibly detailed simulation programs which would produce slightly better results. However, due to the uncertainty of simulation, one cannot come to a definite conclusion as to whether one is right and the other is wrong.

Future Efforts

The number of sites serviced by the effort will gradually increase to about 250 in calendar year, 1980. The first to be added will be in prime market areas (see Table 1). When this target has been achieved, the effort will be re-evaluated to see if it is desirable

to increase the effort further. Also in this time frame, the Index will begin to be delivered seven days per week for those locations where weather service data is available. If it is not available throughout the whole week, it will be delivered five days per week.

Ever since the effort started in 1978, it has been one of the primary objectives to have the Index numbers delivered in a fashion so that they could be included in the early evening T.V. news broadcasts. To accomplish this objective a predictive capability will be added so that the expected Solar Index can be delivered in the mid-afternoon time frame to the using media. An updated Solar Index will be delivered later in the day, as it is currently.

Several individuals have indicated the desire for possibly generating indices for alternative systems such as passive or space heating systems. Such indices can be defined but require some preliminary investigation to determine whether or not they are desirable and for which audience they would be applicable. Such an evaluation will take place during the next few months of operation and then the Department of Energy will make the decision as to whether or not Solar Indices will be generated and delivered for alternate types of solar systems, both passive and active.

Appendix A

SUMMARY OF SOLCOST METHODOLOGY (SYSTEMS PERFORMANCE)

There are two parts to the SOLCOST analysis, consisting of: 1) a solar system performance analysis, and 2) a life cycle cost analysis. The following sections are intended to give the user an overview of the key elements in the SOLCOST solar systems analysis.

Solar Insolation Model: SOLCOST computes hourly solar fluxes incident on the tilted collector for average clear day and average cloudy day conditions for each month of the year. The insolation model is based on a modification of the method contained in Chapter 59 of the ASHRAE Applications Handbook.

Solar Collector Performance: The hourly insolation values are passed to the solar collector performance segment where they are used with time varying ambient temperatures and varying inlet temperatures to predict instantaneous solar energy collection rates. The collector's performance is modeled with an efficiency curve, using the following procedure:

- a) On one hour steps through the day, the parameter $(T_{in} - T_{amb})/q_i$ is computed, where

T_{in} = inlet fluid temperature to the collector

T_{amb} = ambient air temperature

q_i = incident solar energy rate upon the collector.

Beginning at dawn, the inlet temperature is set equal to the storage temperature for the particular solar system being analyzed. The SOLCOST program iteratively solves for the dawn storage tank temperature. The ambient temperature is determined each hour by fitting a curve through the average

minimum and maximum temperature which are assumed to occur at sunup and midafternoon respectively.

- b) Collector efficiency (η) is calculated for the value of $T_{in} - T_{amb})/q_i$ and the rate of solar energy collection (q_{coll}) is computed from:

$$q_{coll} = \eta q_i$$

- c) A heat balance on the storage tank is performed after each time step and the resulting inlet temperature rise is computed from:

$$\Delta T_s = \eta_c (q_{coll} - q_{load} - \text{losses}) / m_s C_{p_s}$$

where:

ΔT_s = the change in storage temperature during the time step $\Delta \theta$ (1 hour)

q_{coll} = rate of energy collected by the collector

q_{load} = energy use rate to satisfy water heating load; the load is varied throughout the day

η_c = efficiency of the collection subsystem (pipes, etc.)

m_s = storage mass in pounds

losses = thermal heat losses

C_{p_s} = specific heat of storage water

d) The above steps are repeated for each hour of the day for both the clear day and cloudy day insolation profiles. Then the solar collection rates are integrated over the day and weighted with the percent of possible sunshine value in the following manner:

$$\begin{array}{rcl}
 Q_{\text{ave/day}} & = & PP \times Q_{\text{clear day}} + (1.0 - PP) \times Q_{\text{cloudy day}} \\
 \text{collection,} & & \text{collection,} \qquad \qquad \text{collection} \\
 \text{Btus/ft}^2 & & \text{Btus/ft}^2 \qquad \qquad \text{Btus/ft}^2
 \end{array}$$

where: $PP = (\text{percent of possible sunshine})/100.$

This weighting of the clear and cloudy day collector performance with the percent of possible sunshine accounts for the variability of the incoming solar energy due to random cloudiness conditions. Confidence in this approach is based on the good correlations obtained between SOLCOST and other sizing methods which have been developed, specifically the FCHART method of Klein, Beckman and Duffie. Their method is based on hundreds of yearly hour by hour simulations which have been empirically condensed into the FCHARTS. Also, the service hot water model has been compared favorably with measured actual performance data.

The Solar Index is calculated by specifying the daily maximum and minimum temperatures and the percent of sunshine, or alternatively, the total daily horizontal radiation. SOLCOST can calculate the percent of sunshine given the latter. Numerically, the Solar Index is defined to be the fraction of the energy supplied by the solar system to heat 80 gallons of water from the ground temperature to the desired temperature, 120°F in this case. More specifically:

$$\text{Solar Index} = \frac{\text{Energy Collected} - \text{Storage Loss Energy}}{\text{Energy to heat 80 gallons of water from 50°F to 120°F}} \times 100.$$

The Solar Index is calculated daily, 5 days per week for those locations listed in Table 1.

Appendix B

WEATHER WIRE DATA COLLECTION AND REDUCTION

The Solar Index will be based on the information typically reported by the National Weather Service (NWS) and Federal Aviation Administration (FAA) weather observing stations. The basic observations, or more commonly called aviation observations, include information such as visibility, altimeter setting, sea level pressure, cloud base height, cloud amounts, wind speed and direction, ambient temperature, dew point temperature, severe weather and obstructions to vision. The NWS and FAA observers are responsible for transforming each hourly observation into a combination of codes, contractions, symbols and abbreviations. The resulting descriptions are then disseminated nationwide by means of the teletypewriter networks. To acquire this information on a real time basis, it was necessary to gain access to these networks. Rather than expending the money and labor to install the required hardware in-house, the services of a private consultant were employed. The consultant, by means of an advanced hardware system and trained analysts, accesses the multitude of information disseminated over the service C, service A and service O teletypewriter systems.* Then users, such as the mini-center, are able to purchase just the information specific to their needs. The consultant segregates the desired data and places it in a private computer account on their mainframe. The SOLCOST Service Center personnel are responsible for maintaining the account and processing the information.

The data allocated to the mini-center includes all the record and special surface observations. A representative example of the information is illustrated in Figure B-1.

* For more information on these systems, consult the "Operations of the National Weather Service", U. S. Department of Commerce, January, 1978, sold by U. S. Government Printing Office, Washington, D.C. 20402, Stock No. 003-018-00087-3.

HVR SA 1458 200 -OVC 15 352/-5-12
 21 1458 200 -OVC 15 352/-5-12/3006/036 CIG LWR SW SU SW 303 1006
 BGM SA 1457 250 -SCT 20 353/-8/-14/3408/037/ 302 1001
 S06 SA 1452 E60 BKN 75 OVC 7 145/10/-3/030612/982/80802 UA
 GEGG:TPRP QRRF FLO70 /TP 320 /IC LGT
 S80
 BTF SA 1453 -X E15 OVC 11/2V 8- 341/-6/-15/0104/022/R34UV11/24
 S3 USRY 1V2/THN SPTS IN OVC/ 50003 1021 90403
 LWT RS 1452 -X E20 OVC 85- 311/-5/-15/3006/015/SA/ 500
 HLN SA 1456 W 12 X 11/25- 292/-1/-14/3107/012/ 30201 90404
 MSD SA 1446 32 SCT M50 BKN 200 OVC 10 216/5/-5/0917025/999 SE10/
 60300 1501 UA /OV MSD 1440 FL UKN /TP 8727 /SK 80 OVC 110
 OVER ALL TOPS 210 /TB LGT CHOP 80-110
 LWS RS 1455 15 SCT M28 OVC 10 080/23/13/0812/972/ MTNS OBSCD SW/ 705 15//
 TWF
 WEY SA 1430 WSX 5F 129/7/5/0000/H/ 60206 90436 04 NOSPL
 MISSING
 BTH SA 1450 25 SCT F45 BKN 200 OVC 85- 226/-4/-20/1508020/985
 OCNL DRFTG SNW/ 500
 RZN SA 1445 E12 BKN 480 OVC 10S- 262/-3/-10/3105/001/IEE415B44 MTN TOPS
 OBSCD ALONGS/ 103
 LVM SA 1455 E30 BKN 50 OVC 20 273/-5/-18/0915/003/PASS W AND MTNS
 ALD15 OBSCD THN SPTS IOVC DRFTG SNW/ 307 UA /OV 7E LVM 1445
 FL 100 /TP PASF /TB LGT CHOP
 MLS SA 1455 W12 X 35-F 327/-1/-4/3307/031/ 207
 RLN SA 1445 W20 X 15- 235/-4/-8/0413/987/ 303/NOSPL
 BOI SA 1455 W3X1/HF 038/28/26/3003/960/ 308
 SHR
 WRL SA 1454 E28 OVC 7 262/4/0/3408/008/ SE40 307
 IDA RS 1455 M25 OVC 15 066/22/18/3406/965/ 303
 QNG
 BIL SA 1455 M11 BKN 25 OVC 4S- 302/-3/-7/0400/019/30300 15// 90404
 QDV
 SDY
 OLF
 BYI SA 1455 E50 BKN 100 BKN 15 025/38/31/1716/960/ 307
 TWF SA 1446 E50 BKN 100 BKN 20 40/31/2012/956
 PIH SA 1452 M32 BKN 00 OVC 20 056/30/24/3407/965/ SWU DMTNS S/ 207.157/
 LND SA 1455 E15 OVC 6S- 184/12/9/3200/988/303 15//
 CRR RS 1452 -XM10 OVC 1S-F 214/7/5/3610/994/R070000YR F5 /30300 17//
 HLD
 RK3 SA 1457 20 SCT A0 SCT E120 OVC 40 085/27/25/0000/970/ BINOVC 302
 RWL RS 1450 E18 BKN 40 OVC 20 085/33/30/0000/976
 LAR SA 1453 60 SCT E140 BKN 180 OVC 30 134/19/14/E1405/980/ ACSL 8W
 CLDS TFG MTNS W 500
 CYS SA 1453 W2 X 1/RS-F 181/17/17/1808/909/ R26UV1/8 ZLE35 SH10/
 30500
 EVW SA 1451 E20 BKN 30 BKN 30 30/H/1806/969/ 31200/NOSPL
 JAC SA 1435 W10X 1S- 24/22/1502/970
 RIH
 SHN SA 1500 FIND
 480 SA FIND
 3HT SA 1450 E15 OVC 4F -5/-9/1204/H/ 400 95 90404
 4/80 1010H113
 61400210
 6/0000/981 PK WND ON 4000000 RND
 1V1 SA 1440 W1X1SW-F 33/30/0000/H/NOSPL
 4ZL-F 205/20/16/1007/000/ZLR35/ 003
 152/26/21/0203/992/ 400 17//
 2/NOSPL/ 400 43905
 OV2 SA 1500 FIND
 4LJ SA 1440 E20 OVC 15 184/24/20/0604/H/NOSPL/ 107 15//
 4U5
 4U8

Figure B-1. Raw Weather Wire Service Data as it is Received.

As a primary filtering program, the mini-center developed software to reduce the data to only the record surface observations relating to the locations serviced by the Solar Index project. Figure B-2 represents the reduction of the data shown in Figure B-1 by the primary filter.

After completion of this stage of processing, the data is transferred from the consultant's computer to a private account on a large local mainframe. This was accomplished by creating system level software and installing it in a small in-house computer operated terminal. The terminal, operated by an analyst, physically takes the data and converts it to a language the local mainframe recognizes.

The data then undergoes a second evolution of reduction. The mini-center analysts execute a secondary filter capable of, character by character, transforming the hand scribed codes and abbreviations into a compacted block of data. Since the observations are coded by hand, the secondary filter must be liberal, allowing for errors such as missing characters, omitted data, data improperly formatted, etc. This software has been flow charted in Figure B-3 and the result is illustrated in Figure B-4. However, one hundred percent conversion is not possible. If errors in the observations are severe, omitting information such as cloud base height or amount, the information is useless. After the secondary reduction is completed, the mini-center saves the information on mass storage devices.

When a sufficient quantity of information has been reduced, the analyst retrieves copies to be further processed. The flow chart shown in Figure B-5 demonstrates the software's logic. Refer to Appendix C

CMH SA COR 1252 M28 OVC 10 SW- 114/29/17/2115/984
 BTU RS 1359 W12 X 1S- 115/9/4/1814/984/ LSR18P
 PWM SA 1357 120 SCT E200 OVC 20 152/9/-11/0000/998
 CON SA 1356 100 SCT E200 OVC 20 151/8/-8/1603/995
 BOS SA 1351 150 SCT E230 OVC 15 152/16/-5/2106/998
 PVD SA 1358 250- @ \ 15
 BAF SA 1350 E120 BKN 200 OVC 25 16/1/2110/998
 ROC RS 1351 15 SCT E38 BKN 80 OVC 5SW- 057/23/15/2113/967/THN
 SYR SA 1353 -XE15 BKN 40 OVC 2VS-B8 075/21/15/1713620/972/S4 USBY 1V3
 BGM SA 1355 W8 X 1S- 089/16/11/1909/970
 AVP SA 1355 15 SCT E25 OVC 21/25- 116/20/10/2506/983
 RDG SA 1340 E25 OVC 8SW- 27/26/2110/990
 CXY SA 1350 E40 BKN 12 135/29/14/1910/991
 RDG SA 1340 E25 OVC 8SW- 27/26/2110/990
 PHL SA 1351 E60 OVC 20 152/26/10/2113/998
 FNE SA 1350 E70 OVC 15 27/6/2317
 TTN SA 1350 E70 BKN 200 OVC 12 25/3/2212/993
 IAD SA 1354 65 SCT E80 OVC 20 143/29/13/1911/994
 DCA SA 1352 E80 OVC 15 156/32/16/2212617/999
 ORF SA 1353 80 SCT E250 BKN 7 196/33/12/2314/011
 DAN SA 1355 250 -SCT 15 182/30/13/2208/004/FEW CU
 GSO SA 1355 250 -BKN 15 183/31/10/2207/005
 RDU SA 1350 E100 BKN 250 BKN 20 193/30/19/1907/009
 BSP SA 1355 250-SCT 30 197/31/13/3204/009
 CAE SA 1355 250 SCT 15 211/36/16/2512/015
 HSV SA 1352 CLR 20 232/35/20/2307/020
 FTY SA 1350 CLR 20 33/18/2010/022
 ATL SA 1355 300- SCT 25 228/35/13/2812/018
 HGM SA 1354 250 -BKN 7 263/37/25/2807/031
 TPA SA 1348 150-SCT 10 281/46/36/0000/036
 PIE SA 1351 200-BKN 7 51/39/0705/035
 MIA SA 1351 CLR 7 263/57/44/3510/031/FEW CU OFSHR
 GRB SA 1350 CLR 12 176/14/4/3314/000/FEW SC
 MSN SA 1356 28 SCT 250 -SCT 10 184/18/8/3410/003/PRESRR SE29
 ORD SA 1351 M23 OVC 15 156/27/19/3316/997
 DPA SA 1350 M30 BKN 10 27/21/3215/997
 CGX SA 1350 E30 OVC 10 29/17/3115/997
 MDW SA 1350 M23 OVC 10 28/19/3310- PK WND 012 000ALSTG 997
 ORD SA 1351 M23 OVC 15 156/27/19/3316/997
 DPA SA 1350 M30 BKN 10 27/21/3215/997
 CGX SA 1350 E30 OVC 10 29/17/3115/997
 MDW SA 1350 M23 OVC 10 28/19/3310- PK WND 012 000ALSTG 997
 FWA SA 1353 E25 BKN 4V SW- 122/26/20/2712/985/ USBY 3V5
 CMH SA 1350 M25 OVC 6SW- 122/29/18/2313/986
 SDF SA 1353 250 -BKN 10 176/34/19/2511/004
 LOU SA 1350 35 SCT 250 SCT 10 33/28/2612/003
 MEM SA 1355 CLR 15 238/40/22/2205/023
 BIS SA 1352 -X 4 SCT E20 OVC 2S- 201/19/14/1308/004/S4
 FAR SA 1350 M110 OVC 20 245/2/-5/0605/018
 DLH SA 1355 250 -BKN 15 224/0/-7/3205/009/SC OVR LK
 MSP SA 1355 E200 OVC 15 233/13/0/3611/017
 RAP SA 1354 50 SCT 90 SCT E230 OVC 35 162/32/27/1104/994
 DSM SA 1350 100-BKN E250 OVC 20 223/23/13/3615/016
 MLI RS 1354 M22 BKN 10 196/24/16/3112/009
 OMA SA 1350 E100 BKN 250 BKN 7 27/25/3506/016
 LNK SA 1350 E100 BKN 20 220/27/24/0000/014
 MCI SA 1346 50 SCT 140 SCT 250 -OVC 12 218/32/25/0000/015/WND LGT VRBL
 JEF SA 1345 250 -SCT 15 34/29/0000/015

Figure B-2. Part of the weather wire data after it has been sorted.

Figure B-3. Flow Chart Illustrating the Procedure Used in Reducing the Wire Service Short Hand into numeric values.

* "COR" designates that the entry is a correction to previous data received.

	Call letter identifier	Greenwich Mean Time	Sea level pressure in millibars	Ambient Temperature, °F	Dew Point, °F	Altimeter Setting, inches of mercury	Visibility, Statute Miles	Obscuring Phenomena Flag	Snow Flag	Fog Flag	# Cloud Levels	Cloud Amount Flag for 1st Layer	Cloud Base Height x 10 ² ft.	Cloud Amount Flag for 2nd Layer	Cloud Base Height x 10 ² ft.
BTU	1359	1011.5	9.	4.	29.84	1.00	0	1	0	0	0	12			
PWM	1357	1015.2	9.	-11.	29.98	20.00	0	0	0	2	2	120	6	200	
CON	1356	1015.1	8.	-8.	29.95	20.00	0	0	0	2	2	100	6	200	
BOB	1351	1015.2	16.	-5.	29.98	15.00	0	0	0	2	2	150	6	230	
BAF	1350	-99.0	16.	1.	29.98	25.00	0	0	0	2	4	120	6	200	
ROC	1351	1005.7	23.	15.	29.67	5.00	1	1	0	3	2	15	4	38	6 80
BGM	1355	1008.9	16.	11.	29.70	1.00	0	1	0	0	0	8			
AVP	1355	1011.6	20.	10.	29.83	2.50	0	1	0	2	2	15	6	25	
RDG	1340	-99.0	27.	26.	29.90	8.00	1	1	0	1	6	25			
CXY	1350	1013.5	29.	14.	29.91	12.00	0	0	0	1	4	40			
RDG	1340	-99.0	27.	26.	29.90	8.00	1	1	0	1	6	25			
PHL	1351	1015.2	26.	10.	29.98	20.00	0	0	0	1	6	60			
PNE	1350	-99.0	27.	6.	29.01	15.00	0	0	0	1	6	70			
TTN	1350	-99.0	25.	3.	29.93	12.00	0	0	0	2	4	70	6	200	
IAD	1354	1014.3	29.	13.	29.94	20.00	0	0	0	2	2	65	6	80	
DCA	1352	1015.6	32.	16.	29.99	15.00	0	0	0	1	6	80			
ORF	1353	1019.6	33.	12.	30.11	7.00	0	0	0	2	2	80	4	250	
DAN	1355	1018.2	30.	13.	30.04	15.00	0	0	0	1	1	250			
GSO	1355	1018.3	31.	10.	30.05	15.00	0	0	0	1	3	250			
RDU	1350	1019.3	30.	19.	30.09	20.00	0	0	0	2	4	100	4	250	
CAE	1355	1021.1	36.	16.	30.15	15.00	0	0	0	1	2	250			
HSV	1352	1023.2	35.	20.	30.20	20.00	0	0	0	1	8	1			
FTY	1350	-99.0	33.	18.	30.22	20.00	0	0	0	1	8	1			
MGM	1354	1026.3	37.	25.	30.31	7.00	0	0	0	1	3	250			
MIA	1351	1026.3	57.	44.	30.31	7.00	0	0	0	1	8	1			
GRB	1350	1017.6	14.	4.	30.00	12.00	0	0	0	1	8	1			
MSN	1356	1018.4	18.	8.	30.03	10.00	0	0	0	2	2	28	1	250	
ORD	1351	1015.6	27.	19.	29.97	15.00	0	0	0	1	6	23			
DPA	1350	-99.0	27.	21.	29.97	10.00	0	0	0	1	4	30			
C6X	1350	-99.0	29.	17.	29.97	10.00	0	0	0	1	6	30			
MDW	1350	-99.0	28.	19.	29.01	10.00	0	0	0	1	6	23			
ORD	1351	1015.6	27.	19.	29.97	15.00	0	0	0	1	6	23			
DPA	1350	-99.0	27.	21.	29.97	10.00	0	0	0	1	4	30			
C6X	1350	-99.0	29.	17.	29.97	10.00	0	0	0	1	6	30			
MDW	1350	-99.0	28.	19.	29.01	10.00	0	0	0	1	6	23			
CMH	1350	1012.2	29.	18.	29.86	6.00	1	1	0	1	6	25			
SDF	1353	1017.6	34.	19.	30.04	10.00	0	0	0	1	3	250			
LOU	1350	-99.0	33.	28.	30.03	10.00	0	0	0	2	2	35	2	250	
MEM	1355	1023.8	40.	22.	30.23	15.00	0	0	0	1	8	1			
BIS	1352	1020.1	19.	14.	30.04	2.00	0	1	0	3	9	-1	2	4	6 20
FAR	1350	1024.5	2.	-5.	30.18	20.00	0	0	0	1	6	110			
DLH	1355	1022.4	0.	-7.	30.09	15.00	0	0	0	1	3	250			
MSP	1355	1023.3	13.	0.	30.17	15.00	0	0	0	1	6	200			
RAP	1354	1016.2	32.	27.	29.94	35.00	0	0	0	3	2	50	2	90	6 230
MLI	1354	1019.6	24.	16.	30.09	10.00	0	0	0	1	4	22			
OMA	1350	-99.0	27.	25.	30.16	7.00	0	0	0	2	4	100	4	250	
LNK	1350	1022.0	27.	24.	30.14	20.00	0	0	0	1	4	100			
JEF	1345	-99.0	34.	29.	30.15	15.00	0	0	0	1	1	250			

Figure B-4. Weather information after it has been decoded into numeric data. From left to right the columns designate: 1) station identifier, 2) time, 3) atmospheric pressure, 4) ambient temperature, 5) dew point temperature, 6) altimeter setting, and 7) the remaining columns designate cloud height and type.

Figure B-5. Flow Chart Illustrating Logic Utilized to Convert Surface Observations to Percent Sun and Average Temperature

for the methodology utilized to determine the integrated global radiation. SOLCOST Service Center personnel execute this program throughout the day until the surface observations have been converted to percent of sun and average temperature for each location. The methodology, described in Appendix D, is then employed to derive the Solar Indices nationwide.

Appendix C*

DESCRIPTION OF CLOUD MODEL USED TO CALCULATE TOTAL DAILY INSOLATION

The purpose of the Solar Index is to increase the public's awareness that solar energy is available and could be working for them. Expansion in the past has been restricted to only the locations with some means of recording radiation and a sufficient staff to provide the information on a real time basis. In order to expand the Index, decrease labor costs and improve the reliability of delivery, it was necessary to "automate" the process used to calculate the Solar Index. This automation required obtaining the weather data through existing weather wires. This posed a problem since neither the actual radiation data or minutes of sunshine are currently disseminated over the weather circuits on a real time basis. As an alternative, it was decided to calculate the daily global radiation using information typically available from the National Oceanic and Atmospheric Administration (NOAA) and National Weather Service (NWS).

As radiation travels through the earth's atmosphere, it is scattered, absorbed and reflected by the atmospheric gases as well as clouds and particulate matter in the atmosphere. As shown in Figure C-1, some of the energy is reflected back into space by the top of the atmosphere and first cloud layer. The ozone, carbon dioxide, oxygen and water vapor in the atmosphere absorb a considerable amount of the incoming radiation. A further portion is scattered by dust and clouds.

Since neither global radiation or minutes of sunshine are available in real time for most locations in the United States, a model had to be selected to account for the attenuation realized by the radiation as it travels

* This development was by Lori Clifton, the SOLCOST Service Center, 2524 E. Vine Drive, Fort Collins, Colorado 80524.

Figure C-1. Atmospheric Effects on Solar Radiation Reaching Earth

(Abstracted from "Solar Heating and Cooling of Residential Buildings; Sizing, Installation and Operation of Systems," U. S. Department of Commerce, January 1977.

through the earth's atmosphere. The selection of the model used to synthesize the global radiation was based on several criteria. These included:

- 1) Use of typical meteorological data,
- 2) Efficient and economical to implement,
- 3) Provide reasonable accuracy in computing daily insolation.

With these criteria in mind, a combination of the clear day model developed by Hoyte [3] and the cloud transmission functions based on Haurwitz's work [2], was selected.

Hoyte's clear day model requires atmospheric pressure, total precipitable water, turbidity and the path lengths of carbon dioxide and ozone as inputs. Each parameter, if not available directly, can be easily derived from other information commonly reported by NOAA and NWS.

Hoyte's model accounts for all the major sources of attenuation to the clear day radiation, including scattering by dust and air, and absorption by water vapor, carbon dioxide, ozone and dust. The scattering ratio for pure air, also known as Raleigh scattering, is expressed as

$$s_a = 1 - f(m^*)^{m^*} \quad (1)$$

The factor $f(m^*)$ is a function of the pressure corrected air mass and is summarized in Table C-1.

The scattering ratio for dust is expressed

$$s_d = 1 - g(\beta)^{m^*} \quad (2)$$

The factor $g(\beta)$ is a function of turbidity, β , and is summarized in Table C-2. Since the turbidity is not typically measured by NOAA and NWS, a relationship expressing turbidity as a function of visibility was adopted [5]. This

TABLE C-1. VARIATION OF THE RALEIGH SCATTERING FACTOR, $f(m^*)$, WITH CORRECTED AIR MASS, m^*

m^*	$f(m^*)$
0.0	1.000
0.5	0.909
1.0	0.917
1.5	0.921
2.0	0.925
2.5	0.929
3.0	0.932
3.5	0.935
4.0	0.937

TABLE C-2. SCATTERING DUST RATIO FUNCTION, $g(\beta)$ AS IT RELATES TO THE ANGSTROM TURBIDITY COEFFICIENT

β	$g(\beta)$
0.00	1.000
0.02	0.972
0.04	0.945
0.06	0.919
0.08	0.894
0.10	0.870
0.12	0.846
0.14	0.824
0.16	0.802
0.18	0.780
0.20	0.758
0.24	0.714
0.28	0.670
0.32	0.626

relationship is

$$\beta = (3.91/\text{vis} - 0.01162)(.001(\text{vis} - 5) + 0.52) \quad (3)$$

The absorption ratio for water vapor is expressed

$$\alpha_1 = 0.11(U_1 + 6.31 \times 10^{-4})^3 - 0.0121 \quad (4)$$

where U_1 is the total pressure corrected precipitable water (g/cm^2). The monthly mean total precipitable water to 500 mb can be related to the dew point temperature, t_d , by the expression [7]

$$\ln U_1 = [.1133 - \ln(\lambda + 1)] + 0.0393 t_d \quad (5)$$

where λ , tabulated in Table C-3, is a function of latitude and season. To determine the total precipitable water to 250 mb, the values were multiplied by 0.81 [3]. Bolsenga found the correlation between total precipitable water and surface dew point decreased with decreasing time intervals. To account for both seasonal and latitudinal dependence, plus the smaller time intervals, Smith's correlation was multiplied by an adjusting factor of 0.75.

TABLE C-3. SEASONAL AND LATITUDINAL MEAN VALUES OF λ

Seasonal latitudinal zone (deg N)	Winter	Spring	Summer	Fall
0-10	3.37	2.85	2.80	2.64
10-20	2.99	3.02	2.70	2.93
20-30	3.60	3.00	2.98	2.93
30-40	3.04	3.11	2.92	2.94
40-50	2.70	2.95	2.77	2.71
50-60	2.52	3.07	2.67	2.93
60-70	1.76	2.69	2.61	2.61
70-80	1.60	1.67	2.24	2.63
80-90	1.11	1.44	1.94	2.02

The absorption ratio for oxygen is expressed

$$\alpha_2 = 7.5 \times 10^{-3} (m^*)^{.875} \quad (6)$$

where m^* is the pressure corrected air mass.

The absorption ratio for CO_2 is

$$\alpha_3 = 0.00235 (U_2 + 0.0129)^{0.26} - 7.5 \times 10^{-4} \quad (7)$$

where U_2 is the pressure corrected path length of CO_2 in cm.

For ozone, the absorption ratio is given by

$$\alpha_4 = 0.045 (U_3 + 8.34 \times 10^{-4})^{0.38} - 3.1 \times 10^{-3} \quad (8)$$

where U_3 is the ozone path length in centimeters at standard temperature and pressure.

The absorption ratio for dust is expressed

$$\alpha_5 = (1 - w) g(\beta)^{m^*} \quad (9)$$

where w is the albedo for single scattering and is taken to equal 0.95.

Thus, the beam solar radiation that theoretically reaches the earth's surface is given by:

$$I = (S_0)(\cos Z) \left(1 - \sum_{i=1}^5 \alpha_i\right) \quad (10)$$

Where S_0 , the solar constant, is corrected for the seasonal eccentricity of the earth's orbit and the zenith angle is corrected for the seasonal variations in the earth's orbital velocity.

According to Hoyte, the diffuse solar radiation for a clear day, is given by:

$$D = S_0 \cos Z \left(1 - \sum_{i=1}^5 \alpha_i\right) (0.5 s_a + 0.75 s_d) \quad (11)$$

where one half the Raleigh scattered radiation and three-fourths of the dust scattered radiation are assumed to be in the forward direction.

The additional diffuse component of radiation, G_+ , caused by the first order reflection between the atmosphere and the earth's surface, can be expressed as

$$G_+ = R_+ \left(1 - \sum_{i=1}^5 \alpha_i\right) (0.5 s'_a + .75 s'_d) \quad (12)$$

where R_+ is the radiation component reflected from the earth's surface on the first pass of the radiation through the atmosphere. Assuming the earth responds as a lambertian surface, the scattering ratios for dust and air are evaluated at 1.66 times the minimum optical air mass. The absorption ratios are determined at an air mass equal to the sum of the pressure corrected air mass and 1.66 times the minimum optical air mass. Thus, the total instantaneous global irradiance for a clear day can be stated,

$$G = I + D + G_+ \quad (13)$$

The transmission functions for various cloud types are tabulated in Table C-4. The total cloud transmission, TC , can be stated

$$TC = \prod_{i=1}^n \{1 - C_i(1 - \psi_i)\} \quad (14)$$

where C_i is the fraction of sky cover.

These transmission functions, excluding the cumulus and cumulonimbus cloud types, were derived by Haurwitz. However, since both cumulus and cumulonimbus are predominate cloud types, they could not be neglected. Initially, the transmission function for stratocumulus was substituted for cumulus, however, large underpredictions occurred. In an attempt to correct this, the new correlation (15) was derived:

$$\psi = .98 - .16 m^* \quad (15)$$

This relationship, since it is based on limited data of questionable reliability, cannot be considered exact but was substituted to avoid large systematic errors. The transmission correlation for cumulonimbus shown in Table C-4 appeared to be an accurate correlation [1].

TABLE C-4. TRANSMISSION EQUATION FOR SEVERAL CLOUD TYPES

Cloud Type	Equation
Fog	$\psi = 0.1626 + 0.0054 m^*$
Stratus	$\psi = 0.2684 - 0.0101 m^*$
Stratocumulus	$\psi = 0.3658 - 0.0149 m^*$
Cumulus	$\psi = 0.9800 - 0.1600 m^*$
Cumulonimbus	$\psi = 0.2363 + 0.0145 m^*$
Altostratus	$\psi = 0.4130 - 0.0014 m^*$
Alto cumulus	$\psi = 0.5456 - 0.0236 m^*$
Cirrus	$\psi = 0.8717 - 0.0179 m^*$
Cirrostratus	$\psi = 0.9055 + 0.0636 m^*$
Nimbostratus	$\psi = 0.1808 + 0.0569 m^*$

A new set of cloud transmission functions are presently being derived with more current, reliable data by Atwater [1]. When these functions become available, they will be incorporated in the present model. Thus, for a cloudy day, the total instantaneous global radiation is equal to

$$G' = (I + D)TC + G_d \quad (16)$$

To arrive at the daily total radiation, the hourly fluxes were integrated using the trapezoidal method.

The additional component of diffuse radiation due to the multiple scattering between the cloud layers and earth's surface was neglected. This results in a slight underestimation of the total global radiation whenever snow cover is present. The correlation which assumes the downward transmitted radiation is increased by the factor

$$G' = G \left(\frac{1}{1 - r_s r_a} \right) \quad (17)$$

where r_s is the surface albedo and r_a is the atmospheric albedo, was tested [12]. The atmospheric albedo for clear skies was set equal to 0.0685 [6] and for cloudy skies

$$r_a = \frac{0.13\tau}{1 - 0.13\tau} \quad (18)$$

where τ was the optical cloud thickness. These correlations were found to extremely overestimate the total global radiation on overcast days with snow cover.

The Solar Index will be derived using the hourly surface observations reported by NOAA and NWS. The information available includes the amount of sky cover and cloud base height for four cloud layers. The sky cover classifications

are broken into six categories: clear, scattered, broken, overcast, obscured, and partially obscured. Clear describes a sky condition where less than 10% of the sky is covered; scattered indicates a sky cover between 10 and 50%, broken, 60 to 90% and overcast, 100%. These six categories are further supplemented with an indication of whether more than half the sky cover is opaque. To reduce the possibility of introducing a systematic error by assuming, for instance, a cloud amount of 30% whenever the sky cover is reported as scattered, the model instead considers, with opacity as a weighting factor, the probability that a sky cover of 10, 20, 30, 40 or 50 percent could have occurred.

Since the cloud transmission functions are based on cloud type, it was necessary to develop a correlation relating cloud base height to cloud type. There was some overlap, but this was improved by determining the seasonal probability of occurrence. At the most, for the locations analyzed, the combination of basing cloud amount and cloud type on the information available from the surface observations increased the standard deviation for a 30 day period 3 percent and most frequently only 1 percent as compared to using the recorded cloud type.

The radiation model was tested using the SOLMET weather data [9]. During the testing period it was noted the clear day model consistently underestimated the mid-day flux but overestimated the flux at high zenith angles. It was suspected this was the consequence of:

- 1) The ozone path length was considered a constant at .318 centimeters. This could have very likely induced a slight error since the ozone path length varies proportionally with the zenith angle. Worldwide, the path length most frequently falls between 0.2 and 0.6 cm (6) which corresponds to attenuations of 2.1% to 3.4%, respectively.

- 2) The carbon dioxide path length, also a function of the zenith angle, was considered a constant equal to 126 cm. This could have induced an error, but nearly negligible since the attenuation of carbon dioxide is on the order of a magnitude of only one percent.

To minimize the effects of this systematic error, the function

$$A = .1213 * (\cos Z)^2 + .0044/U_1 - .05703 \quad (19)$$

was added to the instantaneous global transmission.

The cloud transmission functions, since only a function of corrected air mass and cloud amount, were another source of error in the model. These functions could not distinguish between an instant in time with a large amount of sky cover of high opacity to that with a large amount of sky cover but of low opacity. To reduce this effect, the total cloud transmission was multiplied by the factor:

$$TC' = TC(1/(B)^{.0253} - 0.1 B) \quad (20)$$

where B is the total sky opacity expressed as a fraction of one. However, since the exact opacity is not available, a substitution is made. Instead, the opacity will be approximated by taking the total sky cover and subtracting half the amounts of cirrus, cirrostratus and cirrocumulus [4].

However, all the errors cannot be attributed to the radiation model. Even with the corrections performed on the SOLMET data [9], the data cannot be considered absolute. The model's tendency to predict higher at sunrise and sunset and lower at solar noon than the reported global radiation may have been

the consequence of the pyranometer's cosine* response. The measurement errors inherent in the pyranometer's sensor, with respect to its temperature response and the angle of incidence plus the possibility of improper calibration, sensor degradation and foreign matter on the sensor's dome, cannot be neglected. In fact, in 1972, the strong doubts in the reliability of the solar irradiance data caused the National Climatic Center to stop publishing the monthly and yearly records. The estimated errors in the data ranged from $\pm 5\%$ to 30% [8].

Another typical measurement error is the observer's bias in determining the cloud amount, type and opacity. For instance, one common observer error is overestimating the cloud density at high zenith angles since the light intensity is considerably less. This was found to be particularly true for the summer months in Santa Maria, California.

The synthesized radiation is also susceptible to error on overcast days. The reported cloud amount and opacity, since they are human estimates, are more subjective. Also, the model only accounts for first order reflections, inducing an underprediction on overcast days. An attempt was made to account for the additional component of diffuse radiation due to the multiple scattering between the cloud layers and the earth's surface. However, the model extremely over-predicted on days when both the ground and sky albedo were high. This problem should be further investigated and resolved.

Another source of error in the radiation model particularly evident on cloudy days is the possibility of selecting the incorrect cloud type. Stratocumulus, cumulus and cumulonimbus have overlapping base height ranges. If cumulonimbus was mistaken for stratocumulus, an error results, but is minimal. However, on an overcast day, if stratocumulus were mistaken for cumulus, the model would underpredict by as much as 40% for that observation. The location

* A pyranometer's inability to measure accurately radiation levels at highly glancing angles is called cosine effect.

where this error was apparent was Nashville, Tennessee. Since the predictions were based on observations reported every three hours, the consequence of incorrectly interpreting the sky conditions were much more severe. Results obtained when calculating the Solar Index versus using the measured radiation are presented in the main text.

Radiation to Percent Sunshine

The cloud model just described transforms cloud cover statistics, temperatures and other weather observation data into radiation on a horizontal surface for each hour of daylight. At the end of each day, these hourly values are summed and then converted into percent sunshine. Percent of sunshine and average ambient temperature for the day are the parameters that are used in calculating the Solar Index on a daily basis. The actual Index generation process is more completely described in Appendix D. Percent Sunshine can be defined by the following equation:

$$\text{Percent Sunshine} = \frac{\text{Total observed radiation} - \text{average minimum radiation}}{\text{Average maximum} - \text{average minimum radiation}} \quad (21)$$

The average minimum and average maximum radiation values in the above equation are expressed and calculated on a monthly basis for each site. There are distinct values for January, February, etc. for each location on the Solar Index project. These are the average of the clear and cloudy day values that are expected at each location. The methodology for defining percent sunshine in this manner was first expressed by Angstrom [10] and modified by various other researchers in the field. Later work has been to more precisely define the average minimum and average maximum radiation values from each site. The more precise definitions are thoroughly defined in the SOLCOST User's Manual, Appendix A [11]. This reference has a bibliography of later works in the field.

The recent modification to Angstrom's work are primarily to incorporate clearness numbers which are defined per site which reflect micro-climate variations due to carbon dioxide, water content, dust and smog for clear days. Most of this work has been funded by the American Society of Heating, Refrigeration and Air Conditioning (ASHRAE) and contour maps expressing the clearness number for the United States have been printed in various sources, and most recently calculated for specific sites included in this SOLCOST manual. Concise definition of the clearness numbers is an item of current interest at the Solar Energy Research Institute (SERI).

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Appendix D

SOLAR INDEX CALCULATION PROCEDURE JRE

The current daily calculation procedure is very similar to the old one. Instead of using one data base table for a month where the inputs were percent of sunshine and average daily temperature (Figure 5 in main narrative), now there are two separate data bases (Figure D-1) where the inputs for each are percent sunshine* and ambient temperature. The primary difference for the two data base figures is that one is for the situation when the previous day was sunny (the percent sunshine was 100%) and the other is for situations where the previous day was cloudy (the percent sunshine was 0). In referring to Figure D-1, the reader will observe that if the previous day for a January day for St. Louis, Missouri had an average ambient temperature of 30°F and a percent sunshine of 70%, then the observed Solar Index would be 57 if the previous day was sunny. Similarly, if the previous day was cloudy, the Solar Index would be 75. The measure for sunny and cloudy days is percent of sunshine for the previous day. For example, if the previous day had a percent of sunshine of 50%, then a value half-way between 57 and 75 would be 66%. This added feature is very easy to utilize on a high speed computer. However, it is difficult to manage when creating the Solar Index numbers by hand or using small computers, as has been done in the past.

The information illustrated in Figure D-1 is shown in Table D-1. The data is stored in and utilized by a high speed computer each day the Solar Indices are calculated (see Figure D-3). The computer operation is queried for the percent of sunshine and the maximum and minimum temperatures for those locations where the information was not obtained or derived from weather wire data. Once all the Indices have been calculated for a time zone, the

* Appendix B describes the methodology used in determining percent sunshine.

SOLAR INDEX

Saint Louis, MO - January
(If previous day was sunny)

If the PERCENT OF POSSIBLE SUNSHINE IS 70 and the AVERAGE TEMPERATURE is 30, the SOLAR INDEX would be 57 if the previous day was sunny.

NOTE: Formulas: %SUNSHINE = percent of actual solar radiation received between clear and cloudy expected daily totals.

AVERAGE TEMPERATURE = sum of the maximum and minimum temperatures divided by 2

Figure D-1.a. For a given location and month the Solar Index can be determined graphically as illustrated.

If the PERCENT OF POSSIBLE SUNSHINE IS 70 and the AVERAGE TEMPERATURE is 30, the SOLAR Index would be 75 if the previous day was cloudy.

NOTE: Formulas: %SUNSHINE = percent of actual solar radiation received between clear and cloudy expected daily totals.

AVERAGE TEMPERATURE = sum of the maximum and minimum temperatures divided by 2

Figure D-1.b. For a given location and month the Solar Index can be determined graphically as illustrated.

TABLE D-1.a. NUMBERS USED TO PREPARE FIGURE D-1.a.

Month = 1		Solar Index for St. Louis, MO (previous day cloudy)					
Temperature		0	20	40	60	80	100
0		7.	24.	40.	55.	70.	83.
15		9.	27.	44.	61.	76.	91.
30		14.	32.	50.	67.	83.	99.
45		20.	38.	57.	74.	91.	108.
60		28.	46.	64.	82.	100.	116.

TABLE D-1.b. NUMBERS USED TO PREPARE FIGURE D-1.b.

Month = 1		Solar Index for St. Louis, MO (previous day sunny)					
Temperature		0	20	40	60	80	100
0		-1.	13.	27.	40.	52.	63.
15		-1.	15.	30.	44.	58.	70.
30		-1.	17.	33.	49.	65.	78.
45		3.	20.	38.	54.	71.	86.
60		8.	26.	44.	61.	78.	94.

Figure D-2. Solar Index Calculation Procedure

operator executes a program which reformats the data in a format compatible with the UPI news wire requirements. The operator also telephones the Solar Index numbers to the National Solar Heating and Cooling Information Center for transmission to the interested media who do not subscribe to the UPI wire service.