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An Introduction to Meteorological Measurements and Data Handling for Solar Energy Applications

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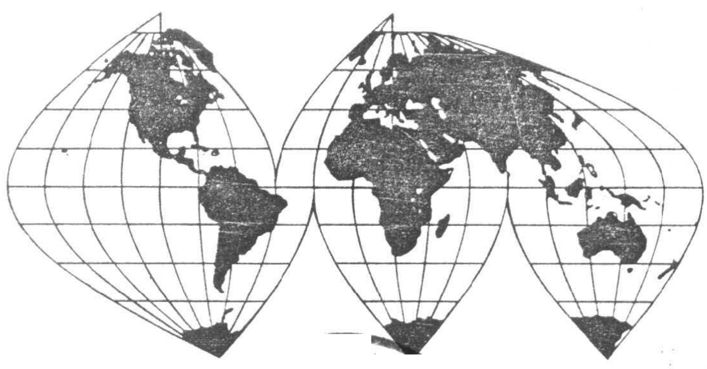
IEA
SOLAR R&D

INTERNATIONAL ENERGY AGENCY
programme
to develop and test
solar heating
and cooling systems

TASK IV–Development of an Insolation
Handbook and Instrument Package

AN INTRODUCTION TO METEOROLOGICAL MEASUREMENTS AND DATA HANDLING FOR SOLAR ENERGY APPLICATIONS



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PREFACE

Recognizing a need for a coordinated approach to resolve energy problems, certain members of the Organization for Economic Cooperation and Development (OECD) met in September 1974 and agreed to develop an International Energy Program. The International Energy Agency (IEA) was established within the OECD to administer, monitor and execute this International Energy Program.

In July 1975, Solar Heating and Cooling was selected as one of the sixteen technology fields for multilateral cooperation. Five project areas, called tasks, were identified for cooperative activities within the IEA Program to Develop and Test Solar Heating and Cooling Systems. Recognizing the importance of resource information, two of the five tasks within the program were designated as meteorological support tasks for solar heating and cooling research and applications. The five tasks and the respective operating agents (lead country responsible for the task) are:

I. Investigation of the Performance of Solar Heating and Cooling Systems – Denmark.

II. Coordination of R & D on Solar Heating and Cooling Components – Japan.

III. Performance Testing of Solar Collectors – Germany.

IV. Development of an Insolation Handbook and Instrument Package – United States.

V. Use of Existing Meteorological Information for Solar Energy Application – Sweden.

This report is one of two products of Task IV.

The objective of Task IV was to obtain improved basic resource information for the design and operation of solar heating and cooling systems through a better understanding of the required insolation (solar radiation) and related weather data, and through improved techniques for measurement and evaluation of such data.

At the February 1976 initial experts meeting in Norrköping, Sweden, the participants developed the objective statement into two subtasks:

1. An Insolation Handbook

2. A Portable Meteorological Instrument Package.

This handbook is the product of the first subtask. The objective of this handbook is to provide a basis for a dialogue between solar scientists and meteorologists. Introducing the solar scientist to solar radiation and related meteorological data enables him to better express his scientific and engineering needs to the meteorologist; and introducing the meteorologist to the special solar radiation and meteorological data applications of the solar scientist enables him to better meet the needs of the solar energy community.

To achieve the objective, papers have been contributed by members of the task and by invited guest solar scientists and meteorologists. These contributions have received peer review within the solar energy engineering and meteorological professions. Every effort has been made to serve not only the solar heating and cooling reasearch and applications data requirements but also the general solar energy community's meteorological data needs.

M. R. Riches, Chairman
Task IV

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Many individuals within the IEA and outside the IEA have contributed significantly to this Handbook. It is impossible to name them all. Therefore, on behalf of Task IV participants, I express sincere appreciation for your efforts and thank you for your contributions.

I would like to recognize E. A. Carter and his staff at the Kenneth E. Johnson Environmental and Energy Center of The University of Alabama in Huntsville for coordinating the final drafts and the reviews. Without their efforts no handbook could have been produced.

I would also like to acknowledge T. K. Won and E. J. Truhlar of the Canadian Atmospheric Environment Service for arranging and managing the final editing. This effort has turned a collection of excellent papers into a useful handbook.

I extend a special thank you to the authors and the Task participants. I know that much of your effort was an additional burden placed on top of an already demanding work load.

M. R. Riches

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CONTENTS

CHAPTER 1

THE SOLAR ENERGY SCIENTIST AND HIS METEOROLOGICAL DATA NEEDS

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1.1 The Problem and Objective

Assessing the solar radiation resource for solar energy applications is a multifaceted problem. The basic questions that must be answered to solve this problem are:

- Who are the end users and what meteorological parameters must be measured for them?
- What must be the data quality to meet user requirements (where quality includes accuracy, precision, and frequency of measurements, coupled with their geographic distribution and format of presentation)?
- What alternatives to measurement exist?
- What data are available and can these data be developed into a quality data set?

These questions overlap, and must be considered together. But the key to assessing solar energy potential is identification of the user community and—above all—its needs.

The objective of this section is to identify the user, define the meteorological parameters that must be measured, and introduce the quality requirements of the user. Subsequent sections and chapters of this Handbook will address (a) statistical analysis of the data, (b) geographic distribution, (c) format presentation, (d) alternatives to measurement, and (e) existing data sources.

1.2 The User

The solar radiation data user community can be classified in many ways: e.g., solar electrical and solar thermal systems, concentration ratio, or other application specific schemes. An example of solar thermal systems is provided in Figure 1-1, where solar thermal applications are classified according to temperature requirements for end use. The temperature requirements specify the concentration ratio: the latter is used to specify the solar radiation sensor requirements.

The classification scheme selected here divides the user community into two basic groups:

- The Researcher, and
- The Designer.

The Researcher is interested primarily in advanced solar energy applications and works at obtaining a better understanding of the physical and biological relationships between the applications and solar radiation. This includes the design of new systems and the adoption of known technologies for new applications in terms of use and geographic location. It should be noted that many of the solar energy researcher's basic data needs will be similar to those of other Earth scientists.

The Designers of solar energy systems are defined as those who plan, design and operate solar energy systems in settings other than a Research and Dev-

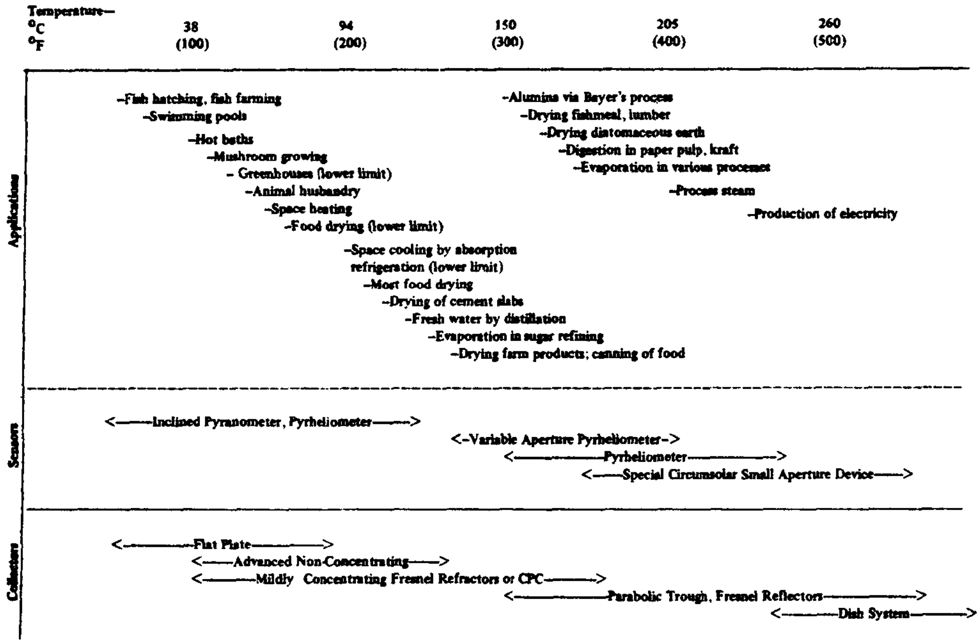

Figure 1-1 Required temperatures for various solar thermal applications (After Hoffman and Rapp, 1976)

elopment (R & D) mode. This group includes a wide range of engineers, chemists, biologists, as well as system owners, bankers, insurance agents.

1.3 Data Needs

The basic meteorological data required for solar energy applications are relatively few: air temperature, dew point (or relative humidity), wind velocity, and appropriate solar radiation data. For research and design activities, data requirements for solar energy applications are summarized in Table 1-1a and Table 1-1b. Specific network suggestions for meteorological measurements related to the users are discussed in the Appendix to this chapter. The specifications for a portable meteorological package proposed by IEA Task IV are shown in Table 1-2 (see references).

The Researcher requires sample, short-term, detailed data sets of the highest accuracy. These data include spectral content of the diffuse, direct, and reflected solar radiation as well as detailed, collateral knowledge of the atmosphere including hazard information. This information may then be used to predict a system component performance, to analyze the actual performance, to investigate optimization schemes, and to develop simplified models (both atmospheric and system design). Additionally, the research data base provides a limited data base (geographically) for future unanticipated uses.

The Designer requires limited research data, synoptic scale data sets, and data estimation and extension techniques. The Designer generally uses products of the Researcher, the national weather services and private data sources. Here the specific data include global, direct and non-horizontal solar radiation data, the principal meteorological parameters, and hazard information (hail, snow and wind loads, lightning, etc.). The Designer then may use this information to optimize and evaluate systems, to perform market analyses, and to plan monitoring sites for large scale applications. His principal concern is that these data are of the quality required for specific applications. That particular quality ranges from on-site and near-research quality for large applications to validated solar radiation models and collateral meteorological data for solar domestic heating, hot water, and cooling applications.

Table 1-1a

Solar Radiation Data Requirements for Research

Research Activity	Data Required
Solar Heating and Cooling of Buildings; and Agricultural and Industrial Process Heat Systems	
• Active Systems (e.g., Flat Plate and Evacuated Tubes) and Passive Systems	Several typical and extreme sample, short term detailed data sets of high quality non-horizontal (including vertical surfaces) and direct beam solar radiation data, IR, UV, albedo and other spectral data for heat loss, materials reliability and selective surface studies; sample micrometeorological studies to assess special design problems and unique solar applications, sample data at short time intervals (1 min) for special systems studies, detail atmospheric data.
• Active Concentrating Systems	As above; sample circumsolar data for CPC[1], Fresnel lens, etc., systems studies.
Photovoltaic Applications	
• Non-Concentrating Systems	As for solar heating and cooling with more stress on spectral information, including spectral diffuse and direct.
• Concentrating	As above, with more stress on direct beam data including spectral circumsolar information.
Solar Thermal Electric Systems	
• Distributed Systems (e.g., water pumping)	As solar heating and cooling, with stress on direct beam and circumsolar data.
• Large Scale Power Systems	As above.
Biomass Production (e.g., plantations)	Spectral quality of total radiation in sample climate regions for systems modeling.

(1)Compound Parabolic Collector

Table 1-1b

Solar Radiation Data Requirements for Design Applications

Design Activity	Data Required
Solar Heating and Cooling of Buildings; and Agricultural and Industrial Process Heat Systems	
• Active and Passive Systems	The same research data set; models to extend global, direct and non-horizontal data; synoptic scale global, direct, and non-horizontal measured data; meteorological data such as temperature, dew point, wind speed and direction, hail frequency, lightning frequency, etc.; standard year data sets; data atlas including monthly means, frequency statistics, etc., including solar and other meteorological variables; data at hourly intervals.
• Active Concentrating Systems	As above; circumsolar data included in model data sets, atlas and standard year data summaries, increased stress on direct beam.
• Site Specific Application (Active)	For large scale or unique systems, special site specific data and specially tailored data sets, such as cloud frequency data, seasonal measured data to test applicability of models (highly project specific).
Photovoltaic Applications	As solar heating and cooling, more stress on spectral in data included in summaries; site specific data at large scale power plants for design refinement.
Solar Thermal Electric Systems	Same as solar heating and cooling with increased need for direct beam solar radiation data; site specific data for large scale power plants.
Biomass Production	As for photovoltaic applications.

1.4 Summary of User Data Requirements

By dividing the solar energy community into these two groups—Researcher and Designer—it can be seen that meteorological data requirements for solar energy are similar to the needs for most other geo-scientists. Increased awareness of the requirements, initiation or modification of research programs, and some additions to the existing meteorological networks will be necessary to respond to the requirements. By increasing the dialogue between meteorologist and solar engineers these changes can be achieved and at the same time the solar engineer can be provided with the skills required for special site specific studies.

Table 1-2

Final Specifications for a Portable Meteorological Instrument Package

Item	Accuracy(1)	Precision(2)	Time of Integration
Direct (Normal Incidence)	±5% or ±25 W m^{-2}(3)	2%	10 min continuous(4)
Global (Direct plus diffuse)	±5% or ±25 W m^{-2}(3)	2%	
Solar on Inclined Surface	±5% or ±25 W m^{-2}(3)	2%	
Incoming IR (Inclined)	±10% or ±25 W m^{-2}(3)	2%	
Output of an Inclined Solar Cell (Opt.)	———	—	
Air Temperature	±1.0°C(5)	±0.5°C(5)	
Wind Speed	±1 m s^{-1} or ±5%(3)	±0.5 m s^{-1}	
Wind Direction	±10°	±5°	
Humidity (Opt.)	———	—	

1 Mean values when in absolute units related to a standard
2 Reproducability of the instrument
3 Whichever is the largest
4 Other integration times optional
5 Higher accuracy or precision optional

Notes:
- Recording method optional
- Record: Date, time, station identity, electronic calibration reference
- Battery takeover for clock, no other power specifications
- Final data output in SI units (from computer processing or possible unit itself)
- Must have a "jack" for on-station data readout equipment

PART 2

HANDBOOK USER GUIDELINES

1.5 Purpose

Part 2 of this introduction is to guide the reader to related portions of the handbook. Because individual topics have been addressed by different authors, similar general topics may be described in more detail in different chapters, but this may not be readily apparent to the reader. Also some topics are treated in detail for the atmospheric scientist which may be beyond the needs of the engineer and user of the information. This guide portion is intended to help the engineer select the topics for specific applications.

1.6 Sun, Earth and Atmosphere

Chapter 2 contains a comprehensive description of the sun-earth relationship which is useful in understanding the variation between local time and solar time and the radiation available for various collector types (flat plate and concentrating) and collector orientation. Applications of the principles may be found in Chapter 3, Section 3.5 and Chapter 4, Section 4.5. The atmospheric effects on the radiation available are described in Chapter 3; specific details of turbidity and precipitable water, in Chapter 8. The methods of measuring the atmospheric variables related to solar energy are described in Chapter 10.

1.7 Types of Radiation

The types of solar radiation measurement methods including all spectral ranges, are discussed in Chapter 4, i.e., global (horizontal), direct (suntracking), diffuse (sky radiation) and radiation available to typical flat-plate collectors at various orientations and locations. Spectral characteristics are defined in Chapter 2 and discussed in detail, including measurement techniques, in Chapter 5. Infrared radiation (wavelength approximately 1 to 100 micrometers, μm) is introduced in Figure 2-7. Chapter 6 describes loss of heat in infrared wavelengths to night sky. Circumsolar diffuse radiation (the forward scattering of the sunlight in the atmosphere resulting in the bright glare within about a 5 deg conical angle around the disc of the sun) and its relation to solar concentrators, is described in Chapter 7. Applications of solar radiation to collecting solar energy are described by Patel (1979).

1.8 Relationship of Clouds and Available Solar Radiation

Clouds and their accompanying weather are the most significant atmospheric phenomena restricting the availability of solar radiation at the surface of the earth. There is certainly a relationship between cloud observations and solar radiation measurements, but due to variations in cloud types, amounts and heights, a close relationship has been elusive. Therefore, the duration of sunshine derived from cloud observations provides only a rough estimate of solar radiation (see Chapter 10, Section 10.5.1). The measurement of the duration of sunshine is more closely related to the solar energy available. Chapter 9 treats the instruments for measuring the duration of sunshine; Chapter 8 addresses statistically the effect of short period fluctuations of sunshine on the useable solar energy and Chapter 10 provides a mathematical means of estimating solar radiation from the ratio of sunshine received to that available.

1.9 Albedo or Reflectance

The albedo or reflectance of natural and manmade surfaces is discussed in Chapter 3, Section 3.6. Appendix II, Table 3, provides specific ground reflectance values for various surfaces.