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STANDARD ASSUMPTIONS AND METHODS FOR SOLAR HEATING AND COOLING SYSTEMS ANALYSES

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ABSTRACT

This paper presents a set of inputs, assumptions, analytical methods, and a reporting format to help compare the results of residential and commercial solar system analyses being performed by different investigators. By the common use of load data, meteorological data, economic parameters, and reporting format, researchers examining, for example, two types of collectors may more easily compare their results.

For residential heating and cooling systems, three locations were selected. The weather data chosen to characterize these cities are the Typical Meteorological Year (TMY). A house for each location was defined that is typical of new construction in that locale. Hourly loads for each location were calculated using a computerized load model that interacts with the system and specified inputs characterizing each house.

Four locations for commercial cooling analyses were selected from among the existing sites for which TMYs were available. A light commercial (nominal 25—ton cooling load) office building was defined and is used in all four locations. Hourly cooling and heating loads were computed for each city and are available on magnetic tape from the Solar Energy Research Institute (SERI).

INTRODUCTION

An analysis of a solar heating or cooling system requires as inputs meteorological data (temperatures, dew point, insolation, and wind speed) and a well-defined structure to determine the load characteristics. In the past, researchers analyzing systems have generally not modeled identical buildings in identical locations using the same weather data. Since these parameters greatly influence the performance of the system, it is difficult for researchers to draw meaningful correlations when comparing systems or analysis methods. Also, because format and content of reported information often differs among investigators, a common format would be very useful.

This paper recommends a set of locations, meteorological data, building descriptions, and load calculation methods for use in analysis of both solar and conventional energy systems. Conditions are not meant to be ideal or typical in every sense, nor do they cover all climates or structures in the United States. Parameters and algorithms specified here are system independent (except for passive systems, which employ the building as part of the heating/cooling system) and should standardize the comparison of the results of analyses of solar and conventional energy systems and of analysis procedures. Methods outlined in this paper may be used by component designers, system designers, university researchers, and private consultants. Detailed illustrations of the applicability of this information and a more comprehensive treatment of the standard assumptions may be found in Ref. 1. Copies of this preliminary report are available from SERI. Because revisions and modifications will be necessary, comments from the user community are strongly urged. Every attempt will be made to incorporate these inputs into future revisions.

Much of the information contained in this paper was excerpted from two studies performed by Science Applications, Inc. (SAI) [2,3] and required common inputs for the simulation of systems in several locations. Through the development of standard inputs and analysis methods, the systems analyzed could be compared and significant conclusions drawn.

METEOROLOGICAL INPUTS

One obstacle to solar heating and cooling studies has been the lack of an accepted year of hourly meteorological data for computer simulations. Also, there are several methods that compute beam radiation from total horizontal radiation and a few algorithms that compute radiation on a tilted surface. Because these methods usually generate different results, they hinder the comparison of the simulation results of various systems. This section recommends one set of meteorological data (called TMY) and one algorithm for computation of beam radiation and radiation on a tilted surface.

The Typical Meteorological Year

Because the simulations of solar systems usually cover a year or less, it was desirable to develop a data base with shorter-term information than the SOLMET [4] data. The Department of Energy (DOE) contracted Sandia Laboratories to develop a typical meteorological year (TMY) for each station (except Stephenville, Tex.) using statistical selection techniques [5]. The 26 TMY tapes generated by Sandia Laboratories are available through the National Climatic Center in Asheville, N. C. By choosing a series of months that emphasize the typicality of global radiation, one can construct a year that is representative of long-term weather patterns at each of the 26 locations. Therefore, long-term average system performance can be predicted with a one-year simulation.

The American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) developed a Test Reference Year (TRY) [6] weather tape for 60 cities, in which the primary criterion for selection was ambient temperature. Although they do not include values for solar radiation, TRY tapes do indicate sky cover and cloud type. Hence, incident radiation can only be roughly estimated when one uses TRY data. Radiation is an important parameter in all solar systems analyses, as well as in conventional energy system evaluations.

Because it is a potential standard meteorological data base and contains information paramount to solar energy systems, the TMY was selected for analyses of all solar systems and performance comparisons between conventional and solar systems.

Radiation Components

The values for direct radiation that appear on the TMY tapes were computed according to the Randall algorithm, a technique developed at the Aerospace Corporation [7] and recommended by SERI.

The radiation received on an arbitrarily oriented surface, such as that of a flat-plate solar collector, is a combination of direct-beam, sky-diffuse, and ground-reflected radiation. Calculation of the direct component of the insolation for a tilted surface is a straightforward geometric transformation applied to the horizontal values that appear on the TMY tapes. However, the calculation of the ground-reflected and sky-diffuse components requires the introduction of assumptions about the nature and distribution of the sky-diffuse and reflected radiation. Many algorithms correlate global radiation with radiation on a titled surface. Tom Stoffel of SERI informed the author that an algorithm developed by Hay [8] of Canada has proved to be most accurate when compared with actual measured data on surfaces of varying tilt. This algorithm is recommended for use in computing radiation on tilted surfaces for solar systems analyses [1].

RESIDENTIAL SOLAR HEATING AND COOLING SYSTEMS

Standardized methods for modeling of residential solar heating and cooling systems are presented in this section. As described in the introduction, the purpose of these inputs is to provide a basis for comparison of systems and simulation codes under development. They are not intended for use in designing or sizing a solar system in a location other than those modeled. Although the chosen locations represent a broad spectrum of climates and weather patterns found throughout the United States, it was impossible to cover every climate. Specifications for the actual homes are based on those typical of new construction in each location. Heating and cooling loads are computed using ASHRAE transfer function techniques [9] in an interactive TRNSYS-compatible load model package [2,10]. Location-dependent and building-specific inputs may be found in Ref. 1.

Selection of Residential Locations

Candidate cities for solar heating and cooling study locations included the 26 SOLMET (TMY) cities. In an attempt to choose from these sites a variety of load profiles and climates for both heating and cooling seasons, an analysis of the distribution of loads across the United States was performed by SAI [2]. From this analysis, it appeared that three cities could reasonably characterize the types of climates found throughout the country. Next, each TMY site was examined for its existing and potential market for solar systems. A large regional population and many building starts were assumed to represent the market. The final choices for residential analyses were Fort Worth, Tex; Washington, D.C.; and Madison, Wis.

Building Descriptions

A typical single-family residence for each of the three locations was selected for analysis. In each location, the chosen house is defined by a set of building characteristics that dominate for that locale. Building characteristics are described briefly for each representative house.

Thermal insulation characteristics were obtained by using ASHRAE 90-75 [11] and Ref. 12. The values developed are based on an economic analysis recommended by the National Association of Home Builders that states a payback period of seven years will result if these insulation guidelines are followed. This procedure specifies houses that are well designed and exceed the minimum guidelines of ASHRAE 90-75. It is assumed that the major axis of the house lies east-west; thus, the structure lends itself to active solar systems. No assumptions are made as to whether the front or rear of the house has the desired southern exposure.

Following is a brief description of the characteristics of each house. More detailed descriptions may be found in Ref. 1.

The Madison house is a 158 m^2 (1700 ft^2), one-story, wood frame Rambler. It has a basement, three bedrooms, and a two-car garage. Walls have 3.35 m^2-°C/W (R-19) insulation, the roof has 5.28 m^2-°C/W (R-30), and all windows are triple glazed.

A one-story, 167 m^2 (1800 ft^2), wood frame, brick-veneered Ranch house typifies Fort Worth. Built on a slab foundation, it has three bedrooms and a two-car garage. The roof has 3.35 m^2-°C/W (R-19) insulation while the walls have 1.94 m^2-°C/W (R-11); windows are double glazed.

The typical house for Washington, D.C., is a 161 m^2 (1735 ft^2) two-story wood frame Colonial with three bedrooms, a two-car garage, and a basement. All windows are double glazed; the walls and roof are insulated with 3.35 m^2-°C/W (R-19) and 5.28 m^2-°C/W (R-30), respectively.

Load Calculation

Maximum accuracy is obtained when building load calculations and Heating, Ventilating, and Air-Conditioning (HVAC) system performance calculations proceed simultaneously in an hourly system simulation, since the effect of the varying interior and environmental conditions on the conditioned space can be accounted for. However, hourly HVAC system and load simulations are prohibitively expensive for system studies in which many sensitivities are of interest unless a simplified load model is available. The ASHRAE transfer function technique [9] is a compromise between very detailed and very simple load calculations; the method approximates load time-lags due to building capacitance.

The ASHRAE transfer function technique has been employed in Version 9.2 of TRNSYS [10], which provides separate roof, wall, and room modules. These three modules were combined into one TRNSYS component module for easier application and for a reduction in computer time over the TRNSYS load package. A listing of the load module, the necessary standard inputs for each location, and a more comprehensive description of the load model theory may be found in Ref. 1.

LIGHT COMMERCIAL SOLAR COOLING

Current federal emphasis on and support of the 25-ton cooling system development prompted the definition of a light commercial application for analysis of solar cooling systems [13].

A small office building (nominal 25-ton cooling load), similar to those found in many office parks across the United States was chosen to represent the standard, bench-mark light commercial building. Locations potentially appropriate for solar cooling of commercial buildings were also selected. Finally, loads for each location were computed and stored on magnetic tape.

This section details the location selection, the building specifications, and the method of load calculation for light commercial applications.

Locations for Light Commercial Solar Cooling Analyses

It was assumed that potential markets for light commercial cooling systems could be characterized by a large number of commercial construction starts and by a fairly warm climate.

An evaluation of the SOLMET sites with respect to the climate and new construction activity constraints performed by SAI [2] resulted in the selection of four locations for light commercial cooling studies. They are: Phoenix, Ariz.; Washington, D.C.; Miami, Fla.; and Fort Worth, Tex.

Building Description

The commercial building described here, a small office building, represents what might be typical for commercial solar energy system applications in the future. A well-constructed building that has a nominal design cooling load of 25 tons, the small office building meets or exceeds ASHRAE 90-75 standards. Additional energy conservation features such as low total lighting levels and a minimum ventilation rate are incorporated.

The following specifications were developed for a building in the Washington, D.C., area. However, they are adequate to describe a typical small office building in any other geographical location. Only the gross air circulation requires a different value for each location. More details may be found in Ref. 1.

Building Type:	A typical, small, one-story office building with brick veneer and a flat roof; no overhangs or protuberances for shading.
Dimension:	A rectangle 43.9 m (144 ft) long, 21.3 m (70 ft) wide, and 3.7 m (12 ft) high; gross area, 936.5 m^2 (10,080 ft^2); the net conditioned area, 874.5 m^2 (9,413 ft^2).
Orientation:	The long axis of the building lies east-west; a single entry door is located on the north wall.
HVAC System:	A variable air volume system supplies each zone with the conditioned air necessary to meet the load; a general return plenum is above the ceiling tile; one central plant serves all zones; enthalpy control is used [14].
Climate Control:	For the cooling season, each zone thermostat is set at 26.1°C (79°F) on and 25°C (77°F) off; system is turned off rather than set back when unoccupied.
Opaque Envelope:	Walls have a 0.1 m (4 in) brick facing over 0.15 m (6 in) concrete block. A 0.01 m (0.5 in) space and 0.04 m (1.5 in) of rigid insulation are sandwiched in between. The gross U value is 545 W/m^2-°C (0.096 Btu/ft^2-°F-hr).

The roof is a metal deck covered by 0.05 m (2 in.) of rigid insulation underneath standard built-up roofing and gravel; gross U value is 488 W/m^2-°C (0.086 Btu/ft^2-°F-hr).

The floor consists of carpeting over a concrete slab on grade; a 0.05 m (2 in.) layer of polyurethane insulation surrounds the perimeter.

Windows: All windows are double glazed, solar bronze, with a U value of 3.55 W/m^2-°C (0.625 Btu/ft^2-°F-hr) and an effective solar transmissivity of 0.25. The north wall has a window area of 29.3 m^2 (315 ft^2), the south wall has a window area of 25.8 m^2 (278 ft^2), and the east and west walls each have a window area of 3.0 m^2 (32 ft^2).

Commercial Load Calculation

Calculating the hourly load for a commercial building is complicated. For residential buildings and buildings with only a few zones, loads may be calculated so that an interaction with the system is possible. Calculating such interactions for a commercial building would require a very complex computer model and a prohibitively large amount of computer resources. A complex model is required because the building is subdivided into many zones. Each zone has its own space conditioning requirements that are met by an appropriate air handling system. These systems merge at a plant that provides the necessary energy for the building. This section describes a method for analyzing solar and conventional energy systems by which commercial loads may be approximated, stored on a tape, and input hourly to an executive computer model.

Recommended for use in commercial building analyses, load tapes for the light commercial building examined here were developed with the aid of a comprehensive computer code developed by the Army call BLAST [15]. BLAST estimates hourly space heating and cooling requirements, hourly performance of fan systems, conventional heating and cooling plants, total plant energy, and solar energy system performance. The loads as seen by the central plant for the light commercial building were computed by BLAST, using the TMY data, building parameters, and the air handling system specifications. Load data thus processed for each city are available on magnetic tape from SERI. Heating as well as cooling loads are included on the tape so that year-long energy system simulations may be performed. Employment of commercial load data is more fully illustrated in Ref. 1.

ECONOMIC ANALYSIS

Life-cycle costing has been demonstrated to be a suitable method of analyzing the economic feasibility of solar energy systems [16,17]. Tax laws are different for residential and commercial systems; therefore, the systems must be analyzed dissimilarly with respect to property taxes, depreciation, and other economic parameters. However, both may be studied using life-cycle costing techniques, and the results may be contrasted with those of similar analyses for conventional systems to determine economic feasibility. Additionally, if several investigators are studying, for example, residential space heating systems using the inputs and methods suggested in this paper, then the results of their economic predictions may be compared to examine the relative economic feasibility of each system.

An excellent application of life-cycle costing to solar energy systems may be found in a paper by Audrey Perino of Sandia Laboratories [16].

Many parameters required as inputs in an economic analysis are difficult to predict precisely. Often, costs are dependent on location or are rapidly changing, which makes it difficult to specify a value. Table 1 contains a list of some parameters needed for an economic analysis of a solar energy system and includes suggested values for each. These values are the recommended standard assumptions and were suggested by Roger Bezdek in Ref. 17.

Table 1. SUGGESTED ECONOMIC INPUTS

	Residential	Commercial
Down payment, % of investment	20	30
Loan interest rate (%)	8.5	8.0
Discount rate (%)	10	10
Inflation rate (%)	5.0	5.0
Income tax rate (%)	30	50[a]
Borrowing period (yr)	30	25
Period of an analysis (yr)	20	20
Accounting lifetime (yr)	30	20

[a]Total, state, and federal.

As the economic picture becomes clearer, more accurate assumptions may be made when predicting the life-cycle cost of an alternative. In the interim, readers are encouraged to consider possible applications of life cycle cost to their problems.

REPORTING FORMAT

The International Energy Agency (IEA), a group established in 1974 to help resolve energy problems, has recently adopted a reporting format [18]. This format for reporting on thermal performance of solar energy systems was prepared by U.S. and Swedish researchers as a part of an IEA task titled "Investigations of the Performance of Solar Heating and Cooling Systems." It is advantageous to adhere to the format in reporting solar system study results for two reasons. First, a common format will facilitate the comparison of systems by use of similar tables, units, and performance parameters. Second, fidelity to this format by U.S. investigators will demonstrate a willingness to cooperate internationally. This format should therefore be adhered to as strictly as possible.

CONCLUSIONS

Standardized inputs and methods for analyzing residential and commercial energy systems were presented. These recommendations help to provide continuity and comparability among solar research endeavors.

For residential systems, three locations (Fort Worth, Madison, and Washington, D.C.) were selected, based on demonstrated and potential markets for solar systems and on the need to characterize a variety of climates. TMY data should be used for these cities. It is recommended that analysts model their systems in each of these locations so that performance may be linked to regional variations in climate. Homes typical of new construction in each city were defined and descriptive parameters provided. An interactive load model developed from ASHRAE [9] algorithms and based on existing TRNSYS [10] modules was recommended.

Four commercial analysis locations were selected: Fort Worth, Washington, D.C., Miami, and Phoenix. One light office building (nominal 25-ton load) to be used in all locations was defined. Heating and cooling loads for each site were computed and stored on magnetic tape for use in system simulations. Again, analysts are encouraged to model their systems in all of the commercial locations to facilitate study comparisons.

TMY data for all three residential and four commercial locations (5 cities total; 2 cities are common to both), as well as loads for commercial analyses, are available from SERI on 9-track magnetic tape.

Users should address their requests to:

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