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Solar Community Systems Analysis Projects

Solar Energy Systems Division

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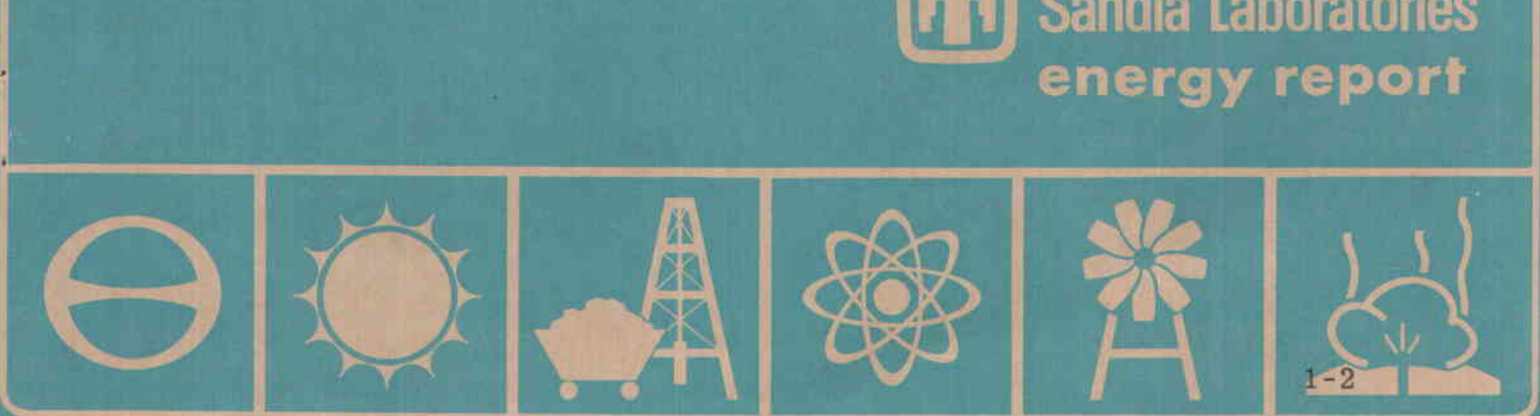

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SOLAR COMMUNITY SYSTEMS ANALYSIS PROJECTS

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ABSTRACT

This report summarizes the solar total energy systems analysis projects funded by the National Science Foundation under grant number AG-564. The projects included development of an analysis computer program, the analysis of a 1000-home solar community, data acquisition, and load definition.

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Introduction

During the past decade, research on the use of solar energy has been conducted in the United States and other countries to investigate its economic feasibility. Some important findings have been made in these studies. In 1966 Farber[1] demonstrated the feasibility of solar-powered air conditioning with performance which appears compatible with concepts for solar energy systems: In their 1970 analyses, Tybout and Löf[2] showed that space and hot water heating could be economically competitive in the Southwestern United States. Doerner, Dietz, et al.[3] and Bronicki[4] showed that turbines using high-molecular-weight fluids could be used to produce adequate electrical power for residential use in a cascaded energy system.

Since July 1972, on the basis of these and other findings, Sandia Laboratories has been undertaking a series of systems studies directed at evaluating the potential of solar energy as a partial solution to the national energy problems. The goal of these studies is to provide a system which (1) could save a significant amount of fossil fuel, (2) could be economically competitive with existing energy systems, and (3) could, at the same time, minimize harmful effects on the environment and remain architecturally attractive. These studies have resulted in the development of a solar total energy system concept. In such a system, energy collected at a central area would be used efficiently to provide electricity, space heating, air conditioning, and hot water. Energy would be conserved and costs reduced by cascading, a process in which high-temperature energy is used for electrical power production and low-temperature power cycle exhaust energy is used for domestic heating, air conditioning, and hot water heating.

Previous analyses indicated that the solar total energy concept offers a large reduction in fossil fuel usage. The importance of a reduction in fuel consumption to the national energy picture is illustrated in Table I, which shows that about 30% of U.S. energy is being directed to residential and commercial use.

Table II summarizes the potential impact both of heating and cooling buildings and of providing solar thermal energy for electric generation and process heat using solar energy. (These predictions were presented in the Project Independence Blueprint for solar energy.[5]) The solar total energy concept includes, and can make a significant contribution to, both.

TABLE I

Energy Uses U.S.A.*
(All values x 10^{15} Btu)

		1970	**	1985	**
1.	Residential and Commercial	15.9	21.07	20.2	35.6
		(25%)	(31%)	(19%)	(29%)
2.	Industrial	21.0		29.1	
3.	Nonenergy	4.0		8.0	
4.	Transportation	16.3		30.2	
	Total	63		106.1	

*Energy distribution patterns for U.S.A. — 1970 and 1985 — from A. L. Austin, Lawrence Livermore Laboratory, April 20, 1972.

**With electric use converted back to required heat energy.

TABLE II

Summary of Potential Impacts of Solar Heating and Cooling and Solar Thermal Technologies[5]
(Units of 10^{15} Btu/yr of output energy provided by solar energy systems)

	1980	1985	1990	1995	2000
Heating and Cooling	0.3	0.6	1.5	2.4	3.5
	(0.01)	(0.03)	(0.6)	(1.3)	(2.3)
Solar Thermal	0	0.002	0.02	0.2	1.5
	(0)	(0.002)	(0.02)	(0.1)	(0.06)
Total vs Demand	93	120	144	165	180

Note: Numbers shown without parentheses are for an accelerated implementation plan; those in parentheses are for a business-as-usual plan.

To advance its solar total energy systems studies Sandia Laboratories has been developing a solar energy system simulation computer program (SOLSYS). In February 1974 a proposal[6] was submitted to the National Science Foundation's Division of Applied Technology, requesting funds to assist in developing the analysis program and to perform system analyses of solar total energy systems using the program.

On May 1, 1974, Sandia Laboratories received a $99,900 grant, number AG-564, to assist the proposed program. Between May 1, 1974, and February 28, 1975, the grant money has supported the following projects:

1. Simulation Program Development

    a. Several new subroutines have been added to the program.

    HLOAD - a subroutine which calculates heating, air conditioning, and hot water demands for a house or building.

    FLTPLTC - a subroutine which models the performance of a flat plate collector.

    WEATH8 - a subroutine which reads a magnetic tape and provides 1962-63 weather data for eight U.S. locations.

    SOLEN3 - a subroutine which extracts real direct and total solar data from a magnetic tape.

    ELECTRQ - a subroutine which computes a house or building's electric load.

    HALFDEM - a subroutine which models a control valve.

    b. Improvements to the program have increased user facility, made possible studying systems having mixed loads, decreased running time, and reduced the size of the program.

    c. A users guide[7] to the program has been written and published.

2. Weather Data Acquisition

Weather data magnetic tapes from the National Climatic Center containing 1962-63 hourly weather data for eight U.S. locations were obtained and information was transferred to a magnetic tape compatible with the SOLSYS system.

3. Solar Data Acquisition

Continuously recorded 1962-63 Albuquerque direct and total solar intensity data charts were obtained from the National Climatic Center. Ten minute interval readings from 1962 have been partially digitized.

4. Electric Load Data Acquisition

Typical Albuquerque electric load data has been obtained for individual houses, attached houses, low- and high-rise apartments, schools, and commercial buildings. This data was obtained from the Public Service Company of New Mexico.

5. One Thousand Home Solar Community Studies[8]

Solar total energy systems which provide various fractions of a 1000-home community's energy requirements have been designed using SOLSYS. In the studies, system performance and fuel consumption were computed and economic parameters for the system were evaluated.

6. Mixed Load Community

A community has been defined, with assistance from the University of New Mexico Architectural Department, which contains detached single family homes, attached homes, low- and high-rise apartments, schools, and a commercial district. Energy requirements for the community will be used in future system studies.

Plans for future systems analyses were initiated during the grant period including studies of a hybrid focusing/flat-plate collector, cascaded/noncascaded system, flywheel energy storage, photovoltaic/thermal system, and a process heat system.

More complete descriptions for each of the above projects are presented in the following sections of this paper.

Simulation Program

Background

Sandia Laboratories' Solar Energy Systems Division has been exploring the feasibility of a solar total energy system since 1972.[9] Such a system would use collected solar energy to power a turbogeneragor which would provide electricity to meet the demands of a community or other energy user, and heat removed from the condenser of the power-generation cycle would be used to supply the user with energy for heating, air conditioning, hot water, and other relatively low-temperature energy needs. A computer program was developed[10] which analyzed various solar energy systems and provided some insight into performance and cost, but it did not have the flexibility needed to study the effects of energy system design modifications and parametric changes. Continued analysis of energy systems called for developing a method which was not restricted to a specific system design because several types of systems, each having a large number of possible modifications, required analysis.

An energy system is composed of many interdependent components whose performances are affected by various transient conditions such as solar intensity, solar position, weather, and demands on the system. Details of system performance are complicated and are most easily determined using a computer model. Since August 1973 the Solar Energy Systems Division has been developing an extensive energy system simulation computer program[6, 11, 12] which has the flexibility to analyze a variety of systems and system modifications and which can predict the details of transient system performance. The program contains a library of component model subroutines, which can be connected in nearly any desired order to form an energy system, and it contains a library of information subroutines which supply time-dependent solar, weather, and load parameters to the appropriate components. The program can be used to predict the performance characteristics of a system to verify a proposed design or suggest alterations. Parametric studies can be performed for optimization and to determine auxiliary fuel requirements. Transient energy losses and gains throughout the system can be calculated and the component sizes required to handle energy fluxes, fluid flow rates, and pressure drops can be determined.

Other energy system simulation computer programs which are flexible and have been used for system analysis have been developed elsewhere.[13-15]

Program Composition

The energy system simulation computer program (SOLSYS) is composed of the following parts:

Executive program
Component model subroutine library
Information subroutine library
Control component subroutine library
Miscellaneous function subroutine library

Executive Program -- The executive program handles input and output, calls appropriate subroutines, iterates to obtain convergence, and controls the program's time incrementing process.

Input to the program consists of program control information and subroutine parameters which the executive program reads, digests, and passes on to the appropriate subroutines. Program output is in the form of printed tables and plotted data which are controlled by the executive program.

The subroutines used to build a system or supply transient information to the system are specified on data cards which are read by the executive program. The executive program calls each subroutine in the order that the subroutine data cards appear in the data card deck. The subroutine call sequence is repeated for every convergence iteration at each time step.

The first call sequence, at the starting time, is used to initialize transient parameters. Subsequent call sequences or iterations at the same time value are used to insure temperature convergence for the components in the system. Components thermally and viscously interact with an inlet fluid to change the fluid's temperature and pressure, and the fluid, with new properties, is passed to the next component in the fluid loop or circuit. A component's outlet temperature may change between iterations and, therefore, iterations must be repeated until the outlet temperatures for each component reach a steady value. The executive program compares each component's outlet temperature for the last two iterations and if they are equal ($\pm 0.1^\circ$) the iteration process stops and one more call sequence is used to compute the change in transient variables during the time step. The executive program increments the time value and, in the first call sequence for the new time value, new information parameters are computed and subsequent iterations are used to reach temperature convergence. The time step-iteration process is repeated until the time value reaches the end time value.

Component Subroutines -- Component subroutines contain mathematical models of fluid-handling components. Inlet fluid undergoes thermal and viscous interactions inside the component which change the fluid's temperature and pressure. Thermal interactions include addition and extraction of energy due to heating, heat exchange, and heat loss processes. Viscous interactions within a component cause a head loss or pressure drop in the fluid. A component's fluid outlet temperature and pressure are, in general, different from the component's inlet temperature and pressure.

Each component is assigned a unique component or subroutine number (a component is assigned a component number for each outlet and components which divide flows are assigned an additional component number) and the number of the component immediately upstream in the fluid circuit is specified. A component's outlet temperature, pressure, and fluid flow rate are indexed with the component's unique number; thus, specifying the upstream component's number specifies the downstream component's inlet fluid conditions. Because of this, components can be connected to form fluid circuits. Some components have two (or more) outlets and inlets and use of these components connects fluid circuits to build a complete system. A component subroutine may be used several times in the same system by calling for the subroutine but giving it a unique component number each time it is called. In most cases several identical components can be placed in parallel by indicating the number of components to be placed in parallel in the subroutine's data cards. Fluid flow is divided equally between the parallel components and performance is based on the divided flow rate. To place identical components in series the component subroutine must be called the appropriate number of times and a unique subroutine number must be used for each.

Components receive information from information subroutines. Some information such as weather and solar data is transmitted automatically, and other information, such as load information, is obtained by specifying the information subroutine's number in the component subroutine's data cards.

There are many parameters which must be specified to determine the performance of a component. The necessary parameters for each component are listed in the subroutine library section of Reference 7 and they are to be specified on the component subroutine's data cards.

Information Subroutines -- Information subroutines provide solar, weather, load, and other transient information to component subroutines. Some of these (solar data, weather data, and electrical loads) get information data from computer tapes, stored tables, or programmed functions, and others (heating and air conditioning loads) compute information parameters using mathematical models. The executive program calls on the information subroutines to provide data at each time value.

Some information subroutines such as load subroutines may be used more than once in a system when loads for more than one energy user are required. Each information subroutine number must be unique (but some information subroutines have no subroutine number because they cannot be used more than once in a system).

Control Subroutines -- Several system control operations such as temperature control and switching can be performed using control subroutines. These subroutines model fluid-handling components and are, thus, part of the fluid circuit system; however, they do not viscously or thermally interact with the fluid. These components alter flow rate, switch the flow from one channel to another, or direct the appropriate flow to more than one channel. If the control component divides the flow, it has more than one outlet with each being the start of a fluid channel.

Miscellaneous Function Subroutines -- Peripheral tasks such as monitoring energy gains and losses, integrating parameters, and doing economic studies can be performed using special subroutines.

Subroutine Library

Before NSF grant number AG-564 was received on May 1, 1974, the SOLSYS program contained the subroutines described below.

Collector Subroutines --

FOCOL - A specified fraction of the incident solar energy is added to the fluid flowing through the collector. The subroutine calculates the temperature change in the fluid between inlet and outlet. Pressure is not altered in the collector.

FOCMWE[16] - Program FOCMWE determines the performance of a focusing cylindrical parabolic collector using the following assumptions:

1. The system is in equilibrium.
2. The incident sun's rays are parallel.
3. The reflector has a perfect parabolic surface.
4. Envelope and collector tube temperatures are uniform circumferentially.
5. The envelope and collector tube walls are thin and have no temperature gradient through them in the radial direction.

Energy balance equations for the envelope and collector tube consider the following:

1. Solar energy reflection and transmission.
2. Infrared radiation transfer between the collector tube surface and separate silvered envelope and envelope window surfaces.
3. Radiation energy losses from the envelope's outside surface.
4. Convective heat transfer from the collector tube to a fluid flowing in the collector tube.
5. Convective heat transfer between the collector tube and envelope.
6. Convective losses from the envelope to the ambient.
7. Wind velocity over the envelope.

Collector tube and envelope temperatures which solve the energy balance equations are determined using a nonlinear equation solver, and the temperature rise of the fluid flowing through the collector tube is computed.

End effects due to the sun's rays not being perpendicular to the collector's axis are considered.

Orientations for east-west, north-south, and tracking collectors are determined as functions of the sun's azimuth and elevation angles.

Storage Subroutines--

STORE 1 - The storage unit consists of two reservoirs which may contain two different fluids. Heat is transferred from the warmer to the cooler fluid through a separating wall. Temperatures in each reservoir are assumed to be uniform (perfect mixing) and the outlet fluid temperature of each reservoir is equal to the reservoir temperature. Reservoir temperatures change with time due to heat transfer between reservoirs and due to the reservoir's inlet fluid temperature being either warmer or cooler than the reservoir's temperature.

STORE 2 - This storage unit contains a fluid with a uniform temperature. Fluid flows into the unit and mixes with the fluid already there and an equal amount of fluid leaves the unit at the mixed temperature of the unit.

STORE 3 - One fluid enters the storage unit on one side, passes through a heat exchanger and leaves the unit. The same process occurs at the other side. Energy is exchanged between the two fluids and the storage medium. The local heat-transfer coefficient and the temperature of the storage medium are assumed to be uniform. The amount of heat transferred between the storage medium and the flowing fluid depends on the local fluid temperature, the heat-transfer coefficient, and the surface area per unit length of the heat-exchange surface. The total heat-transfer rate is found by integrating local heat-transfer rates, and the storage temperature is determined by integrating the total heat-transfer rate over time.

TCSTORE - The storage unit is assumed to contain a thermally stratified fluid with two uniform temperature regions. Warm fluid is pumped into the top of the unit on one side and out the other. Cool fluid is pumped out of the bottom on one side and in the other. Inlet fluid is mixed with the fluid already in the temperature region into which it is pumped. If the inlet temperature on the warm side is not between a specified maximum and minimum the fluid is diverted to the bottom of the tank and is mixed with the low-temperature fluid. There are no heat losses from the sides of the unit and no heat transferred across the thermocline. It is assumed that a discontinuous change in temperature is maintained across the thermocline.

Power Generation Cycles --

TUCOPU - The turbine loop (turbine, condenser, pump, generator) is considered to be one component in this subroutine. The temperature of the heat-supplying fluid falls as energy is extracted in the boiler and the temperature of the cooling fluid rises in the condenser. Inlet and outlet pressures are equal. The energy required is determined by the total power demand from the system, and by the efficiency of the cycle. The energy which is not used by the cycle is exhausted at the condenser.

RANKCYC[17] - This subroutine models and analyzes various Rankine cycle systems including supercritical cycles with or without regeneration and subcritical cycles with or without regeneration and/or superheat. The subroutine will accommodate a variety of working fluids, generating the required thermodynamic properties internally using a modest number of input constants. The cycle is treated as a component which requires a heating fluid to add heat to the preboiler, boiler, and superheater and a cooling fluid to extract heat from the regenerator and condenser.

Transmission and Distribution --

PUMP - The pump restores fluid pressure to a specified value and computes the necessary power.

PIPE - Thermal and viscous losses are modeled using a heat loss equation and a frictional pressure drop equation respectively.

MIXJNT - The component specified in MIXJNT receives fluid from two upstream components, mixes the fluid, and sends it on.

DIVJNT - Subroutine DIVJNT models a component which receives fluid through an inlet at a volume flow rate and rejects fluid through two outlets, each with a specified fraction of the inlet flow rate.

DISTSYS - Subroutine DISTSYS designs a two-pipe, low-temperature-water thermal distribution system for a community of identical load houses or other buildings. The design is used to determine energy losses and pressure drops in the system. The system is defined by specifying a number (N_H) of identical houses and their relative spacing along a street. N_S of these streets are spaced along a lateral, N_L of the laterals are spaced along a main, and N_M mains are spaced along a supermain. The maximum energy extracted per house, Q_{max}, and the allowed temperature drop, T_H, are used to determine the maximum flow rate of hot water which a house will require. The peak flow rate is then summed appropriately throughout the system to determine the peak flow rate through each section of pipe. The flow rates and the allowed pressure head drop (H_{max}) per meter of pipe are used to determine pipe diameters for each section of pipe. Necessary fittings, valves, and meters are added to the system and a system cost, including personnel, maintenance, and initial construction, is computed. The design is used to compute thermal losses and pressure drops in the system when the system is used to supply a time-varying energy requirement to each house.

Heat Exchangers --

HTEXC - The counterflow heat exchanger is assumed to have a uniform heat-transfer coefficient between the two fluids. The local heat transfer depends on the heat-transfer area, the heat-transfer coefficient, and the temperature difference between the two fluids. The temperature gradients due to local heat transfer are integrated to determine outlet temperatures.

COOLTOW - If the fluid's inlet temperature is above the prescribed outlet temperature, this component extracts energy from the fluid and reduces its temperature to the prescribed value.

House Equipment --

SPHEAT - The space heater removes energy from its inlet fluid and returns it at a specified lower temperature. The energy removed depends on the heating demand.

HOTWAT - The hot water heater removes energy from its inlet fluid and returns the fluid at a specified lower temperature. The energy removed depends on the demand for hot water.

AIRCOND - The air conditioner removes energy from its inlet fluid and returns the fluid at a specified lower temperature. The energy removed depends on the demand for cool air and the COP of the unit.

Auxiliary Energy --

AUXFUR - The inlet fluid temperature to the auxiliary furnace is monitored and, if it is below a specified value, heat, derived from burning a fuel, is added at a given efficiency.

Miscellaneous Components --

DUMCON - This subroutine furnishes fluid at a constant temperature and pressure to its downstream component.

Control Subroutines --

TEMCON - This subroutine adjusts the flow rate in a fluid loop to give the desired outlet temperature of a specified component.

SWITCH - Component switch monitors the outlet temperature or some other parameter of a specified component. The value of the monitored parameter determines which of two outlets the switch's flow will exit through.

DEMVAL - DEMVAL has two outlets. The flow through each outlet is determined by the requirements of downstream components.

Information Subroutines --

WEATH1	- Outside, or ambient, temperature is computed by interpolating between the equinox and solstice data which were extracted from Albuquerque Weather Bureau information for several previous years. Humidity, wind speed, and wind direction are set equal to zero.
SOLEN1	- The program determines the sun's azimuth angle (from south) and elevation angle using results of a geometric analysis. Insolation is calculated as a function of time using National Climatic Center data taken from a series of "clear" 1962 Albuquerque days for each season.
DEMANDS	- Electric demand is computed for a house by multiplying the average demand, 860 watts, by a time-dependent distribution function.* For hot water, demand is computed using an average, 0.00525 kg/s, and multiplying by the distribution function mentioned above. Heating and air conditioning demands are derived using the temperature difference between inside and outside the house, the house's floor area and the house's heat loss factor. The building has thermal mass so heating and cooling demands do not respond immediately to heat loss or gain. The heater and air conditioner are either on at maximum capacity or off. The building only requires energy between specified start and end times. However, temperature is allowed to drift due to heat gains and losses all of the time.

Miscellaneous Functions --

ECONAL	- The simplified economic analysis program computes a total initial cost by adding the initial costs of the components and the added initial cost specified in the input. A total monthly cost is computed by dividing the cost of total consumables by the number of months of operation and adding the monthly operational cost. From this

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*Average demands for hot water and electricity are based on average values from several years for two typical houses. The distribution function is based on Public Service Company data.

information the program calculates the monthly payment required to operate the system and pay off the initial capital loan, and it also calculates the initial quantity of money which will pay for the initial investment and pay the plant's operational costs for a specified number of years.

QMETER - Subroutine QMETER measures the energy added to a fluid in a component or in a string of components. Up to 10 strings and components can be monitored. Results can be either printed or plotted.

Subroutines Added

Between May 1, 1974, and February 28, 1975, NSF grant money was used to improve SOLSYS. The load and solar input modeling capabilities of the program were greatly improved by adding subroutines in these areas. A flat-plate collector model was added to allow studies of systems using flat-plate collectors, and a new control component subroutine was added to perform necessary functions not performed by other control components. These subroutines are described below.

Collector Subroutines --

FLTPLTC - Subroutine FLTPLTC models a flat-plate collector with up to nine equally spaced glass plates above the collector plate and insulation below.

The model considers visible spectrum and infrared radiative transfer between the glass and collector plates, convective and radiative losses from the top plate, conductive transfer across the gaps between the plate surfaces, conductive losses through the insulation, and convective energy transfer into the fluid assuming a uniform temperature collector plate. Energy balance equations for the glass plates and collector plate are solved simultaneously to determine temperatures. The amount of energy added to the fluid is calculated.

Control Subroutines --

HALFDEM - HALFDEM is a component which receives a fluid flow from its upstream component, divides the flow and sends it through two outlets. The flow rate sent through the first outlet is determined by the demand from a downstream component. The flow rate sent through the second outlet is the difference between the inlet flow rate and the first outlet flow rate.

Information Subroutines --

HLOAD - The heating, air conditioning, and hot water requirements of single zoned buildings are modeled by this routine using the techniques described in the ASHREA Handbook of Fundamentals.[18] The program uses overall heat-transfer coefficients to compute conductive heat flow through the walls and roof. Perimeter heat loss from the building slab is considered. A percentage of the exterior wall surface (normally 10%) is defined as window to allow computation of fenestration. Infiltration of outside air is handled on a number of room changes per hour basis. Infiltration may also be increased to provide cooling, if needed, when the solar load on a building results in an interior temperature greater than the ambient temperature. A psychrometric routine is available for determination of humidification loads if desired. Thermal loads other than those imposed by the environment are also incorporated. Through input of nonzero hourly schedules the program considers heat due to people within the space. Additionally, a percentage (85% is currently being used) of the hourly electric energy supplied to the building (see ELECTRQ) for lighting and machines is added to the base heat load of the building. Hourly hot water requirements for residential structures are computed using the design values recommended in Reference 18 together with the user profile reflected by actual data for residential electric hot water heaters supplied by the Public Service Company of New Mexico. Nonresidential hourly use profiles were obtained from the ECUBE[19] Application Manual.

Knowledge of the building heat flow permits determination of the concomitant change in building temperature. HLOAD employs a building heat capacity input as data for this determination. Heating and air conditioning loads are computed only if the building heat flow would result in the interior temperature drifting beyond the building high or low thermostat temperatures.

WEATH8 - WEATH8 reads hourly weather data from a magnetic tape. The weather data consist of the following:

Wind direction (degrees from north)

Wind speed (m/s)

Dry-bulb temperature (K)

Wet-bulb temperature (K)

Dew point (K)

Relative humidity (percent)

Atmospheric pressure (N/m^2)

Fractional opaque sky cover

The data was taken from 1962-63 National Climatic Center records for the following locations:

Location	Station Number
Albuquerque	23050
Boston	14739
Fort Worth	03927
Los Angeles	23174
Miami	12839
Nashville	13897
Omaha	14942
Seattle	24233

SOLEN3 - This subroutine provides realistic solar data input for SOLSYS. The data consist of four weeks of actual recordings of the intensities for both direct radiation on a normal surface and total radiation on a horizontal surface. The four weeks of data were selected to provide samples of solar data which are representative of the four seasons in Albuquerque. The first step in the selection process was computation of the long-term weekly averages of total radiation for each of the four seasons in Albuquerque. Then, in each of March, June, September, and December, 1962, a week was selected for which the total radiation in Albquerque was about equal to the long-term average for that respective season. Finally, a visual check of the solar strip charts for those weeks was made to be sure that each week contained a somewhat typical combination of clear, cloudy, and partly cloudy conditions.

Readings were taken from the total and direct solar strip charts and recorded at simultaneous 10-minute intervals. The readings of total radiation were adjusted using the pyrometer-correction factor suggested by Hanson.[20] The total insolation readings were also adjusted for the response drift indicated by the change in calibration from 1962 to 1966. The drift was assumed to be linear.

ELECTRQ - This subroutine provides electrical load data from two hourly data tables read as input. The first, schedule 1, is the primary load schedule while schedule 2 is used for a specified number of days at weekly intervals, for example, weekends. During specified shutdown periods no electricity is required.

During the grant's 10-month period several modifications were made to SOLSYS to improve its output, facilitate its use, increase computational efficiency, and decrease the computer space it requires. A complete user's guide[7] was written which describes the program, explains how to use it, and details subroutine contents. It is anticipated that the guide will be made available to those interested in systems analyses in the future.

Solar and Weather Data

Because insolation varies with time of day and year, geographic location, and climate, the information needed for realistic analyses is very complex. Moreover, the solar energy collection schemes under consideration demand a subdivision of insolation into types. Solar-cell development involves knowledge of the different wavelengths of solar insolation. Flat-plate solar collectors are capable of absorbing total solar insolation, which includes diffuse radiation from the solar disc. The development of concentrating collectors requires data on the direct-beam insolation, because concentrators cannot focus diffuse radiation. These latter data are especially important because virtually all schemes designed for the conversion of solar to electrical energy use collectors requiring direct-beam insolation.

To provide realistic solar radiation input into their various solar systems analyses, Sandia obtained the individual recorder strip charts for direct radiation and total radiation in Albuquerque for each day of 1962 and 1963. These analog charts are being digitized at 10-minute intervals, and the charts for January through August of 1962 have been processed so far. Current plans call for digitizing only the charts for the additional four months of 1962; it was felt that the value of also having the digital data for 1963 did not warrant the time and effort that it would require.

After the initial processing, the data will be "cleaned up" by filling in gaps and applying the best available correction factors. These correction factors are based upon the report by Hanson, et al.,[20] and upon initial and terminal instrument calibration records. Finally, the data will be put on magnetic tape with several other meteorological variables such as temperatures, wind data, cloud cover, and solar and standard time. All solar data that is either created or adjusted will be so marked on the tape. These tapes will be made available to the engineering and scientific community.

The solar data on the analog charts seems to be quite complete and, so far as can be ascertained, reasonably accurate. About 90% of the charts are free of flaws. The most serious difficulty is that the times on the direct intensity charts do not agree with the times on the total charts; differences of from 1 to 3 minutes are typical. While this has minimum affect on solar energy systems analysis, it does detract from the usefulness of this data in parallel studies to correlate direct and total insolation. Because of this difficulty, the correlation studies being performed at Sandia are based upon four weeks of sample solar data selected from the four seasons and carefully hand-digitized at 10-minute intervals with times coordinated.

Solar system analyses will be performed for cities other than Albuquerque. Tapes containing hourly weather and total solar insolation data for the following eight cities have been obtained: Albuquerque, Boston, Fort Worth, Los Angeles, Miami, Nashville, Omaha, and Seattle. These eight cities were chosen because the tapes were available and because the cities represent a good cross section of the various types of weather conditions found in the United States. For example, Boston has a high heating requirement in the winter combined with low solar intensity. On the other hand, Miami has low heating but high cooling requirements combined with high solar intensity. It is felt that these cities constitute a wide enough spectrum of heating, cooling, and solar loads to determine where and under what constraints the solar total energy concept is viable.

The correlation between direct and total insolation mentioned above will be needed to compute direct solar intensity data from the recorded total insolation values available for the cities other than Albuquerque. Information on direct beam insolation is extremely limited with only three other stations in the U.S. recording this information: Blue Hill, Massachusetts; Omaha, Nebraska; and, Tucson, Arizona. No data on direct insolation exists for most geographic and climatic locations in the country.

Electrical Load Data

Data on the demand for electric power are required by the SOLSYS program, and the representation of this demand for a typical community requires a mix of residential, commercial, and industrial loads. Through the courtesy and cooperation of the Public Service Company of New Mexico, Sandia Laboratories has available load data representative of various facilities within each of the categories mentioned above. Load data has been reduced and is presently available to the program on the following facilities:

Single-family residential housing

High-density apartment housing

A public high school

A food and general merchandise retail sales facility

Single-Family Residential Housing

Data representing this type of load was taken from the electric power supplied to a 474-residence subdivision within the city of Albuquerque. Public Service Company equipment monitors and records, at 15-minute intervals, the feeder line power supplied to the subdivision. These records for a 15-month period from May 1973 through July 1974 were made available to Sandia Laboratories. The data were digitized and reduced to an average consumption history per residential customer. An independent check on the level of energy consumption was available as this feeder line was separately metered and meter readings were taken at about one-month intervals. Excellent agreement between integrated values of the recorded demand data and the metered power consumption was obtained.

No data quantifying the homes within this subdivision are presently available. Included in the total of 474 residences are about 35 low-cost, apartment type rental units. The remainder are single family dwellings. Visual reconnaissance of the area suggests this area represents a settled, middle-class residential area containing a representative mix of homes with respect to size and value. The size range of homes in the area is estimated to vary from 90 m^2 (1000 ft^2) or less to a few exceeding 280 m^2 (3000 ft^2). The average size home is probably close to 140 m^2 (1500 ft^2).

Analysis of the reduced data disclosed unusually high consumption levels within this subdivision. Investigation of this anomaly disclosed that power to a city water well and water system booster station was being supplied through the same feeder line as the residential subdivision. The pumps operated at this booster station are driven by the following electric motors: two 200 horsepower (149.2 kW), one 250 horsepower (186.5 kW), and three 350 horsepower (261.1 kW).

A mathematical filtering technique was developed to point out each step change in consumption between adjacent 15-minute segments which exceeded in absolute value a level of 150 horsepower (112 kW). Step changes of this magnitude in the consumption level were arbitrarily assumed to represent a pump switching either on or off. These data were then reduced to a running schedule of the six water pumps. This schedule was used to extract from the original power-consumption data an amount of power corresponding to the pumps in operation during each time interval. This procedure has been completed for four one-month periods representative of the four annual seasons. Thus, electric power-load histories based primarily upon single-family residential usage is available to the SOLSYS program in one-month segments representing the four seasons.

High-Density Apartment Housing

Where load demands of individual commercial and industrial customers exceed a given consumption level, the Public Service Company customarily provides a continuous recording of the electric power consumption. Such a record of power consumption by a 292-unit apartment complex was used to define the load history for high-density housing models. This particular complex contains a total heated area of 20,530 m^2 (221,000 ft^2). Individual apartment sizes vary from 56 m^2 (600 ft^2) to 117 m^2 (1260 ft^2) with an average size of 69 m^2 (743 ft^2). Water and space heating is done with gas; however, the apartments use refrigerated air conditioning during warm summer months. Electric appliances provided with the apartments include a free-standing electric range, a combination refrigerator-freezer, a dishwasher, and a disposal. The diurnal load cycle for high-density housing was defined using the apartment data from January 1973 through November 1973; however, the average demand level on a unit-area basis was based upon the electric power consumption during the noncooling season to eliminate the air conditioning from electric power demand data.

Public School Facilities

The load history for public school facilities was taken from the continuous recording of the electric power consumption at one of the newer public high schools within the city of Albuquerque. This school facility was constructed in the campus style with a number of separated buildings occupying a 52-acre site. The total physical plant contains 24,484 m^2 (263,540 ft^2) and serves a student population of approximately 3100. The school load histories include an optional load profile to account for the variation in power consumption on weekends when school is not in session.

Commercial Facilities

Load histories for modeling commercial retail sales outlets were taken from the continuous recording of electric power consumption at a large, modern, combination grocery and general merchandise retail sales facility. This facility offers a floor space of 11,150 m^2 (120,000 ft^2).

The electric load is principally lighting, food refrigeration, air circulation, and in the summer months air conditioning. The store data span a time period from December 1972 through December 1973. There are slight variations in the diurnal load cycle at different seasons of the year. The average power consumption per unit area was based on data from the noncooling season to exclude air conditioning from the simulation.

Future efforts on electric load definition will be directed toward the addition of other commercial and industrial facilities to the existing catalog of load data. Also an evaluation of the variations in load profile for such facilities due to location in various areas of the country will be pursued.

Analysis of a 1000-Home Solar Total Energy Community

Performance Analysis

Studies of a solar total energy system were performed using the SOLSYS system analysis program. A hypothetical community, located in Albuquerque, New Mexico, and composed of 1000 individual homes, was selected for study. Each home is separated by 34.5 m (120 ft), has 139.5 m^2 (1500 ft^2) of floor space; and the total energy system supplies all of the electricity, heating and cooling, and hot water demands. Figure 1 is a schematic of the system as modeled by the computer program. Details of this analysis may be found in Reference 8 and only the results are presented here.

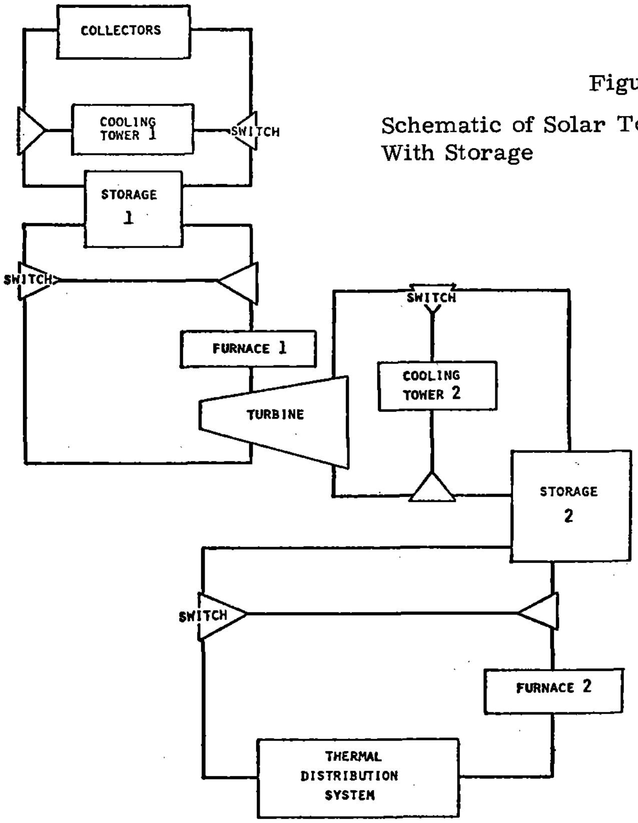

Figure 1

Schematic of Solar Total Energy System With Storage

The primary components are focusing parabolic collectors, high- and low-temperature sensible heat storage systems, a turbogenerator for electrical generation, cooling towers to dissipate the energy collected when the storage units are full, fossil-fuel auxiliary furnaces to provide supplementary energy, and a thermal distribution system to provide thermal energy to the homes. For most of the studies, the clear-air solar intensity for Albuquerque was used as solar input and the thermal loads were computed using the HLOAD subroutine. Computations were made every half hour for four 4-day periods (solstices and equinoxes) and these 16 days were then used to represent a year. It should be noted that maximum and minimum temperatures do not occur on solstices, and days requiring no heating or cooling do not coincide with the equinoxes. Toward the end of the contract period, actual 1962 solar data for four 7-day periods for Albuquerque became available. These data, which include atmospheric and cloud effects, were used to perform an analysis on the same system at 10-minute intervals and the results are described briefly at the end of this section.

Figure 2 is a plot of the ambient air temperature and the calculated house temperature for the four seasons. The house temperature is permitted to vary between 20°C (68°F) and 25°C (77°F). This relatively close temperature control could require both heating and cooling during the equinoxes. In practice, people accept a greater temperature variation. Consequently, during the summer and fall the temperature at night is permitted to drift downward below the lower limit. Also to simulate window openings during spring, infiltration of outside air is sharply increased during the daytime hours when the solar load on the house tends to drive the house temperature above the upper limit. The ragged response in the house temperature curve around noon in the spring period is a result of this increased infiltration.

The loads for each of the periods are shown in Figure 3. The electric loads vary throughout the day and average near 1.0 kW per house. The mean hot water demand is approximately 0.6 kW with a peak near 0.9 kW. Cooling is required during summer and fall, and heating is required during winter and spring. These curves contrast the seasonal variation in thermal demands with the relatively constant electric and hot water demands. During summer and fall the thermal requirements are 4.2 and 3.4×10^8 J/day, respectively, and those for heating in spring and winter are 2.0 and 5.9×10^8 J/day. Clearly the thermal demands are significantly higher for winter and summer than for spring and fall. Furthermore, other choices of spring and fall days may reduce those thermal requirements significantly and make the difference even greater.

To provide energy for this community, cylindrical, parabolic, single-axis tracking collectors were used. The total collector area was varied by changing the number of individual collectors in the array. The collectors heated Therminol 66 to 317°C (602°F) for use in the boiler of a Rankine cycle system using toluene as the working fluid. The toluene was superheated to 307°C (584°F) with boiler and condenser temperatures of 211°C (411°F) and 94°C (200°F), respectively, to give an overall cycle efficiency 17.9%. Preheat, boiling, and superheat energy was extracted from a high-temperature, stratified storage unit with a temperature drop across the unit of 90°C (162°F). The cooling water was transmitted from the condenser to low-temperature storage at 88°C (190°F).

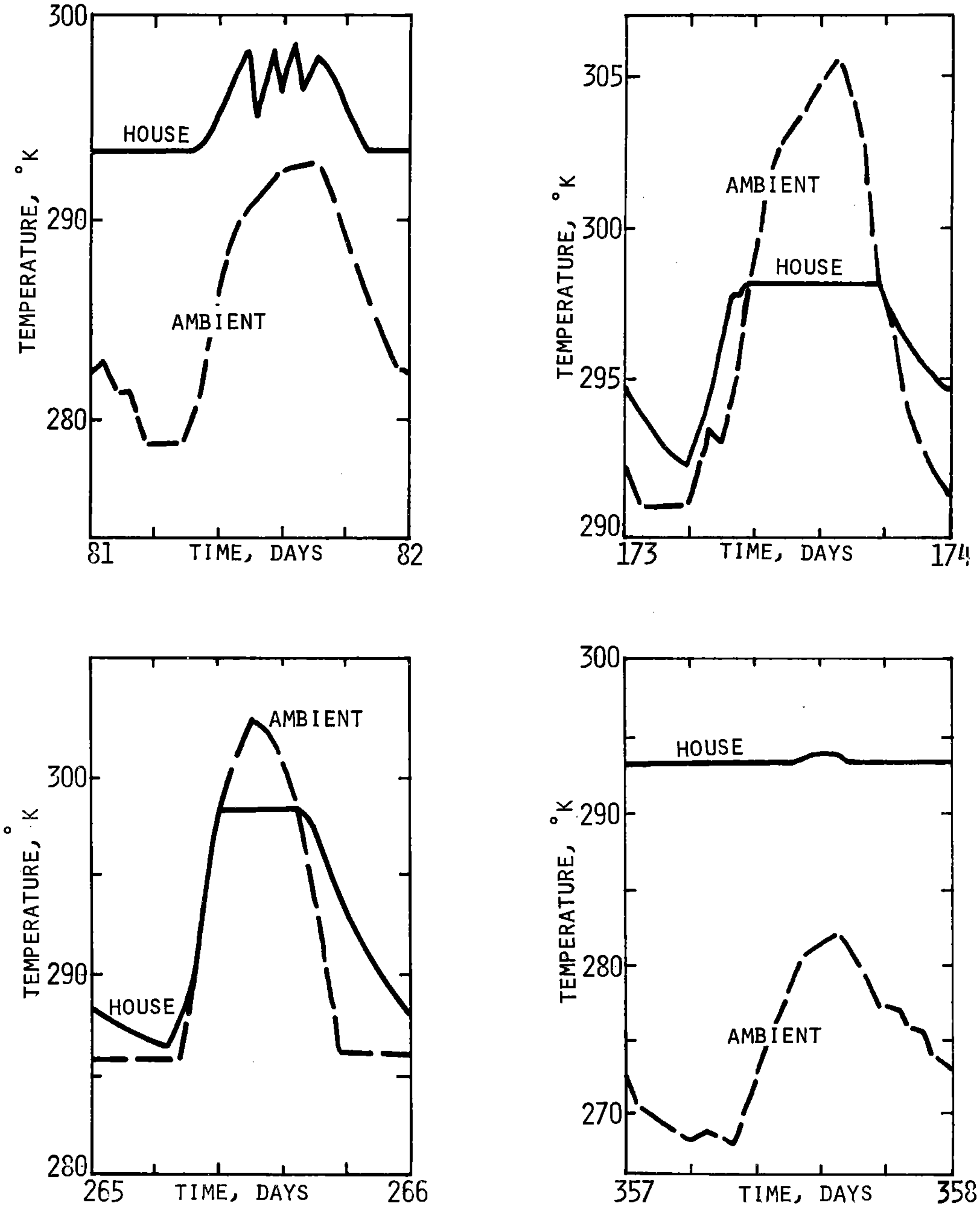

Figure 2. Temperatures of Ambient Air and House Located in Albuquerque

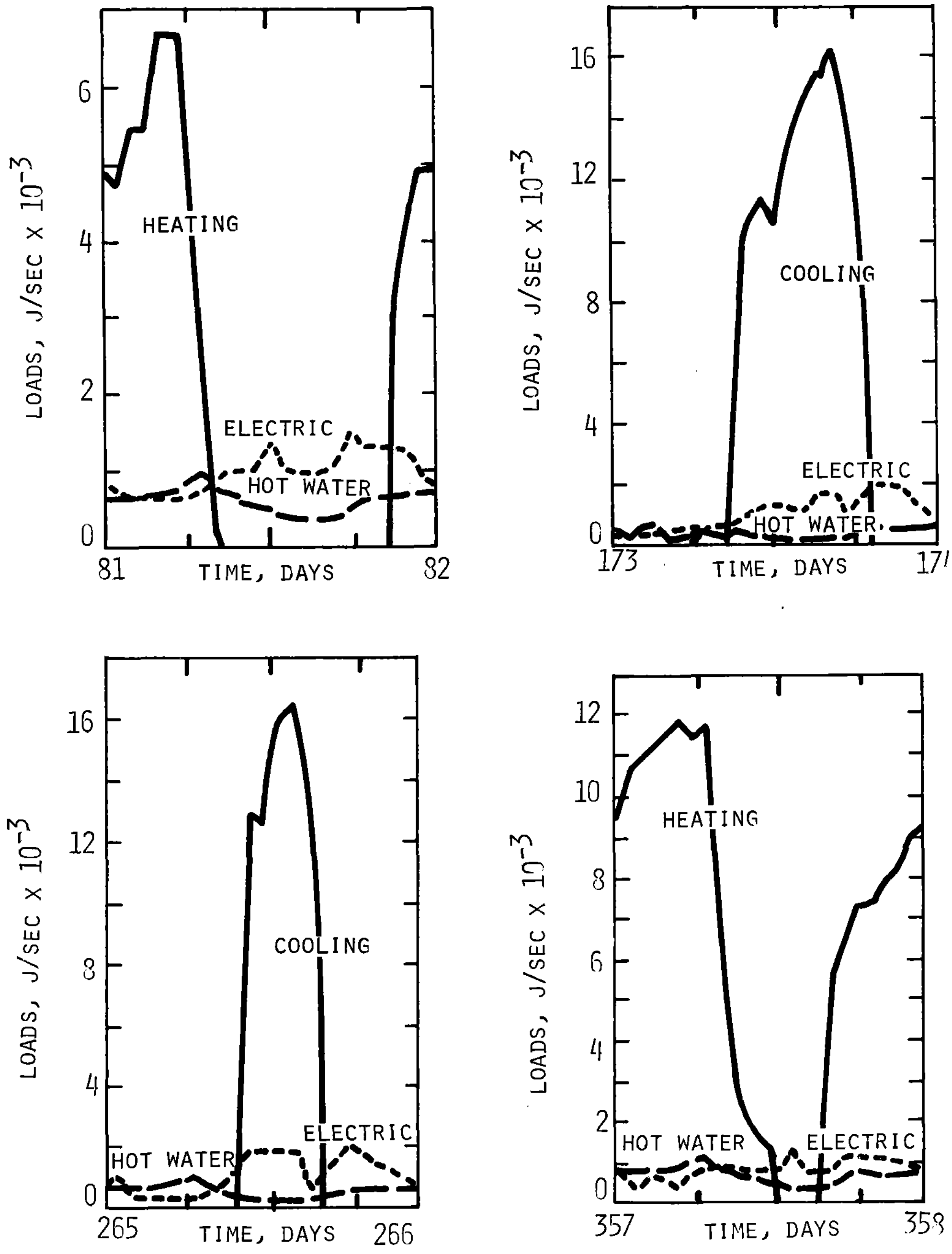

Figure 3. System Loads for a House Located in Albuquerque

Horizontally oriented east-west cylindrical collectors and north-south cylindrical collectors elevated to both 35° and 50° were studied. The collector area for north-south collectors in the study was varied from 0 to 27,700 m^2, producing systems which supplied from 0 to 77% of the community energy needs from solar energy. The east-west collector area was varied from 17,430 to 34,870 m^2, producing systems which supplied from 34 to 75% of the energy requirements. The high-temperature storage volume depends on collector area, but in no case was more than overnight storage provided.

Table III presents a summary of the performance of the collectors, cooling towers, and the auxiliary furnaces for each of the collector areas analyzed for both north-south and east-west collectors. Using the guideline that solar energy is expensive and thus should not be dissipated during any period of the year, between 20,770 and 24,230 m^2 of north-south collectors, or near 34,870 m^2 of east-west collectors, are optimum to minimize the fossil fuel required. As expected, more area of east-west collectors is required to produce the same percentage of solar input into the system.

TABLE III

Comparison of Solar System Operation in a Community Total Energy Concept

Collector Area (m^2)	Storage Volume, Storage 1 (m^3)	Percent Solar	Average Solar Energy Collected (J/Day x 10^{-11})	Average Fossil Fuel Consumed (J/Day x 10^{-11})		Average Energy Dissipated (J/Day x 10^{-11})	
				Furnace 1	Furnace 2	Tower 1	Tower 2
			North/South Collectors				
0	0	0	0	6.1	1.66	0	0.19
5,575	150	15	1.15	4.73	1.66	0	0.19
10,385	250	30	2.14	3.48	1.66	0	0.19
13,850	500	41	2.86	2.49	1.66	0	0.19
20,770	1250	63	4.28	0.74	1.66	0	0.19
24,230	1500	73	5.01	0.20	1.66	0.27	0.19
27,700	1500	77	5.72	0.0	1.66	0.91	0.19
			East/West Collectors				
17,430	500	34	2.45	3.0	1.66	0	0.19
24,400	1000	50	3.43	1.78	1.66	0	0.19
34,870	1600	75	4.85	0.0	1.66	0.1	0.19

Figure 4 presents the response of the high- and low-temperature storage systems for a collector area of 24,230 m^2 (17.5% of the total home roof area). The storage was sized to provide energy for overnight operation with the clear-air insolation data. In all seasons except winter, 1400 m^3 (49,400 ft^3) of high-temperature storage is adequate. The low-temperature storage system cycles daily. In both summer and winter the system is depleted and significant fossil fuel augmentation is required. During winter, the low-temperature storage is depleted overnight for heating, whereas during summer it is depleted during the day for cooling. Fourteen hundred (1400) m^3 (49,400 ft^3) of low-temperature storage is required.

For the same collector area, Figure 5 shows the operation of the two auxiliary fossil fuel systems which operate when the corresponding storage systems are depleted. During spring the high-temperature furnace operates in the morning just before the beginning of solar insolation, but the low-temperature furnace operation is not required. During summer and fall the high-temperature furnace does not operate but the low-temperature system does, to augment the depleted storage system in meeting the cooling load. During winter both systems operate with the low-temperature system operating extensively during the night to satisfy the high heating demands.

Figure 6 shows the operation of both cooling towers for the same collector area. Both operate in the spring when the storage systems are filled because the loads are less than during other seasons. During summer and fall the high-temperature tower operates for a very limited time, while during winter neither tower operates because of the higher winter loads. Throughout the year, approximated by the 16-day sample, less than 4% of the energy collected is dissipated in the cooling towers.

Figures 4, 5, and 6 illustrate the seasonal variation in the operation of the system. The criteria for this design was that minimal solar energy be dissipated in the cooling towers. The storage is sized for overnight use and cycles daily throughout most of the year. In addition, consumption of fossil fuel is minimized.

When the 1962 Albuquerque weather data became available, selected designs which were found to be nearly optimum using the clear-air solar intensity were reanalyzed to evaluate the cloud effects. In particular the 63% solar system shown in Table III with 20,770 m^2 of collector was used in the reevaluation. The collector output for a six-day winter period is shown in Figure 7. Cloud effects during the last two days of the interval are apparent and similar periods were also observed in the data for the remaining three seasons.

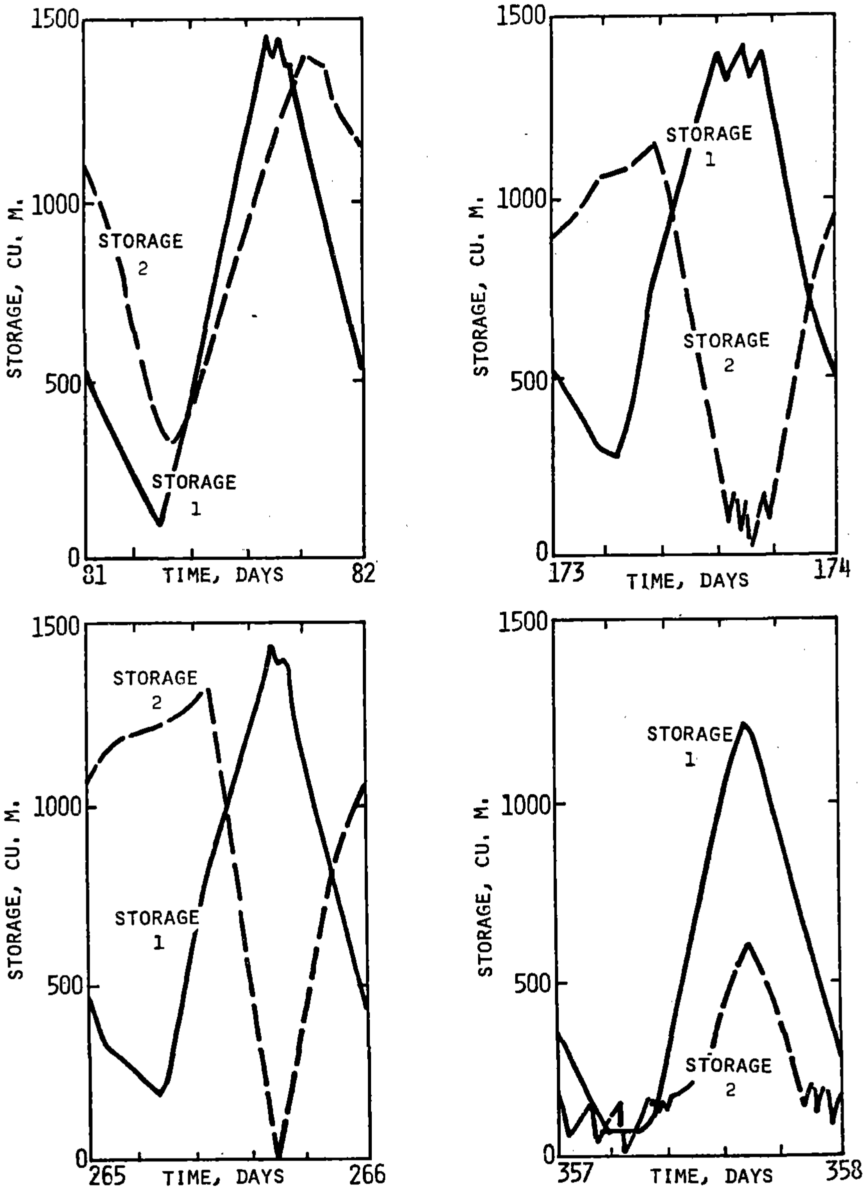

Figure 4. Storage Response for Overnight Storage for a 1000-Home Community in Albuquerque

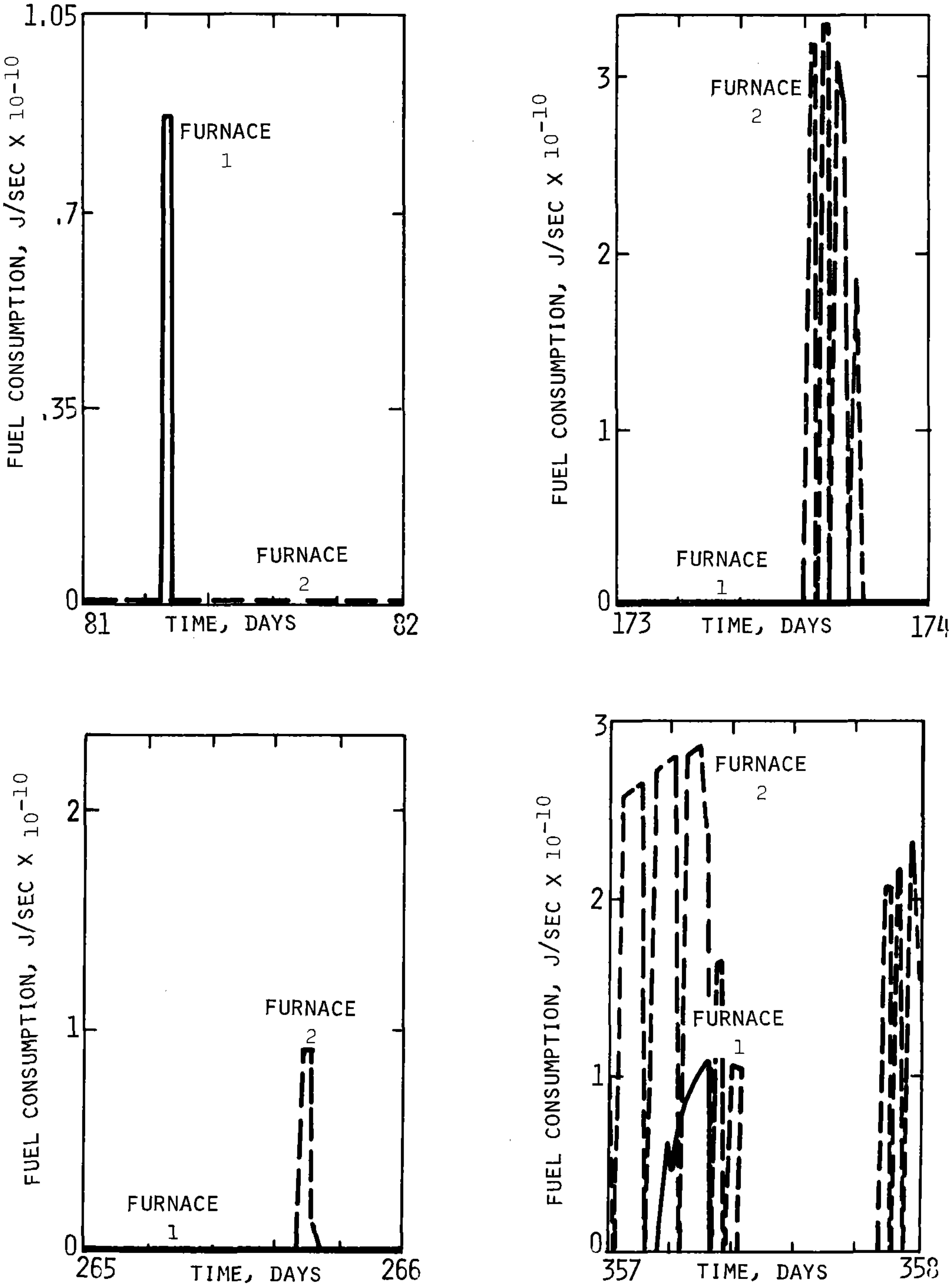

Figure 5. Response of Auxiliary Furnaces for a 1000-Home Community Using North-South Collectors in Albuquerque

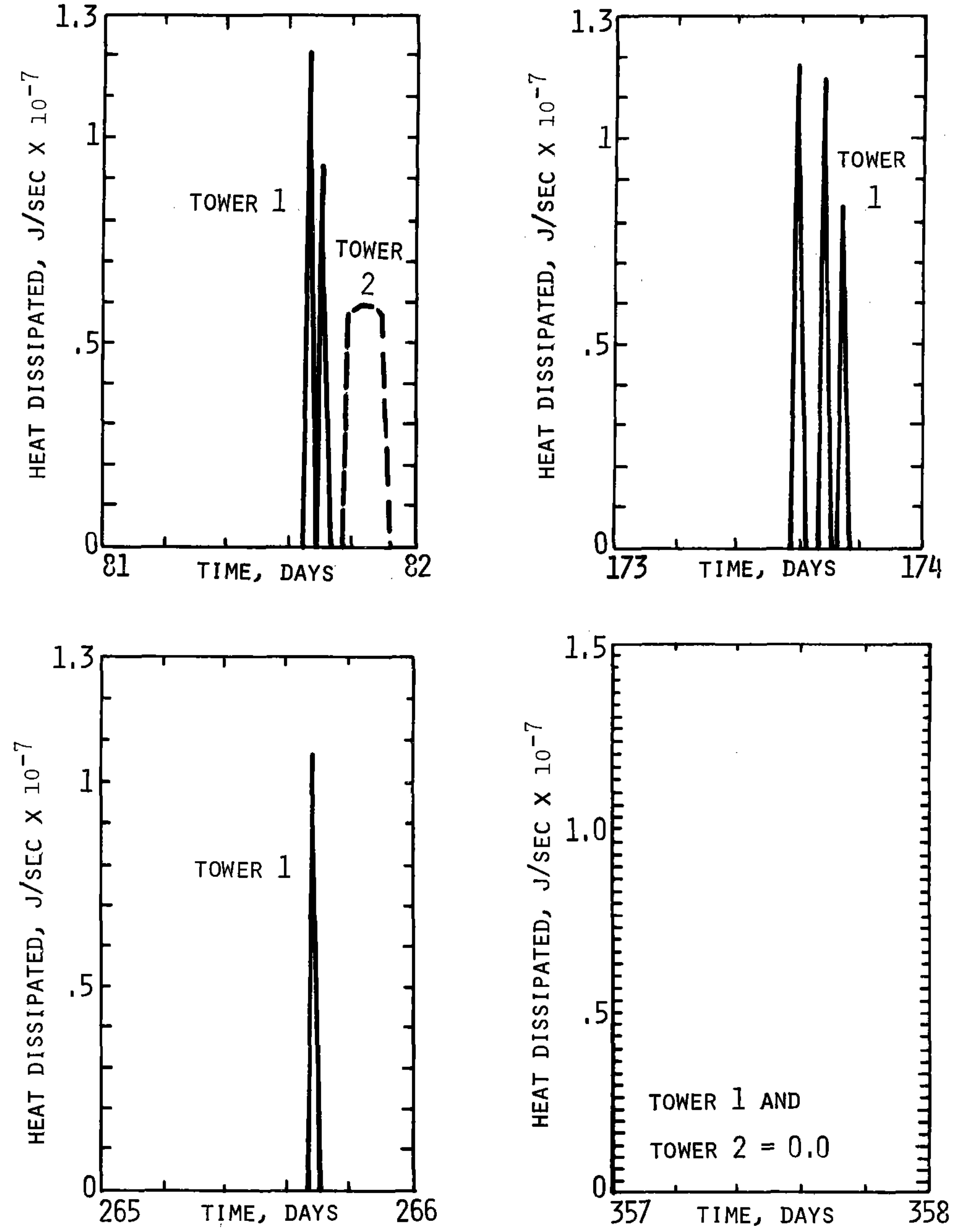

Figure 6. Energy Discharge in Cooling Towers for a 1000-Home Community in Albuquerque

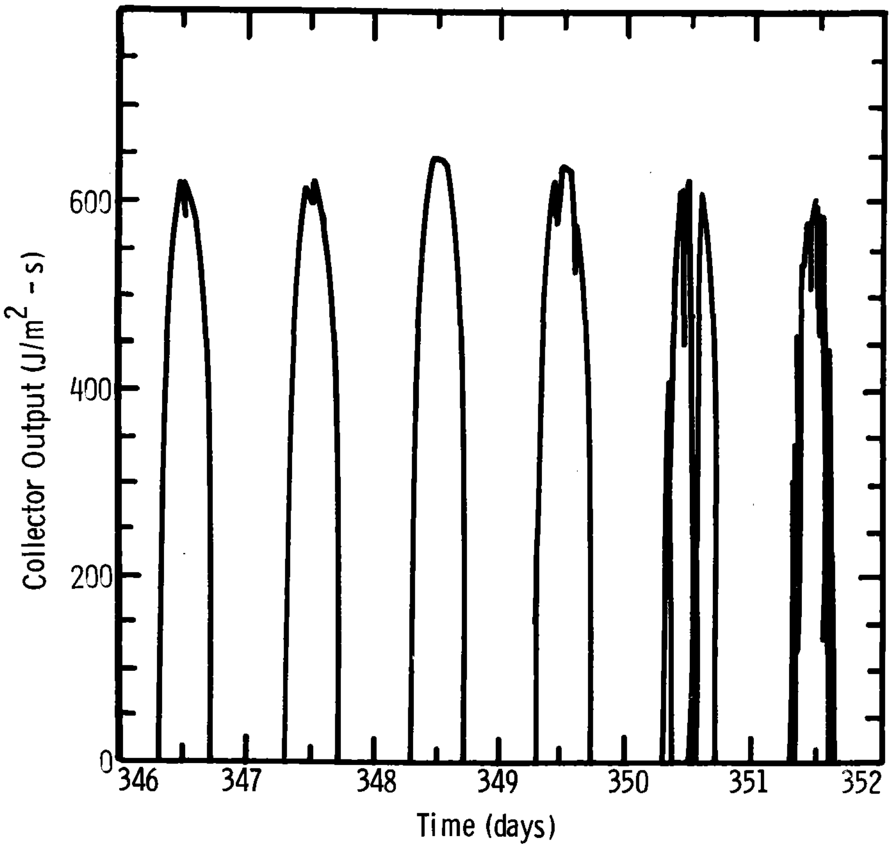

Figure 7. Collector Output for Winter Season

Modifications to the HLOAD subroutine and improved estimates of the heat-transfer coefficients for individual homes resulted in reduced thermal loads on the system. The revised loads are shown in Figure 8 and comparison with the winter loads shown in Figure 3 illustrates the reduction. The revised loads are 8000 J/s (27, 300 Btu/hr) peak and 3900 J/s (13, 400 Btu/hr) average for the winter day.

The response of the two storage systems is shown in Figure 9 and may be compared with the winter response shown for clear-air insolation in Figure 4. The reduced insolation for days 350 and 351 is obvious from the much smaller increase in the volume of Storage 1 during the day.

Assuming as before that the average of these days from the four seasons satisfactorily represents the average annual performance, one can estimate the percentage of the community energy needs supplied by solar energy. For this particular area, 59% of the energy needs were supplied by solar input compared with 63% for the clear-air insolation. Thus the reduced solar input and reduced thermal loads combine to cause little net effect on the relative contributions of solar and fossil fuel input compared to the results of the clear-air insolation.

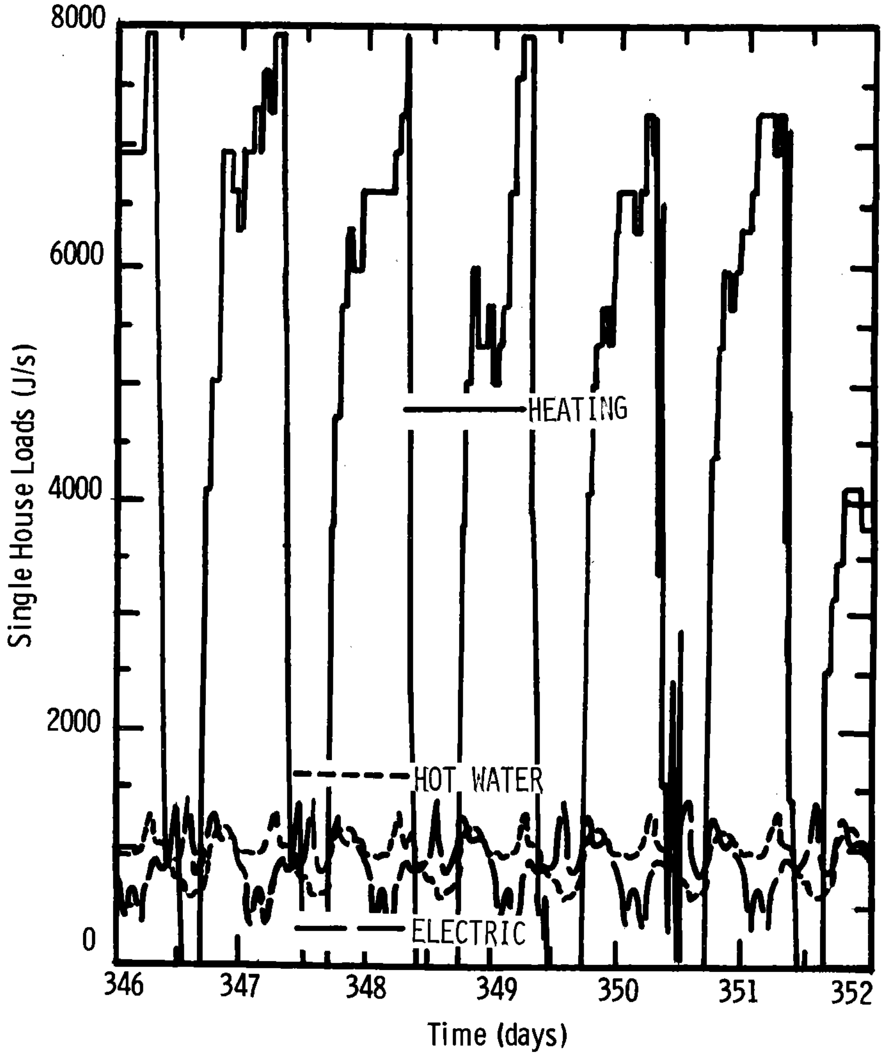

Figure 8. System Loads for Winter Season

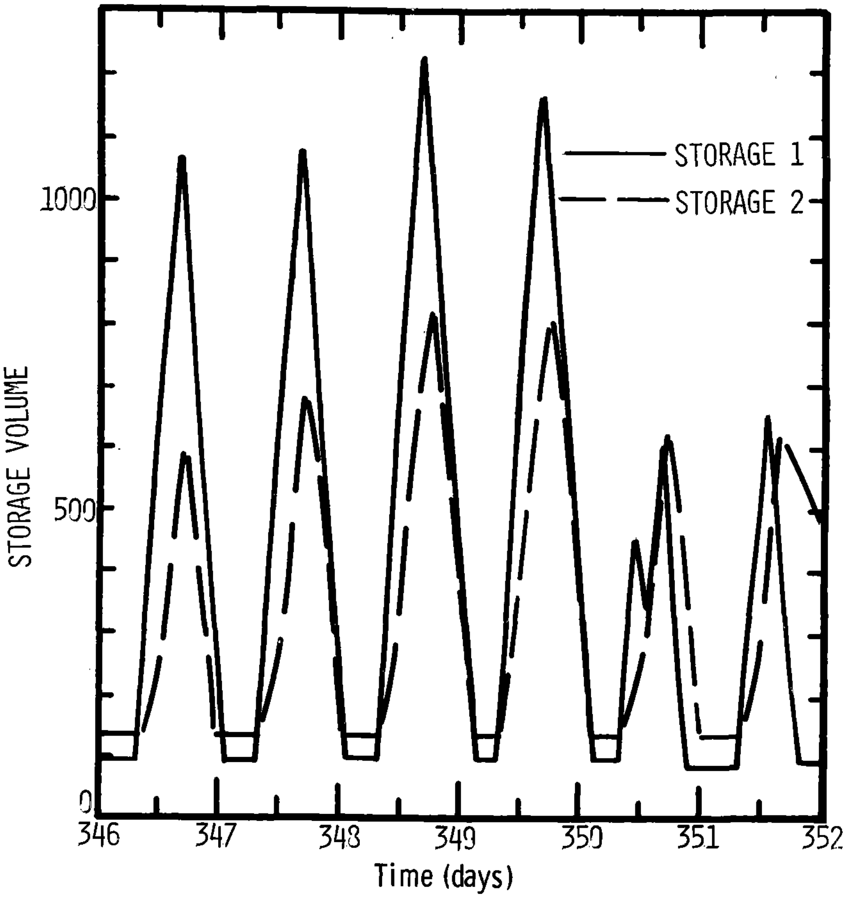

Figure 9. Response of Thermal Storage Systems for Winter Season

Economic Analysis

An important factor in the potential use of solar energy is the economic advantage or disadvantage of the system. To help answer this question, an economic analysis was developed by personnel in the Auditing Department at Sandia Laboratories. These economic evaluations are based on the concepts underlying the Revenue Requirement Technique. This technique takes into consideration the need for an adequate return on investment as well as the items considered as costs in the usual accounting determinations. The methodology for the calculation of annual revenue requirements is based on formulas derived from Grant and Ireson.[21]

Among the factors required in the analysis are the inflation rate, the interest rates on both borrowed money and stock, the relative amounts of the total financing in stock and borrowed capital, the number of years to amortize the system, and the cost of fossil fuel. All of these factors significantly affect the economic results, and values must be predicted for future years.

The difficulty in accurately predicting these values is attested to by their fluctuating behavior over the past years. However, to perform an analysis, specific assumptions must be made. Three values for each of the parameters, designated as Rate A, Rate B, and Norm, were used in an attempt to reflect these uncertainties. The Norm is based upon inflation and interest rates which roughly indicate average values for the past 20 or 30 years and upon projected increases in the cost of fossil fuel which were provided by a representative of the natural gas industry. Rate A is based upon inflation and interest rates which are higher than the Norm but more consistent with values observed in recent years. The projected fossil-fuel costs are the same as for the Norm. In Rate B the inflation and interest rates are between those for the Norm and Rate A, with values about 15% higher than Norm. Again, the projected fossil-fuel cost increases are the same as the Norm values. Values for each parameter of interest for the three cases are shown in Table IV.

TABLE IV

Projected Costs of Energy

	Rate A	Rate B	Norm
Inflation Rate, %	7.5	5.0	3.5
Interest Rate, %	10.9	8.4	6.0
Common Stock Rate, %	10.0	8.5	8.0
Amount in Common Stock, %	40.0	40.0	40.0
Fixed Charges Rate, %	2.6	2.6	2.6
Number of Years	30.0	30.0	30.0
Fossil Fuel Behavior			
1974 Costs, $/MJ	0.43	0.43	0.43
Increase Rate, %	45.0	45.0	45.0
Years	2.0	2.0	2.0
Increase Rate, %	11.5	11.5	11.5
Years	9.0	9.0	9.0
Increase Rate, %	1.5	1.5	1.5
Years	19.0	19.0	19.0
Increase Rate, %	0	0	0
Years	0	0	0
Collector Costs, $/m^2	107.0	107.0	107.0
Storage Costs, $/MJ			
High Temperature	4.75	4.75	4.75
Low Temperature	1.90	1.90	1.90

An analysis of the costs of the primary components in the system was made using the Norm parameters; the results are shown in Figure 10. These curves show the levelized annual costs in dollars per year for the total energy required by each house as a function of the percent of energy supplied by solar radiation. The projected fossil-fuel prices, in 1974 dollars per gigajoule ($1 \text{ GJ} = 10^9 \text{ J}$), are shown in an inset curve. In the system there are certain components whose costs are independent of the type of energy input and, to a certain degree, the type of load. These are the conventional equipment (viz., turbine, pumps, cooling towers, etc.), the general offices and personnel, the electrical distribution system, and the low-temperature storage system. An additional component, the thermal distribution system, does not vary for a specific geometry for the thermal load, but can vary significantly for different geometries. The component costs which vary significantly are, as expected, the fossil-fuel costs, the collector costs, and the high-temperature storage costs.

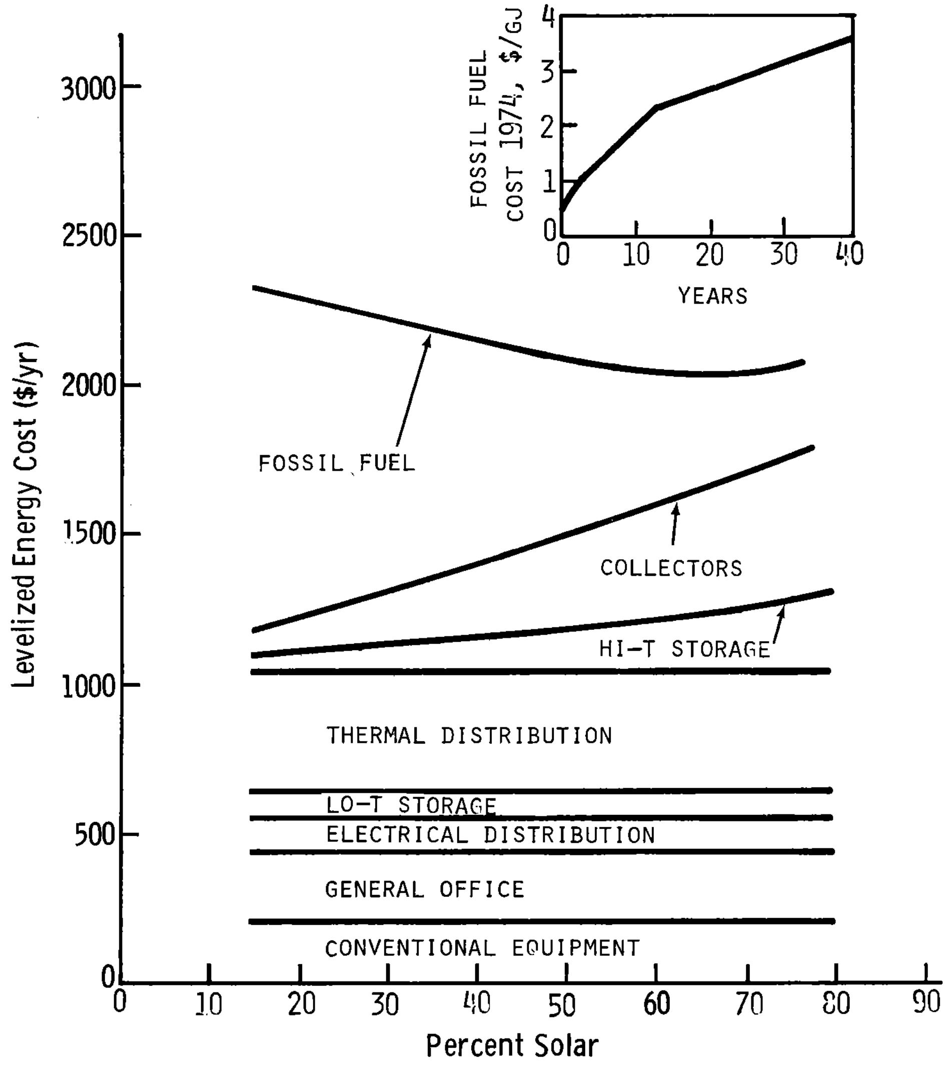

Figure 10. Energy Costs for 1000-Home Community in Albuquerque

These results show that the energy costs for a 0% solar system are greater than those for a 64% total energy system using solar energy. In particular the levelized annual cost for a system near 64% solar and 36% fossil fuel is a minimum. At a cost of 107 $/m^2, collectors can be added to the system and decrease the overall cost until the collector area is sufficiently large to supply the daytime energy needs and replenish the thermal storage system for overnight use. Further increase in the collector area causes an increase in the overall cost since the energy collected cannot be stored because of the overnight storage capacity limit, but rather is dissipated to the atmosphere when the storage is filled.

A second factor of interest from these data is the relative percentage of the costs of the different components. Figure 11 presents charts showing these comparisons for a total fossil fuel system and a 64% solar/36% fossil fuel system. For the 0% solar system the primary costs are those associated with the fossil fuel. In addition thermal distribution system and equipment costs are also significant. For the combined solar/fossil fuel, no single factor dominates but the thermal distribution, fossil fuel, collector, and equipment costs are the largest factors.

Total costs were computed for the different solar systems using the economic data shown in Table IV and these results are shown in Figure 12. For all economic conditions the levelized cost decreases as the solar percentage increases to solar input values near 60 to 70%.

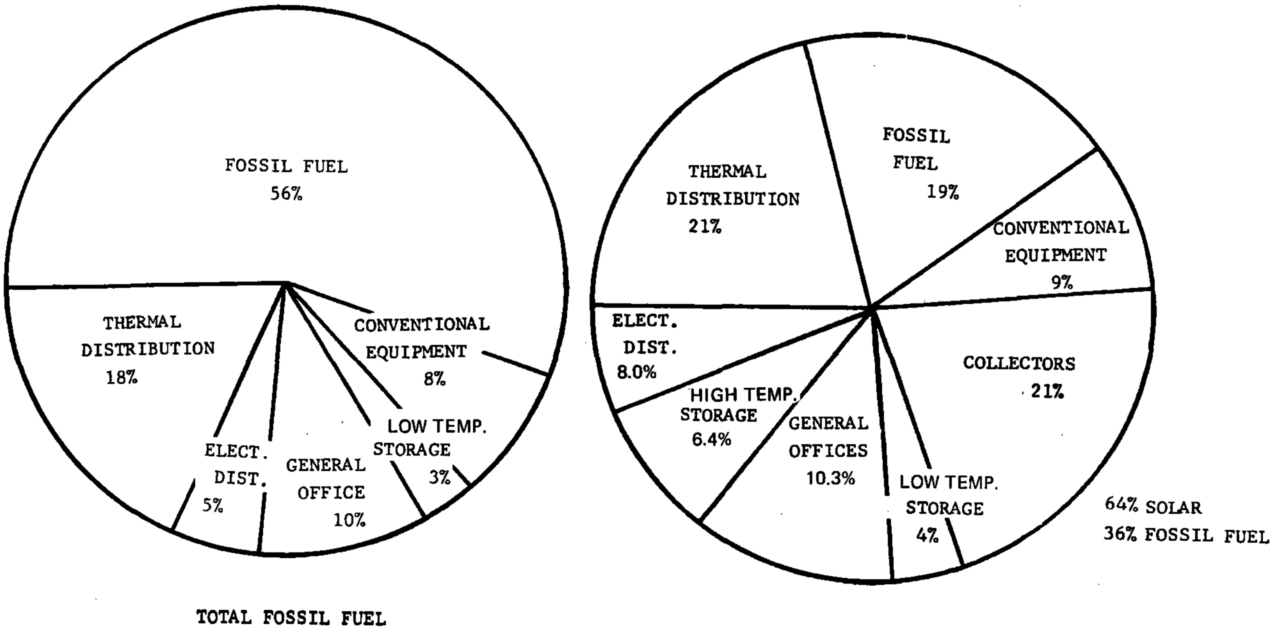

Figure 11. Comparison of Costs of Components of Solar Total Energy System

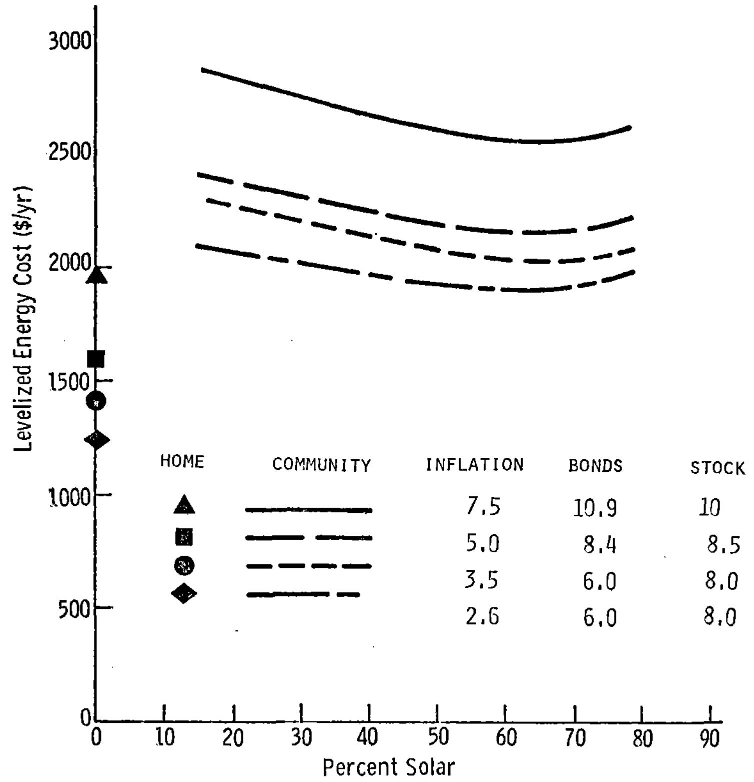

Figure 12. Effect of Economic Condition on Energy Costs

The general conclusion that can be drawn from these data is that, for the various assumptions of inflation, interest, and fossil-fuel costs, solar energy is on a cost parity with a low-temperature total energy fossil fuel system for this application. Therefore, significant fossil fuel can be saved at no added increase in cost. For example, the 73% solar energy system provides a 75% savings in fossil fuel based on clear-air solar intensity. As discussed previously, reduced solar intensity will increase the demand for fossil fuel supplementation.

A simplification of the cost analysis program has been prepared to calculate a level annual revenue requirement for individual homes for comparison to the solar total energy system's annual revenue requirement. This calculation is needed to make a meaningful comparison of the essentially different types of expenses. Comparing the level annual revenue requirement of the solar system, including the effects of inflation, to today's energy costs for a home would be incorrect; future cost increases in energy for the homes must be considered.

A comparison of the cost of energy in this 1000-home total energy system with the cost of energy in a present day individual home was made. The levelized annual energy costs for a single home were calculated. The electrical and thermal demands shown in Figure 3 are provided, respectively, by electrical energy from a utility company and fossil fuel in individual home heaters. Levelized annual costs were calculated using the economic data shown in Table IV. Present electrical energy costs were assumed to be 0.025 $/kWh and fossil-fuel costs were 1.00 $/MBtu. Both costs were inflated and the fossil-fuel costs were also increased according to the projected increase. The results for each set of assumptions on inflation and fossil-fuel cost increases are shown on Figure 12 as single points on the 0% solar line. Clearly the energy costs for the total energy system are twice as high as the levelized individual home costs. This was not unexpected. Total energy systems for individual homes are not used in the United States today because fossil fuel, especially natural gas in areas like Albuquerque, remains relatively inexpensive and can be delivered economically to individual home furnaces. The conclusion drawn from these comparisons is that this particular example (i.e., the separated home community) is not the optimum application for total energy systems. Based on these cost calculations and comparisons, more desirable applications can be suggested. For example a complex of multidwelling apartments would offer the advantage of almost totally removing much of the cost associated with thermal and electrical distribution systems, general office, and conventional equipment. A combination of homes, apartments, schools, shopping areas, and offices would also offer significant advantages over the individual home system.

Mixed Load Community

A flexible community description, incorporating statistical architectural data, has been prepared with the aid of the Architectural Department of the University of New Mexico. The community contains a total of 2000 dwelling units and is subdivided by building type as shown in Table V. Each subdivision is considered an independent subset (e.g., low-rise apartment) of the community, complete with its own thermal energy distribution system. All subdivisions are connected to the central solar power facility by a common thermal distribution network.

Employment of a subdivision concept is important in that it provides facility for analysis. Isolated parts of the community such as high-density residential areas may be independently analyzed, and community design may be easily modified by changing the relative location and size of various subdivisions. Employment of a subdivision concept reflects the actual practice of community zoning.

TABLE V

Definition of 2000 Dwelling Unit Community

	Structures	DU per Structure	DU per Acre	Floor Area per DU	Percent of Community
A. Residental					
Single Family Detached	504	1	6	139 m^2 (1500 ft^2	25
Single Family Attached*	160	5	10	116 m^2 (1250 ft^2	40
Low-Rise Apartment*	48	10	20	103 m^2 (1104 ft^2)	24
High-Rise Apartment**	4	54	54	114 m^2 (1225 ft^2)	11
B. Schools					
Elementary	2	-	-	2529 m^2 (27,225 ft^2)	-
Jr. High	1	-	-	2453 m^2 (26,406 ft^2)	-
High School	0	-	-	-	
C. Commercial	1	-	-	14,864 m^2 (160,000 ft^2)	-

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*Two stories.

**Thirteen stories.

Future Systems Analysis Plans

Future analyses will attempt to determine the breadth of application for the basic concept. The studies will include a variety of loads, architectural styles, different energy systems, and a variety of locations.

Loads

The load configuration previously studied was 1000 identical homes, separated from each other in the manner of typical suburban development. By contract with the University of New Mexico (School of Architecture) other configurations of higher density and different use were prepared (Table V) and a composite load configuration was chosen, more representative of urban construction. This composite load consists of six separable parts, so that different combinations can be made if desired. For example, the four high-rise apartment houses could be studied separately or the commercial load might be run separately to determine the effect of a large electrical-to-thermal load ratio.

Profiles for military bases at various locations have also been obtained.[22]

Energy Systems

Because of the flexibility designed into the mathematical model, SOLSYS, a number of combinations of components may be assembled and evaluated, both technically and economically. In addition to the cascaded system using focusing collectors, use of flat-plate collectors will be studied in both a cascaded and noncascaded configuration. A system using focusing collectors for high-temperature energy and flat-plate collectors for low-temperature energy will be evaluated, in both a cascaded and noncascaded configuration. A total energy system which stores energy after conversion to kinetic or electrical energy will also be evaluated. In this case, the high-temperature storage will be eliminated, and thermal energy collected during the day will be immediately converted to electrical energy and stored as kinetic energy in a flywheel, or as electric energy in batteries or other storage systems. Thermal energy not converted to electricity will be stored in a low-temperature thermal storage system. A concentrating collector configuration using photovoltaic cells located on the receiver tube will also be evaluated. In this system, the receiver tube is maintained at a temperature high enough to produce useful thermal energy. Excess electrical energy from the photovoltaic system is stored in a storage device such as a battery or flywheel for later use.

Locations

As mentioned previously, data tapes of weather and solar data have been obtained for eight selected cities. The selection was based on available complete yearly tapes and data from the TRW Phase 0 study of heating and cooling of buildings. Cities were selected in order to obtain extremes of solar input in conjunction with heating loads of winter and cooling loads of summer. The cities chosen were: Albuquerque, Boston, Fort Worth, Los Angeles, Miami, Nashville, Omaha, and Seattle. The utilities serving these cities have been contacted to obtain present and predicted future fuel costs to use in economic comparison studies.

Direct solar normal incidence data is available in only three of the chosen locations, Albuquerque, Omaha, and Boston. A model for constructing normal incidence radiation from the total radiation data, which has been obtained for all eight cities, is nearly complete. After further verification of the model, normal incidence radiation information will be added to the existing data tapes for use in analysis.

Summary

A study of various loads, energy systems, and locations will allow an evaluation of the economic and technical limitations to the application of moderate-temperature solar process heat and total energy systems throughout the United States.

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