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Brief Description of SOLSYS—Energy System Simulation Computer Program

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BRIEF DESCRIPTION OF SOLSYS—ENERGY SYSTEM SIMULATION COMPUTER PROGRAM*

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ABSTRACT

This is an abridged version of "Energy System Simulation Computer Program —SOLSYS," SAND75-0048, Sandia Laboratories, May 1975.

Program (SOLSYS) is used primarily to simulate the transient performance of solar energy systems. The program consists of a component subroutine library, an information subroutine library, a control-component subroutine library, and an executive program. Component subroutines model the performance of fluid-handling components which can be connected to construct almost any desired energy system. The component subroutine library presently contains 21 subroutines modeling collectors, storage units, power-generation cycles, transmission and distribution hardware, heat exchangers, house equipment, and auxiliary energy components. Some components are modeled very accurately and others use simple energy-conservation models Information subroutines supply time-dependent information such as insolation data, weather data, heating requirements, air-conditioning requirements, hot water requirements, and electrical requirements to the program. Control-component subroutines model components which control temperatures in the system and components which switch a fluid flow between fluid channels when switching is necessary. The executive program handles input and output and calls on subroutines in the appropriate order.

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BRIEF DESCRIPTION OF SOLSYS--
ENERGY SYSTEM SIMULATION COMPUTER PROGRAM

Introduction

Sandia Laboratories Solar Energy Systems Division has been exploring the feasibility of a solar total energy system since 1972.[1] The system uses collected solar ènergy to power a turbogenerator which provides electricity to meet the demands of a community, and heat removed from the condenser of the power-generation cycle is used to supply the community with energy for heating, air-conditioning, hot water, and other relatively low-temperature energy needs. A computer program was developed which analyzed various solar energy systems and provided insight into performance and cost,[2] but it did not have the flexibility needed to study the effects of design modifications and parametric changes. Continued energy system analysis depended on a method which was not restricted to a specific 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 which has the flexibility to analyze a variety of systems and their modifications and which can predict the details of transient system performance.[3,4,5] The program contains a library of component model subroutines which can be connected in almost any order desired 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, either to verify a proposed design or to 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.[6,7,8]

Program Composition

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

1. Executive program
2. Component model subroutine library
3. Information subroutine library
4. Control-component subroutine library
5. 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 it 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 set the initial 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 (±0.1 deg) 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 reaches its end 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 than 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. Several identical components can be placed in parallel in most cases 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 is transmitted automatically, such as weather and solar data, 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 components. The necessary parameters for each component are listed in the subroutine library section of this report 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 (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 must have a unique subroutine number (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.

APPENDIX

Subroutine Library

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[9] - 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.

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.

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 enter 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[10] 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 fuild 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.

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

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.

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.[12] The program

*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.

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 numidification 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 11 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[12] 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 No.
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 Albuquerque 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.[13] 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.

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 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.

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