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ANL/CNSV-TM-40

SUITABILITY OF THE CASES SOFTWARE FOR EVALUATION
OF DISTRICT HEATING SYSTEMS BASED ON
ANNUAL STORAGE CYCLES

by

James M. Calm and Gerard R. Sapienza*

Energy and Environmental Systems Division

July 1980

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PREFACE

This report summarizes an examination of the suitability of the CASES computer program for evaluation of district heating and cooling systems that operate on annual cycles of thermal energy storage. This work was performed for the Heat-Pump-Centered Integrated Community Energy Systems (HP-ICES) Project. This project is an element of the Department of Energy's (DOE's) Community Systems Program; it is managed by the Energy and Environmental Systems Division of Argonne National Laboratory. The project seeks to conserve energy in the United States by development and demonstration of heat pump systems for district heating and cooling.

The CASES software was written by the Johns Hopkins University Applied Physics Laboratory (APL) for evaluation of the community annual-storage energy system (CASES) concept for the Community Systems Program.

The suitability of the CASES software was considered for evaluation of three systems, developed as part of the HP-ICES Project, and their application to selected communities. The first HP-ICES is based on sensible thermal storage in aquifers. Groundwater from an aquifer is distributed by a two-pipe system to user heat pumps and then reinjected to the same or another aquifer. This concept and its application-feasibility have been investigated by the University of Alabama.

The second HP-ICES employs central ice-making heat pumps to produce hot water for space and service water heating. The ice is stored at the central plant in a bin and later melted to provide cold water for air-conditioning. The hot and cold water are distributed to users in a four-pipe distribution system. This concept has been studied by the Dubin-Bloome Associates.

The third HP-ICES also involves phase-change thermal storage, but uses distributed ice-making heat pumps. These heat pumps are connected to a central storage pond by a closed, ice-slurry distribution loop. An open variation of this system uses groundwater or surface water as a source and disposes of the resultant warmed water or ice slurry. The closed system employs both short-term storage in the individual buildings and annual-cycle storage in the central pond; the open system employs only the short-term storage. This system was developed by the Honeywell Energy Resources Center.

Detailed descriptions of the HP-ICES concepts and studies of their potential for application to selected communities are available in the references. These references also include a project summary and reports on the CASES software development.

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SUITABILITY OF THE CASES SOFTWARE
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by

James M. Calm and Gerard R. Sapienza

ABSTRACT

The CASES computer program is a software package for evaluation of community annual-storage energy system concepts. The software models energy systems that provide space and water heating by cascaded heat pumps and cooling by melting of stored ice. CASES computes thermal demands of individual buildings, aggregates these demands into community demands, models system response, and estimates the overall system costs. The Heat-Pump-Centered Integrated Community Energy Systems (HP-ICES) Project has produced a number of system concepts involving annual-storage cycles for which preliminary application feasibility studies have been performed. More rigorous examination of these concepts as well as detailed simulation and analysis of application feasibility would increase understanding of their potential. The CASES software was considered for these purposes, but was found unsuitable for evaluation of HP-ICES concepts and their application feasibility. No alternative software has been identified which will provide these capabilities, and extensive effort would be required to upgrade CASES for the intended concept evaluations.

1 CASES SOFTWARE DESCRIPTION

1.1 PROGRAM FEATURES

1.1.1 Description

CASES is a computer program for evaluation of community annual-storage energy systems. These thermal utilities would provide space heating and cooling to various buildings in a community based on an annual thermal energy storage cycle. This software affords simplified concept evaluation, but may not be suitable for precise analysis or design due to inherent assumptions.

CASES estimates thermal loads, thermal performance, operational costs, and capital investment for a community annual-storage energy system based on the following user supplied design data: weather, zoning, building use patterns and construction, operational strategy, and the costs of electricity and capital. An executive program controls interaction between three subprograms. The first subprogram calculates loads for individual, user defined buildings. The second aggregates the individual loads into community demands, sizes the terminal and distribution equipment, and determines their costs. The third

sizes storage and central plant facilities and simulates plant operation. Each of the subprograms may be run independently if data files emulating output from the previous steps are provided. A fourth subprogram to modify central plant and storage sizing to reduce system costs may also be called. An earlier version of CASES is also available in which the first three subprograms are separately run with manual sizing of the equipment and storage.

1.1.2 Configurations Analyzed

CASES analyzes a community consisting of groups of identical buildings. Each group of buildings is considered to be an end node of a branching distribution system originating at a central plant. The system employs ice-making central heat pumps and water-source, heating-only heat pumps in individual buildings to supply space heating. Cooling is provided by melting stored ice and using the cold water in fan-coil units.

Individual buildings are constrained to be square structures of user specified construction with equal window areas on all faces. Default physical characteristics of nine representative building types are supplied with the software. Chilled and hot water are pumped between terminal users and the central plant via a buried, uninsulated, two-pipe, distribution network. The distribution system is closed and no accommodation for changes in distribution temperatures is provided. Annual storage is provided by a large ice/water reservoir with a floating, insulated roof. Near term storage is provided by smaller warm water and chilled water fixed roof reservoirs. Other annual storage concepts, such as sensible heat storage in aquifers, are not addressed by the current model. The central plant consists of large ice-making heat pumps with supplementary electric heaters to maintain distribution fluid temperature if needed.

1.1.3 Program Capacity

CASES allows a maximum of 20 building types. There is no limitation on the number of buildings per homogenous group. The number of distribution end nodes, or building groups, is limited to 60.

1.1.4 Methods

The load calculation procedure used by CASES is based on a routine employed by the Massachusetts Institute of Technology Thermal Distribution System Simulation Code (TDIST). TDIST combines a simplified version of the National Bureau of Standards Load Determination (NBSLD) program and the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) load calculation procedures. Hourly space conditioning requirements are calculated by a steady state energy flow analysis which includes effects of heat conduction from the buildings to surroundings, infiltration, solar radiation, internal heat gains, and building use patterns. Hot water consumption is calculated as the product of user supplied part load factors and a peak demand. CASES automatically divides large buildings into two zones, core and exterior. Hourly thermostat settings are adjusted seasonally from user supplied thermostat settings.

The terminal equipment and the distribution system are sized by scaling individual building loads. The scaled loads are combined to estimate the thermal demand of each zone of like buildings and then matched to internally stored equipment and piping characteristics to meet peak demand requirements. Hourly electrical and thermal demands for each building are calculated based on terminal equipment performance. These demands are aggregated into hourly electrical energy usage as well as water flow rate from the central plant. In addition, the unit costs of all terminal equipment and distribution piping, based on pipe cost and excavation volume, are summed to estimate investment. Interbuilding and intrabuilding piping costs are computed as hook-up charges based on building dimensions. Distribution losses and pumping burdens are not determined.

The central plant simulation assumes that hourly demand can be met at all times by some combination of ice melting, ice making, short term storage, and electric heating. Central plant ice making heat pumps operate either at peak performance or not at all, determined by hourly decisions subject to control parameters relating plant operation to the time of day, reservoir levels, and deviation from "typical" load patterns. CASES chooses the number of ice machines and the sizes of reservoirs.

Limited economic optimization is attempted by a trial and error procedure which determines investment and operational cost sensitivity to ice/water reservoir size, short term storage capacity, and the number of ice machines installed in the central plant. The total annual cost of systems is assumed to be electric power cost plus 15% of the capital invested.

1.1.5 History

The software was developed by APL for ANL under DOE sponsorship between July 1977 and November 1978. This effort was a continuation of the development of the community annual-storage energy system concept by APL for the Energy Research and Development Administration (ERDA), now part of DOE.

1.1.6 Status

The program has not been validated or released for general use and has not been tested except by its authors.

1.1.7 Planned Modifications

No modifications are planned at present.

1.1.8 Software Description

The software is written in IBM FORTRAN-IV. The program requires 250K bytes of core storage and 1500K bytes of direct access storage. The source code length is approximately 4100 lines.

1.2 INPUT

1.2.1 Requirements

Building definition and load calculation require building data including dimensions, infiltration and ventilation, construction indicators, solar absorptivities, window shading coefficients, building orientation, occupied area temperatures, hot water usage, internal heat gains, allowable temperature drifts, and building mass. In addition, hourly weather data detailing dry bulb temperature, wind, and insolation conditions are read from a user prepared file. Standard National Oceanographic and Atmospheric Administration (NOAA) weather tapes require editing and reorganization before use.

Distribution system and terminal equipment sizing require the user to specify pipe routing. A number of design parameter values assumed by CASES may be modified by the user.

User input for central plant simulation requires only water main temperatures, reservoir temperatures, and the time interval used to determine anticipatory central plant operation. The user has the option of specifying parameters related to simulation duration, electrical charge rates, and reserve ice storage.

In addition to the analysis parameters already listed, program control variables are also required to control execution and output options. Input for all subprograms of CASES is required even when executing only portions of the program.

1.2.2. Form

Input may be entered in a specified format by card, disk, or tape devices. No interactive or free-format input is presently available.

1.3 OUTPUT

1.3.1 Description

Energy use and costs are provided in hourly, monthly, and annual reports, which include an input echo. Complete information on calculated loads, temperatures, central plant and terminal equipment coefficients of performance, and equipment sizes is available. A summary of economic optimization iterations is also provided.

1.3.2 Form

All CASES output is available as reports arranged in headed tables. Subprogram output is written into disk or tape files for subsequent use.

1.3.3 Options

The user may request any of the outputs described above or suppress selected outputs.

CASES provides an optional summary of monthly and annual system costs and performance whenever the distribution system and terminal equipment sizing and costing subprogram is executed. A summary of optimization iterations is provided if the economic optimization procedure is executed.

1.4 VALIDATION AND APPLICATION

No attempt has been made to validate the program or the simplifying assumptions used in the load calculations.

1.5 DOCUMENTATION

Documentation exists in the form of an unpublished user's manual and supporting reference documentation. The user's manual provides information on the use and operation of CASES and a sample input deck and reference community description. The supporting documents describe the program's development and methods.

1.6 AVAILABILITY

CASES is a public domain code that has not been released for public use. It is available in source or object versions to ANL and DOE users from:

Dr. William R. Powell
The Johns Hopkins University
Applied Physics Laboratory
Johns Hopkins Road
Laurel, MD 20810

301/920-3370 or FTS/920-3370, Extension 2046

The code is available on 9-track 1600 BPI standard label magnetic tape or in other standard tape or card formats.

1.6.1 Hardware Requirements

IBM 360 or 370 with FORTRAN-IV G or H (not H extended) compilers.

1.6.2 Software Costs

Software copies may be subject to reproduction and shipping charges.

The run cost based on sample executions is expected to be under \$50 without system optimization and under \$250 with optimization.

1.7 MAINTENANCE AND SUPPORT

CASES is not maintained or supported at present.

2 USE OF CASES FOR HP-ICES EVALUATION

2.1 OBJECTIVE

The Heat-Pump-Centered Integrated Community Energy Systems (HP-ICES) Project has produced a number of system concepts for which preliminary application feasibility studies have been performed. Among these are three concepts involving annual thermal energy storage cycles including the systems studied by the University of Alabama, Dubin-Bloome Associates, and the Honeywell Energy Resources Center. A related study of the CASES concept was previously performed by the Johns Hopkins University Applied Physics Laboratory (APL). More rigorous examination of these concepts as well as detailed simulation and analysis of application feasibility would increase understanding of them and their potential. The following discussion addresses the feasibility of using the CASES software for these purposes.

2.2 COMMUNITY LOAD CALCULATION

2.2.1 Building Representation

A simplification incorporated in the CASES software significantly limits its utility. This limitation is imposed by a requirement that all buildings be square and have equal fenestration on each face. While these assumptions result in greatly simplified load computation, the penalty paid for them is of concern. Since HP-ICES are basically conservation technologies, it is reasonable to assume that the communities they might serve would also consider obvious conservation approaches in the design of building envelopes. One obvious consideration is use of passive solar architecture with which the CASES building assumptions are in conflict.

The impact of these assumptions is to distort typical diurnal profiles, an important consideration in evaluating short-term storage and morning recovery peak effects.

2.2.2 Interbuilding Diversity

The aggregation algorithm used by CASES in combining individual building demands into community loads is highly suspect. The approach employed is to scale the building demands by the number of buildings. Concurrent heating and cooling demands in different buildings are then assumed to offset each other. Finally, an unjustified smoothing function is applied to further account for diversity. This function reduces both peak demands and the magnitude of changes in demand from hour to hour. As such it crudely addresses thermal inertia in the distribution system (i.e., inherent storage in the distribution system), but no physical relation exists for it. The CASES documentation indicates that a refined algorithm may be added in future versions of the software. It appears that intra- and interbuilding load diversity are presently distorted due to the approximation discussed in the previous section as well as the aggregation approach employed.

2.2.3 Concept and Application Analyses

Load calculation accuracy is generally of less consequence for concept evaluation than for application feasibility analyses. Approximations are often sufficient for the former since the communities served may be somewhat arbitrarily selected. In such cases, it is necessary that the load profiles be realistic, although not necessarily precise. Site-specific feasibility analyses, however, can be misleading when capacity sizing and system response are distorted by load errors. When increased accuracy is required for either, loads can be externally computed and the loads portions of CASES bypassed.

2.3 SYSTEM MODELLING

2.3.1 Configurations

A major restriction of the CASES software is the lack of flexibility in system configurations that it can model. In the CASES software, a central, ice-making heat pump provides hot water and produces ice which is stored in a pond. Cold water is supplied by melting the ice as required, without heat pump operation. Both the hot and cold water supplies are pressurized by distribution pumps, and short-term sensible storage is provided for each. The terminal systems consist of water source heat pumps with bypass water coils. When heating is required, the terminal subsystems extract heat from the hot water mains and use it as a source for water-to-air heat pumps. When cooling is required, cold water bypasses the terminal heat pumps through fan coils without heat pump operation. As such, heating is essentially a cascaded heat pump system and cooling is essentially free cooling from central ice melting without heat pump operation. The CASES software does not model other systems. Specifically, sensible storage schemes, as in the University of Alabama concept, cannot be modelled. Similarly, central ice-making schemes as in the Dubin study cannot be modelled due to the terminal equipment configuration differences as well as the differences inherent between two- and four-pipe distribution systems. Distributed ice-making heat pump systems, as in the Honeywell study, are also not accommodated.

2.3.2 System Variations and Sensitivities

An important goal in use of detailed simulation for concept and application evaluation is the examination of system variations. It is believed that such variations may result in concept enhancement and may produce viable systems when initial concepts are found to be unattractive. Specific illustrations of the tailoring options contemplated include variations in distribution temperatures, substitution of prime movers (i.e., engines or steam turbine drives in place of electric motors), bin versus tank storage, in-situ ice-making versus external ice making with transport to storage, variable volume and/or temperature distribution, and so forth. More complex configurational variations, such as examination of one-, two-, three-, four-, or six-pipe distribution schemes, differences between loop and branching distribution, ice-slurry circulation, insulated versus uninsulated piping, multi-mode operation of either central or terminal heat pumps, and seasonal sensible storage are not possible.

2.3.3 Simulation Algorithms

Examination of the simulation algorithms employed by CASES reveals a number of inherent deficiencies of significant concern. These include the performance efficiency assigned to the heat pumps, the part-load modelling of the terminal heat pumps which is inconsistent with the performance of actual equipment, and the failure to model distribution burdens and parasitics. As a consequence, the validity of results is in question even for the specific configuration addressed; this item is further discussed in section 2.6 below.

2.4 REFERENCE SYSTEMS

The CASES software does not model alternative systems as references for comparison with HP-ICES concepts. As a consequence, alternative simulation or evaluation techniques would be required to determine corresponding performance and economics of competing community and conventional energy systems.

2.5 SOFTWARE AND SUPPORT

2.5.1 Software Accessibility

The CASES software and its documentation is available to ANL and is compatible with conveniently available computer systems. The software has been installed successfully both at APL and ANL.

2.5.2 Support

No support or maintenance is presently available for the CASES software. Its authors have indicated that prior obligations would preclude their involvement prior to 1981 and would be contingent on sponsorship.

2.6 VALIDATION

No attempt has been made to validate the CASES software or to extensively test it. As a consequence, results from its use could not be relied upon and would, in view of the above observations, be suspect. Deficiencies resulting in differences between CASES and other analytical findings could not be definitively attributed to either.

2.7 ALTERNATIVES

No alternative software suitable for the above objectives is known to exist. Specific portions of the work can be performed with various single-purpose programs. It is anticipated that the Optimization and Simulation of Integrated Systems (OASIS) computer program, presently under development by the Community Systems Program, will supply the desired capabilities in the future. At present, however, OASIS does not model some necessary components including distribution subsystems, water-source and ice-making heat pumps, or

phase-change storage.* OASIS also does not calculate service demands, but this can be separately performed.

2.8 NOTE ON CASES

In fairness to the CASES software, it should be noted that the above discussion goes beyond the original purpose of CASES. The CASES program was written to allow evaluation of a specific concept and not as a generalized simulation technique. While some of the deficiencies cited hold true even for that concept, the present objective as outlined in section 2.1 demands a broader capability.

Contractual compliance for development of either the CASES concept or software is not at issue and has not been examined in this evaluation.

*OASIS allows the user to define additional components. It would not be practical to do so for the present purpose since most of the major components would require user definition. Data collection and reduction to the appropriate form for this would require a very extensive effort.

3 CONCLUSIONS AND RECOMMENDATIONS

The CASES software is not suitable for evaluation of HP-ICES concepts or their application feasibility. No alternative software has been identified which currently provides these capabilities, although OASIS is expected to do so in the future. Extensive effort, far beyond that presently available, would be required to upgrade either CASES or OASIS for the intended purposes.

In the absence of an appropriate analytical method, manual analyses are possible. Their practicality is in doubt in view of the complexity of the desired analyses as well as the number of systems and variations to be considered.

Accordingly, the following recommendations consider not only the inherent problems of using the CASES software, but also future requirements for analytical techniques:

- HP-ICES evaluation should not be attempted using CASES.
- CASES should not be released for public use until:
 - identified deficiencies pertaining to the specific system it was intended to model are resolved,
 - it has been extensively tested and validated,
 - maintenance and user support are available, and
 - its documentation is published.
- Future ANL or DOE efforts to develop or upgrade CASES or similar software should be redirected towards acceleration of OASIS completion and improvement. Release of OASIS should be contingent upon the same criteria as cited above for CASES.

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