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A Review of Computer Software Applicable to the MIUS Program

William L. Carroll
John R. Schaefgen, Jr.

Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

October 1977

hudmius
MODULAR INTEGRATED UTILITY SYSTEMS
improving community utility services by supplying electricity, heating, cooling, and water/ processing liquid and solid wastes/ conserving energy and natural resources/ minimizing environmental impact

Prepared for

U.S. Department of Housing and Urban Development
Division of Energy, Building Technology and Standards
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ABSTRACT

Thirteen computer programs are examined for potential application to the Modular Integrated Utility System (MIUS) program. The software programs considered calculate all or partial combinations of: heating and cooling loads, simulation of physical systems to determine the energy requirements necessary to satisfy those loads, prediction of optimal operation schedules and associated costs, and accomplishment of full life-cycle economic analyses. A set of criteria for evaluation of this software is presented. Information regarding the programs, obtained from user manuals and a series of seminar presentations, is collected and systematically summarized in a standardized format using information available as of June 1974. An evaluative summary of each program as of that date is given. Program comparison activities are discussed and evaluated. Conclusions regarding applicability, validity, and utility of the programs are reached. Recommendations are made concerning future software development and utilization.

Keywords: Computer programs; cooling; energy analysis; financial analysis; heating; load calculation; MIUS; modular integrated utility system; simulation; utility services

FOREWORD

The Department of Housing and Urban Development (HUD) is conducting the Modular Integrated Utility System (MIUS) Program devoted to development and demonstration of the technical, economic, and institutional advantages of integrating the systems for providing all or several of the utility services for a community. The utility services include electric power, heating and cooling, potable water, liquid waste treatment, and solid waste management. The objective of the MIUS concept is to provide the desired utility services consistent with reduced use of critical natural resources, protection of the environment, and minimized cost. The program goal is to foster, by effective development and demonstration, early implementation of the integrated utility system concept by the organization, private or public, selected by a given community to provide its utilities.

Under HUD direction several agencies have participated in the HUD-MIUS Program, including the Energy Research and Development Administration (ERDA); the Departments of Defense (DOD); Health, Education and Welfare (HEW); and Interior (DOI); the Environmental Protection Agency (EPA); the National Aeronautics and Space Administration (NASA); and the National Bureau of Standards (NBS).

This publication is one of a series developed under the HUD-MIUS Program and is intended to further a particular aspect of the program goals.

Drafts of technical documents are reviewed by the agencies participating in the HUD-MIUS Program. Comments are assembled into a Coordinated Technical Review. The draft of this publication received such a review and all comments were resolved.

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1. Introduction

In the conceptual development and technology evaluation phase of the multi-agency HUD-MIUS Program, the use of computerized calculation procedures by several of the participating agencies started early and played an important role in analyses ranging from site load determination, to determination of overall soundness of different concepts and technologies, to detailed evaluation of total MIUS designs. The NASA and ORNL developed computer programs to estimate building thermal loads and the subsequent required energy input to various plant configurations which satisfy those thermal loads. At the request of HUD, the NBS team of the HUD-MIUS Program examined the various calculational procedures in use for soundness of approach, and for compatibility of efforts of the different agencies. In addition, some commercially available software was examined in order to determine if there were any programs which could be of use. This report describes the information derived from the effort, and results in a series of recommendations to the HUD Program Manager both as to those programs best able to satisfy present MIUS needs and to what additional computer program development is needed for future work.

All programs were evaluated with respect to their potential contribution to the generation and evaluation of MIUS designs in the demonstration and follow-on phases of the MIUS effort. The program descriptions and evaluations are based in part on training courses presented by program developers and in part on published descriptive material concerning the programs.

The reader is cautioned that computer programs are constantly evolving. The descriptions and evaluations which follow are based on the information available as of June 1974. Changes which have been made to several of the programs since that date are not addressed.

This evaluation gives consideration to some past comparison activities and summarizes their findings. It is noted that there are no publicly available evaluations of program accuracy, only evaluations of relative agreement between programs. Three of the comparisons were carried out by government agencies participating in the MIUS effort.

Several conclusions are reached concerning MIUS needs for computer support. Recommendations are made for implementation of specific computer programs which come closest to satisfying the identified MIUS needs. Due to the simulation flexibility required for MIUS studies, only programs for which the plant systems simulation package was available to participating agencies in source language form could be recommended.

This report of the evaluation effort is presented with the intention that the program description data, evaluative summaries, comparison activities and conclusions will assist in subsequent MIUS efforts for the design and energy analysis of community energy systems.

2. Evaluation Criteria

A particular perspective was established from which all of the computer programs described herein were examined in forming an evaluation. Applicability and usefulness in furthering MIUS project goals were a primary concern. In addition, the validity or quality of the consitutent algorithms was examined to the degree possible without actual line-by-line algorithmic analysis. This examination was based on available program documentation, training seminars, and oral and written communication with the authors of the computer programs. Although previously initiated comparison test case activities are discussed and evaluated in Section 4 of this report, no specific test-case comparisons were involved in the present effort.

To best accomplish this effort, a set of evaluation criteria were developed by which the characteristics and capabilities of each program were systematically examined. These criteria are divided into four general categories: a) applicability to the MIUS effort; b) simulation adequacy; c) user factors of the programs; d) implicit simulation bias.

The first area of concern is that of program applicability, i.e. does a given program or software system calculate something that is needed in a MIUS analysis. Determination of technical and economic feasibility is necessary for survival of the MIUS concept. The early efforts of the MIUS program were largely directed to this end. Critical to achieving this determination is the ability to predict, either in an absolute or in a comparative sense (the importance of the distinction between these will be discussed in connection with the next general area), the energy utilization or economics or both of a MIUS configuration which satisfies a given set of utility demands. It is important that comparative information on energy utilization and economics is sufficient to enable determination of an optimum configuration (this is likely to involve several iterations) and also to allow comparison with conventional utility systems satisfying the same demands. The determination of the various utility demands as a function of time for a given site application is an activity peripheral to the MIUS program scope. However, it is necessary that MIUS staff be capable of determining utility services demands, even though work in this area does not directly support the HUD-MIUS program objective to evaluate alternative methods of satisfying these demands. A clear distinction must be made between the study of factors in the end-use structures which affect the utility services demands, and the factors which affect MIUS performance in satisfying those demands. A software system which proposes to do energy analyses, but primarily concerns itself with analysis of in-building energy transfer systems, and only secondarily with the types of energy transfer systems that occur in a MIUS plant configuration, is of limited use to the MIUS effort for either conceptual or design evaluation. However, MIUS design optimization is enhanced by an accurate calculation of site utility loads, and for this reason computer programs which accomplish this are considered in this report.

A second general area of evaluative concern is the nature and adequacy of the simulations, or mathematical models, that lie at the core of the different analyses. This concern is related to quantifying the concept of the accuracy, or reliability of a calculated result and is particularly important in the case of the energy performance aspects the MIUS. A mathematical model of a complex configuration such as the MIUS is obtained by examining its constituent parts, developing separate models for each of those parts, and then combining the individual models in an appropriate logical configuration that matches the hardware interconnections of the real system. In principle, if the mathematical model (assuming no errors in concept) is created in enough detail, it can come arbitrarily close to simulating the behavior of the real system of interest. In practice, limitations of cost and effort involved in obtaining a perfectly accurate simulation model are great, and simplifying assumptions are introduced that also have the effect of decreasing the accuracy. The question then is to determine the amount of accuracy needed in a model that is sufficient to satisfy the needs of the user. In the case of MIUS energy performance simulation, there is in fact not a single answer to this question, since there are differing needs. To determine comparative performance either for feasibility or optimization studies, a simple steady-state or equilibrium model will siffice. For the case where an estimate of absolute performance is needed, or where a question of control stability under certain conditions of demand and response must to be answered, a more complicated model which simulates transient response has to be incorporated. For the programs discussed in this report, the adequacy of the simulation will be considered in light of the use for which the program is intended.

The third general area of evaluation centers around the various aspects that become important in utilization of a program and may be called "user factors." These depend strongly on who the user is - in this case, primarily the professional technical staffs of the agency participants who are involved in performing calculations for the MIUS effort. They are generally knowledgeable in the hardware engineering aspects, in the various concepts of performance simulation and programming techniques, and are using computer programs as research and development tools. To this type of user, flexibility and adaptability of a program to a wide range of problems are more important than clear input or output which appeals to the non-technical user who occasionally purchases the services of a commercially available program. Another aspect of importance is the logical structure of the program. One that is constructed in logical modules is more accessible to evaluation, debugging, and alteration; and to the addition of increased capabilities at some future date as the need arises. In the case of programs (commercial or otherwise) developed elsewhere, documentation quality is of great importance, as is availability. For those commercial programs that might be of use, cost and ownership are both important considerations, the latter being by far the most important. It is imperative that agency users know exactly how a program arrives at a solution in order to determine to their own satisfaction that a valid procedure is being used. It is this single factor more than anything else that leads to a general recommendation against the use of proprietary software even for those programs that have good reputations.

The fourth area, which is related to the preceding discussion, is the concern that commercial programs may be biased in such a way as to systematically favor particular configurations over others. This idea of built-in bias is a very difficult one to assess. Even though they are very complex, no evidence of favoritism of one type of system over another has been found in the algorithms that have been examined. On the other hand, the complexity of the program itself can be used as a subtle tool for bias by making it more difficult to analyze some configurations than others. This tends to discourage a complete examination of the widest range of systems that could be considered for a given application, and instead concentrates the analysis of those types of systems that the owner/supplier of the program wants his client to see. In terms of motive, one would not expect this to be a problem with all of the commercial programs, but only with those developed and marketed by interests that use the program as a tool to "market" certain types of systems. In those latter cases if the program can be examined in detail, this type of bias can be guarded against. Even if the program cannot be examined in detail, user control over specification of the system configuration which is to be analyzed still affords some protection.

In summary, the four areas discussed above form the basic criteria against which the programs selected for this study were reviewed. They can be stated as applicability, simulation adequacy and comprehensiveness, user factors and implicit bias. As will be described in more detail in the next section of this report, the description of each program is broken down into categories and is concluded by an evaluative summary. The evaluative summary for each program consists of a discussion of the program characteristics evaluated with respect to the criteria discussed above. The systematic description format provides an effective way of presenting the information about program characteristics in order to aid in the evaluation of each program.

3. Program Data and Evaluations

In order to aid in systematic individual analyses relative to the previously described criteria and in comparison of the programs that were studied, a set of 21 characteristics were devised. Descriptions of each of the programs studied were made in terms of these standard characteristics. Individual agencies were requested to accomplish this task for programs they developed, while NBS completed the summaries for the commercial programs. The characteristics tended to fall naturally into three broad categories. The first deals with administrative items such as source(s), availability, cost and other characteristics of immediate interest to a potential user of a software system. The second category contains characteristics related to the computational aspects of the system, such as the types of calculations made, inputs, outputs, and the logical structure of the system. The third category is associated with detailed technical characteristics of the software itself, such as the source language, the hardware on which it is currently implemented, responsibility for maintenance and updating of the software and so forth. Detailed descriptions of each of the 21 characteristics follow:

Administrative Category

1. Abstract:
   A short summary of software system (program) capabilities.

2. Author(s):
   Person(s) who developed the software, if known, or known contact(s) who are technically very familiar with the software contents.

3. Owner(s):

Person (organization) who has ownership rights over the software system.

4. Availability:

How easy (or difficult) is it to obtain the system, or the use of the computational services provided by this system (program).

5. Cost:

The expense of obtaining the system itself, or obtaining the use of the system, in arbitrary units (e.g. $/"run", $/minute). It is recognized that the pertinent quantity to be used will be different, depending on whether the program is proprietary or not. It should be noted that purchase and use costs are quite different and serve different purposes. Also, use costs alone can vary widely even for the same program depending on individually negotiated contracting arrangements. Additional information on program costs is given in reference [1].*

6. Human Factors:

Amount and difficulty of input preparation required. Clarity of the output.

7. Turnaround:

Time required to get results from the time input sheets are filled out. User procedures required for processing.

8. Documentation:

Identification, availability, and a short content summary of documentation available for the software system (program).

Computational Category

9. Scope:

From a technical point of view the most important category in this outline. A summary statement of what the system can do and how it achieves this.

10. Output:

Quantities presented on the final printout. This may include echoes of input data as well as calculated results. Availability of options on output completeness.

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*Numbers in brackets indicate references listed at end of text.

11. Input:

Input quantities necessary to do an analysis. How few? How many? Availability of default options if partial input is desired.

12. Logical Structure:

The logical flow of the system elements.

13. Flexibility:

The range of applicability of the system.

14. Interfacing:

Identification of complementary, independently developed systems for which software linkages to this system exist.

15. Limitations:

Explicit and/or implicit limitations in the ability of the system to produce useful results. One type of limitation may be, typically, a limited range of applicability, another type would be questionable or simplistic model of a physical process.

Software/Hardward Technical

16. Source Language:

e.g. ASA Fortran, PL/1, and so forth.

17. Hardward Implementation:

Known hardware environments on which the software system (program) is operational.

18. Portability:

Difficulty involved in transferring this system (program) from one hardware environment to another.

19. Diagnostics:

Completeness and scope of system (program) in monitoring itself (i.e. detecting internally developed faults) and in protecting against improper (inapplicable) use.

20. Maintenance:

Person or organization responsible for maintaining the software.

21. <u>Adaptability/Expandability</u>:

Ease (or difficulty) of implementing changes or additions to the software, if it were desired to modify the present scope of the system.

Data on the surveyed programs follows the above format. The characteristics are not universally applicable to the programs considered. In the case of proprietary programs, information pertinent to many characteristics is often not available.

Based on the presented data for each program, the actual evaluative process was conducted systematically and with respect to the criteria described in the last section. An evaluative summary follows the data for each program as the twenty-second item. The summaries are based on the program characteristics as delineated in the categories. The evaluation is with respect to the criteria described in the previous section of this report. These summaries by their nature highlight the most significant findings and do not in some cases describe the complete evaluation process.

3.1 Heating-Cooling Calculation III (HCC-III)

1. Abstract:
   A computerized procedure for calculating design heating and cooling loads for buildings in accordance with American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) methodology.
2. Author(s):
   Unknown
3. Owner(s):
   Automatic Procedures for Engineering Consultants, Inc. (APEC)
   Suite M-15
   Grant-Deneau Tower
   4th and Ludlow Streets
   Dayton, Ohio 45402
4. Availability:
   Available to members of APEC as a user service.
5. Cost:
   APEC membership fee is required. There is also a service charge related to amount of program use.
6. Human Factors:
   Unknown
7. Turnaround:
   Unknown

8. Documentation:
User's guide, which is available at a cost of $25, states the program operation, engineering, technical aspects, appendix, references and complete instructions.

9. Scope:
The program is design oriented and lends itself to energy analysis studies only by way of definition of peak load conditions. Load calculations are performed on a room-by-room basis. Solar load calculations consider latitude, longitude, daylight saving time factors, atmospheric clearness, ground reflectivity, color and shading devices. Cooling calculations are performed for each of 24 hours and radiant load components are time averaged in accordance with building mass.

Design goals are to provide, for any designated geographical area and weather system, an hour-by-hour evaluation of the interrelating effects of various interior conditions, time-variable interior load producing sources, and building environmental surfaces, in order to determine peak load conditions, calculate cfm quantities, and arrive at actual system loads for the project and its various sub-parts.

10. Output:
Complete breakdown of all input factors, and cooling and heating peak load components.

11. Input:
Room data for each master room indicating room dimensions, type number and count or dimensions of all exposed surfaces, and quantities of internal load producing items as well as any special override factors involved.

12. Logical Structure:
Unknown

13. Flexibility:
Not Obtained

14. Interfacing:
Unknown

15. Limitations:

Primary limitations derive from the relatively small IBM/1130/8K single disk computer configuration for which the program was actually written, and are related to project size.

16. Source Language:

Fortran IV

17. Hardware Implementation:

IBM/1130 Systems (8K CORE, 1132 printer)

18. Portability:

Unknown

19. Diagnostics:

Unknown

20. Maintenance:

By Owner

21. Adaptability/Expandability:

Unknown

22. Evaluative Summary:

The major limitations of HCC-III in usefulness to the MIUS technical effort are related to its proprietary nature and scope. Only a computational service based on the program is available, and not the program itself. The resultant inability to verify or adapt program algorithms greatly decreases its usefulness as a research tool for MIUS. Its only potential use would be in a situation where it had computational capabilities not otherwise available in a non-pripríetary program in the possession of the MIUS technical staff. Since its scope is limited to the calculation of peak heating and cooling loads only, this is not the case.

3.2 Trane Air Conditioning Economics Program (TRACE)

1. Abstract:
   This program computes energy loads, fuel requirements, and heating/cooling system costs for different building and mechanical system design alternatives up to a maximum of four per run, and compares the results.

2. Author(s):
   Unknown

3. Owner(s):
   The Trane Company
   LaCrosse, Wisconsin

4. Availability:
   Proprietary; used through Trane engineering representatives. Information regarding program use is available from Trane local offices.

5. Cost:
   $800/run (four building/system design alternatives).

6. Human Factors:
   One input manual is completed per run from project design information. Assistance is available from Trane, and the input and users manuals also contain clear and complete detailed information. Estimated input preparation time is 3 man-days. Completed input manual is sent to home office for key punching of input data and computer batch processing. Output is returned by mail.

7. Turnaround:
   Approximately one week per manual; limited by mails and Trane keypunch in addition to computer turnaround time.

8. Documentation:
   Documentation manual [2] and input manual [3] are available on request from TRANE.

9. Scope:
   Loads: Actual weather data for one year are condensed by a special procedure into 12 "typical days", one for each calendar month in the year. Each of these typical days consists of a 24-hour profile. These are in turn used, along with recommended ASHRAE procedures (1967) [4] for heating and cooling space load calculations. Base loads are included by separate schedules. Simulation: Eleven common air-side systems are simulated (see item 13), primary equipment is

simulated by energy performance curves that are functions of the demanded output of the equipment. Performance curves can be supplied by user, or in the case of some equipment models predetermined performance curves can be accessed (mostly Trane equipment models). Financial Analysis: Computes annual owning and operating costs for each alternative and between alternatives. Computes incremental payback, and present value rate of return.

10. Output:

Design values, monthly fuel usage (water, electricity, etc.) economic input echo, PITI, depreciation (tax and book), cash flow, P + L, present worth of total owning and operating costs; comparison basis P + L, cash flow, cumulative cash flow, and discounted cash flows to equity and first cost.

11. Input:

Room design conditions; base utilities (per schedule); lights, people, and miscellaneous (per zone per schedule), glass, wall, shading for external zones; economic input (installed costs, maintenance cost, depreciation, mortgage life, and so forth), rate structures; air side input (type, economizer, usage schedule, etc.); equipment type code and number of units.

12. Logical Structure:

Program is in 5 blocks which run sequentially, generating internal files to feed the next program. Weather data and equipment performance are read from tapes.

13. Flexibility:

A maximum of four alternative schemes can be analyzed per run. A maximum of ten base and auxiliary load schedules can be input per alternative. Each alternative can have up to 20 thermal zones and one or two air-side systems specified. The following air-side systems are simulated:

a. High velocity variable air volume.
b. Low velocity variable air volume.
c. Double duct
d. Multizone
e. Terminal reheat

f. Packaged terminal air conditioner.
g. Hydronic heat pump.
h. Fan coil.
i. Induction.
j. Radiation
k. Variable temperature constant volume.

14. Interfacing:
The program does not presently interface with any other software systems.

15. Limitations:
No simulations exist for T/E plants or bulk thermal storage devices. Due to the remote batch processing procedure, no mid-stream evaluation is possible.

16. Source Language:
Fortran

17. Hardware Inplementation:
Unknown

18. Portability:
Unknown

19. Diagnostics:
Unknown

20. Maintenance:
Maintenance by The Trane Company at times unknown.

21. Adaptability/Expandability:
There is no option for anyone outside of the Trane Company to adapt or expand the program. Trane plans to include other equipment (e.g. other manufacturers and T/E models) at some indefinite time in the future.

22. Evaluative Summary:
TRACE is one of five commercial computerized systems considered in this report which accomplishes a multi-step total project analysis consisting of loads determination, mechanical equipment simulation, resultant energy requirements determination, and a comparative economics analysis between alternative systems. Because of the batch mode of processing, the output of one analysis section is automatically input into the subsequent one. Therefore no midstream evaluation of partial results is possible. The period of performance analysis is usually taken to be one year.

Load calculation procedures follow ASHRAE recommended procedures (1967) [4]. Although weather data is input for the whole year (8760 hours), the program calculates from this data twelve "typical weather days" (each with values for 24 hours), one for each calendar month. All subsequent monthly energy requirements are based on use of the same "typical weather day" profile for a whole month. Building loads based on this type of calculation are less suitable for determining a prediction of actual energy performance than they are for determining comparative energy performance of different mechanical systems (or the same system controlled in different ways), for the same building configuration.

All simulations of air-side systems and mechanical equipment performance are of an equilibrium nature. Part load performance curves for equipment can be either input by the user, or by user option, some are available on computer files.* A wide range of total system configurations can be simulated by utilizing appropriate individual simulations. Separate scheduling of different types of base and auxiliary loads allows for close reproduction of actual situation. Total energy plant configurations and thermal storage devices are not simulated.

The prime limitation with respect to MIUS use of this program is its proprietary nature. It is, as a result, not subject to verification of the exact nature and validity of its algorithms by detailed analysis of the software. In addition, the cost of use as a service precludes its use as a research tool, where many computer runs are often necessary to complete a specific project need.

*Mostly Trane equipment

3.3 Computerized Evaluation of Energy Requirements, Equipment Selection, and Economic Comparison for Building Systems (E-CUBE)

1. Abstract:
   For a zone or a building energy system: estimates hourly, monthly and annual energy requirements, determines the energy consumption of various types of systems which may be used to meet those energy requirements, compares total owning and operating costs of the various systems being considered.

2. Author(s):
   Contact for Technical Matters:
   W.E.Evers, Jr.
   Laclede Gas Company
   St. Louis, Missouri

3. Owner(s):
   American Gas Association (AGA)
   1515 Wilson Blvd.
   Arlington, Virginia 22209

4. Availability:
   Software is proprietary; purchase of the computational service only is available, either directly through the CDC CYBERNET Network, or through selected local gas utilities. Previous accounting and billing procedures have to be arranged before the service can be used. User information is available from AGA.

5. Cost:
   Approximately $50 for a complete analysis including economic comparison (a maximum of four alternate systems may be considered for a given building).

6. Human Factors:
   Engineering knowledge necessary to complete input data forms, which are preformatted and come with instructions for use.

7. Turnaround:
   Depends on mode of access. Terminal response would make this mode inherently much faster than batch processing mode.

8. Documentation:
   A copyrighted, complete users input instruction manual is available [5]. The introduction contains short qualitative descriptions of the logical structure of the programs and their interrelationships.

9. Scope:

a. Energy Requirements Program: From design point values for thermal and base electric loads, calculates hourly loads for a weather year by scaling according to variations in dry bulb and dew point temperatures, solar radiation, and cloud cover. Building use and operation schedules can account for thermostat setback or system shutdown. Building thermal storage and delay effects are considered. Simultaneous heating/cooling requirements can be accounted for.

b. Equipment Selection and Energy Consumption Program: Calculates actual energy required by equipment to meet energy requirements calculated in (a). Up to four different plant systems can be evaluated in each run.

c. Economic Comparison Program: Rate of return calculation performed for each plant system analyzed in (b) is examined comparatively.

10. Output:

a. A tape with hourly thermal and electrical loads; a printout of peak heating, cooling, electrical, and process loads for each month and the time that they occurred, cumulative values of loads.

b. Printout of monthly summary of gas, fuel, electricity consumed; peak electric demand; number of operating hours for each generator and chiller; evaluation of thermal energy usage.

c. Relative to the cheapest first-cost system, the following differences: annual interest, taxable income, annual tax, after taxes cash flow, net cash flow.

11. Input:

a. Design point (peak) loads and base electric loads, weather data, solar data, occupancy profiles, system operating schedules, setback schedules, lighting and process load profiles.

b. Fuel heating values, system characteristics, generator schedule, chiller schedule, equipment performance data.

c. Initial and operating cost data, tax rates, interest rates, depreciation rates, irregular annual operating cost data.

12. Logical Structure:

Modular.

13. Flexibility:

This program contains five subroutines which are used to simulate five general types of system configurations. The detailed performance of any chosen configuration is variable due to user control of specific equipment performance curves. The five configurations are:

a. Total Energy System with Boilers.
b. Total Energy System with Direct Fired Heater.
c. Conventional System with Boiler.
d. Conventional System with Direct Fired Heater.
e. All Electric System.

14. Interfacing:
Not Known

15. Limitations:
Limited as to the maximum number of input schedules and air-side simulation systems. Limited to a maximum of four alternatives per run.

16. Source Language:
Fortran

17. Hardware Implementation:
CDC 6600

18. Portability:
Not Known

19. Diagnostics:
Not Known

20. Maintenance:
By Owner

21. Adaptability/Expandability:
Unknown

22. Evaluative Summary:
This program is another which falls in the category of offering a complete energy analysis of a single or multi-building project, from building loads to mechanical systems energy requirement simulation, to utility costs based on those requirements, to economic comparisons between alternate configurations. The period of performance analysis is usually taken to be one year. Thermal load calculations are done on an hourly basis for this entire period. Transmission loads are obtained by scaling, according to weather conditions, from peak load values and their associated weather conditions, which must be supplied to the program. Loads based on this type of calculation are less suitable for prediction of actual energy performance than they are for determining comparative energy performance of alternate

systems. In fact, with the number of system simulations (all steady state, equilibrium type) limited to five configurations (for which different performance data may be supplied each time a run is made) the program is mostly limited to the comparison of various total energy configurations to conventional systems, which was the primary reason for its development by GATE.

The basic limitation with respect to the use of this program for the MIUS effort is its proprietary nature, for the same reasons that were discussed in the previous evaluative summary.

3.4 The Meriwether Energy System Analysis Series

1. Abstract

   Calculates building loads, simulate air side systems, determine energy requirements for mechanical and electrical components for every hour of the year and make annual summary. Also performs economic analysis of various systems.

2. Author(s):

   Ross F. Meriwether

3. Owner(s):

   Ross F. Meriwether & Associates, Inc.
   1600 N.E. Loop 410
   San Antonio, Texas 73209

4. Availability:

   Computer Science Corporation
   INFONET System,
   University Computing System
   Time sharing as well as batch modes.

5. Cost:

   Depending upon the extent of analysis, it could be as small as $10/run or as large as $750/run.

6. Human Factors:

   Need comprehensive knowledge of air-side systems, not too easy to use otherwise. It is important that the user understand the computer system simulations.

   Approximately one hour is required for data preparation and key punch per zone.

7. Turnaround:

   1/2 to 1 minute computer execution time per zone per weather year.

8. Documentation:

   No algorithm ever published, since software is proprietary. A user's manual, available only from the program owner, has instructions which are complete, however.

9. Scope:

   The heating and cooling load calculation is similar to Carrier manual method. Air-side system simulation includes terminal reheat, induction fan coil, dual duct, VAV and VAT. It can handle gas, oil, electric, total energy, and heat pump systems. Hot water thermal storage can also be simulated. Utility cost analysis and economic comparison programs are quite comprehensive.

10. Output:

Detailed output as well as selective and simpler output are possible. Monthly summary, annual summary, space summary and system summary are available for energy consumption as well as for the demand.

11. Input:

Building data is very simple but system data, and operational data are very detailed. Approximately 30 data sheets are attached in the user's manual.

12. Logical Structure:

Five main programs, which each utilize numerous specialized subroutines, are run sequentially to accomplish a complete analysis. The names of these program blocks are descriptive of their functions.

a. Energy Requirements Estimate (ERE)
b. Total Coincident Requirement (TCR)
c. Equipment Energy Consumption (EEC/A,B)
d. Monthly Utility Costs (MUC)
e. Economic Comparison of Systems (ECS)

13. Flexibility:

Equipment and air-handling systems configurations are variable because separate types of equipment have separate simulations which can be linked in many possible ways. The air-handling system simulations available are:

a. No excess cooling or reheating, demand coil leaving temperatures.
b. Terminal reheat with scheduled (or fixed) cold coil discharge temperature during cooling.
c. Terminal reheat with scheduled (or fixed) cold coil discharge temperature during cooling or heating.
d. Induction or fan-coil type system with scheduled primary air temperature.
e. Terminal reheat with cold coil discharge temperature set by maximum demand of any section.
f. Dual-duct or multi-zone with scheduled (or fixed) hot and cold deck temperatures.
g. Dual-duct or multi-zone with deck temperatures set by greatest demand.
h. Variable volume system for solar and internal loads, with separate single-duct system to offset transmission.
i. Standard variable volume system.

14. Interfacing:

It has been interfaced with NBSLD and is being interfaced with the TACS program at the Dept. of Public Works of Canada. (See NBSRFM data form).

15. Limitations:

Although the system simulation is very comprehensive for the conventional system analysis, the program may need improvement for the accurate temperature simulation of heavy structures, residential buildings and other non-conventional buildings. T/E type systems are not simulated per se, but can be "constructed" from the individual element simulations. The system is limited as to the maximum number of building auxiliary load schedules and system simulations, even though the total number of configurations available is large.

16. Source Language:

Relocatable files on INFONET-UNIVAC. Source language is Fortran.

17. Hardware Implementation:

Univac 1108 System

18. Portability:

It is on time sharing files.

19. Diagnostics:

Diagnostics are very comprehensive and complete.

20. Maintenance:

R.F.Meriwether

21. Adaptability/Expandability:

Unknown

22. Evaluative Summary:

This program series is another of those that fall in the class which offers a complete energy analysis of a single or multi-building project, from loads determination to energy requirements simulations of building air-side systems and plant equipment systems, to utility costs estimates based on those requirements, to economic comparisons between alternative candidate configurations. In this series mid-stream evaluation of results is possible. The period of performance analysis is usually taken to be one year. Thermal load calculations are done on an hourly basis for this period. In this particular case, the transmission loads are calculated by scaling, according to weather conditions, from peak values and associated weather conditions, both of which are supplied to the program. Building loads based on this type of calculation are less suitable for prediction of actual energy performance than they are for determining comparative energy performance of different mechanical systems (or the same system controlled in different ways), for the same building. All simulations of air-side systems and mechanical equipment energy performance are of a steady-state, energy balance nature.

3.5 National Bureau of Standards Load Determination Program (NBSLD)

1. Abstract:

This program determines building heating and cooling loads and variations of the interior environment, based on actual weather data, on an hour-by-hour basis. It was developed as a research tool to aid in the thermal design of buildings.

2. Author(s):

Dr. Tamami Kusuda
Thermal Engineering Systems Section
Center for Building Technology, NBS
Washington, D.C. 20234

3. Owner(s):

Public (U.S. Government)

4. Availability:

Symbolic source decks or tapes (in either BCD or ASCII coding) available on request for the cost of production. Available to all Federal government workers through the Computer Sciences Corporation INFONET system under GSA contract. Further availability details can be obtained from the author.

5. Cost:

Depends on costs charged by a particular computer center. Execution time is 4 minutes per zone per typical weather year, on the UNIVAC 1108, EXEC-8 system at NBS.

6. Human Factor:

Input data form available and although straight forward to prepare, it is detailed. Output has option of either abbreviated or detailed printout, it can also be written on magnetic tape for later use.

7. Turnaround:

Processing at NBS is done in batch or time-sharing mode. It takes about one hour to keypunch data for the first zone in a building, additional zones are 10 minutes each. For execution time see Item 5.

8. Documentation:

A user's manual is available as an NBS Building Science Series publication. Contents include description of program, listing of completed program, and algorithms of the main program and subroutines [6].

9. Scope:

The program will compute the following:

a. Design loads based on a design weather cycle.
b. Hour-by-hour loads based on actual weather data of any locality, for a fixed room temperature or a fixed range of room temperature fluctuation.
c. Hour-by-hour loads based on actual weather data using the ASHRAE "weighting factor method".
d. Room temperature hour-by-hour fluctuation when limited or no heating (and/or cooling) are supplied, and a non-zero load is computed.

10. Output:

a. Abbreviated: Response factors for walls; daily maximum and total cooling and/or heating loads; hour of occurance for maximum load.
b. Detailed: Input data, response factors for walls, hourly dry and wet bulb temperature (outside), hourly inside dry bulb temperature, hourly cooling and/or heating load, and daily maximum and total loads.

11. Input:

a. Schedules of lighting, equipment, and occupant loads, and their respective maximum values.
b. Locality data (longitude, latitude, weather data tape, time zone, etc).
c. Wall construction data (number of layers, thermophysical properties of each layer).
d. Building, zone, or room dimensional data.

12. Logical Structure:

Two main programs:

a. Main program to decode the weather tape from Weather Bureau into binary code and put onto tape.
b. Main program for NBSLD with approximately 35 subroutines connected to the main program or with each other (See Figure 1).

13. Flexibility:

The two main programs above can either be run separately, or run together with (a) followed by (b). Any type of building with known construction and internal heat generation can be analyzed.

14. Interfacing:

Has been interfaced with Ross Meriwether's system simulation and economic programs package directly (see following NBSRFM form). Also could be used as input for any specially written individual system simulation program.

15. Limitations:

a. Apply to any building under item 9 above, types (a) and (c).

b. Apply to any building which can be divided into rectangular shaped zones for item 9, types (b) and (d).

c. Cannot simulate partial exterior shading from adjacent buildings, trees, hills.

d. Calculates space loads only, does not have air-side or plant system energy simulations as an integral part (but see item 14).

16. Source Language:

Fortran V

17. Hardware Implementation:

Main program for load computation can be used on any computer system with a core memory larger than 50,000 words, or less if overlay or segmentation capability is available in the system. Main program for decoding the Weather Bureau type can be used only on Univac System.

18. Portability:

Program can be copied into BCD code on another tape and recompiled by other system's Fortran compiler.

19. Diagnostics:

These are of a limited and basic nature.

20. Maintenance:

Dr. T. Kusuda is responsible for the updating of the program with the assistance of Messrs. J. Hill, S. Liu, and J. Barnett of NBS.

21. Adaptability/Expandability:

Modification of the program (main or subroutines) for a particular application with special requirements is straightforward.

22. Evaluative Summary:

NBSLD was specifically developed as a research tool which, when properly applied, can accurately predict the thermal loads and interior space conditions of a wide variety of building design configurations. It computes loads and interior space temperatures on an hourly basis, usually for a complete weather year (but can be for any part thereof), using actual weather data. In order to be able to simulate the greatest possible number of building design configurations, the thermal response properties of the building structure itself are calculated from a detailed description of the thermophysical properties of the structural components and also individual details of the construction.

External effects such as solar loading and air infiltration are correctly accounted for. One shortcoming in the technical aspects of the load calculations done by NBSLD is the inability to account for shading by objects external to the building itself, such as trees or other buildings. This last factor could result in a major overestimate in the cooling load, for example, of a tall building which, during sometime period each day is largely in the shade of an adjacent building. In the hands of a knowledgeable user who is aware of this limitation, misapplication of the program could be avoided.

There is a trade-off that is made in achieving great flexibility in application: The amount of data required for computation is greater than for other programs. Therefore, the amount of user effort necessary to assemble and input this data, and the associated probability of some error in so doing is correspondingly greater. Another factor associated with the program complexity is the greater amount of computer execution time required, compared to other programs. There is no significant resultant effect, in terms of human factors, however, when computer execution time is on the order of minutes instead of seconds. However, the aspect of the increased execution time that would be significant to some users would be the related cost of such a system.

The effect of the increased execution time on computer costs is for the most part not significant to MIUS agency users who would implement NBSLD on their own systems.

The lack of energy requirement simulations for building mechanical systems and plant equipment is the major limitation of NBSLD in terms of its usefulness to the MIUS effort. In principle, the development of the NBSLD/Meriwether Energy System Analysis Series hybrid shows that this limitation can be overcome. In practice, however, that hybrid (see the related Evaluative Summary) is probably not the best final solution.

As a system standing by itself, the primary value of NBSLD to MIUS is the capability it can provide for the reliable verification of building thermal loads for specific designs. This capability may well be necessary in the evaluation process for MIUS demonstration proposals. In any use of NBSLD by the MIUS effort, the assistance of its author in guaranteeing its proper application would be available.

3.6 The Meriwether Energy System Analysis Series/NBSLD Hybrid (NBSRFM)

1. Abstract:

   This hybrid combines the load calculation capabilities of NBSLD with the system simulation capabilities of the Meriwether Energy System Analysis Series.

2. Author(s):

   Ross. F. Meriwether
   T. Kusuda (NBS)

3. Owner(s):

   Ross F. Meriwether & Associates, Inc.
   1600 N. E. Loop 410
   San Antonio, Texas 78209

4. Availability:

   Computer Sciences Corporation INFONET System (time sharing mode). Contact owner for information.

5. Cost:

   By special arrangement for long term use contracts by government agencies. Similar to costs of Meriwether Analysis alone on a per run basis.

6. Human Factors:

   See NBSLD, Meriwether sections of this report.

7. Turnaround:

   Approximately the sum of turnarounds for each program system separately.

8. Documentation:

   The separate user manuals are sufficient for use of the hybrid system, with additional information available from the owner.

9. Scope:

   The hybrid combines the capabilities of the separate constituents.

10. Output:

    A combination of the outputs of NBSLD and the Meriwether Analysis Series.

11. Input:

    The sum of inputs required for each of the programs separately, except that weather and building thermal property data are not repeated.

12. Logical Structure:
NBSLD replaces the load estimation function that is a normal part of the Meriwether system.

13. Flexibility:
Combines the NBSLD abilities to calculate loads for a wide range of building configurations with the flexibility of the Meriwether air-side and equipment simulations.

14. Interfacing:
The necessary software linkage to accomplish the hybridization exists and is debugged.

15. Limitations:
Same as for each system separately.

16. Source Language:
Fortran. Relocatable Files on the INFONET-Univac system.

17. Hardware Implementation:
Univac 1108

18. Portability:
Unknown

19. Diagnostics:
Comprehensive

20. Maintenance:
R.F.Meriwether
T.Kusuda

21. Adaptability/Expandability:
Software modifications would be technically straight forward.

22. Evaluative Summary:
Conceptually, the linkage of the two program series that comprise this hybrid combines the complementary capabilities of both into a single entity, with a concomitant increase in total computational power and flexibility. In particular, substitution of the more sophisticated and accurate NBSLD in place of the Meriwether load estimating procedure improves the capability for performing predictive analyses of actual energy performances which is a more difficult task than determination of an optimum configuration by the comparative analysis of several alternatives. Along with the increased capability obtained from hybridization, however, there is a related increase in effort and difficulty in its use, which is approximately the sum of the efforts for each of the programs when used individually.

This hybrid also occupies a unique position regarding its ownership status and consequent availability. Because one of the constituents of the hybrid is proprietary, the whole is in effect controlled by the owner of that constituent. It therefore suffers (in terms of usefulness to MIUS) from the same shortcomings of any such program; verification of program validity by direct examination of the software is not possible, and any computational services of the hybrid must be purchased. The government contract with the owner of the Energy Systems Analysis Series (Meriwether) under which the hybrid was first made operational has since expired. A need to make the hybrid available for MIUS analysis would require new contractual arrangements with the owner. Because of the problems associated with lack of access for program verification, if a definite need is found for a substantial amount of this sort of wide-scope computational analysis, it would probably be more advantageous for the MIUS effort to obtain or develop a set of non-proprietary system simulations to link up to NBSLD. It should be noted that at this time, none of the existing government developed MIUS type simulations have the configurational flexibility of this hybrid.

3.7 Computer Program for Analysis of Energy Utilization in Postal Facilities (TACS), et al.

1. <u>Abstract:</u>
   This program series has evolved over a period of several years. There are four identifiable versions of it, named as follows:
   a. Version I - Computer Program for Analysis of Energy Utilization in Postal Facilities.
   b. Version II - Unknown
   c. Version III - Unknown
   d. Version IV - Energy Utilization Analysis of Buildings Computer Program.

   All versions calculate heating/cooling loads and simulate air-side and primary systems on an hourly basis. All versions have a separate subprogram which performs an economic analysis of alternatives.

2. <u>Author(s):</u>
   Metin Lokmanhekim, et al.

3. <u>Owner(s):</u>
   a. Version I - Public (U.S. Government)
   b. Version II - General American Research Division (GARD) of General American Transportation Corp. (GATX) Niles, Illinois
   c. Version III - Hittman Associates, Columbia, Maryland
   d. Version IV - Metin Lokmanhekim Ellicott City, Maryland 21043

4. <u>Availability:</u>
   a. Version I - GARD/GATX will provide a Fortran source listing on magnetic tape. The source listing is also informally available on request from several user government agencies.
   b. Version II - Proprietary
   c. Version III - Proprietary
   d. Version IV - The source deck, binary, or computational services are all available from Metin Lokmanhekim.

5. <u>Cost:</u>
   a. Version I - Source tape from GARD/GATX about $675. Source tape from government agencies at cost. Cost per run depends on user facilities.
   b. Version II - Unknown
   c. Version III - Unknown
   d. Version IV - By negotiation.

6. <u>Human Factors:</u>
   a. Version I and II - Input data is required zone by zone. Detailed input requires knowledge of building geometry

and shading and takes about four days per run for the familiar user.

b. Versions III and IV - Data may be input in blocks and zone by zone. Buildings described in detail require two days of input data preparation by an experienced user. Rough estimates of energy consumption using block inputs only require four hours.

7. Turnaround:
Depends on user facilities; for block input on Version IV, turnaround is about two days.

8. Documentation:
A user's manual for Version I only [7].

9. Scope:
All versions calculate heating/cooling loads and simulate air-side and primary systems on an hourly basis. Later versions provide more equipment simulations, utilize the building response factors in the load calculations and permit internal temperature variation. Version I calculates the response factors. All versions include a separate subprogram which performs an economic analysis of alternatives.

10. Output:

a. Version I - Building heating and cooling load design hours; maximum and minimum heating and cooling loads by zone; wall and roof specification; sensible, latent, lighting, and electrical loads by zone; plots of the thermal load on a daily, weekly, monthly, or yearly basis; edited thermal loads set up for simulation; air-side system ratings and zone air flows; summary of equipment sizes; monthly energy requirements by energy type; monthly plant water requirements, input economics echo; and annualized owning and operating costs.

b. Versions II, III, and IV - Similar output.

11. Input:

a. Version I - Hourly weather data (dry - and wet-bulb temperatures, cloud amount and type, wind velocity, and atmospheric pressure), latitude, longitude, time zone, infiltration, load, various schedules, surface coordinates and descriptions for each surface bounding or shading a zone, number and type of plots, design set points of equipment, type of air-side systems, energy types, types of chillers; capital and operating costs, interest rate, lifetime, and purchased energy rates.

b. Version II and III - Unknown
c. Version IV - Building data can be input in blocks instead of surfaces zone by zone; surface descriptions do not require layer U-values; a greater choice of equipment simulations is offered; temperature schedules are permitted; parametric design evaluation requires a card change.

12. Logical Structure:
a. Version I - Seven subprograms run in series.

b. Versions II and III - Unknown
c. Version IV - Four subprograms; loads, temperature variation, systems simulation, and economics.

13. Flexibility:
a. Version I - The program can handle very detailed building information.

Air-side systems are single zone, multi-zone, dual duct, single zone reheat, unit ventilator, unit heater, and floor panel heating. Five types of chillers and four energy sources are allowed. No part-load curves are permitted.
b. Versions II - Unknown
c. Version III - Unknown
d. Version IV - In addition to the above, two- and four-pipe fan coil units, through-the-wall units, split system, and varying volume with time can be simulated.

14. Interfacing:
Versions I and IV thermal load outputs can be read into the AXCESS program.

15. Limitations:
a. Version I cannot simulate a T/E plant using turbines or anything but steam-based cooling, nor can it simulate fan coil and induction units.
b. Version IV cannot simulate induction units and has the same limited simulations of T/E systems.

16. Source Language:
All versions are written in Fortran IV. Version IV is also available in Control Data Fortran.

17. Hardware Implementation:
All versions are operational on IBM 360 and 370 series, CDC 3600,64601, 6600 and 7600 series, and Univac 1108. The weather decoding subroutines is machine dependent on these machines.

18. Portability:

The program is very portable due its wide application base and the fact that everything but the weather decoding routine is non-machine dependent.

19. Diagnostics:

a. Version I - None
b. Version II - Unknown
c. Version III - Unknown
d. Version IV - Coded printouts but no accompanying manual; logical errors cause abortion of run.

20. Maintenance:

a. Version I - None
b. Version II - Unknown
c. Version III - Unknown
d. Version IV - By Metin Lokmanhekim

21. Adaptability/Expandability:

a. Version I - The source listing may be expanded by the user.
b. Versions II and III - Potential unknown.
c. Version IV - By user if source has been obtained; by Metin Lokmanhekim if negotiated.

An expanded simulation base is not difficult to achieve due to modular program construction.

22. Evaluative Summary:

All versions of this program offer a complete energy analysis of a single or multi-building project, including load determinations, air-side system simulations, plant equipment simulations, and annualized owning and operating costs. A modular series program structure permits midstream evaluation of results. The period of analysis is usually one year. All calculations are performed on an hourly basis in an equilibrium or steady-state simulation. The thermal loads are actually computed from building thermal properties, not scaled as in the Meriwether program series. Building loads based on these calculations are suitable for prediction of actual energy performance. Simulations of a total energy plant are limited to engines with steam recovery for either absorption or steam turbine centrifugal chillers. Equipment is sized on the basis of the peak hourly heating and cooling loads, and no part-load efficiencies may be input.
The preparation of input material is difficult and time consuming for all but the single block analysis, requiring a two to four day effort by competent and knowledgeable engineers. The complexity of the input process increases the probability of input errors. The block input option which permits quick

parametric analysis in the conceptual design is only available with Versions III and IV. In Version I, response factors are calculated from surface descriptions by methods comparable to those used in NBSLD. The internal temperature set-point may be varied only in Version IV. The number of equipment simulations of Version I is limited, but expansion of this section is not difficult.

Versions II, III, and IV are proprietary, and suffer the same disadvantages for MIUS use mentioned previously. The source deck of Version I is presently in the possession of several participating agency teams, and though the source deck of Version IV is available, it would have to be purchased. The excellent thermal load calculational procedures of this program and limited equipment energy simulation base make it a prime candidate for either marriage to a program with a strong and flexible simulation base, or for use by itself with the development of the most likely MIUS plant equipment simulations.

3.8 Alternate Choice Comparison for Energy System Selection (AXCESS)

1. Abstract:

   The AXCESS Energy Analysis Computer Program provides estimates of the comparative energy uses of alternate methods of meeting the energy requirements of buildings or processes, and an economic analysis of the alternatives.

2. Author(s):

   For technical matters contact:
   Edward Douglass
   Computer Applications
   Edison Electric Institute

3. Owner(s):

   Edison Electric Institute
   90 Park Avenue
   New York, New York 10016

4. Availability:

   The AXCESS program was released to investor owned electric utilities through a nationwide series of user training programs beginning in November 1972. Each of these companies has been furnished with a program source deck, user's manual sample problem and help in achieving implementation on its own computer AXCESS is also available to these utilities through a remote service bureau. Under similar conditions, it has also been made available to MIUS agency participants.

5. Cost:

   Depends on user system.

6. Human Factors:

   Relatively large time and effort requirements for preparation. One run batch for entire energy analysis.

7. Turnaround:

   Depends on user system.

8. Documentation:

   a. Engineering Analysis:Users manual [8] and a programmer's manual [9] are available on request.
   b. Financial Analysis: Users manual [10] and a programmer's manual [11] are available on request.

9. Scope:

   The program uses standard engineering principles but bases all its calculations on input, so that as the quality of input increases, so will the quality of the output. It is well, however, to remember that the program's purpose is to provide a comparison of alternate designs and the results for each scheme have much more validity when reviewed in relation to each other.

The submetering capability allows the calculation of actual demand contributions of incremental loads to the total permitting alternate fuel source capability within one scheme.

10. Output:
   a. Hourly meter reading: usage and demand.
   b. Hourly deficit or excess KW and KWH if the T/E scheme satisfies the load first.
   c. Day by day meter readings: use and demand.
   d. Time of day of occurrence of maximum meter reading.
   e. Total Btu heat rejected from all chillers, by month.
   f. Monthly excess/deficit of heat.
   g. Annual excess/deficit of heat.
   h. Net Present Value or Internal Rate of Return.

11. Input:
   a. Project Description data including building operation schedules.
   b. Base load items of usage including usage profiles and special period profiles.
   c. Waste heat utilization-item usage.
   d. Heating/cooling load data.
   e. Space type data.
   f. Zone description data.
   g. On-site generation system performance.
   h. Terminal and primary system description including waste heat utilization and dual fuel operation description.
   i. Meter description and fuel codes.
   j. Capital costs.
   k. Maintenance and operating costs.
   l. Tax rate.

12. Logical Structure:
Single run with all parameters input at start, modular program structure .

13. Flexibility:
For the same building, with the same usage, the program permits simultaneous comparison of up to six alternate methods of meeting the energy requirements. Such things as the HVAC system and the lighting levels may vary among these six "schemes", while the building occupancy pattern is assumed to be the same for each scheme. The air-handling and plant system simulations available are:

   a. Dual Duct.
   b. Multi-Zone
   c. Single Zone Reheat
   d. 100% Variable Volume
   e. Variable Volume with Reheat
   f. Ceiling Induction

g. Heating and Ventilating
h. 2-Pipe Induction
i. 4-Pipe Induction
j. 2-Pipe Fan Coil
k. 2-Pipe Unit Ventilator
l. 4-Pipe Fan Coil
m. 4-Pipe Unit Ventilator
n. Unitary Cooling Units with Separate Heating
o. Unitary Heat Pumps
p. Boilers
q. Furnace
r. Refrigeration
s. Simultaneous Heat Pumps
t. Changeover Heat Pumps
u. On-Site Generation-KW Balance
v. On-Site Generation-Thermal Balance

14. Interfacing:
Presently interfaced with TACS (Version I) and the Lokmanhekim revision (Version IV) of the Lokmanhekim series.

15. Limitations:
This is a tool that enables the designer to make a comparison of various designs, not to generate a design. While the program makes some normal design assumptions in the event of a missing input, it always requests the design as input.

16. Source Language:
Fortran

17. Hardware Implementation:
IBM 360 and Univac 1108.

18. Portability:
Moderately Portable

19. Diagnostics:
None

20. Maintenance:
Software revision notices sent to holders of software by owner.

21. Adaptability/Expandability:
Since the Fortran source program deck is available and because of the modular structure of the software, expansion and adaptation of the program to model MIUS designs is possible.

22. Evaluative Summary:

This program series offers a complete energy analysis of a single or multi-building project, including load determinations, air-side system simulations, plant equipment simulations, and annualized owning and operating costs. The series consists of a complex energy analysis program and an independent short financial analysis program. Midstream evaluation is not possible in either program. The period of analysis is usually one year.

The thermal load calculations and complete energy analysis are accomplished each hour before proceeding to the next hour. Therefore the program will not size the plant equipment and base part-load efficiencies on that size. All calculations assume steady-state or equilibrium conditions. As in the Meriwether program series, the thermal loads are scaled based on design loads and design weather conditions. Building loads based on these calculations are suitable for comparison of alternatives, but not for prediction of actual energy performance. Response factors may be input (from another program) or default values for light, medium and heavy construction may be utilized.

The air-side and plant systems simulation package is one of the most complete of the program series surveyed. Addition or adaptation of equipment simulations is facilitated by the modular package structure. Estimated equipment size is a required input for part-load performance curves. If the demand exceeds capacity, the design efficiency will be used.

The preparation of input material requires experience and time; one to three days for experienced engineers. The complexity of the input process increases the probability of input errors or meaningless final product. A block input option is available which simplifies the input process for conceptual design evaluation.

Though this program is proprietary, the source deck is available to EEI member utilities and MIUS participants at a reasonable charge. The strong and flexible simulation base of this program and the ease of block input for conceptual design analysis made it a prime candidate for MIUS use. It will provide an excellent base for simulation of a MIUS. For a detailed predictive evaluation of energy requirements at a specific site, this program is a prime candidate for marriage to a program with detailed thermal load calculational procedures.

3.9 TACS/Lokmanhekim/AXCESS

1. Abstract:

   In Version I, the thermal loads computed by the TACS program are input to the energy systems simulation subprogram of AXCESS. In Version II, the thermal loads computed by the Energy Utilization Analysis of Buildings Computer Program are input to the energy systems simulation subprogram of AXCESS.

2. Author(s):

   Authorship of the individual programs has been previously mentioned. The interface in Version I is a part of the AXCESS program. The interface in Version II was written by Metin Lokmanhekim.

3. Owner(s):

   Ownership of the individual programs has been previously mentioned. The interface in Version II is owned by Southern California Edison.

4. Availability:

   As previously mentioned, except that the interface in Version II is also proprietary.

5. Cost:

   As previously mentioned for the individual programs.

6. Human Factors:

   As previously mentioned for the individual programs.

7. Turnaround:

   Depends on user facilities.

8. Documentation:

   Version I - The interface mechanics are in the AXCESS documentation.
   Version II - Interface documentation unknown.

9. Scope:

   Version I - The thermal loads computed by the Computer Program for Analysis of Energy Utilization in Postal Facilities are input to the energy systems simulation subprogram of AXCESS.

   Version II - The thermal loads computed by the Energy Utilization Analysis of Buildings Computer Program are input to the energy systems simulation subprogram of AXCESS.

10. Output:
As previously mentioned for the individual programs.

11. Input:
As previously mentioned for the individual programs.

12. Logical Structure:
Thermal loads from either program mentioned above are input to the energy systems simulation subprogram of AXCESS. The AXCESS structure is followed from there.

13. Flexibility:
Either version of this hybrid provides excellent program flexibility. Both versions offer a great number of energy systems simulations. Version I precedes the simulation with a detailed calculation of loads. Version II permits block analysis of conceptual designs and facilitates the parametric analysis of changes.

14. Interfacing:
These hybrid programs are based on interfaces.

15. Limitations:
These hybrid programs suffer the limitations previously mentioned, of those portions of the individual programs which are used in the hybrid.

16. Source Language:
As previously mentioned for the individual programs.

17. Hardware Implementation:
As previously mentioned for the individual programs.

18. Portability:
As previously mentioned for the individual programs.

19. Diagnostics:
As previously mentioned for the individual programs.

20. Maintenance:
As previously mentioned for the individual programs, with maintenance of the interface in Version II by Metin Lokmanhekim.

21. Adaptability/Expandability:
As previously mentioned for the individual programs.

22. Evaluative Summary:

These hybrid programs provide the greatest flexibility of any computer program series investigated. For MIUS use the thermal load calculation procedures provide a predictive accuracy comparable to that of NBSLD. Either version of this hybrid can account for the effects of shade on thermal loads. Version II provides the flexibility in user input and system simulation which facilitates parametric analysis of different conceptual designs. Version I is not proprietary and could be implemented with a minimum of effort since both constituent programs are in the possession of agency participants, and AXCESS can be easily modified to create the necessary linkage. Although version II is proprietary, a source deck, including the interface could be purchased. The two versions of this program and NBSRFM provide greater configurational flexibility than any of the existing MIUS type simulations developed by the government.

9. Scope:

The BIN program analyzes the modular integrated utility system shown diagrammatically in Figure 2.
It computes and compares the fuel requirements for this system with the fuel requirements of a conventional system when used to supply identical electrical, domestic hot water, space heating, and air conditioning loads to consumer models. The BIN program uses as part of the input data the outputs of the sub-programs HEATEN, CØØLEN, or SØLAIR. The HEATEN program estimates the space heating energy requirements of the consumer. The CØØLEN and/or SØLAIR programs are used to estimate the consumer space cooling energy requirements. These sub-programs utilize temperature frequency occurrence (bin) data from Chapter 6 of the Air Force Manual AFM-88-8 [16] or as compiled from National Weather Records Center Data.

10. Output:

The BIN program presents the results of the analysis for each month of the year by means of several tables.

a. Table 1: Consumer loads.
b. Table 2: System loads at the central equipment building.
c. Table 3: Required makeup by auxiliary boiler and engine waste heat unused.
d. Table 4: Air conditioning load to motor-compressor and absorption chiller.
e. Table 5: Total electrical load on engine generator.
f. Table 6: Fuel requirements for the T/E system.
g. Table 7: Total conventional system loads.
h. Table 8: Fuel requirements for the conventional system.
i. Table 9: Comparison of T/E system fuel consumption with conventional system fuel consumption.

11. Input:

Fifteen (15) data statements are required for the BIN program including the following input quantities:

a. Number of consumer dwelling units.
b. Yearly hot water heating load.
c. Yearly electrical load.
d. Hot and cold water pipe line transmission loss.
e. Quantity of refuse burned in auxiliary incinerator-boiler, if any.
f. Heat content of refuse.
g. Factor to allow for added fuel for complete combustion.
h. Consumer complex auxiliary electric load.
i. Monthly central equipment building auxiliary electric load.
j. Monthly space heating load (output of HEATEN program).
k. Monthly electricity usage as percent of total yearly load.

l. Monthly air conditioning load (output of CØØLEN or SØLAIR program).
m. Monthly domestic hot water usage as percent of total yearly load.
n. Monthly ceiling on beneficial use of waste heat.
o. Efficiency of motor compressor refrigeration system.
p. Efficiency of engine-generator for electrical load.
q. Type of fuel burned in engine and auxiliary boiler.
r. Efficiency of auxiliary boiler in total energy system.
s. Heating value of fuel.
t. Monthly auxiliary electric load for conventional system.
u. Efficiency of boiler for space and hot water heating in conventional system.
v. Central station plant efficiency in conventional system.
w. Heating value of fuel used in conventional system.

12. Logical Structure:

The complete system consists of several independent programs (HEATEN, CØØLEN, or SØLAIR) which must be run to compute the space heating and space cooling energy requirements. The outputs of these programs are then used as input to the main BIN program, which consists of approximately 200 statements.

13. Flexibility:

Although the programs are specifically designed to analyze a total energy system similar to Figure 7 and compare its fuel requirements to a conventional system, the programs can also be used to analyze variations of the total energy system by assuming appropriate values for the program input parameters. The programs have been applied to:

a. A total energy system in which all electricity, space heating and cooling, and domestic hot water are supplied to the consumer from an equipment building located on-site.
b. A T/E sysgem similar to A except that the entire cooling capacity is provided by absorption refrigeration system chillers.
c. The HEATEN and CØØLEN programs can be applied to the analysis of conventional heat pump systems.
d. A conventional district system in which electricity is purchased from a regional utility system.
e. A T/E system in which a part of the fuel burned in the auxiliary boiler consists of solid wastes.
f. Various sensitivity studies in which the effect of varying different input parameters on fuel consumption can be analyzed.

14. Interfacing:

The BIN, HEATEN, CØØLEN, and SØLAIR programs are all written in BASIC language for the time-sharing PDP-10 computer at

ORNL.

15. Limitations:

The following quotation presents several limitations of the "bin" method for estimating heating and cooling load energy requirements [17]:

"While the basic bin method provides for load calculations at various temperatures and at some variation in operating conditions, it still assumes that internal load and solar radiation load are constant during the operating period covered by the temperature bins. This drawback can be overcome somewhat by establishing temperature bins on 5 F deg and 1-hr increments instead of 8-hr increments. This would allow the internal load to be varied each hour of the day and matched to the solar load for that hour. However, this does not permit various types of occupancy and operational days during the month. Other factors which the bin method is not able to accommodate are latent heat load variations and the effect of heat storage and release during periods of setback or shutoff. A computerized version of the bin method permits the use of small increments and many sets of operating over the degree-day method or equivalent full-load hours methods."

16. Source Language:

BASIC

17. Hardware Implementation:

PDP-10 at ORNL

18. Portability:

Punched tapes can be prepared of the programs and used wherever there is a compatible time-sharing computer system.

19. Diagnostics:

Errors in command, compliation of data, or in execution are recognized and the appropriate diagnostic message is immediately typed out by BASIC.

20. Maintenance:

The maintenance of the software is done by the author of the various programs (C. L. Segaser) and changes in the programs are made as necessary.

21. Adaptability/Expandability:

Changes or additions to the software in BASIC are easily accomplished by simply changing or deleting statements and adding additional statements as required.

22. Evaluative Summary:

The ORNL BIN Program was an early development at that agency for the purpose of comparative energy performance evaluation of MIUS utility delivery configurations versus conventional configurations. Since that time an hourly analysis program (described in the following section), with more sophisticated and accurate load determination procedures and some improvements and additions to the steady-state energy simulations has been developed by ORNL. Because of this subsequent development, the BIN program has been effectively superseded.

3.11 ORNL 1973 MIUS Comparative Energy Analysis Program

1. Abstract:
   Uses hourly weather tapes, generalized building description data, hourly consumption data on electricity and water, desired indoor temperature and humidity schedules, and machinery performance data to calculate relative space heating and cooling loads, heating and chilling coil loads, fuel requirements and components thereof for different MIUS applications compared to conventional systems on an hourly, monthly, or annual basis. Uses algorithms in 1972 (ASHRAE Fundamentals Handbook [18].

2. Author(s):
   John V. Wilson,
   Oak Ridge National Laboratory,
   Oak Ridge, Tennessee
   FTS (615) 483-7622 or (615) 483-8611, ext. 3-7622.

3. Owner(s):
   Public domain.

4. Availability:
   Although this program was intended solely for internal use and is not formally documented, all or part will be made available upon request if approved by the sponsor (HUD-MIUS project).

5. Cost:
   Cost of obtaining cards or tape is only service charge for copying and mailing - estimated $25 or less depending on material desired. Run time is 6 seconds per weather year per Building type on IBM 360/91, or 30 seconds per weather year per building type on IBM 360/75. Consulting services for running the program could probably be arranged.

6. Human Factors:
   Each building type requires two cards of general data such as areas, four cards of heat transfer functions selected from ASHRAE tables, and 22 cards with hourly schedules for occupancy, water use, electricity use, etc. As many as 15 building types may be included. Three additional cards containing holiday designations, machinery data, and solid waste burning data for the project as a whole are also needed.
   Output is labelled only enough for internal use, and is frequently changed for requirements of the occasion. More output is printed than is normally required for any one specific study or application.

7. Turnaround:
   For internal use results are normally available in less than one working day. Jobs can be submitted by messenger

service, remote terminal, or teletype.

8. Documentation:
No user's manual is available or planned. A program description is given in Appendix B of reference [19]. Since the program closely follows the ASHRAE Fundamentals Handbook for most of its length, a user possessing that handbook should have little difficulty following the calculations.

9. Scope:
This computer program is intended for use in calculating relative energy and fuel requirements for different utility systems and development projects being studied in the HUD-MIUS project. For each conceptual type of building, space heating and cooling requirements are calculated hourly using weather data from tapes and building data and occupancy or usage schedules provided as input data. The algorithms in the 1972 ASHRAE Fundamentals Handbook are used [18]. From these requirements and the temperature control schedule the heating or cooling coil loads are calculated. From these in turn the hourly operating requirements for an engine generator, an auxiliary boiler (which may burn solid waste), an air conditioner of either absorption or motor-driven type, and for heat rejection are calculated. Finally, the fuel requirements for each hour are calculated. Results are summed and printed for selected time periods.

10. Output:
Input data are echoed with terse identifications. Some or all of the following are output for intervals selected by the user:

a. Electric load.
b. Space heating load.
c. Space cooling load.
d. Hot water heating load.
e. Heater coil load.
f. Chiller coil load.
g. Absorption chiller Btu.
h. Motor-compressor chiller KWH.
i. Total generator load KWH.
j. Auxiliary boiler Btu.
k. Heat rejected Btu.
l. Fuel used.

Components of the space heating load owing to transmission, ventilation, electric usage, occupants, solar radiation, and humidity control may be printed if desired. Various other outputs are printed from time to time for specific investigations by program changes.

11. Input:

For each building type the input data are: a. Floor area and associated heat transfer function coefficients. b. Roof area and associated heat transfer function coefficients. c. Window area and associated area and heat transfer coefficient.

Hourly schedules for both "occupied" and "unoccupied" status for each of the following:

a. Shading coefficient.
b. Inside temperature.
c. Inside humidity.
d. Occupancy.
e. Hot water heating.
f. Interior electricity.
g. External auxiliary electricity.
h. Ventilation/infiltration.

For the whole system data include:

a. Holiday schedule.
b. Machinery capacities and efficiencies.
c. Solid waste burning data.
d. Latitude and longitude.
e. Various option selectors and calculational controls.

12. Logical Structure:

Program consists of one main program of about 350 Fortran statements and twelve specialized sub-routines, plus standard library functions. The whole comprises about 1000 cards. The main program is very simple logically but is long because of various tallies and sums that are zeroed, incremented, and printed, and because it prints some of the input echo and some of the final output.

13. Flexibility:

The system can handle a MIUS or a total energy system or a conventional system consisting of up to 15 types of buildings. The user will have to interpret the printed output in various different ways, however, to achieve these results.

14. Interfacing:

Most of the specialized subroutines could probably be used almost unchanged in a merger with another system. Probably at least half of the main program would have to be completely rewritten.

15. Limitations:
The program provides only a simplified model of a conceptual type of building. The program does not calculate heat transfer function coefficients from basic materials properties data as NBSLD does, but rather must have these coefficients provided in the input data. The program does not include models of different ventilation systems.

16. Source Language:
IBM Fortran IV

17. Hardware Implementation:
IBM 360/75 and 360/91.

18. Portability:
In principle, it should be easy to convert this program to ASA Fortran or Fortran V, since Fortran IV is supposedly a subset of Fortran V. No doubt some problems would arise in handling format statements owing to different word lengths in different computers, and owing to some variations in names of library functions.

19. Diagnostics:
No significant diagnostics are provided.

20. Maintenance:
The author is using the program frequently, and changes and updates it frequently as various new demands arise.

21. Adaptability/Expandability:
The program logic is comparatively simple and changes/additions should be no more difficult than for the typical Fortran program.

22. Evaluative Summary:
The ORNL 1973 MIUS program is one of four programs discussed in this report which were developed specifically around a MIUS type of energy performance simulation. Its purpose has been for comparative analysis of different systems based on energy requirements. At this time, no economic analysis is performed. Program content consists of a building loads determination, and a subsequent steady-state energy requirements simulation for a typical MIUS plant configuration. Building thermal loads are calculated on an hour-by-hour basis and are based closely on procedures recommended in the 1972 ASHRAE Handbook of Fundamentals [18]. Base and auxiliary loads, including thermal requirements for hot water heating are calculated according to input schedules. Building orientations, for purposes of solar loading calculations, are set up in a fixed manner, for both single and multi-building configurations, and can be changed only by internal modification of the program itself.

Because of the lack of energy performance simulations for air-side systems, the program cannot model, in the same building in the same hour, simultaneous heating and cooling loads. It can model simultaneous heating and cooling loads only in different buildings in a particular hour. In a given building, it can account for a change from heating to cooling (or vice-versa) from one hour to the next. This limits program analysis capability mostly to hypothetical building project configurations, since it could not correctly model many existing types. All these considerations suggest that the loads produced by this program are limited in suitability to comparative analyses of plant systems designed to satisfy these loads, and not actual, realistic predictions of actual performance. It should be noted that ORNL has mentioned this point in a description of the program [19]. In the present program then, the model assumes that the total building thermal loads are found each hour, and with a correction estimate for distribution losses, are applied directly as the necessary thermal energy requirements that the plant system must modify. The ORNL program energy system simulation, to which the loads are applied, consists of only one typical MIUS configuration: a total energy plant with addditional features of incineration heat recovery and thermal storage, feeding a district heating and cooling system (Figure 2 and reference [20]). Any alteration in this simulation would have to be accomplished by internal program modification. There is thus a resultant lack of user flexibility in the application of this program. The energy performance simulation is of a steady-state, equilibrium nature, and calculations are made on the same hourly basis as the thermal loads supplied to the plant. Energy conversion models used for plant equipment in the simulation, except for the heat recovery power generation, uses fixed conversion efficiencies, which are less adequate than models which employ part load performance data for equipment. The resultant simplicity of this simulation compared to the complex performance of real equipment makes this energy simulation less suitable for prediction of actual performance than for comparative analyses.

On the basis of the preceding discussion, the ORNL 1973 MIUS program seems to be best suited for conceptual level estimates of comparative energy feasibility of a MIUS configuration with different performance factors. It would be most suitable to compare these results with similar calculations for a conventional utility configuration responding to the same demands, something which is not done automatically. This program, in its present form, could not be expected to accurately predict, on a reliably consistent basis, actual energy performance of a variety of real systems, due to the limitations discussed above. It is therefore of little use in the evaluation of real system designs. At this time, no economic analysis is performed.

3.12 Energy Systems Optimization Program (ESOP)

1. Abstract:
   The ESOP was written primarily for the purpose of predicting energy consumption of a MIUS system, including solid waste, water treatment, power generation, and comfort conditioning.

2. Author(s):
   The Urban Systems Project Office, Johnson Space Center, NASA and the Lockheed Electronics Company
   Allen E.Brandli, USPO-JSC, Technical Monitor

3. Owner(s):
   National Aeronautics and Space Administration

4. Availability:
   National Aeronautics and Space Administration
   Urban Systems Project Office
   Johnson Space Center, Houston, Texas

5. Cost:
   Unknown

6. Human Factors:
   Variable input options are possible. Those parameters not input are assumed to be zero. There is a total of less than 100 parameters in the input list covering all phases of MIUS simulation. Output is straightforward and easy to read.

7. Turnaround:
   This is dependent upon the computer system to be used. A general estimate is on the order of one to several minutes for the time required to run a job for a complete weather year, on a Univac 1108 Exec 8 System.

8. Documentation:
   Detailed Users Manual is available from owners [21].

9. Scope:
   The ESOP provides for analysis of energy reclamation systems only i.e., the use or recycling of process material products such as solid waste is not included in the simulation. ESOP predicts hourly, daily, monthly, seasonal, and yearly operational characteristics for any or all of thirty different MIUS configurations.

   ESOP has the capability of analyzing two types of MIUS; a diesel/turbine prime mover system and a steam power plant (boiler) prime mover system. The selection of system type analysis is a user option. Both systems use the same solid waste disposal system options.

10. Output:

The output from ESOP is fixed and in sufficient detail to allow for analyses and comparisons as required. Output categories include:

a. An echo of input data.
b. Recovered heat and operating dollar values for waste processing.
c. Daily profiles for hot water, space heating, and space cooling demand.
d. Fuel requirements and cost for conventional system (seasonal and yearly).
e. Fuel requirements for MIUS option considered (seasonal and yearly).
f. Hourly thermal storage, if applicable

11. Input:

Input is straightforward and logical. There are approximately 100 parameters of which some 24 are required for input. The namelist option, defined under FORTRAN V, is used to input all data to ESOP. Five namelists are required input for each data case. Descriptions of these five namelists follow:

a. WASTE - Namelist WASTE contains input variables which define the amount of waste to be disposed of, the waste, heating value, the quality of the waste, the cost of the required fuel, capacity of the incinerator unit, the total quantity of recovered waste, and the waste heat usage profile.
b. PYRINC - Namelist PYRINC contains input variables which define the operating characteristics of the pyrolysis process and heat recovery efficiencies of both the incineration and pyrolysis processes.
c. INPUT - Namelist INPUT contains variables which define the construction of the building to be analyzed, the number of buildings, number of apartments in each building, the hot water heating demand per building, and a cloud factor which is not used in the analysis at present.
d. ENVRHR - Namelist ENVRHR contains input variables which define twenty-four hour profiles of; inside and outside dry bulb temperatures and air enthalpies, domestic and auxiliary electric demands, occupancy, hot water usage, apartment ventilation rates, window shade factor, direct solar radiation through windows, window heat gain (convection and radiation), and "equivalent temperature differentials" for the building roof and walls.

e. CONST - Namelist CONST contains input variables which define diesel and turbine rated loads, a generator rated load (for the Waukesha 500 KW diesel system), boiler efficiencies (for both 24 and 12 mode systems), coefficients of performance for air conditioning systems, percentage absorption/compression for the fixed ratio mode, boiler operating characteristics (for the steam power plant), program logic flags for season, prime mover system, and low grade heat utilization selection, low grade heat recovery and usage characteristics, and water cooling tower operating characteristics.

12. Logical Structure:

ESOP consists of 5 general analytical components covering waste disposal, heating/cooling loads determination, power generation and a conventional utility system, plus other processing/interpolativetype subroutines. The overall structure of ESOP is shown in Figure 3. The five major components are:

a. Solid Waste Disposal Subroutine (SWDP):
SWDP calculates operating parameters and daily total energy input required for three types of solid waste disposal systems; incineration, pyrolysis, and combination incineration/pyrolysis. Process byproducts and recoverable waste energy are also calculated.

b. Generator Subroutine (GENRAT):
GENRAT calculates the hourly energy requirements for specific prime mover/generator units as a function of input electrical load demands. It also computes the hourly rate of waste heat energy that is recovered or recoverable from prime mover heat exchanger systems.

c. HEAIR:
HEAIR calculates the heating and cooling loads on a specific building with given internal and external environmental conditions for each hour of a 24-hour day.

d. CONVEN:
This subroutine calculates the hourly energy requirements for a conventional utility power system to meet the total system load demands. The configuration is composed of a boiler system identical to MIUS and a commercial electrical power generating source operating at a constant 30% efficiency level for delivered power. Only compression type air conditioning is utilized and no waste heat energy is utilized or recovered. Daily, monthly, and seasonal energy requirements are calculated for comparison with MIUS energy requirements.

e. STEAM:
This subroutine calculates the energy requirements and operational characteristics of a MIUS-type steam power plant. Four configurations are available as options.

13. Flexibility:
The ESOP will operate with a minimal number of input terms being specified, thus sufficing for a preliminary design. On the other hand, it will accommodate quite detailed input information to suffice as a more thorough design tool. The number of configurations simulated through various combinations of individual equipment simulations are 24 for diesel/turbine prime mover MIUS designs, 12 for steam power plant MIUS designs, and one conventional utility delivery design (described above under 12d). Detailed lists of all these configurations are presented in the ESOP user's manual [21].

14. Interfacing:
The ESOP is an "open" program and is written in such a manner as to easily allow modification of either input to or output from it to accommodate an interfacing with many other type programs as desired.

15. Limitations:
There are presently hardware/equipment simulation limitations in the ESOP, however, the capabilities can be easily expanded. Comparisons can be made only on an energy consumption basis and not on a dollar basis since there are no economic criteria considered in ESOP. Separate parts do not operate independently, and no midstream evaluation is possible. There are no building air-side simulations, and there is not a capability to account for simultaneous heating and cooling loads. Only four 24-hour weather days are analyzed (one for each season) instead of the 365 days accomplished for a true hourly calculation for loads.

16. Source Language:
The source language of ESOP is Fortran V.

17. Hardware Implementation:
It has been implemented on Univac equipment under both EXEC II and EXEC VIII.

18. Portability:
ESOP is hardware independent, within the limitations of Fortran compiler variability.

19. Diagnostics:
There are no printed diagnostics as such. Standard UNIVAC systems diagnostics are available, but printing is suppressed in ordinary use.

20. Maintenance:

Maintenance of ESOP will be handled by the authors.

21. Adaptability/Expandability:

ESOP can be readily changed or adapted to virtually any operation desired.

22. Evaluative Summary:

The NASA ESOP program system is one of four programs described in this report which was specifically developed to simulate the energy performance of typical MIUS configurations, and to compare that performance with a conventional utility system satisfying the same loads. At this time, no comparative economic analysis is available as part of the system. The various subprograms calculate building loads and subsequently accomplish, a steady-state energy requirements simulation of several MIUS configurations and a conventional one. Building thermal load calculations are based on 1965 ASHRAE recommended procedures [22] and utilize Trane solar data [23]. This method is based on finding a hypothetical "equivalent temperature difference" which yields a calculated fictitious transmission thermal load which is equal to the real thermal load due to all the various possible sources of effects: transmission, radiation, solar loading, building heat storage, ventilation, etc. Subsequent ASHRAE recommendations [18] have largely superseded this method. Base and auxiliary loads, including thermal requirements for hot water heating, are calculated from input schedules. A shortcoming of these schedules is their lack of ability to account for variations in occupancy and activity patterns caused by weekends and holidays. The schedules are assumed to be the same for all days of the year. The loads calculated are on an hour-by-hour basis. However, this is only done for four 24-hour weather profiles representing seasonal average characteristics. The subsequent loads obtained from these four seasonal days, are then multiplied by monthly and seasonal time durations to get related energy consumptions for those time periods. Thus, the calculation is not truly and hour-by-hour analysis for the whole year. In fact, it makes little sense to calculate a monthly energy consumption based on the properties of a seasonally average day. In addition, because of the lack of energy performance simulations for air-side systems, the program cannot account for the existence of simultaneous heating and cooling loads. This limits program analysis capability mostly to hypotheical building project configurations, since it cannot model the many existing building types that do present simultaneous loads. All these considerations suggest that the loads produced by this program are limited in suitability to comparative analyses of the plant systems designed to satisfy the loads, and not actual, realistic predictions of actual performance. It should be noted that a recognition of this limitation by the developers of the program system

is implicit in the title chosen: "Energy Systems Optimization Program."
The energy requirements simulations include a total of thirty six variations of possible MIUS configurations which differ as to the combinations of the various individual thermal processes: solid waste processing, power generation, and energy supply for heating and cooling. All simulations are of the steady state, energy balance type, and are done on the same hourly basis as the load calculations. There is a mix of both fixed conversion efficiencies in some processes, and part-load performance curves in others (e.g. power generation). In particular, it is possible to input an hour-by-hour COP profile for a chiller system, but since chiller COP usually correlates with the amount of the load, it is not clear what the hourly profile flexibility accomplishes. There is a pyrolysis simulation available in this program, a feature available nowhere else at this time. It is not clear, however, whether the assumption that byproduct gas created by this process should be sold for an operating dollar credit takes the best advantage of the integration possibilities of such a subsystem into a total MIUS configuration. In particular the possibility of recycling this gas as a MIUS fuel for an energy "credit" should be examined. The power generation subroutine simulates the performance characteristics of six prime-movers alternatives, four of which are diesel engines, and two of which are turbines. It should be noted that of the four diesel performance simulations, two of them are for models produced by a company which has now ceased operations (Nordberg). The resultant overall nature of the simulation available indicates that this program system is best suited for conceptual level estimates of comparative energy feasibility of the various configurations simulated for a particular set of site loads, both with respect to alternative MIUS configurations, and with respect to the one conventional configuration which is simulated. This program, in its present form, could not be expected to accurately predict, on a reliably consistent basis the actual energy performance of many real systems, due to the limitations discussed above.

3.13 MIUS SINDA Models

1. Abstract:

Two MIUS simulation models have been developed for operation on the Systems Improved Numerical Differencing Analyzer (SINDA) program. SINDA is a program capable of performing transient or steady-state analyses on any system which may be represented in lumped parameter fashion (nodalized) and whose operation is governed by diffusion equations. The program was initially designed for thermal analysis of spacecraft structures, but is not limited to that field.

One of the two MIUS models developed for operation on the SINDA program describes a MIUS equipment configuration which was designed for the 648-unit garden apartment trade study. The second was developed to simulate the MIUS Integration and Subsystems Test (MIST) hardware configuration, which is at NASA-Johnson Space Center, Houston, Texas.

2. Author(s):
   a. SINDA Program: TRW Systems, Inc., and NASA Johnson Space Center (JSC), Structures and Mechanics Division.
   b. MIUS SINDA Models: TRW Systems, Inc., The Boeing Company, and NASA, JSC, Urban Systems Project Office (USPO).

3. Owner(s):
   a. SINDA: Public (U.S. Government)
   b. MIUS SINDA Models: Public (U.S. Government)

4. Availability:
   a. SINDA - available through R. L. Dotts at NASA-JSC.
   b. MIUS Models - available through USPO.

5. Cost:

Operation cost is very model dependent and is a function of the type of analysis (steady-state, transient, etc.), time steps required to force mathematical stability because of physical properties of MIUS components, etc. The cost of performing specific analyses with the program is largely dependent upon the extent of modifications required for the particular MIUS configuration to be considered. Minor modifications can be accomplished quite readily in approximately one man-week.

Typical execution times for the current model configuration on the Univac 1110 Exec VIII system at JSC are less than one minute per day of real-time plus approximately two minutes for editing and compliation. Costs would be dependent on the particular computation center where the system is implemented.

6. Human Factors:

Preparation of input data and changes to the model are fairly easy if the user is familiar with the SINDA program and Fortran. Output is completely flexible and is controlled by the user either through the use of SINDA output subroutines or user-written output formats.

The MIUS model is not easy to use and modify due to its complexity and flexibility. However, a familiarization with the SINDA program and Fortran will enable the user to tailor the program to a wide vareity of applications.

7. Turnaround:

Turnaround at the JSC computing facility varies from approximately 2-3 hours to 2-3 days depending primarily on availability of hardware, when processing is done in batch mode.

8. Documentation:

The SINDA program has been documented with a user's manual [24], and an engineering program manual [25] which have been published and are available.

9. Scope:

One current MIUS model was developed specifically to simulate a 648-unit garden apartment MIUS. This model currently predicts flow rates and temperatures throughout the system, and from those predictions derives fuel consumption, energy losses, equipment operation schedules, etc. The second model simulates the behavior of similar physical parameters for the MIST hardware model, which is constructed at NASA-USPO. The models are truly applicable only to the particular MIUS configurations simulated; however, modifications will allow analysis of a fairly wide variety of MIUS configurations and/or control techniques.

10. Output:

For both models the user has complete control over all output through the use of either standard SINDA output routines or through his own Fortran statements. Any or all output is available at any time during the solution or at any time interval. The models output all temperatures and flow rates as well as several parameters which define the particular system operation at hourly intervals. Also available are seasonal and yearly totals of several system parameters such as fuel consumption.

Due to the detailed nature of the models, the output is currently quite lengthy and requires a familiarity with the models and their nodalization for meaningful interpretation.

11. Input:

The current MIUS models are retained on magnetic tape at the JSC computer facility. Thus, to execute them, the only input required is an appropriate set of system control cards and SINDA control cards necessary to load and compile and appropriate model from tape. Parameters such as load profiles, equipment performance curves, temperature profiles, etc., may be input as required by modifying the stored data through standard editing procedures. Input to the SINDA program to define each complete model includes a description of all nodes and conductors (for the RC network system simulation procedure), thermal sources, solution sequence and technique desired, and special purpose user-supplied subroutines required, and output logic desired.

The garden apartment model will accept magnetic tape input of building loads from the Post Office program.

12. Logical Structure:

The SINDA program is composed on three primary sections:
(a) A preprocessor which compiles, sorts, and stores all input data, user supplied logic, and order of solution.
(b) Standard solution routines which are called upon to solve the network constructed by the preprocessor.
(c) A large library of optional subroutines which are available to perform a wide variety of special purpose functions input/output control, mathematical manipulations, etc.

Both of the MIUS models have been developed as an application of the SINDA logical structure.

13. Flexibility:

The SINDA program is extremely flexible for analysis of any system which can be represented by a lumped parameter (nodal) network governed by diffusion equations. The existing SINDA subroutine library is quite comprehensive and can be supplemented with user-supplied subroutines.

The current MIUS models are also somewhat flexible, as long as major changes from the programmed physical configurations are not required. A wide variety of MIUS analyses may be readily performed with only minor variations in the model.

Ultimate flexibility is limited only by resources available for new model development within the framework of the SINDA system and computer hardware limitations.

14. Interfacing:
Numerous interfaces between SINDA and other software systems have been accomplished, and the extent of required modifications is a function of the particular application. The MIUS garden apartment model has been interfaced with the Post Office program to provide automated input of MIUS thermal loads.

15. Limitations:
The limitations of the SINDA program for MIUS modelling is dependent primarily upon the abilities of the user and the resources available for model development. The effort required to accomplish major modifications in the model makes detailed analyses of different physical configurations impractical in short periods of time. Another limitation in the use of the SINDA program is the degree of familiarity with SINDA required for effective use of the program.

The limitations of the existing MIUS models include largely those of the SINDA program. The existing models include representations of diesel and gas turbine-driven generators, absorption and compression chillers, boilers, incinerators, distribution piping, heat exchangers, and rairly extensive control logic. Currently, the models contain only thermal networks integrated with fluid flow. No pressure networks are included. The HVAC loads are assumed to be concentrated at one central heat exchanger rather than from individual sources. No air side simulation is included. Simulation of waste water treatment equipment is limited to the EPA sewage plant design program and is not integrated with the remaining MIUS equipment. Currently, no heat storage equipment is simulated. The items listed can be added to the model with a relatively minor effort in most cases.

16. Source Language:
The SINDA source language is primarily Fortran V, although a small amount of SLEUTH machine language is used, which is machine dependent.

17. Hardware Implementation:
The MIUS model is operational on JSC's Univac 1108, 1106, and 1110 under Exec II and Exec VIII monitor systems. SINDA is also operational on CDC 6600, IBM 360/370 and others.

18. Portability:
SINDA is fairly hardware dependent and often requires a relatively large effort to change environments. However, several versions of the program are available, and once it is operational in a given environment, only minor modifications, if any should be required to operate the MIUS models.

19. Diagnostics:

SINDA diagnostics and modeling aids are quite good. A few special diagnostics have been added through user input for the MIUS models.

20. Maintenance:

SINDA - Robert L. Dotts, Johnson Space Center
MIUS models - Urban Systems Project Office, Johnson Space Center

21. Adaptability/Expandability:

Changes to the SINDA program usually require a very thorough knowledge of the program and a fairly large effort. Special purpose subroutines can be easily formatted for standard SINDA calling sequences and added to a special source tape. Variations on the MIUS models could be greatly expanded within the SINDA framework and are limited only by familiarity with SINDA and computer hardware limitations. The current models can be expanded considerably with no hardware problems on the JSC Univac 1110 Exec VIII system.

22. Evaluative Summary:

The application of the SINDA program to the two model simulations discussed in this section constitute the only programs developed for MIUS simulations which have the capability of accomplishing true transient simulations of the various energy conversion processes. To date, however, only steady-state simulations have been performed, and the transient simulation capabilities have not been utilized. Compared to other programs discussed in this report, the SINDA models require a greater amount of effort to accomplish a simulation. In addition, although SINDA is very flexible itself, each of the actual simulation models developed are fixed in configuration. Any change in a model involves actual changes to the software itself; it is not possible under user control by simple changes of input data cards. In a sense, in fact, most of the input for a simulation is built in to the program itself. This difficulty of input also leads to an increased possibility of error, an example of which is examined in a discussion of the ESOP/MIUS SINDA garden apartment simulation in the next section. In view of the fact that the amount of effort involved in developing an operational simulation model with SINDA is so much greater than for the other programs discussed in this report, and because of the effort involved in modifying simulations, it is being misapplied in performing steady-state analyses, and should be used only when the transient analysis capabilities are utilized. It is hoped that, particularly in the case of the MIUS SINDA model, the transient analysis capability will be employed.

In that application, it will probably be of benefit in systematically examining transient behavior, and should be able to indicate methods of optimizing overall performance through proper design of control processes. It is in areas such as this, where the unique transient simulation capabilities of this system can be utilized, that use and further development of simulation models based on SINDA are justified.

4. Program Comparison Activities

Many others have previously recognized the need for validation of program predictions, with respect to actual performance, and for intercomparison with each other. A number of program comparison activities have been carried out, four of which are described below, along with comments regarding the pertinence of their findings to the MIUS effort.

A. Boeing-Lockheed MIUS Simulation Program Correlation (SINDA/ESOP)

In a supporting effort to NASA-USPO, the Boeing Corporation compared the calculated annual electrical and fuel energy requirements using the SINDA and ESOP programs for an early version of the NASA 648-unit garden apartment configuration using typical weather conditions for Houston, Texas and Seattle, Washington. In both cases, the operation logic of the MIUS system consisted of generating the required electrical power and utilizing the waste heat in the most efficient manner to satisfy the hot water and domestic heating and cooling demands. The ESOP and SINDA simulations are different in both the simulation models and in calculational logic, leading to different and non-comparable methods of describing component and subsystem interfaces and operational interactions in each of the programs. Thus the only two calculated parameters that could be directly compared were the annual electrical power and fuel consumptions for the modelled configuration. Results showed annual electrical and fuel consumption agreements of about 3% and 5% respectively for Houston and about 1% and 5% respectively for Seattle.

B. ESOP/Meriwether/E-CUBE

NASA USPO has also accomplished a comparison of their internally developed ESOP program and the commercially available services of the E-CUBE and Meriwether programs. This comparison was limited to predicted heating and cooling energy requirements for the Park Towers South Office Building model used in the NASA-USPO Office Building Trade Study. The weather data used was based on four typical seasonal days for Houston, Texas which was input directly to ESOP. The seasonal days were modified to simulate the full year of weather data necessary for E-CUBE and Meriweater analyses. An important variable was cloud cover, which ranged from none to "full", and was handled differently by each program. Variations in the predicted heating energy requirements between the other two programs, with ESOP results as a reference, ranged from 22% lower to 16% higher depending on the cloud cover parameter. The analagous variations in the cooling energy requirements ranged from 7% lower to 40% higher than the ESOP results as a reference base. A comparison of electricity and fuel requirements was not made due to ESOP program limitations. Since no actual building energy consumption data was available, it was not possible to determine which of the programs would have made the best actual prediction of enegy performance. The activity was therefore a comparative one, based on examining consistency of results for the different programs.

C. ASHRAE "Project Crosscheck"

In 1967 ASHRAE established a task group to investigate and propose improved methods for estimating the energy requirements for heating and cooling buildings. This task group decided that it would be beneficial to compare several computer-based algorithms that had been developed. In what was to become the first phase of "Project Crosscheck", five different programs attempted to predict the heating and cooling loads of a hypothetical 20 story building assuming five independent zones. The five participants were:

1. Alabama Power Company
2. American Electric Power Service Corporation
3. Ross F. Meriwether and Associates, Inc.
4. Texas Electric Service Corporation
5. Westinghouse Electric Company, Inc.

Plots of the results showed that all five participants found essentially the same variations in loads with weather conditions, e.g. the magnitude of the worst case exterior zone monthly heating and cooling loads were within a bandwidth of 19% and 14%, about the means respectively. These bandwidths were both on the south face indicating differences in the treatment of solar load. The maximum differentiation of ± 100% from the mean occurred in the core zone of the building.

The ASHRAE Task Group was later given formal standing as Technical Committee 1.5 on Computer Applications. This committee realized a need not only for the evaluation of precision, as shown in Phase I, but also for an evaluation of program accuracy. Under funding from the National Science Foundation, Ohio State University (OSU) had instrumented the Law Center on the OSU campus in Columbus, Ohio. The data obtained included heating and cooling power requirements (not loads) and weather data in addition to an extremely accurate model of the building system. The committee decided to compare the various current computer programs using Columbus, Ohio weather data to the OSU model using the same weather data [26]. The following participants are involved in Phase II:

1. Ross Meriwether and Associates (represented by the Dept. of Public Works, Canada)
2. Electric Energy Association
3. Texas Electric Service
4. American Electric Power Service Corporation

The result of this effort is described in [27].

D. NBSLD/E-CUBE Omaha High-Rise Comparison

At the request of HUD, an analysis of building energy (natural gas and electricity) consumption for a selected typical weather year was conducted by NBS on Kay-Jay Towers, a 12 story, 118-unit apartment building in Omaha, Nebraska, using the computer program NBSLD and a simple building system simulation program developed for this particular building [28]. The purpose of this effort was to compare the NBSLD results both with similar results calculated by the Northern Natural Gas Company using the E-CUBE program and with actual metered 5-year average energy consumption data which was available. Both programs used the same zone configurations in the thermal modelling of the building and simulated the same mechanical and air handling aspects of the building plant. Both employed actual equipment and building operating schedules and indoor environmental conditions. While NBSLD accounted explicitly for the effects of air infiltration on space thermal loads, the data input to E-CUBE did not.

Although there were wide monthly discrepancies in energy use predictions by both programs compared to the metered data, the annual consumption totals for both programs nevertheless agreed with the actual use to within one percent for natural gas and a few percent for electricity. It is unclear at the present time how these results are to be interpreted, but they do raise the important question of how E-CUBE came so close to the actual consumption while neglecting the large effects of air infiltration throughout the analysis year.

None of the above activities has produced a comprehensive validation or comparison of energy analysis computer programs. The most notable reason for their failure was the use of incorrect comparison methodologies. They were all "one-point" comparisons, in the sense that a given applicational ("site") situation was picked, which in turn determined the utility loads to be satisfied, and the system energy performance was then calculated by the different computer programs involved in the comparison. The results were then examined for the quality of the agreement among themselves. There are two shortcomings to this approach. First, unless there is also measured performance data available for a real system reacting to the same loads (and which the computerized systems must stimulate) then there is no way of knowing whether the computer predicted results are in fact accurate or not. All that can be determined is how well the results of the different programs agree or disagree among themselves. Of all the comparison activities that have been undertaken, only the NBSLD/E-CUBE comparison on the Omaha building also had actual energy consumption data available, and the orientation of that whole effort was to examine the energy requirements of a particular building, not a utility supply system. The second deficiency with this "one-point" test methodology is an inability to provide the data base for comparison of optional energy systems. A meaningful comparative test among programs should be designed in a way that determines whether or not the programs come to the same relative conclusions, i.e. that they agree on the optimal utility system configuration for a given set of loads. To accomplish this, a set of several configurations or a continuous variation over a range of configurational performance parameters need to be simulated by each of the programs being compared. In response to a given set of loads, the performance simulations of the whole set of configurations should then be carried out by the participating programs. Finally, the results should be compared to see whether or not the programs all predict the same relative performance (including the "optimized configuration") for the range of configurations simulated. This is the kind of interprogram test that has meaning for the comparative types of simulation programs, not the single-point comparison. The above considerations apply to both building load determinations and energy systems simulation.

A more recent report describing a comparison of selected programs on several building types is presented in reference [1]. This study gives a particularly valuable description of the differences in user factors for the programs involved.

5. Conclusions and Recommendations

During the course of this study, a clearer definition of MIUS requirements for computer program capability was formed, and is summarized in this section of the report. This definition was the result of interaction between initial software utilization plans and this analysis of the actual capabilities of available software. Six areas of analysis which require the use of computer programs are identified below. Conclusions regarding the adequacy of programs described earlier in this report and recommendations for additional development are discussed in the context of these six areas.

A. Equilibrium Comparative Analysis

The first area of analysis requiring computer assistance is the comparison of alternative MIUS and conventional plant configurations with respect to energy performance using simplified steady-state energy balance simulations. This capability is necessary to determine the optimal plant which will satisfy given site utility loads. This capability will be used throughout additional conceptual studies, demonstration evaluation, and as the core of a later "MIUS Optimizer".

It is clear that the NASA ESOP and ORNL 1973 Comparative Energy Analysis programs, which include simulations of likely MIUS configurations, are the most applicable existing programs. Close followers are the commercial AXCESS program and the TACS/AXCESS hybrid. Because of their non-proprietarity, availability, flexibility, and quality, as discussed in the appropriate evaluative summaries, these last two programs have the greatest present value to MIUS of the commercial programs considered in this study. All of the programs mentioned here are flexible, and do not have the limitations inherent in proprietary programs. The implementation of these programs on participating agency computers would make them cost-effective as research tools. In addition, the modular structure of these programs lends them especially well to being modified in response to changing or increased interest in the future.

It is possible then to conclude that with the capability represented by the various programs in the possession of the agencies, and the level of simulation detail they contain, there exists a comparative energy analysis capability suitable for the needs of the MIUS effort. However, implementation of AXCESS and the TACS/AXCESS hybrid on a participating agency computer is yet to be accomplished. It is recommended that implementation of these programs be pursued, or alternatively that a new program be developed with similar or better capabilities. In addition, a multi-point comparison should be conducted between these programs to determine if they agree on relative performance of the system configurations that are simulated. The test should be based on a "typical" application with several regional weather data sets and a set of loads from a probable development configuration, for example, the NASA Community Study, or the ORNL Live Model Study.

B. Economics

The second area of analysis requiring computer assistance is the economic comparison of alternative MIUS and conventional plant configurations. This requirement parallels that of the energy feasibility analysis described above. Several of the complete energy analysis program series studies include an economic analysis of alternatives. It should be added that while the economic comparison exists as a set of computational algorithms, the economic data base necessary to do actual comparisons for real systems at this time appears to be incomplete and not in a form amenable to automatic accessing by a computerized comparative system.

C. Transient Response

The third need for computer assistance is in the development of more sophisticated transient MIUS simulation models. These are needed to provide improved conceptual optimization, accurate plant performance predictions, and cost effective control schemes. The models will be used in conjunction with MIUS demonstration to predict and validate the best control system methodologies.

While the present level of detail of the simulations may be adequate for comparative performance evaluations, it is not possible to also conclude, however, how accurate the simulations are in the prediction of the actual performance of a given MIUS configuration. At this time there is no data to conclusively confirm or deny the simulation adequacy under these circumstances. Greatly simplifying assumptions are inherent in the equilibrium type of model. Even if they allow for thermal capacities in the form of storage and losses they do not allow for the actual effect of a real control system on the time-response of the MIUS to time-varying loads. This immediately leads one to consider such a model suspect in its prediction of actual performance, unless it is proven by actual testing to be adequate. What is then first needed is a real system from which actual performance can be measured, and which can also be modeled on the computer. In this way the present simulation programs can have their absolute performance predictions compared against the measured data. Candidate systems for this comparison activity are the NASA/MIST facility and the HUD Jersey City Operation BREAKTHROUGH instrumented Total Energy plant. If a simulation model is proven to be inadequate, then steps should be taken to devise those necessary models which are in fact adequate for an actual performance simulation. Before undertaking the major development of new simulation models, the alternative benefits to be derived from generation of a reliable performance data base should be considered. Any simulation is, at best, as accurate as the equipment performance data it utilizes. If the present data base can support a higher level of simulation, and this additional level of complexity is necessary to adequately predict actual performance, then such a development should be initiated. It is felt the first area of development, with the greatest immediate benefit would be an attempt to obtain better models of how the control systems at the component, subsystem and system level actually cause a MIUS configuration to respond to a particular time dependent utility load variation. At the present time, only the NASA developed SINDA MIUS models have the potential for this type of analysis in the public domains.

D. Building Energy Requirements

The fourth area of analysis requires the ability to accurately determine building thermal loads and energy requirements. Valid building loads and energy requirements are essential for plant optimization and accurate prediction of site energy requirements at a particular site. A program of this type will be used to translate MIUS site characteristics into plant requirements. Four program series have strong capabilities in this area, and others are presently under development. NBSLD, through probably the most accurate and flexible building load calculation program, and in fact developed as a research tool, lacks air-side mechanical systems and equipment simulation. A final comment on the relative importance of loads calculations, air-side systems simulations, and plant equipment simulations is in order. In any program series which has all of these capabilities, it is probably not cost effective to finance development of new software which leads to a significantly greater level of sophistication in any one of these areas. The need for loads calculation and air-side system simulation capabilities is adequately satisfied by the program series discussed above. It is recommended that agency participants utilize the above program series in calculation of site energy requirements.

E. Digital Control

The fifth area of analysis requiring computer assistance is the development of the actual monitoring and control algorithms for digital computer control of a MIUS. These evolving algorithms will be the product of the knowledge gained from the simulation programs described above, and from operating experience at early demonstration sites. Although no existing algorithms were located in this study. Numerous commercial firms and government agencies have a demonstrated capability in this area. The NASA SINDA MIST model has the potential for providing useful information. In addition, the instrumented Operation BREAKTHROUGH Jersey City, MIUS demonstration will provide valuable experience in this area.

F. Optimization

The **ultimate** need for computer assistance is in producing a user-oriented "MIUS Optimizer". This program will be a commercial tool for automatic comparison of alternative MIUS designs. It will enable MIUS designers to select the best configuration for the site under consideration. The purpose of this development is to provide increased incentive for commercial implementation of the MIUS concept by making it possible to easily produce good designs. The next section outlines current developments in this area.

G. Current Developments (1977)

Two programs are currently being developed for community-oriented energy analysis which will have significant impact on satisfying needs identified in areas A, B, and F as outlined above. Complete descriptions of these programs are not available at this time, but the following summaries are included to indicate their scope.

1. Analysis of Advanced Coal-Using Communities (ACUCS).

The overall objective of the ERDA-sponsored ACUCS program is the development of practical alternative systems for communities use that will utilize coal in a clean and efficient way. This would lessen the dependence of the community on oil and gas and facilitate the utilization of traditionally wasted heat to satisfy some community energy requirements. Three major programmatic activities are evaluation and characterization of technologies needed for coal-based systems, collection and evaluation of community load data, and the development of computerized system design methods.

The purpose of the computer model will be to provide good community energy system designs over the widest possible choice of central system configurations and end-use fuel allocations. The synthesis/optimization program is designed to analyze all types of technologies and to consider all types of fuel-service assignments. The results are at a generic process level (e.g. low pressure coal pyrolysis). Consequently the program is expected to be used for preliminary design by planners and design engineers.

The design program will be a mathematical optimization model that determines the minimum cost energy system (or other measure of effectiveness) that satisfies the energy needs of a community. The program requires as input the description of a set of generic central conversion processes along with a physical description of a community and its energy needs stated as service demands, i.e., BTU's for heating, cooling, etc. The program determines the following (optimal) system configuration, parameters, and operating characteristics;

- the number of each type of central conversion device to install in the community;
- the allocation of fuels to user demands, i.e., gas for heating, electricity for cooling. These allocations can be different for different geographical areas and different economic sectors. Thus the heating in an area near the central plant may be provided by thermal heat while areas farther from the central plant may be served with gas heating systems;
- the number and type of storage device to be installed;
- the operating levels of each conversion process and storage device for each time period in the year being modeled;
- the overall system efficiency;
- individual process efficiencies;
- initial investment costs, yearly maintenance costs, and yearly fuel costs;
- related system measurements such as land area required, water resources required, pollution levels, etc.

Input requirements will include, but not be limited to the following:

- General community characteristics (e.g., available land, zoning, and buildings)
- Service (e.g., space heating) and/or energy (e.g., electricity) demands
- Weather profile
- Time horizon
- Financial limitations
- Types of coal available
- Air and water pollution limits
- Reliability standards
- Characteristics of existing equipment
- Limitations on equipment to be considered

Output options and results of analysis will include:

- Selection of generic processes for fuel conversion and storage at central and secondary sites within the community.
- Identification of community zones and fuel types distributed to each.
- Assignment of fuels to end-use service demands by community zone and building type.

2. Advanced Technology-Mix Energy System Program (ATMES)

The ERDA-sponsored ATMES Program, managed by Argonne National Laboratory, is concerned with development and evaluation of central energy supply systems for communities. Existing and emerging technologies are being scanned for their potential application in such systems, and the most promising design concepts are evaluated in detail. It is anticipated that a large number of different system configurations will have to be considered and therefore a highly flexible and modular computerized energy modeling program is needed to aid the design team. Strong emphasis is also placed on short run times and ease-of-use.

The program will simulate the quasi-steady state operation of a user-defined component configuration for a selected period of time, generally in hourly increments. Plant operation will be simulated in accordance with one of the following:

a. User-defined operating rules.

b. Weighted resource energy minimization.

c. Operating and maintenance cost minimization.

A library of component subroutines will be provied with the program and will contain performance and economic data for various central plant components. This library will be updated as new data and components are evaluated. Component subroutines will be readily modifiable by the program user.

The executive program will process the input data utilizing the default dictionary to generate a standard file, analyze the information flow in the system and decide on the order in which the components have to be simulated. The program will then simulate the operation of the plant and calculate fuel inputs for time increments requested by the user. A novel optimization algorithm was developed which can "operate" the plant to minimize fuel input or costs. This will represent a significant improvement over simple simulation and will indicate the capabilities or limitations of the system when operated according to the optimal strategy. An economic analysis will evaluate initial, operational, and life-cycle costs of the plant. It could be run independently of the simulation portion of the program.

The input into the program will consist of two parts:

a. Description of the plant configuration, operating procedures, reports required, etc., given in the System Definition and Control Language (SDCL).

b. A file containing community energy requirements to be supplied by the plant (generally in hourly increments), e.g., electricity, hot water, steam, chilled water, etc., and other variables, such as weather. The structure of this file can be specified in the SDCL.

The basic output of the program will consist of the following elements:

a. Amounts of fuel input into the plant during time intervals specified by the user.

b. Plant outputs, distinguishing between outputs used to satisfy community demand and those produced for sale to other users outside the community.

c. Information on plant operation. For example, statistics of equipment usage (possibly in a form of a load duration curve), and operating strategies used by the optimization feature of the program.

d. Results of economic analysis, i.e., first, O&M, and life-cycle costs of the plant.

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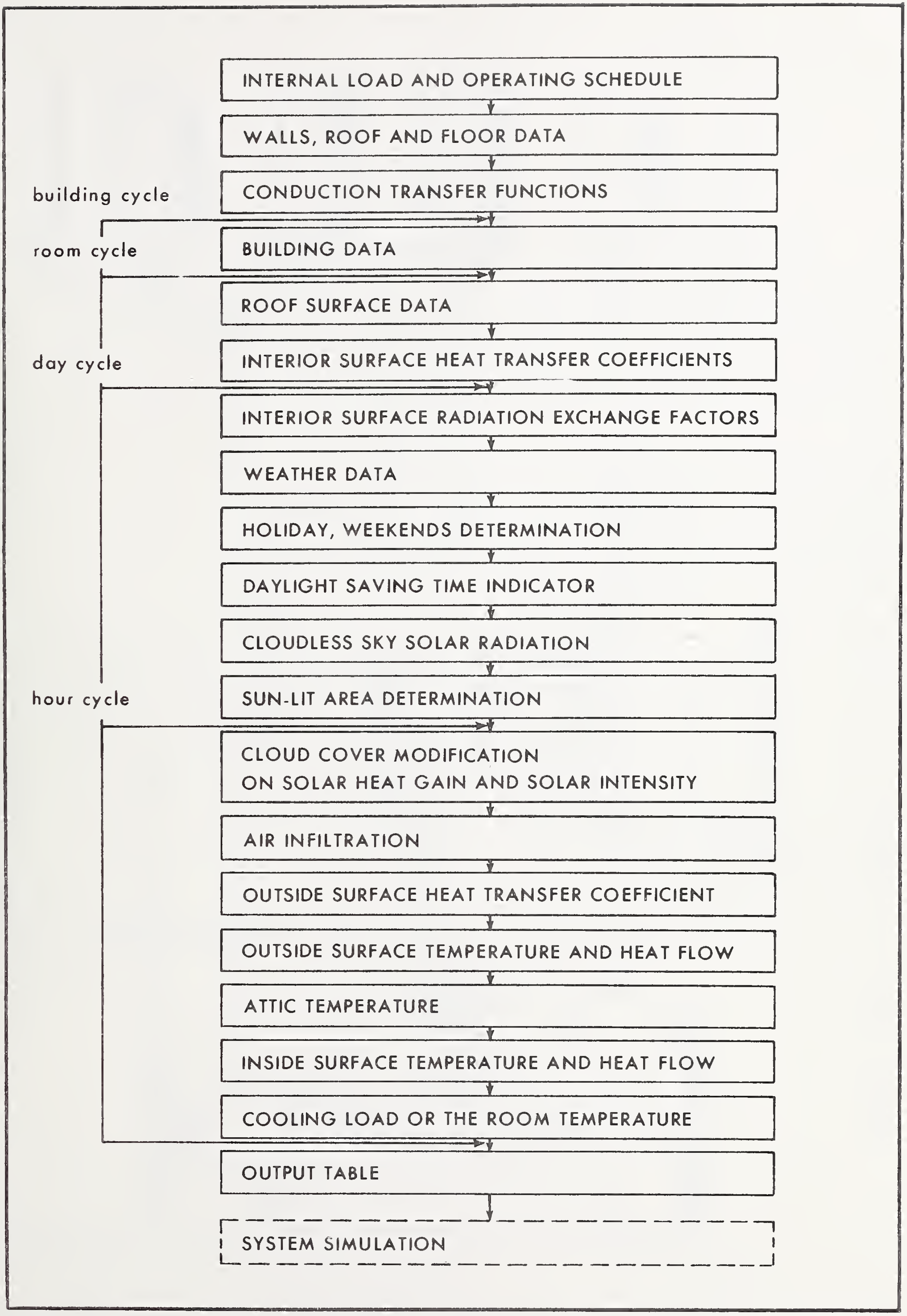

Figure 1 NBSLD Program Sequence

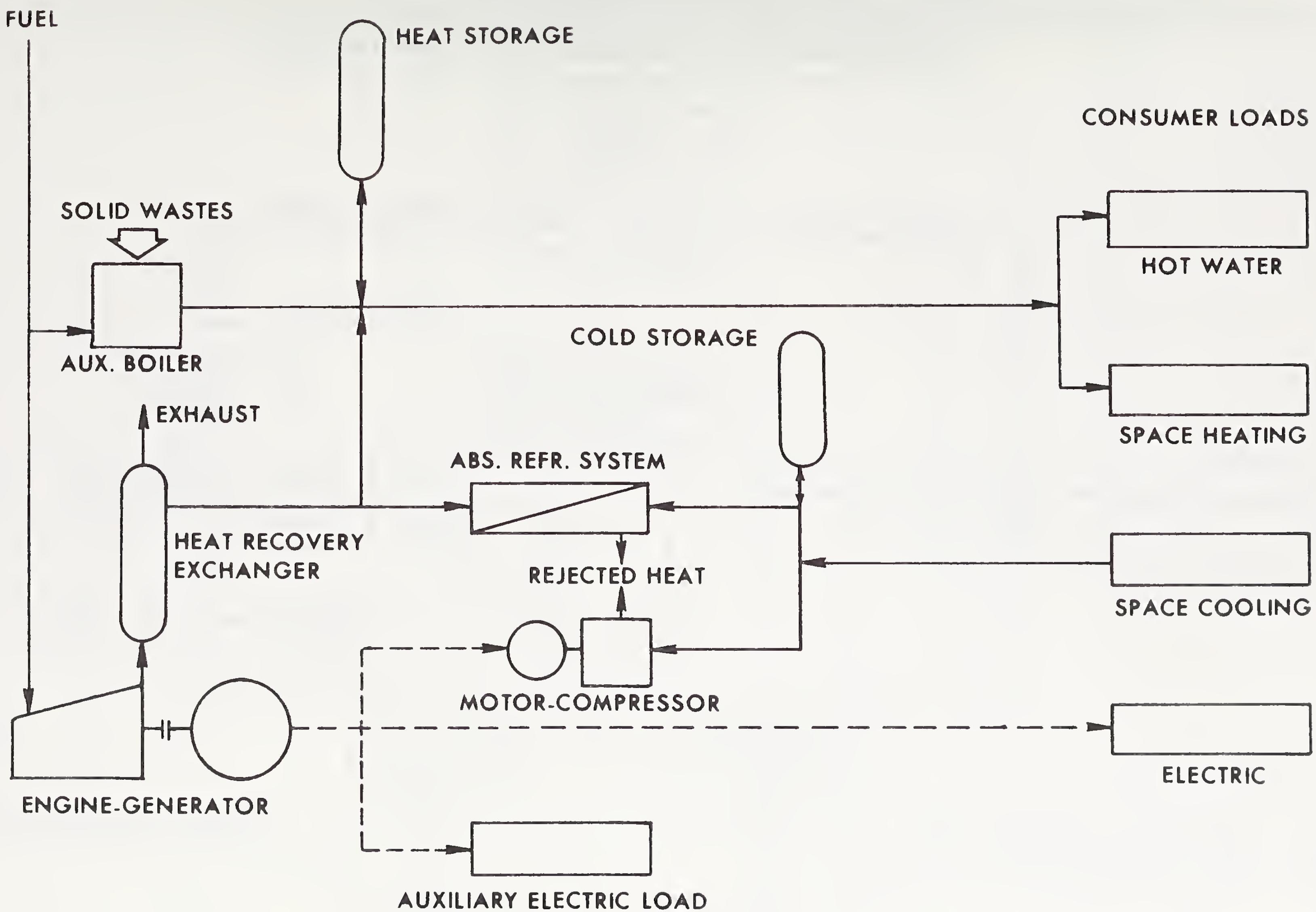

Figure 2 ORNL 1973 MIUS Comparative Energy Analysis Program Simulation Configuration

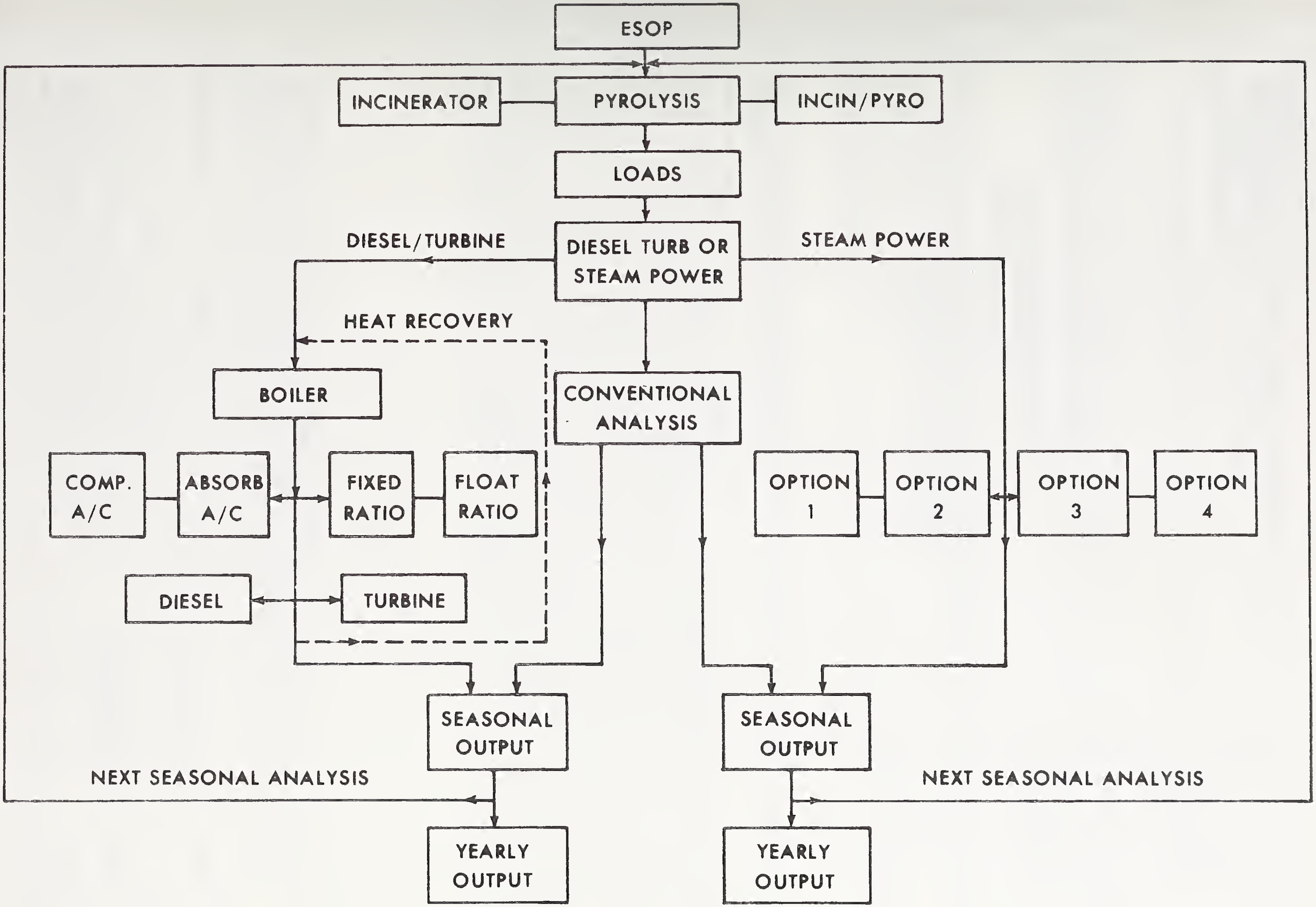

Figure 3 ESOP Program Sequence

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Thirteen computer programs are examined for potential application to the Modular Integrated Utility System (MIUS) program. The software programs considered calculate all or partial combinations of: heating and cooling loads, simulation of physical systems to determine the energy requirements necessary to satisfy those loads, prediction of optimal operation schedules and associated costs, and accomplishment of full life-cycle economic analyses. A set of criteria for evaluation of this software is presented. Information regarding the programs, obtained from user manuals and a series of seminar presentations, is collected and systematically summarized in a standardized formal using information available as of June, 1974. An evaluation summary of each program as of that date is given. Program comparison activities are discussed and evaluated. Conclusions regarding applicability, validity, and utility of programs are reached. Recommendations are made concerning future software development and utilization.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Computer programs; cooling; energy analysis; financial analysis; heating; load calculation; MIUS; modular integrated utility system; simulation; utility services

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