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# Building Energy Systems Program

# 1990 Annual Report



*Applied Science Division*

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**Please note name change:**

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# Building Energy Systems Program 1990 Annual Report

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LBL-30868

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# Contents

# Introduction

The main theme of the Building Energy Systems Program is the comprehensive simulation, analysis, monitoring, and evaluation of the energy performance of whole buildings, particularly nonresidential buildings. Many of our projects develop and apply comprehensive computer models for integrating performance analyses of heating, cooling, and daylighting systems. A further activity has involved research on absorption heat pumps for solar cooling and gas-driven applications.

The Simulation Research Group maintains and continues development of DOE-2, a public-domain computer program for detailed, hour-by-hour simulation of energy use in buildings. DOE-2 is used by some 5,000 users throughout the United States and 36 other countries to design energy-efficient buildings and to research innovative building technologies. A new version of the program, DOE-2.1E, was started in 1990. Major new features will include evaporative cooling, ice storage systems, switchable glazing, a new window library, and integration into DOE-2 of the WINDOW-4 glazing heat transfer model.

The Simulation Research Group has continued its work on developing the next generation of simulation software, for use in the 1990's and beyond. Two major efforts are under way. The first is the development of a modular software environment—an Energy Kernel System (EKS)—that will allow users to generate customized simulation programs that suit their particular analysis needs. In 1990, we successfully tested EKS on a variety of complex problems in thermal analysis of energy flow in buildings. In addition, substantial advances were made in the Neutral Model Format translator, the Macsyma/EKS interface, multivariable links into EKS, and development of additional library objects.

The second major advanced-simulation effort entails incorporation of EKS methods into DOE-2, leading to a new whole-building energy simulation program, **DOE-3**. DOE-3 will allow models for new HVAC technologies to be quickly built up from component modules without having to make modifications to the underlying computer code. In 1990, we conducted a proof-of-concept for DOE-3 by effectively replacing the SYSTEMS part of DOE-2 with an EKS calculation for an HVAC system, verifying the result vs. a standard DOE-2 calculation for the same HVAC system type.

To estimate more accurately the energy-consumption impacts of retrofit measures in institutional buildings, the Building Systems Analysis Group has continued to develop a building-specific Retrofit Energy Savings Estimation Model (RESEM) for the DOE Institutional Conservation Program (ICP). RESEM is a user-friendly tool that will allow state and regional ICP staff to use readily available information to reliably determine energy and cost savings directly attributable to ICP-supported retrofits for a single building. Initial field testing occurred during 1990, including a limited beta-test using several state energy and DOE operations offices. Many formal and informal presentations served to introduce the RESEM capability to numerous potential end-users. Work is under way to produce a comprehensive end-user Reference Manual and an extensive weather library for over 200 locations.

The Building Systems Analysis Group has also continued to investigate the performance of solar commercial buildings as part of the U.S. contribution to the International Energy Agency (IEA) Task XI and the U.S./U.K. Bilateral Agreement. Two existing buildings were selected for detailed atrium simulations—one in Norway and one in the United Kingdom. Analysis in the U.S. was coordinated with monitoring performed in Norway and the United Kingdom. Actual measured data was used to calibrate the simulation results for the atrium building in Norway. The calibrated simulation model was then used to conduct parametric studies, examining the sensitivity of energy performance to changes in a number of variables, including operation, control, and glazing parameters.

The results are being incorporated into the Atrium Chapter of the Source Book, the main deliverable for IEA Task XI.

During 1990 the Solar Absorption Cooling project concluded its joint program with the Technion (in Haifa, Israel) on modeling and simulating the performance of high efficiency absorption chillers and heat pumps. As a test case, both organizations used their newly developed computer models to simulate the performance of the generator-absorber exchange (GAX) cycle, an advanced, high-efficiency cycle using ammonia-water as the working fluid pair. Even though the calculational approaches taken by LBL and Technion were quite different, the two independently calculated sets of cycle performance parameters evidenced close agreement.

## Solar Absorption Cooling

*M. Wahlig, J. Rasson*

Work at Lawrence Berkeley Laboratory (LBL) as part of Annex VIII to the Agreement between the U.S. Department of Energy and the Israel Ministry of Energy and Infrastructure on Simulation and Analysis of High Efficiency Absorption Systems for Solar Cooling was concluded during 1990. Under this Agreement, LBL and the Technion (in Haifa, Israel) developed techniques to model and simulate the performance of high efficiency chillers and heat pumps, enabling calculation of the expected performance of solar cooling and heating systems using these advanced types of cooling equipment.

In general, a capability has existed for many years to model simple and complex absorption cycles that use water-lithium bromide, or similar water-salt solutions, as the working fluids. However, the use of *ammonia-water* introduces calculational complexities in simultaneous-equation solution methods; these usually result in non-convergence of the set of equations that describe the cycle performance. This calculational problem is a result of the strong nonlinearity of the properties of the ammonia-water solution. As a consequence, up until this project, only the simplest ammonia-water single-effect absorption cycles had been modeled in detail. More complex ammonia-water absorption cycles had eluded detailed simulation, except for ad hoc methods used by individual researchers to obtain approximate results.

This joint research program was undertaken by LBL and the Technion specifically to develop this capability of modeling the performance of absorption cooling and heating cycles that use ammonia-water as the working fluid pair. LBL and the Technion pursued complementary approaches to develop the required chiller and heat pump models.

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FLOWSHEET PRESENTATION OF GAX CYCLE SIMULATED AT LBL

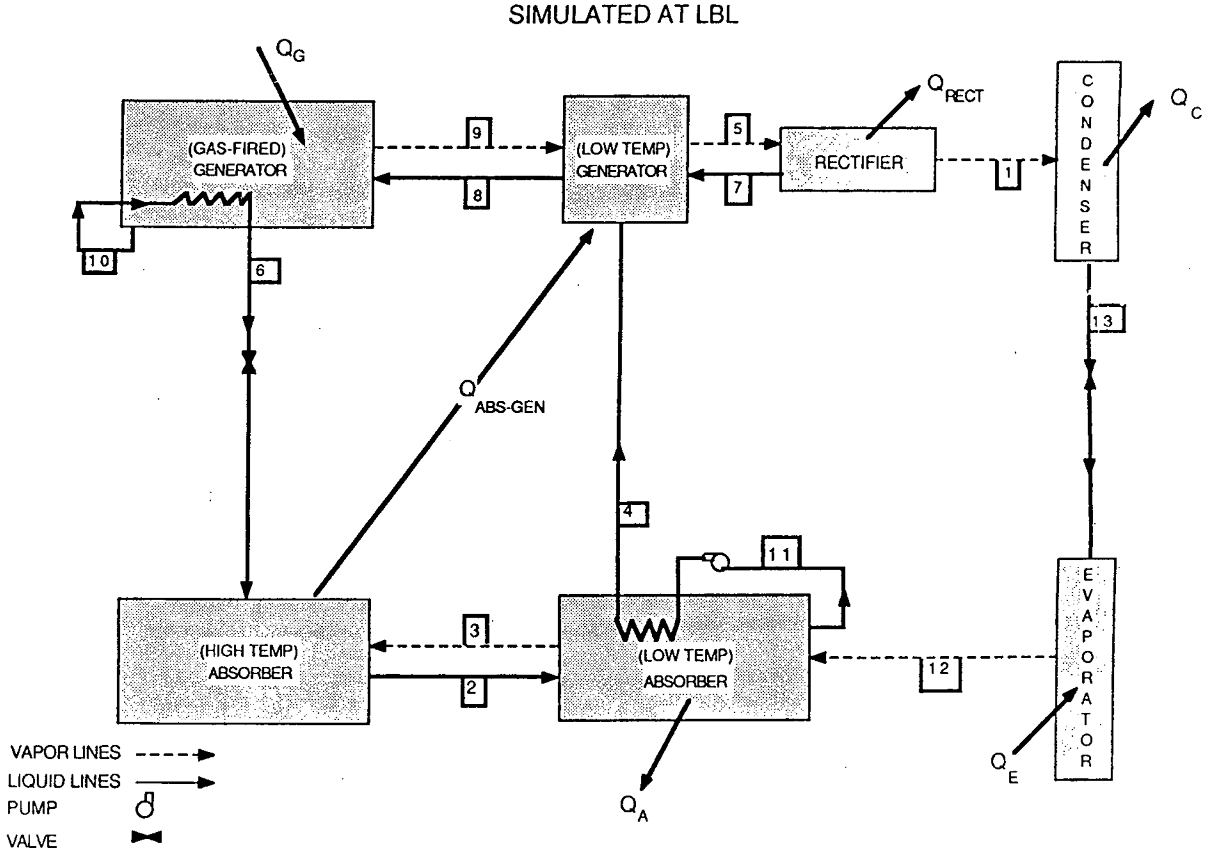


Figure 1. GAX cycle configuration used by LBL.

The Technion approach was an extension of Professor Gershon Grossman's modular computer program to enable the modeling and simulation of new and more complex chillers/heat pumps, cooling processes, and solar cooling systems. This approach utilizes a simultaneous solution method. The LBL approach was to use and adapt existing public-domain computer programs and solution techniques, in particular the chemical process flowsheet simulator ASPEN (Advanced System for Process Engineering). This is a sequential solution method.

Prior to this year, LBL succeeded in incorporating ammonia-water absorption cycle capabilities into ASPEN. LBL used this model to simulate the performance of several advanced absorption cycles, including the generator-absorber exchange (GAX) cycle, which had been selected as the test case for comparing LBL and Technion results.

In parallel, LBL developed a linearized solution technique (called HPSIM) that incorporated the HYBRID solver. This solution technique is considerably easier to use than the more comprehensive ASPEN method, but is more limited in its capabilities. HPSIM is adequate to generate on-design cycle solutions, but the broader capabilities of ASPEN are required for off-design calculations. LBL showed that the results of the ASPEN model and the HPSIM model agreed to within ±2% in calculating the performance of one of the advanced ammonia-water absorption cycles. LBL's modeling of the GAX cycle using HPSIM was then used as the basis for comparison with the Technion's calculations of the GAX cycle performance.

An important objective of the joint LBL-Technion effort was to produce a user-friendly model that contained the full modeling capabilities. Although ASPEN is a powerful simulation tool, its use has several drawbacks. It is a large, comprehensive computer program that involves considerable cost in computer run time and storage charges, and in the user time required to learn the program and to prepare input files for each run. Since the Technion model had the advantage of being relatively user-friendly, plans called for its likely use as the framework for the final version of the jointly developed model. It was anticipated that a solution method similar to that used in the LBL-developed HPSIM-HYBRID solution technique might have been incorporated into the Technion computer code to assist in achieving convergence.

The Technion group devoted considerable effort during 1989 and 1990 to the solution of the convergence problem. Features were added to the computer code to perform calculations in terms of the water concentration instead of that of the ammonia, and the properties of the ammonia-water mixture were converted from tabular form to equation representation. These changes were made to avoid any discontinuities in the derivatives of the properties, which was suspected to be a possible cause of the convergence problem. In addition, subroutines were added to the computer program to model additional generator and absorber components needed for the GAX cycle.

Following continued problems in attaining convergence of the cycle calculations, the Technion group tried a different approach. They partitioned the cycle configuration into three groups of components, were able to obtain a convergent solution separately for each group, and then manipulated the inputs and outputs of the separate groups to obtain an overall cycle simulation that converged. However, this convergent solution technique was accomplished at considerable expense in user-friendliness. Also, it remained to be determined whether this technique was robust enough to attain solutions for a full range of off-design conditions. The Technion results allowed comparison with the prior LBL calculations of GAX cycle performance; figure 1 shows the GAX cycle configuration used by LBL, which was essentially identical to that modeled by the Technion.

The LBL and Technion simulations used the same set of running conditions: generator at 362°F, condenser at 95°F, absorber at 97°F, evaporator at 40°F, solution flow rate of 146 lb/hr, and ammonia flow rate of 73 lb/hr. For the most important performance parameter—the Coefficient of Performance (COP)—the Technion and LBL calculations showed very good agreement: Technion calculated 1.315 and LBL calculated 1.293. The difference, 1.7%, is within the accuracy of the thermodynamic property data for ammonia-water mixtures: Technion used properties derived from the Jennings tables, while LBL used the IGT tables.

Other aspects of the results, such as the amount of heat transferred to and from the various cycle components (the heat duties), were also in good agreement. For example, the heat transferred to the evaporator (which is a measure of the cycle capacity) was 36.4 KBtu/hr for the Technion calculation and 36.5 KBtu/hr for the LBL calculation.

Although both LBL and the Technion achieved successful simulation of the advanced ammonia-water GAX absorption cycle, none of the three modeling techniques (ASPEN, HPSIM, Technion method) was user-friendly. Without this attribute, it is unlikely that the method will be used in the future by other research and industry groups, which has been an important long-term objective of the work.

A promising method of overcoming this constraint emerged recently, with the availability of a personal computer (PC) version of ASPEN, which features a user-friendly input interface. This new computer development thus provides a vehicle with which the original program objective could be attained: the generation of a user-friendly computer tool capable of modeling the performance of complex ammonia-water absorption cycles over a broad range of operating conditions. Accordingly, we proposed to DOE that this PC-ASPEN option be explored as a follow-up research activity.

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## Building Systems Analysis

*R.C. Kammerud, W.L. Carroll, D. Dumortier, and R.J. Hitchcock*

### ICP Retrofit Energy Savings Estimation Model (RESEM)

To improve the quality of aggregate estimates, Lawrence Berkeley Laboratory is developing a building-specific Retrofit Energy Savings Estimation Model (RESEM) for the DOE Institutional Conservation Program (ICP). RESEM is a user-friendly tool that will allow state and regional ICP staff to use readily available information for reliably determining the energy and cost savings directly caused by ICP-supported retrofits for a single building. (For maximum accuracy and validity, pre-and post-retrofit energy use—and thus savings—must be directly based on utility billing data.) We have developed design and performance criteria for RESEM and have largely completed the software implementation of the tool.

Highlights of the operational computer tool include the user interface, which is based on a paradigm of dynamic pop-up windows for specialized data entry; and an overall menu design sequence that leads the user through a complex sequence of savings analyses. The Figure shows the level of detail accessible as well as the strong visual contexting provided by the pop-up window design. In addition, simplified simulation capabilities have been shown to compare favorably to more detailed hourly simulation programs such as DOE-2. The simulation speed is quite fast, requiring less than 30 seconds (on an IBM/AT-class personal computer) to simulate a typical building. Finally, automatic features such as complete-default building generation and "pushbutton" ECM descriptions have worked quite well in early use experience, saving the user time and effort in describing the buildings and the retrofit measures.

In 1990 we shifted our focus from software development to initial field testing, to product announcements and pre-

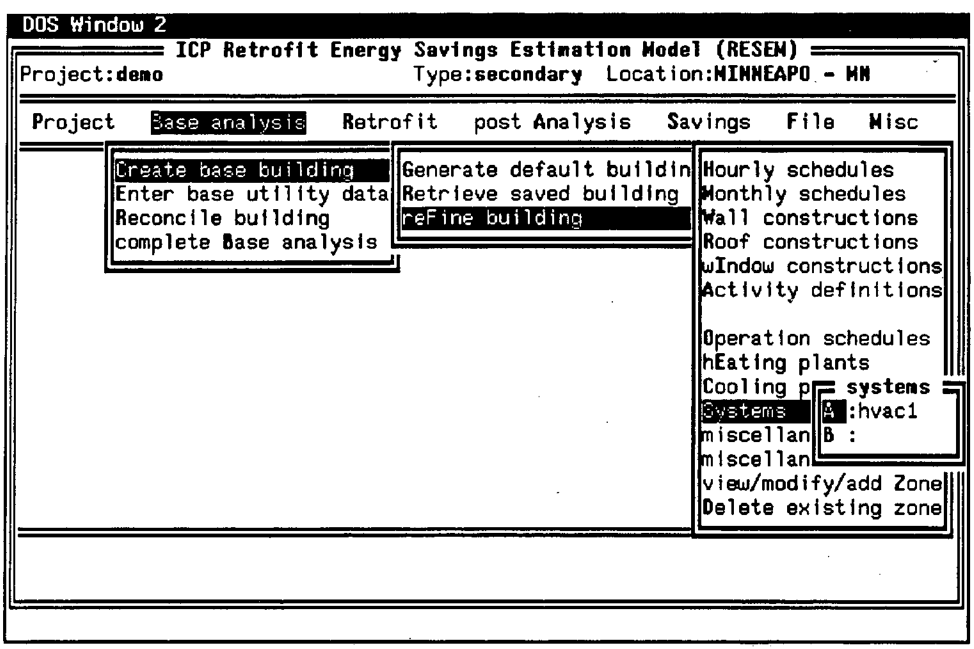


Figure. Computer display illustrates use of the Retrofit Energy Savings Estimation Model (RESEM), a software program that allows determination of the energy and cost savings caused by building retrofits.

sentations aimed at introducing RESEM to potential end users, and to the development of supporting materials. A limited beta-test was carried out using several state energy and DOE operations offices. Formal demonstrations of RESEM were made at two conferences of national energy program managers and numerous informal demonstrations were given to interested parties. Work was initiated on expanding the previous technical Software Documentation into a comprehensive end-user Reference Manual. Work continued on developing an extensive weather data library covering in excess of 200 locations.

In 1991, RESEM and many support materials will be completed and ready for general dissemination.

## Atrium Research Related to International Agreements

Large numbers of atria are being built in the United States and overseas. Most of these atria do not conserve energy; in fact, most atria waste significant amounts of energy. Design guidelines which incorporate the energy implications of atrium design decisions are badly needed to turn this situation around. Development of such guidelines will help to provide the designer with a better understanding of the energy implications of his decisions and guidance as to what those decisions should be. It will also provide information on the comfort conditions which can be expected in such spaces, to allow the designer to match the energy systems to the function (and comfort requirements) of the space.

Buildings equipped with atria display a microcosm of some of the critical issues affecting all solar commercial buildings. As is the case with many other integrated solar technologies, the effectiveness of atria must be evaluated by combining the energy effects of daylighting, cooling, and heating. The critical indirect energy implications of comfort conditions in atria mirror similar effects in many solar buildings, where control is not as precise as in traditionally conditioned spaces. Developing atrium analysis capabilities improves analysis of all solar commercial building technologies.

To address these concerns, LBL has for several years been evaluating and analyzing the performance of solar commercial buildings as part of the U.S. contribution to the International Energy Agency (IEA) Task XI and the U.S./U.K. Bilateral Agreement. The work for Task XI has emphasized analysis and evaluation of selected atrium buildings, as well as synthesis and interpretation of the results of the monitoring/analysis of a range of atrium buildings.

Two buildings—one in Norway and one in the United Kingdom—were selected for detailed atrium simulations. The analysis being conducted in the United States is coordinated with the monitoring being performed by research groups in Norway and the United Kingdom and complements those groups' independent analyses. The buildings were selected because of the high expected quality of the Norwegian and British experimental data and because the physical configurations of the two buildings under examination are representative of many atrium configurations found in U.S. buildings.

In this project, results of building simulations are compared to monitored data from the building to ensure that the model accurately represents the building's energy performance characteristics. This "calibrated" model is then used to explore significant performance issues which may be addressed through additional simulations or through monitoring. The simulations will be used 1) to determine the effectiveness of the current situation; 2) to test alternative solutions which address weak areas of the existing design; 3) to develop new strategies appropriate to U.S. designs; and 4) to test the effectiveness of such strategies under varied climates and building configuration/operation.

Because of the critical energy implications of conditioning atria, the comfort conditions that can be expected in atria and in adjacent spaces are of special interest and have therefore been emphasized in the analysis. A better understanding of comfort conditions will allow some functions to take place in atria using limited conditioning. The techniques developed for such analysis have value for many system applications besides atria.

During 1990, the simulation model, which had been calibrated in 1989 using actual measured energy performance data for the ELA atrium building in Trondheim, Norway, was used to conduct parametric studies. We investigated analytically the sensitivity of expected energy performance to operation, control, glazing solar transmission, and glazing thermal conductance parameters.

The data collection for the Gateway II atrium building in the United Kingdom was delayed, and did not arrive in time to allow that building to be included in this IEA Task XI project.

The results of the calibrated simulation model analyses were incorporatd into the Atrium Chapter of the Source Book, the main deliverable for IEA Task XI. The first draft of this chapter was prepared (by LBL and others) during 1990 and will undergo extensive review by the multi-national Task XI participants during 1991.

## Building Simulation Research

*F.C. Winkelmann, B.E. Birdsall, W.F. Buhl, K.L. Ellington, A.E. Erdem, J.M. Nataf, E.F. Sowell, and G. Zweifel*

The Simulation Research Group (SRG) has the long-term objective of providing the architectural, engineering, and research communities with software tools to assist in the design of energy-efficient and cost-effective buildings. The ongoing research of the SRG has two main focuses: 1) to develop and maintain the current-generation benchmark energy analysis program (DOE-2); and 2) to develop the next generation of building-performance calculation tools (the Energy Kernel System and DOE-3).

DOE-2 is a public-domain computer program that performs an hour-by-hour simulation of the building's expected energy use and energy cost given a description of a building's climate, architecture, materials, operating schedules, and HVAC equipment. DOE-2 is widely used in the United States and 36 other countries to design energy-efficient buildings, analyze the impact of new technologies, and develop energy conservation standards.

The Energy Kernel System (EKS) is a modular simulation environment for developing customized models for analysis of complex building energy components and systems.

DOE-3, a hybrid of DOE-2 and EKS, will be a whole-building energy analysis program for modeling new HVAC technologies.

### DOE-2

SRG maintains an ongoing research effort to develop enhanced versions of DOE-2. This work includes: 1) introduction of algorithm description techniques into the code; 2) modeling of building envelope components and systems; and 3) simulation of HVAC equipment and associated control systems. A new version of the program, DOE-2.1E, was started in 1990 with funding from Southern California Edison and Pacific Gas and Electric, two California utilities. Major new features will include:

- *Evaporative cooling.* Models are being developed for stand-alone evaporative cooling systems and evaporative cooling units integrated with conventional HVAC systems. This feature will allow cost-benefit analysis of evaporative cooling as an alternative to vapor-compression cooling systems.

- *Ice storage.* Modifications to the DOE-2 PLANT program will allow simulation of a variety of cool storage systems such as ice-on-coil, ice-harvester, brine, and ice slurry. Such systems have the potential for reducing cooling costs by allowing ice to be made at night when electricity rates are low.

- *Switchable glazing.* This feature will allow simulation of "smart" windows whose solar-optical properties can change according to environmental conditions. An example is electrochromic glass that can be switched from clear to reflective by changing the applied voltage in response to a control variable such as incident solar radiation. Switchable glazing has the potential for providing better solar control than conventional glazings, with resultant lower cooling loads.

- *Glazing library.* A new window library has been assembled containing about 200 glazings. Included are the latest high-technology windows such as those with low-emissivity coatings and gas fills. The library was created using the WINDOW-4 computer program in a collaborative effort with the Windows and Daylighting Group. In addition, the WINDOW-4 glazing heat transfer model was integrated into DOE-2, yielding a more accurate calculation of conduction and solar gain through windows.

### Advanced Simulation

The search for more energy-efficient building designs has led to components, systems, and whole building structures that are extremely complex and therefore difficult to analyze. Because existing programs like DOE-2 were conceived in an era when design questions were much simpler than they are today, the analytic capabilities of these programs are fundamentally limited. There is a need for modular, computationally efficient, easily extendible techniques to accurately simulate new HVAC technologies and to model the thermal interactions between a building's envelope components and its HVAC system. Analysis of complex designs and advanced technologies requires substantially improved building energy performance simulation programs.

To continue to meet DOE's objective of providing up-to-date and reliable analysis tools to researchers and designers, SRG carries out research and development of advanced building energy simulation techniques. There are two major efforts in this area. The first is the development of a modular software environment (the *Energy Kernel System* or *EKS*) that will allow users to generate customized simulation programs that suit their particular analysis needs. The EKS is intended to be an efficient way of creating models that can be used in a stand-alone fashion or for integration into multipurpose environments such as computer-aided design (CAD) systems, expert systems, or energy management systems. The second effort is incorporation of EKS methods into DOE-2, leading to a new whole-building program, *DOE-3*, in which models for new HVAC technologies can be quickly built up from component modules without having to make modifications to the underlying computer code.

*Energy Kernel System*

Figure 1 shows the overall organization of EKS. The user interacts with the program in four basic ways: defining objects (e.g., component models); defining simulation problems by linking objects together; specifying run-time data (e.g., coefficients and time-varying data); and specifying desired output. The objects are defined in text files, either as mathematical equations or as component models in Neutral Model Format. These files are processed symbolically with programs written in Macsyma, producing C language functions and objects that are stored in libraries. Problems are defined by interconnecting objects using a graphical user interface, producing a problem specification file in the Network Specification Language (NSL). The nucleus or kernel is the dynamic *SPANK* program system. SPANK works from the NSL description, generating internal data structures based on graphs. Matching and reduction algorithms are employed with these graphs to automatically devise an efficient solution algorithm, producing an executable program for a particular problem. This program reads constant and time-varying data from files, then produces the solution at each timestep by iteratively solving the set of coupled, non-linear differential equations corresponding to the problem network. The output processor reads the result file and generates graphical displays according to interactive user requests.

In 1990, EKS was successfully tested on a variety of complex problems in thermal analysis, including lighting/HVAC system interactions, desiccant cooling, multiroom air flow, and variable-air-volume (VAV) systems. Other major advances in 1990 were: A translator from Neutral Model Format to EKS was written. (The Neutral Model Format, developed as part of our advanced simulation research, is a standard way of expressing component models that is independent of any particular simulation environment. This format makes international exchange of calculation objects possible, thus saving duplication of effort.) Extensions were made to the Macsyma/EKS interface, which allows users to express calculation objects symbolically (much as they would be written out on paper), thus relieving the user from having to write and debug computer code. The extensions include creation of objects involving differential equations and linking of already-existing objects from the EKS library into more complex macro objects.

Additional objects for the EKS library were developed, including models for a cooling coil, heating coil, hot-water

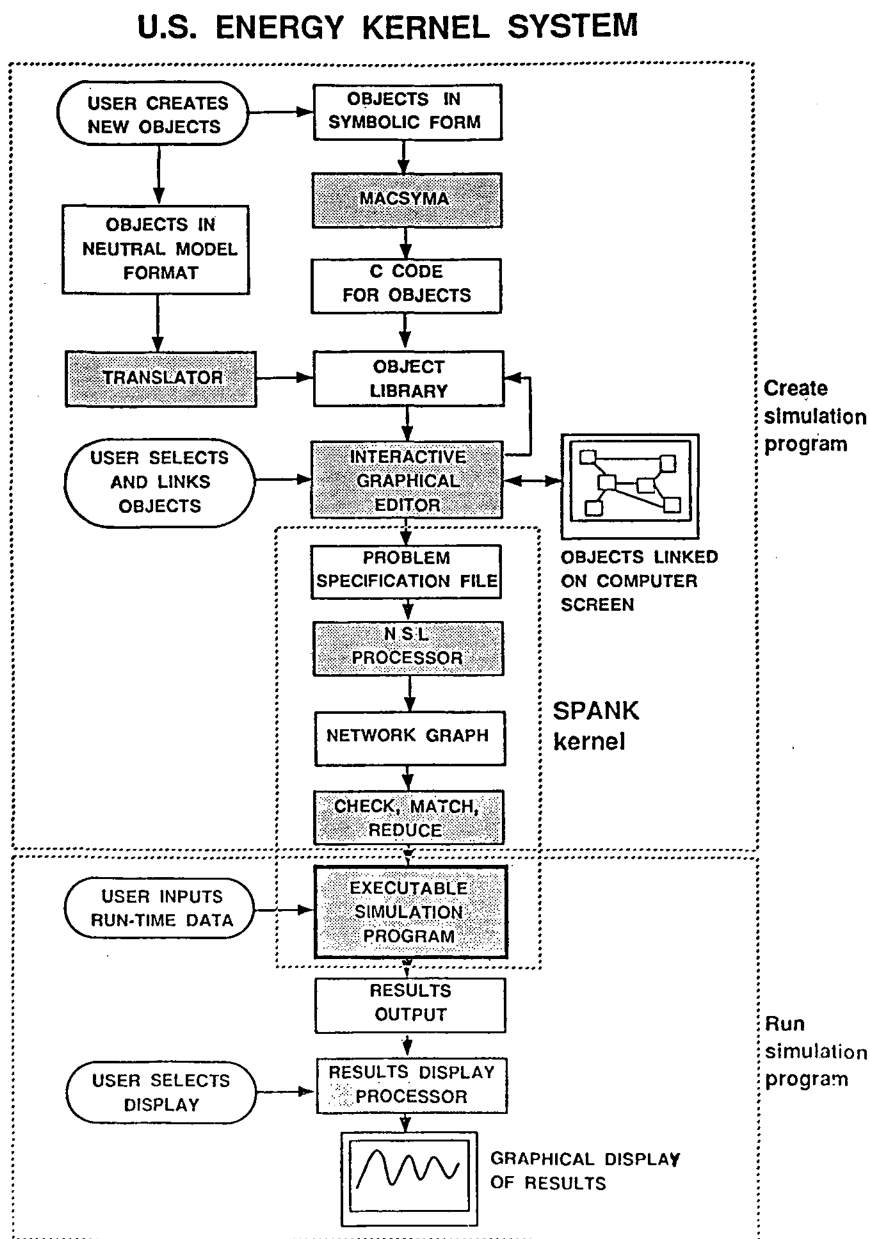


Figure 1. Configuration of the Energy Kernel System which allows users to easily configure and execute simulation models of complex building systems. Shaded boxes are programs; unshaded boxes are files. Ovals show user actions.

radiator, thermostatic valve, and a complete VAV system.

Work was completed on introducing multivariable links into EKS. Previously, a link could have only a single variable, such as mass flow. Object connection is facilitated with links that have multiple variables associated with them, such as mass flow and temperature and humidity ratio.

### *DOE-3*

A critical shortcoming of DOE-2 is that modeling new building systems, components, and control methods (such as those being incorporated in the new DOE-2.1E version described above) requires expensive and time-consuming modifications to the computer code by computer experts. This severely inhibits the usefulness of the program for analysis and design of innovative HVAC technologies. A major new version of the program, to be called DOE-3, is needed to give users the flexibility to model HVAC systems of arbitrary design and complexity *without requiring changes to the underlying computer code.* The resulting program will be useful throughout the building life cycle: design, commissioning, and operation.

As shown in Figure 2, a DOE-3 user would call up to the computer screen any desired set of HVAC components from a library and link them into systems with a user-friendly graphical editor; then DOE-3 would solve for the energy performance of the system. DOE-3 will be constructed by integrating into DOE-2 the component-based simulation methods that have been developed for the EKS.

In 1990 we established a proof-of-concept for DOE-3 by generating an HVAC system model with EKS and then running this model with hourly building heating and cooling loads calculated by DOE-2.

In effect, the DOE-2 SYSTEMS calculation was replaced by an EKS calculation, as illustrated in Figure 2. The hour-by-hour values for the coil loads and space temperatures from this test version of DOE-3 were found to be almost the same as the corresponding values calculated by DOE-2 for the same HVAC system type, establishing confidence in the DOE 3 approach.

In 1991, we will continue to maintain and support the DOE-2 program and to publish the quarterly *DOE-2 User News.* The DOE-2.1E version of the program will be completed and released to the public. EKS development will continue, with emphasis on completion of the graphical user interface, expansion of the library of calculation objects, and addition of the capability to solve partial differential equations using finite difference methods. Work will continue also on DOE-3.

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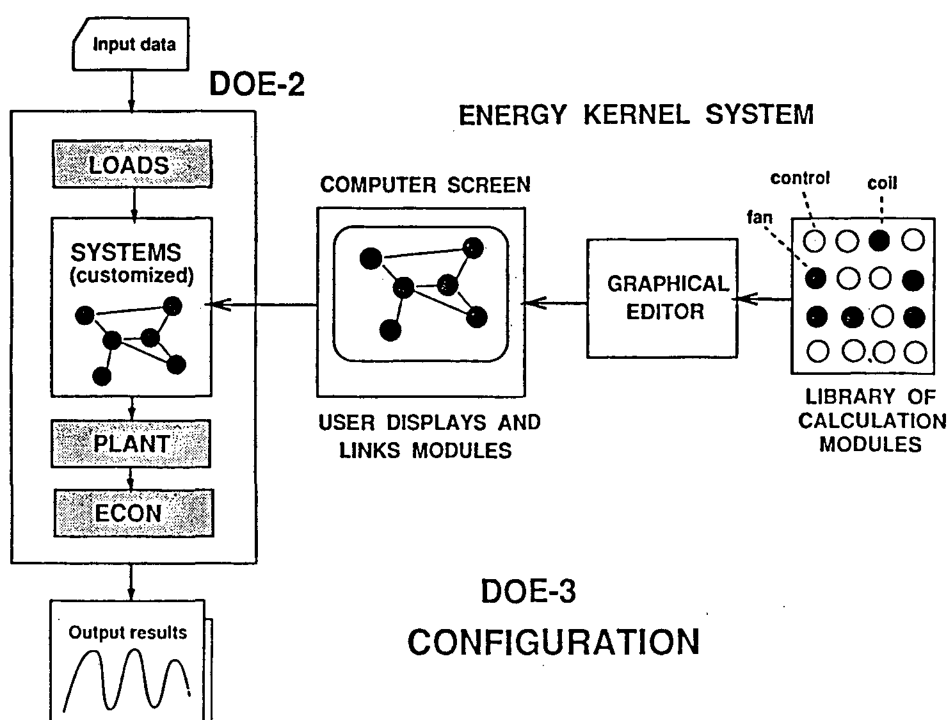


Figure 2. Schematic of the DOE-3 program in which object-oriented techniques from the Energy Kernel System are incorporated into DOE-2. DOE-3 users will simulate complex heating and cooling systems by connecting calculation objects representing system components. A graphical editor permits display and linking of components on the user's computer screen.

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