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FY 1988 Annual Report

Building Energy Systems Program

March 1989

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APPLIED SCIENCE DIVISION ANNUAL REPORT

BUILDING ENERGY SYSTEMS PROGRAM

FY 1988

Elton J. Cairns
Director, Applied Science Division

Michael A. Wahlig
Program Leader, Building Energy Systems Program

Applied Science Division
Lawrence Berkeley Laboratory
1 Cyclotron Road
Berkeley, California 94720

Prepared for the U.S. Department of Energy under Contract No. DE-AC03-76SF00098

BUILDING ENERGY SYSTEMS PROGRAM STAFF

Michael A. Wahlig, Program Leader

Brandt Andersson
Bruce Birdsall
Fred Buhl
William Carroll
Dominique Dumortier
Kathleen Ellington
Ahmet Erdem
Brenda Hatfield
Robert Hitchcock
Ronald Kammerud*
Jean-Michel Nataf
Cindy Polansky
Joseph Rasson†
Edward Sowell‡
Charlotte Standish
Mashuri Warren
Frederick Winkelmann*

*Group Leader
†Engineering Division
‡Participating guest

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BUILDING ENERGY SYSTEMS PROGRAM

INTRODUCTION

The main theme of the Program is the comprehensive simulation, analysis, monitoring, and evaluation of the energy performance of whole buildings, emphasizing nonresidential buildings. Many of the projects develop and apply comprehensive computer models that enable integrated performance analyses of heating, cooling, and daylighting systems. A further activity 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 in wide use in the U.S. and thirty other countries to design energy-efficient buildings and to research innovative building technologies. During FY 1988, new capabilities were added to DOE-2, enhancing its usefulness.

The Simulation Research Group is also developing the next generation of simulation software, for use in the 1990's and beyond. A plan has been formulated in collaboration with groups in the United States and United Kingdom to create an "Energy Kernel System" consisting of an extensive library of software modules and an executive program that will allow users to produce a wide variety of customized simulation programs. In FY 1988, LBL continued development of the Simulation Problem Analysis Kernel (SPANK) as the first prototype of the Energy Kernel System.

The Building Systems Analysis Group continued investigating the performance impacts of energy technologies in nonresidential buildings. As part of a bilateral research agreement, a simplified technique for evaluating long-term energy performance of daylit buildings (based on short-term monitored data) was applied to buildings in the United Kingdom. The technique has proven to be useful, and its continued application and refinement—focusing on energy performance of atria spaces—are being undertaken as part of U.S. contributions to an International Energy Agency (IEA) collaboration.

In collaboration with the IEA Task XI work on passive commercial buildings, we have begun to investigate the daylighting, heating, cooling, and functional effects of atria in large buildings, including the resulting comfort conditions. We have developed new simulation tools to evaluate atrium effects.

A project was initiated to develop a methodology for sizing thermal energy storage (TES), used in cooling systems of nonresidential buildings. Simulations were carried out for two prototypical buildings in three diverse climates in order to identify the climate, design, and operating variables that are significant in determining cool-storage-capacity requirements (and that therefore must be accounted for in the sizing methodology). Existing calculation techniques were found to be acceptable for use in TES sizing from a mathematical perspective, but accepted applications practice must be modified in order to avoid undersizing the system (with resultant loss of cooling).

Development of a computerized tool for evaluation of the energy consumption impacts of retrofit measures in institutional buildings was initiated. This project was motivated by an evaluation of the DOE Institutional Conservation Program completed during the previous year. The evaluation indicated that estimates of energy savings due to retrofits based on monitored data are often at least partially masked by changes in energy use caused by retrofit-independent alterations in the functional or operational environment of the building. The tool being developed allows estimates of energy savings to be corrected for these additional changes, thereby improving the quality of retrofit evaluations.

Several small projects—new-building and retrofit studies—have been carried out for the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, examining the energy performance of Department of Defense (DOD) facilities. Most notably, simulations compared the energy performance effectiveness of existing DOD building design standards with new federal standards developed by the Department of Energy. For most of the building and climate combinations examined, the existing standards proved to be at least as stringent as those now being promulgated.

The Absorption Heat Pump Project continued research on regenerative absorption heat pumps for high-efficiency solar-driven and gas-driven systems for cooling and heating. As part of a joint U.S./Israel effort, computer models are being developed to enable the detailed analysis and design of these and other new types of advanced absorption heat pumps. These models were used during FY 1988 to simulate the performance of three specific types of high-efficiency absorption cycles, for a wide range of configurations and operating conditions. In addition, an initial cost estimate was made for one of the heat pumps.

Building Systems Analysis*

R.C. Kammerud, B. Andersson, B. Birdsall, W.L. Carroll, D. Dumortier, B. Hatfield, R.J. Hitchcock, J. Eto, F. Winkelmann, and E. Vine

ATRIUM RESEARCH RELATED TO INTERNATIONAL AGREEMENTS

In FY 1987, LBL developed a strong collaborative arrangement as part of the US/UK Bilateral Agreement to use a monitored British building to test a daylighting evaluation method. Because the United States is doing far less monitoring of commercial buildings than are several European countries, this relationship with LBL atrium research is being continued and extended to the broader-based International Energy Agency Task XI on Solar Commercial Buildings.

The United States committed LBL to a limited role in IEA Task XI, as Leader of Subtask B (Simulation) and active member of the Task's Atrium Working Group. LBL is also continuing to work with the UK, both within the Bilateral Agreement and as part of the IEA Atrium Group.

The atrium work completed in FY 1988 focused on developing tools that can be used to better evaluate the critical issues in atria, namely the interplay of daylighting and thermal-energy conservation techniques, as well as the resultant comfort levels in the atrium. Several buildings were evaluated for possible inclusion in the LBL atrium simulation plans.

As Subtask Leader, LBL provided considerable assistance to the IEA Task by coordinating simulations and by providing weather data, software, and expertise to members of the Atrium Working Group and other participants in the Task. LBL has also acted as a conduit for significant information exchange between U.S. and European researchers.

Two key buildings were selected for detailed atrium simulations, one in Norway and the other in the UK. Data on the construction and monitoring of these buildings will be provided to LBL as a basis for the simulation studies. Three additional buildings were identified for further testing of the daylighting evaluation method, two in the UK and one in Sweden.

Initial building simulation models will be established for each of the atrium buildings. The results from these simulations will be compared to data provided from the building monitoring, and modifications will be made to the input descriptions until the model provides an accurate representation of the actual building results. Site visits will be made to both buildings in March in order to clear up any remaining discrepancies.

Figure 1. Gateway 2 Office Block, Oxford: UK/US Atrium Case Study. (XBB 8812-11756)

Simulations will test the sensitivity of atrium energy use to glazing modifications, ventilation, daylighting effects, HVAC integration options, and controls and building operation. Resulting comfort conditions in the atria will be evaluated to determine the potential functionality of atria under different energy scenarios.

LBL will act as consultant and provide support as needed to the British and Swedish researchers applying the daylighting evaluation method (DPEM) to their buildings.

THERMAL ENERGY STORAGE SYSTEM SIZING

The use of cool storage to provide air conditioning in commercial buildings is becoming a widely accepted load management technique. Electric utilities are providing favorable off-peak rates to encourage shifting the air conditioning load away from peak periods. Utilities benefit by deferring addition of new generation capacity and by making better use of efficient base load plants; the customers benefit by having lower electricity bills.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of State and Local Assistance Programs, Institutional Conservation Program Division, the Office of Solar Heat Technologies, Solar Buildings Technology Division, and the Office of Buildings and Community Systems, Building Systems Division of the U.S. Department of Energy; and by the Electric Power Research Institute and the United States Army Construction Engineering Research Laboratory through the Department of Energy, under Contract No. DE-AC03-76SF00098.

Although some storage systems have been undersized, most are believed to have been oversized, detracting from their economic effectiveness. This is difficult to confirm or refute because the existing literature on sizing procedures and performance does not allow the effectiveness of installed systems to be assessed as it relates to sizing. Our project was undertaken to 1) identify the major problems with sizing cool storage systems, 2) develop a preliminary sizing methodology, and 3) identify long-term research issues relating to thermal energy storage in buildings, and 4) develop a plan for addressing these issues.

Sizing methods used for conventional cooling systems are not directly applicable to thermal energy storage systems which operate on a diurnal (or possibly longer) cycle. For conventional cooling systems, equipment size is determined by the peak rate of extraction of thermal energy from the air stream at the cooling coil, accounting for coincident supply air requirements for all zones in the building. In contrast, sizing of cooling systems using thermal energy storage must be based on estimates of peak extraction requirements for all zones integrated over the operating cycle; design sizing must be based on the hour-by-hour coil load profile.

In our study, these coil load profiles were calculated for prototypical buildings using DOE-2. Simulations examined hourly and daily cooling capacity requirements during the cooling season for a 20,000-square-foot, single-story office building and for a 160,000-square-foot, two-story building serving only retail sales functions. The buildings were simulated for Miami (Florida), Dallas/Fort Worth (Texas), and Chicago (Illinois) climates using TMY weather data. These building types and climates were selected because they represent relative extremes, effectively bounding the range of storage sizing issues of importance. Analyses did not include simulation of any specific storage system; instead, buildings were simulated with a conventional cooling system; daily coil energy requirements were interpreted as the total capacity that must be available from the cooling system. This energy may be supplied by a combination of storage and chiller (partial storage or demand-limiting strategy) or by the storage system alone (full-storage strategy). Peak daily coil-energy requirements define the necessary storage capacity.

Based on these simulations, we concluded that the peak integrated load occurs during multi-day periods of severe weather. These periods typically do not include the most severe day or hour in a particular climate; for this reason, traditionally accepted descriptions of peak climate characteristics are inadequate.

We found that much of the integrated coil load at peak consists of energy accumulated during periods when the building is not cooled and is allowed to reach space temperatures above the design temperature. Under these conditions, energy is stored in building materials and furnishings that must be removed by the cooling system in order to satisfy comfort requirements during the subsequent occupied period. The magnitude of the stored energy at peak depends on the length of the uncooled period and of the severe climate period, and on a host of building design parameters relating to thermal capacity and climatic interactions. The magnitude of the peak is also substantially influenced by internal gains and climate interactions considered in sizing calculations for conventional systems.

The only sizing calculations believed to account adequately for the full range of variables that affect peak integrated loads are hourly simulations; this is the sizing procedure recommended here. Guidelines have been documented in order to ensure that the simulation provides a technically sound estimate of peak integrated loads on which to base the storage capacity calculation. Of particular importance, these guidelines ensure that the simulation effectively approximates the heat removal characteristics of a storage system. It is believed that this is a major source of error in sizing TES systems.

We have also considered the appropriateness of other sizing calculation techniques, most notably the simplified method currently recommended by ASHRAE and widely used in design of conventional systems. This method, based on cooling-load factors (CLFs) and on cooling-load temperature differences (CLTDs), can provide reliable estimates of peak integrated coil loads if three refinements are made: first, the CLFs and CLTDs must be refined to provide an improved estimate of the underlying coil load under steady periodic climate and operating conditions; second, a method must be developed for superposing that portion of the coil load that is due to deviations in building operating schedule from the steady periodic assumptions. A preliminary suggestion in this regard has been investigated as part of this project; third, a representation of peak climate conditions that reflects multi-day climate severity must be developed. Preliminary suggestions in these regards have been made.

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.| In FY 1988, we developed design and performance criteria for RESEM, developing methodologies that could not be acquired elsewhere, and began software implementation of the tool.

Technical Capabilities and Methods

RESEM is sophisticated enough in its energy modeling to reflect explicitly the influence of a wide range of design, operation, and weather parameters, as well as the full range of actual building designs and specifications actually

encountered in ICP. The model also interacts with the full range of Energy Conservation Measures (ECMs) allowed under the ICP program.

The engineering model used in RESEM is based on existing public domain methods and algorithms in order to minimize validation efforts and to provide a credible finished model. Building energy consumption is broken down into components of fuel type and end use. This breakdown is key to both the billing-data reconciliation process and the allocation of savings to specific ECMs.

The basic premise of the energy model calibration is that a building's actual utility billing history is the most reliable starting point for determining "real" savings resulting from ECM installation. RESEM uses a specially developed method to accomplish this reconciliation, yielding a "calibrated" modification of the building input description (thereby reproducing actual billed consumption). Reconciliation is done for pre- and post-retrofit building configurations.

RESEM uses a specially developed allocation method for estimating the effects of each ECM in producing the total observed energy savings. To the degree allowed by the energy simulation model, this method takes into account the interactive effects that occur when multiple ECM are installed simultaneously.

Other Features

RESEM is designed to run on currently available, "upper-end" PCs and workstations, decentralizing ECM savings analyses to state and regional levels. RESEM runs fast enough that the session time for an interactive analysis consists mostly of the time the user needs to collect, organize, and input data.

RESEM is a self-contained and complete software package that needs no additional software routines for operation. The model contains all supporting information necessary for a building analysis except specific user-provided information about the building being analyzed; general supporting information such as weather, fuel costs, and defaults are available directly to the user from a comprehensive data base built into RESEM. RESEM has an easy-to-use interface, providing real-time diagnostic messages to help users recover from input errors, command syntax errors, or ambiguities; real-time status messages to keep users informed at all times about the progress of the analysis; and an online help feature that provides context-dependent information based on menu and analysis status when the help request is made. This feature makes written documentation largely unnecessary.

Although only a minimum of information specific to a given building need be input, RESEM can provide a detailed description of any or all aspects of the building when detail is necessary for the most accurate estimates of ECM savings. At any level of input detail the interface shows users explicitly what input parameters are defaulted, what the default values are, and allows users to selectively alter these defaults for the analysis.

RESEM knows all 74 ECM types recognized in the ICP program, and codified in the Grant Tracking System (GTS). Input screens for each ECM type allow a detailed description of the ECM, accurately reflecting design changes to a retrofitted building.

Users can automatically generate verification summaries of all inputs; analysis status during the analysis process; and analysis results including pre-and post-retrofit energy use broken out by end-use and fuel type, retrofit savings for each ECM, and economic measures of ECM performance. Future RESEM development will provide a "Performance Profile" of the building energy consumption and savings (comparing these to average data for an entire class of similar buildings) and an aggregation capability that will allow for total savings realized over a given period in various geographical regions and subregions, building types, and retrofit types.

CORPS OF ENGINEERS' EFFICIENT BUILDINGS

The U.S. military has significantly reduced energy consumption in the past ten years through increasingly stringent energy use standards. DOD standards are a straightforward performance standard, whereas the new DOE energy standards applying to all federal (including military) buildings are both prescriptive and performance standards. The Army Corps of Engineers would prefer to retain DOD standards because they are familiar, easier to apply, and the Corps believes the DOD standards are more stringent than the new DOE standards. The Corps asked LBL to establish whether the DOD standards exceed those of DOE. If so, compliance with the DOD standards would simultaneously meet DOE standards.

Six standard buildings were compared (barracks, battalion HQ, chapel, child care center, warehouse, and maintenance facility), developing a reference building for each according to the DOE procedure. This required application of prescriptive DOE standards to a building of the

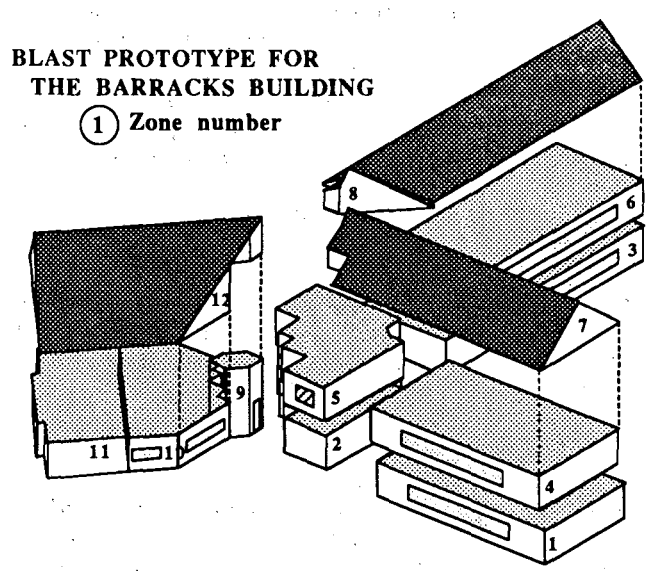

Figure 2. Detailed Zoning for Simulation of Standard Barracks. (XBL 8812-4339)

same type, size, and height as the building under investigation. A BLAST simulation was then run to calculate an energy budget which DOE would allow for that building. This budget was then compared to the DOD energy budget. This was done for six climate regions.

For three of the buildings, the DOD standards always implied compliance with the analogous DOE standards. For two other buildings, the DOE standards were slightly better in only two climates. For the remaining building—the child care center—DOE standards required considerably lower energy use in several climates.

We plan to examine more closely the two buildings that have marginal differences in the standards to determine whether these differences are within the range of uncertainty of DOE procedures and therefore effectively equivalent. The child care (school) building type will be investigated to determine whether the DOD standards must be improved or whether the DOE standards for schools are unrealistic.

Other work will include a life-cycle cost analysis of two building types to determine optimum insulation levels. A set of BLAST input "templates" will be prepared for typical DOE building types to make application of the DOE standards easier for those using BLAST for federal buildings or for other buildings to which DOE standards might apply.

Absorption Heat Pumps*

M. Wahlig, J. Rasson, and M. Warren

Research has continued on development of high-efficiency thermally driven chillers and heat pumps that use *regenerative* absorption cycles. Constant-temperature (instead of constant-pressure) input and output conditions allow regenerative cycles to achieve higher efficiencies than do most (or all) other classes of absorption cooling cycles.

In previous years, simplified calculational methods predicted that a double-effect regenerative (2R) absorption-cycle chiller would operate at about 55%—and a single-effect regenerative (1R) absorption chiller at about 70%—of the ideal Carnot coefficient of performance (COP). Because these cycles are well suited to variable input temperatures between 180 and 280°F, they were explored with solar cooling applications in mind. A 2R chiller was built and tested, and it attained the predicted performance.

*This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Solar Heat Technologies, Solar Buildings Technology Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098; the Department of Engineering Research, Pacific Gas and Electric Company under Contract No. Z19-5-269-87; and the Oak Ridge National Laboratory under Contract No. 10X-SB315V.

Previous work had also identified a gas-driven regenerative cycle configuration, called an absorber-coupled double-effect regenerative (ADR) cycle, that could attain a higher efficiency than the 1R cycle by taking advantage of the high, constant temperature of a gas source.

During FY 1988, we continued development of simulation models that would enable calculation of the performance of high-efficiency absorption-cycle chillers and heat pumps that use ammonia-water as the working fluid pair (work supported by the DOE/Solar Buildings Program as part of a joint U.S./Israel project). We also calculated the detailed performance of a 1R-cycle heat pump over a full range of operating conditions (work supported by the DOE/Buildings Conservation Program, through the Oak Ridge National Laboratory). In addition, we calculated the performance and made an initial estimate of the manufacturing cost of an ADR heat pump (work supported by the Pacific Gas and Electric Company (PG&E) and the Gas Research Institute through PG&E).

The public-domain chemical process flowsheet simulator ASPEN (Advanced System for Process Engineering), selected as the basic tool for modeling the absorption cycles, had been successfully adapted to simulate the 2R cycle. In FY 1988, ASPEN was further modified to simulate the more complex 1R cycle. Convergence problems (in initial attempts to model certain 1R components) were overcome, and the full 1R cycle was simulated successfully.

An in-house, LBL-developed simulation technique (HPSIM) had been developed during FY 1987 to simulate absorption cycles. Although not as comprehensive as ASPEN in its computational ability, HPSIM uses far less computer storage capacity and run time. HPSIM uses a combined simultaneous equation-iterative solution method, using the solver HYBRID. In FY 1988, after the modification of ASPEN for modeling the 1R cycle was completed, the 1R performance predictions of the ASPEN and HPSIM models were found to agree within $\pm 2\%$.

The HPSIM model was then used to calculate the performance of the 1R cycle for different configurations and operating conditions. In particular, the number of pressure steps in the 1R cycle could be reduced from seven to four with a decrease of only about 4% in the cooling COP. Further reduction to three pressure steps reduced the COP another 10%. These results showed that a substantial reduction in cycle complexity (and therefore in manufacturing cost and operating reliability) is possible with only a small decrease in cycle efficiency. The four-pressure-step 1R cycle was calculated to operate at about 65% of the Carnot COP over the full operating range.

The design of the ADR-cycle heat pump was modified to simplify considerably its manufacture and reduce its cost, only modestly reducing its efficiency. Because the ADR cycle uses a higher input temperature than does the 1R cycle, the efficiency of the ADR cycle is expected to be less sensitive to the number of pressure steps. This was confirmed in simulations of ADR cycle performance using the HPSIM model. Reduction from seven to three pressure steps resulted in a negligible decrease in the cooling COP over the full range of operating conditions. A

further reduction to two pressure steps produced a COP reduction of 10–15%.

We then calculated the expected performance of a three-pressure-step ADR heat pump for a full range of cooling-mode and heating-mode operating conditions. At standard ARI rating conditions, the cooling-cycle COP is about 1.69 using water-cooled operation and about 1.35 using air-cooled operation. The heating-cycle COP is about 2.13 at 47°F outdoor temperature, and about 1.66 at 17°F outdoor temperature. These are cycle COP values and do not include combustion efficiency or parasitic electric power for the pumps or fans.

A "first-cut" manufacturing cost study was conducted by Pioneer Engineering and Manufacturing Company for a four-pressure-step ADR heat pump. Detailed cost estimates were made for the new heat exchangers unique to the ADR heat pump design, and existing cost estimates were used for components common to other heat pumps operating at the same pressures and using ammonia as the refrigerant. A rough estimate for the solution pump cost was based on available information, resulting in an estimated total manufacturing cost of about $1550 for a 3-ton ADR heat pump. A similar cost study for a three-pressure-step design would be expected to result in a slightly lower cost. Iteration in design detail could also have a substantial effect on reducing manufacturing cost.

A primary objective of the joint U.S./Israel project being conducted by the Technion and LBL is to develop a simulation model suitable for all types of absorption chiller and heat pump cycles. Initial attention is being focused on the generator-absorber heat exchange (GAX) cycle because it is likely to be the first advanced absorption cycle to be available commercially and is therefore a candidate for being driven by evacuated-tube solar collectors that can operate efficiently up to 400°F.

Accordingly, the Technion and LBL are using separate calculations of GAX cycle performance as a measure of agreement between the various computer models for absorption cycles. The intention is to combine the best solution methods into a single computer model, which will most likely be an improved version of the user-friendly model originated by the Technion group. The GAX cycle was successfully simulated at LBL using HPSIM, and intercomparisons of LBL and Technion results of GAX cycle simulations—as well as resolution of any differences that may occur using different models—are expected to take place during FY 1989.

Simulation Research*

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

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, cost-effective buildings. The ongoing research of the SRG has two main focuses: 1) to develop and maintain the current-generation benchmark program (DOE-2), and 2) to develop the next generation of building performance calculation tools (the Energy Kernel System).

DOE-2 is a public-domain computer program which, given a description of a building's climate, architecture, materials, operating schedules, and HVAC equipment, performs an hour-by-hour simulation of the building's expected energy use and energy cost. DOE-2 is widely used in the United States and 35 other countries to design energy-efficient buildings, analyze the impact of new technologies, and to develop energy conservation standards. Details of the development and structure of the DOE-2 program are available.[1–11]

The Energy Kernel System will provide basic tools and information to allow SRG and other groups to develop future simulation programs. It will also provide a mechanism for exchanging research results and technology advances, and a basis for integrating performance simulation into computer aided design (CAD) and expert system software.

DOE-2

SRG maintains a research effort to develop enhanced versions of DOE-2. This ongoing research is divided into three parts: 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. The next version of the program, DOE-2.1D, is scheduled for public release in FY 1989. Several major new features follow:

User-Defined Functions. A new FUNCTION command added to the DOE-2 SYSTEMS program permits modification, enhancement, or replacement of DOE-2 calculations without recompiling the program. Users write

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†Visiting scientist. Permanent address: Department of Computer Science, California State University at Fullerton, Fullerton, California.

their own algorithms in a FORTRAN-like language and place this information in their input, along with information indicating how and where the new algorithms are to be used. This feature allows researchers to add new HVAC simulation features, such as innovative control schemes, that could not be modeled by the regular DOE-2 calculations.

Generalized Library. A new library feature allows DOE-2 users to create custom libraries containing descriptions of any building component or system of components. Libraries may be defined to contain such data as room geometry, standard operating schedules, or frequently used HVAC system descriptions. This feature will greatly simplify input preparation.

Improved Fenestration Calculation. Because heat gain and loss through windows greatly affects the energy performance of most buildings, DOE-2 window thermal calculations are being improved to calculate automatically the shading of diffuse solar radiation by neighboring buildings and by architectural elements such as overhangs (previously only the shading of direct solar radiation was calculated); to more accurately calculate skyward infrared radiation loss from the building envelope, taking into account atmospheric conditions and architectural obstructions; and to more accurately calculate the amount of sky diffuse radiation falling on windows and walls.

Desiccant Cooling. In most climates, occupant comfort during warmer months requires that room air be dehumidified. Several companies are developing desiccant cooling systems in which a hygroscopic material such as lithium bromide removes moisture from the supply air stream. The desiccant is "regenerated" for further use by drying it with hot air from a gas-fired heater. Gas-fired desiccant systems of this type can replace or supplement conventional electric-driven cooling systems; however, almost nothing is known about the economics of desiccant systems for different climates, building types, and utility rate structures. For this reason, SRG (with funding from the Gas Research Institute via the GARD Division of the Chamberlain Manufacturing Corporation) is creating DOE-2 models to simulate the performance of a variety of desiccant systems currently under development. GRI will use these DOE-2 models to identify the most cost-effective desiccant cooling schemes.

Advanced Simulation

In recent years, the search for more efficient building designs has led to components, systems, and whole building structures which are extremely complex and therefore difficult to analyze. Because existing programs like DOE-2 were initially conceived in an era when design questions were much simpler than they are today, the analytic capabilities of these programs are fundamentally limited. Generalized, computationally efficient, easily extendible techniques are needed to accurately simulate the interactions between building-envelope components and HVAC equipment. Analysis of complex designs and advanced technologies requires substantially improved building performance simulation programs. To continue to meet DOE's long-term objective of providing up-to-date and reliable analysis tools, basic research has begun into new simulation techniques. This work will lead to replacement of DOE-2 with a tool designed to meet the needs of architects and engineers in the 1990's.

An international collaborative effort between SRG and research groups in the U.K. has been initiated to produce the new software. This effort will provide not only a significant advance in building performance simulation but also a mechanism for communicating and exchanging results among diverse communities of designers and researchers.

Within the general goals and structure of the advanced simulation software,[12-15] the primary goal is to provide a software environment (the **Energy Kernel System** or **EKS**) for developing new simulation programs. This environment would allow a high level of model construction flexibility and facilitate state-of-the-art integration of new techniques with old. Other goals are to permit different modeling approaches, to encourage collaboration among model developers, and to take advantage of emerging software engineering in the area of multiprocessing.

The EKS (Figure) will consist of 1) a library of software modules or *objects* representing different building components, physical processes, and mathematical solution techniques, and 2) an executive program or *harness* which allows users to link software objects to form customized energy models. The EKS user will first construct a *template* which defines a model as a collection of objects and a set of messages controlling the order of execution of the objects and the flow of information among them. The template is used by the harness to construct the final program in the form of source (or executable) code.

The EKS is designed for use by model *developers*, not by model users. It is intended to be an efficient way of creating simulation 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.

SPANK: A Prototype Energy Kernel System. In FY 1986 the SRG began developing new software called the Simulation Problem ANalysis Kernel (SPANK) as a first prototype of the EKS.[16,17] SPANK views a simulation problem as a network — the nodes represent nonlinear equations, and the lines linking the nodes (called links or arcs) represent variables in the equations. The network representation of a simulation problem is completely equivalent to describing the problem as a set of simultaneous, nonlinear algebraic and differential equations. The network representation allows use of graph theory techniques to reduce the size of the problem to be solved.

A simulation problem in SPANK consists of a set of coupled equations. Each equation or relation among variables is known as a *primitive object*. Primitive objects may be combined into *macro objects*, and primitive and macro objects can be combined into more complex macro objects. Thus modules (sets of equations) which represent complicated physical processes or entities can be built up

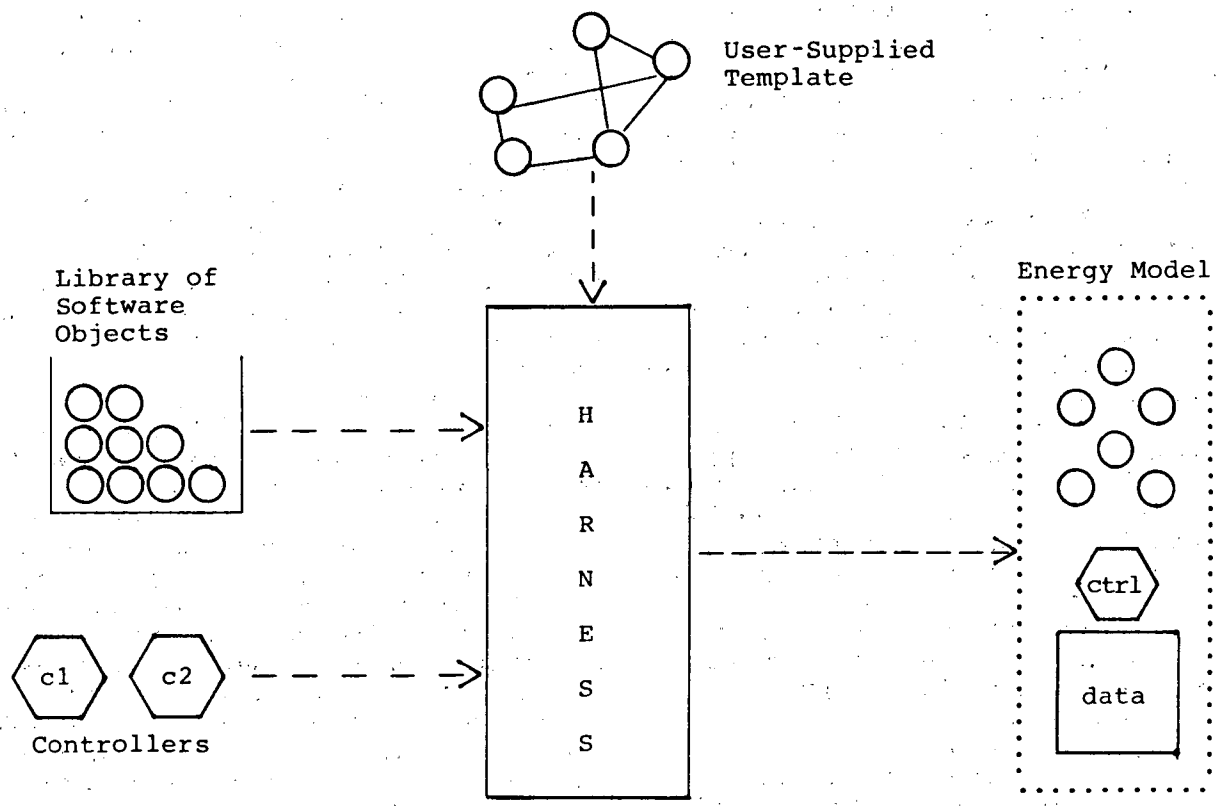

Figure 1: Proposed Energy Kernel System for creating building energy simulation models. (XBL 8712-5767)

from simple components. After the necessary objects (simple or complex) are defined, the problem description is completed by "linking" the objects together, i.e., by specifying the variables common to given equations.

Users need only define the simulation problem and do not need to choose a computation sequence (e.g., write a procedural algorithm in FORTRAN or other language) to solve the set of equations.

SPANK creates the solution sequence in two steps. First, a particular relationship (equation) is selected for each variable and inverted to give a formula for that variable. After the matching is accomplished, the second step is to find a set of break variables—a *cut set*. that become the iteration variables in the solution sequence. (Initial values are guessed and then used to solve for all the variables using the set of relationships. This procedure yields new values for the cut set variables. A scheme such as Newton-Raphson iteration is then used for choosing the next guess for the cut set.)

When faced with solving a system of nonlinear equations, most simulation programs simply iterate on all the variable, i.e., the cut set includes all variables in the problem. One of SPANK's major contributions is to use graph theory methods to reduce the cut size greatly and thus effectively reduce the problem size.

In FY 1988, object-oriented techniques were developed to allow SPANK to simulate time-dependent processes by integrating first-order differential equations.[18]

In FY 1988, we will continue to maintain and support the DOE-2 program and to publish the quarterly *DOE-2* User News. An improved version of the program, DOE-2.1D, will be completed and released to the public.

The SPANK program will be released for outside review after in-house testing of new SPANK features, including a graphics-based input processor, dynamic simulation, and symbolic manipulation of objects. Detailed specifications for the EKS will be developed.

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LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
1 CYCLOTRON ROAD
BERKELEY, CALIFORNIA 94720