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Building Energy Systems Program
1989 Annual Report

Applied Science Division

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DISCLAIMER

Building Energy Systems Program 1989 Annual Report

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April 1990

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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-2.1D, was completed during 1989 and was released to the public. Major new features include consideration of desiccant cooling, improved fenestration calculations, and user-defined functions.

The Simulation Research Group has continued its work on developing the next generation of simulation software, for use in the 1990's and beyond. The major effort in this area is the development of a modular software environment—an Energy Kernel System—that will allow users to generate customized simulation programs that suit their particular analysis needs. In 1989, LBL continued development of the Simulation Problem ANalysis Kernel (SPANK) as a working prototype of the Energy Kernel System. We have generated a dynamic version of SPANK that solves time-dependent problems by integrating differential equations. We have used this version to solve sample problems.

Also during 1989, we launched a major new effort to accelerate the availability of advanced simulation capabilities by incorporating SPANK's object-oriented simulation techniques into DOE-2. The new program (to be called *DOE-3*) will permit new heating, ventilation, and air conditioning (HVAC) technologies to be modeled without requiring time-consuming modifications to the DOE-2 code. With DOE-3, users will be able to simulate complex HVAC systems by graphically linking together component models for system components such as fans, coils, heat exchangers, and controls.

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. Fast, simplified simulation capabilities within RESEM compare favorably to more-detailed hourly simulation programs such as DOE-2. Many automatic and user-friendly features have been incorporated into RESEM and have been tested.

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 have been selected for detailed atrium simulations—one in Norway and one in the United Kingdom. The analysis in progress in the U.S. is being coordinated with monitoring being performed in Norway and the United Kingdom, and actual measured data is being used to calibrate the simulation results. Because of the critical energy implications of conditioning atria, the comfort conditions which can be expected in atria and in adjacent spaces are of special interest and are therefore a focus of the analysis.

We have continued our work for the U.S. Army Corps of Engineers, Construction Engineering Research Laboratory, in examining the energy performance of Department of Defense (DOD) facilities. Activities in 1989 focused on quantifying the life-cycle cost impacts of a range of energy-conserving envelope designs. Various building configurations and climate regions were considered in these analyses.

A new project begun during 1989 by the Building Systems Analysis Group aims to identify new energy conservation opportunities provided by various buildings materials; the group will calculate the degree to which the energy performance of buildings is affected by the use of new or modified materials. Conversely, comparative analyses of buildings and building systems with a range of thermal, optical, and physical properties of constituent materials will serve to identify desired materials characteristics. These comparative analyses will be used to set technical objectives for research on building materials.

The Solar Absorption Cooling project's major activity during 1989 was to investigate the performance of solar cooling and heating systems that incorporate advanced evacuated-tube solar collectors coupled to advanced absorption chillers or heat pumps. Notwithstanding design conditions set for gas-driven operation, results of preliminary analyses have shown the feasibility of driving advanced absorption heat pumps at their full design conditions with advanced solar collectors.

— *Absorption Heat Pumps* —

Solar Absorption Cooling

M. Wahlig, J. Rasson

Our major activity during 1989 investigated the performance of solar cooling and heating systems that incorporate advanced evacuated-tube solar collectors coupled to advanced absorption chillers or heat pumps.

The absorption heat pump, which operates in both the cooling and heating modes, was taken to be similar to the generator-absorber heat exchange (GAX) unit under development by Phillips Engineering. This unit was selected because it is likely to be one of the first of a new generation of absorption heat pumps to achieve market penetration. Initial development has been aimed at the residential market, but the technology can be scaled up (at least to small commercial applications).

The GAX heat pump is being developed for gas-driven applications. For the solar cooling systems we are considering, we assume that an additional coil is added to the generator section of the heat pump such that the unit can be driven by hot water as well as by a gas burner. This is not a major modification; "breadboard" models of absorption heat pumps are commonly driven by hot-water coils to facilitate laboratory testing before a gas burner is installed on the unit.

In the solar cooling system, the hot-water input to the heat pump is provided by the output of the evacuated-tube solar collectors. For simplicity, no thermal storage is assumed. The characteristics of the solar collectors are taken to be those of the internal-reflector, stationary, evacuated-tube concentrating (ISEC) collector under development by the University of Chicago.

In general, heat-pump efficiency increases as the driving temperature increases, and the relatively high combustion temperature of a gas flame has a distinct advantage over the output temperature from a solar collector. However, for absorption heat pumps, the maximum driving temperature is limited by the properties of the absorption-cycle working fluid. This temperature is about 400°F for the ammonia-water solution used in the GAX heat pump. This is within the range of a good evacuated-tube solar collector: the ISEC collector is expected to operate in the range of 50-60% efficiency at an output temperature of 400°F.

When driven by a high-temperature gas flame, the GAX input temperature can be kept near 380°F (its input design condition), maintaining highly efficient operation independent of ambient conditions. However, for solar-collector-driven operation, a tradeoff must be considered between collector efficiency and GAX heat-pump efficiency when ambient conditions change. When the ambient temperature or the insolation level decreases, constant input temperature to the heat pump can be maintained only at the expense of decreased collector efficiency. Alternatively, a constant collector efficiency may be maintained by allowing its output temperature to fall, taking a penalty in lower heat-pump efficiency. To determine the best operating strategy, both the collector and heat pump efficiencies must be known as a function of temperature. Selection of their coupling temperature–or a range of temperatures–is a critical element of an operating strategy and is a primary concern of our analysis. A characterization of the efficiency of the ISEC collector as a function of temperature and solar insolation has been obtained from the University of Chicago group.

Calculation of the expected GAX heat pump efficiency as a function of its input temperature is quite complex, requiring simulation of off-design operation. We have made on-design GAX efficiency calculations using a solution technique for ammonia-water absorption cycles developed over the past few years. This technique uses the HYBRID solver routine and for several cases has been verified against the more comprehensive ASPEN chemical process flowsheet method.

To obtain a preliminary observation of the off-design performance, we made several simplifying assumptions and approximations and used the HYBRID solution method. Although this procedure should give answers approximately correct for operating conditions near the design values, it is likely to give erroneous results at conditions unlike the design conditions. However, the procedure should indicate general trends in performance as the heat pump's input temperature varies, and this indication should be sufficient for purposes of our preliminary study of the cooling system. The more accurate solution procedure is planned as part of our 1990 activities.

Two conclusions can be drawn on the basis of this preliminary analysis: 1) advanced, evacuated-tube solar collectors are capable of efficiently (50% or higher efficiency under most ambient conditions) driving advanced absorption heat pumps at their full design-point operating conditions, even when design conditions assume gas-driven operation; and 2) the preferred operating strategy for the cooling-mode system under most ambient conditions calls for the solar collectors to be run at the constant outlet temperature (about 380°F) at which the heat pump is designed to operate.

Even at this early stage of our analysis, the results obtained suggest that an experimental test program should be initiated. Meanwhile, we plan to proceed with more detailed calculations of expected off-design performance should be made.

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— *Building Systems Analysis* —

Building Systems Analysis

R.C. Kammerud, B. Andersson, B. Birdsall, W.L. Carroll, D. Dumortier, R.J. Hitchcock, K. Poliakoff, and S. Sewell

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. Figure 1 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 will shift our focus from software development to initial field testing and to development of other supporting materials such as comprehensive weather data libraries, documentation, and user-training programs—all aimed at general dissemination of RESEM.

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

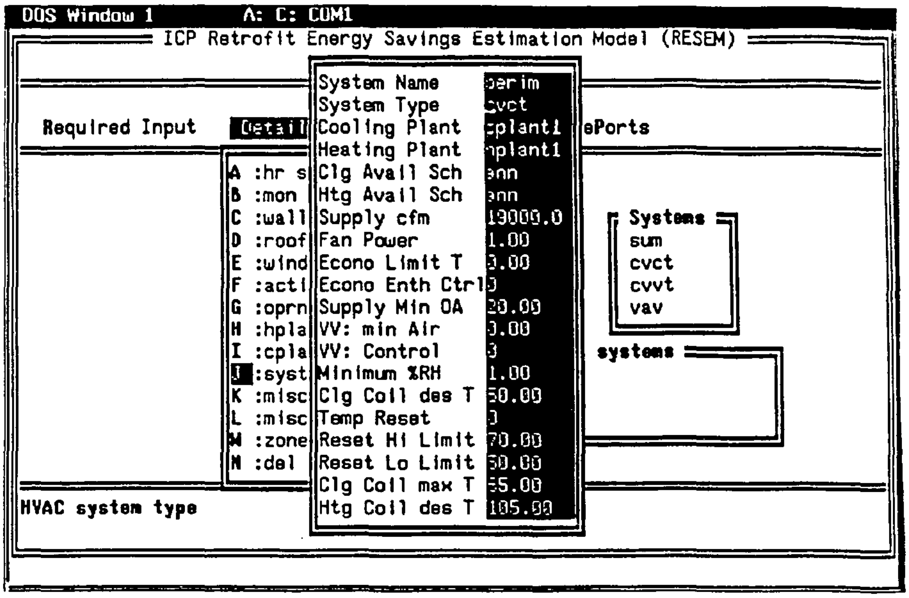

Figure 1. Typical example of pop-up screen display possible during the RESEM analysis sequence. Note how overlapping screens provide visual context.

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—have been 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 1989, initial simulations were made of the ELA atrium building in Trondheim, Norway, and of the Gateway II atrium building in Basingstoke, United Kingdom. Visits to the two facilities assisted in 1) completing accurate descriptions of the building and its operation, and 2) gaining familiarity with the monitoring plans. Actual energy performance data for the ELA building have been used to calibrate the simulation model. Within uncertainties in the climate data, the predicted energy consumption of the atrium and adjacent office/laboratory/classroom spaces agreed with the monitored data.

Using the calibrated simulation model, parametric studies of the ELA building will begin in the next fiscal year. Sensitivity of energy performance to operation, control, glazing solar transmission, and glazing thermal conductance parameters will be investigated. We expect data collection for the Gateway building to begin early in the 1990 calendar year. The simulation model for this building will be calibrated as soon as appropriate data are available This work will be followed by parametric sensitivity studies—similar to those now being carried out for the ELA building—using the calibrated model, .

CORPS OF ENGINEERS EFFICIENT BUILDINGS

The Department of Defense (DOD) mandates building energy standards that are closely comparable to Department of Energy (DOE) standards. In addition, the DOD standard recommends energy-conserving design features above and beyond its minimum requirements if these design features are cost effective. Because conducting field evaluations of energy use and economy can be difficult, DOD has developed a set of semi-prescriptive "envelope requirements" that can be applied as alternative requirements. We have quantified the life-cycle cost impacts of a range of energy-conserving envelope design options and have indicated the corresponding levels of life-cycle cost reduction achievable for common building types in various configurations and locations developed as part of the U.S. Army Corps of Engineers Standard Design Program.

Three general classes of building configurations were analyzed: *base standard configurations*, designed to jointly meet the DOE and DOD standards; *minimal envelope buildings*, which contain all the characteristics (in terms of size and use) of configurations meeting the standard, but have no insulation in the walls or roof and contain single glazing only; and *enhanced envelope performance configurations*, which begin with the minimal envelope building and include designs that extend beyond the base standards for energy conservation.

The projected energy performance of the various configurations was determined by computer simulations for four climates (selected according to population-weighted means of four key climate variables) based on the geographical distribution of military-base personnel: Homer, Alaska, representative of a very cold climate with no cooling season; Colorado Springs, Colorado, representative of a cold climate with a cooling season; Raleigh, North Carolina, a mild climate; and San Antonio, Texas, a hot climate.

Determining the life-cycle cost requires estimates for several variables: construction cost; other initial costs of the configuration; operational costs related to the configuration's energy use (typically, utility bills) over the time period defined as the economic life of the configuration; and any other economic assumptions needed to convert the lifetime stream of energy costs into a present value. We simplified the economic analysis by assuming that all initial costs and energy costs can be expressed relative to one of the reference building configurations. This approach allows formulation of correct relative life-cycle costs.

A summary of the results of these analyses (for the standard Corps of Engineers building types and across the climatic range studied) led to the following observations:

- Compared to the minimal envelope buildings, the base standard buildings save fossil-fuel energy primarily, more of this energy being saved in severe heating climates.
- The life-cycle costs of base standard buildings are greater than the life-cycle costs of the corresponding minimal envelope buildings.
- Enhanced performance configurations—i.e., those that include additional energy-conserving insulation and energy-efficient window performance—save almost no energy compared to the corresponding base standard configurations. Almost without exception, the enhanced performance configurations have higher life-cycle costs. Thus, starting from the base standard buildings, essentially no additional cost-effective energy savings opportunities are available.
- Analysis of a range of alternate economic assumptions (lower construction costs, cheaper fuel costs, lower discount rates, etc.) does not significantly alter the previous two observations, indicating that this result is not simply due to "special" DOD economic circumstances.
- Building designs intermediate between the minimal envelope configuration and the base standard building design can allow energy savings essentially as great as those provided by the base standard buildings but that have significantly lower life-cycle costs (Figure 2). The existence of these intermediate designs implies that design tradeoffs can be made while satisfying the standards, thus introducing design flexibility.

ADVANCED BUILDING MATERIALS ANALYSIS

This strategic analysis project, begun in 1989, identifies new opportunities for using energy conservation materials in buildings and building systems. The project also conducts technical assessments of materials research and development. The work has three specific objectives:

- to identify generic materials that would beneficially impact building and building system performance. This will be based on analyses that define the fundamental thermodynamic mechanisms that determine energy use in buildings, thereby defining opportunities for improved energy performance through development of new materials and through modification of existing materials.
- to identify desired characteristics for these materials based on comparative analysis of buildings and building systems that contain a range of thermal, optical, and physical properties of constituent materials. This identification will define the technical objectives for research on specific materials.
- to provide a coherent framework for evaluating materials research progress, thereby providing a basis for refining the objectives.

The analyses are expected to identify promising directions for materials research, including new materials concepts, modifications to existing materials to enhance their effectiveness, and improvements in the processes used to produce the materials. This work will address two related, underlying needs in a building materials program. First, a clear subsystem-system-building context must be maintained in order to identify new materials opportunities and to evaluate technical progress in developing these materials. Because the materials ultimately will be used in buildings, their impact and importance will be determined by how they are integrated with other materials in building systems, thereby influencing the whole. The second need is to broadly understand the basic sources of energy consumption "problems" in buildings; such understanding allows us to identify limitations of existing materials and subsystems as well as opportunities for new materials. This understanding also provides a sound basis for conceptualizing materials whose development is certain to have a beneficial impact on energy use.

The first phase of this work, begun in 1989, was to conduct a scoping study. This study was designed to identify several promising new directions for the materials program and to develop a strategic plan for longer-term definition and evaluation of materials options. Initial activities within the scoping study have included review and assessment of ongoing research, development, and application activities on materials and subsystem technologies. Preliminary subsystem analyses have been conducted to determine when materials technology advances approach the point of diminishing returns. We have also begun analyses which will estimate potential impacts of advanced static and dynamic materials.

During our early analysis, insulating materials with variable resistances emerged as a concept to be investigated more thoroughly. Such materials would allow the interior of a building to be isolated from the environment during periods when heat gains or losses increase use of cooling or heating energy. These materials would also permit a building's interior to communicate "freely" with the environment when gains or losses through the envelope reduce energy consumption. We will continue to study the energy impacts of these and other promising materials during 1990.

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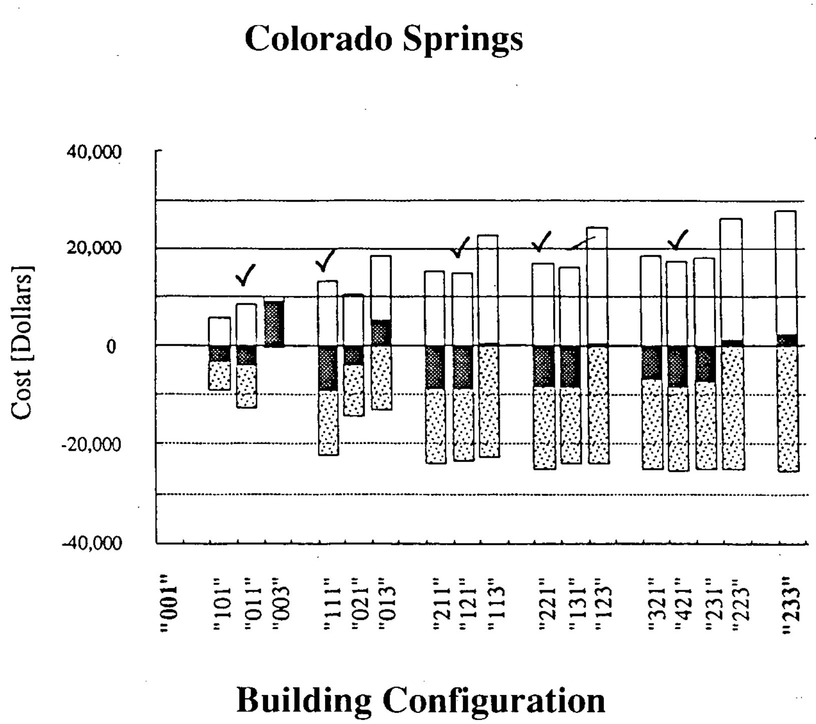

Figure 2. Life-cycle costs for configurations "intermediate" to the minimal envelope and base standards buildings for Colorado Springs. Values are in 1989 dollars relative to the minimal envelope configuration.
- □ Initial cost
- ■ 25-yr Life-cycle cost
- ▨ 25-yr Energy cost
- ✓ Best of the 3 retrofit measures, used as base fdor next 3 measures

— Simulation Research —

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 long-term objective of the Simulation Research Group (SRG) is to give architects, engineers, and researchers software tools that will assist in the design of energy-efficient, cost-effective buildings. Ongoing SRG research has two main emphases: to develop and maintain the current-generation benchmark program, DOE-2; and to develop the next generation of building-performance calculation tools—the Energy Kernel System.

DOE-2 is a public-domain computer program that performs an hour-by-hour simulation of a 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 in 36 other countries for designing energy-efficient buildings, for analyzing the impact of new technologies, and for developing energy conservation standards.

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

DOE-2

SRG maintains an ongoing research effort to develop enhanced versions of DOE-2. This work 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. A new version of the program, DOE-2.1D, was completed in 1989 and has been released to the public. Major new features include:

• *User-defined functions*

A new FUNCTION command added to the DOE-2 SYSTEMS program permits expert users to modify or enhance DOE-2 calculations without recompiling the program. Users write their own algorithms in a FORTRAN-like language and place them in their input, along with information indicating how and where these new algorithms are to be used. This feature allows researchers to add new HVAC simulation features, such as innovative control schemes, which cannot be modeled by the regular DOE-2 calculations.

• *Improved fenestration calculation*

Because heat gain and loss through windows greatly affects the energy performance of most buildings, DOE-2 window thermal calculations have been 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*

Several companies have been developing desiccant cooling systems in which a hygroscopic material such as lithium chloride removes moisture from the outside airstream. To regenerate the desiccant for further use, it is dried using hot air from a gas-fired heater. Gas-fired desiccant systems of this type can replace or supplement conventional electric-driven cooling systems; however, little is known about the economics of using desiccant systems in different climates, in different building types, and in different utility rate structures. For this reason, SRG (with funding from the Gas Research Institute via the GARD Division of the Chamberlain Manufacturing Corporation) has created 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

The search for more efficient building designs has led to components, systems, and whole building structures that are extremely complex and therefore difficult to analyze. Because existing programs such as 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. Modular, computationally efficient, easily extendible techniques are needed to accurately simulate new HVAC technologies and to model the thermal interactions between building-envelope components and HVAC systems. Analysis of complex designs and advanced technologies requires substantially improved programs for simulating building performance.

To continue to meet DOE's objective of providing up-to-date, reliable analytical tools for researchers and designers, SRG has begun to research and develop new simulation techniques. The major effort in this area is development of a modular software environment (the Energy Kernel System, EKS) that will allow users to generate customized simulation programs to suit their particular analysis needs. EKS is intended to be an efficient way of creating models that can be used in a standalone fashion or integrated into multipurpose environments such as computer-aided design (CAD) systems, expert systems, or energy management systems.

SPANK: A Prototypical Energy Kernel System

In 1986, SRG began to develop new software—the Simulation Problem Analysis Kernel (SPANK)—as a working prototype of the EKS. SPANK views a simulation problem as a network: the nodes represent nonlinear equations, and the lines (called *links* or *arcs*) linking the nodes 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

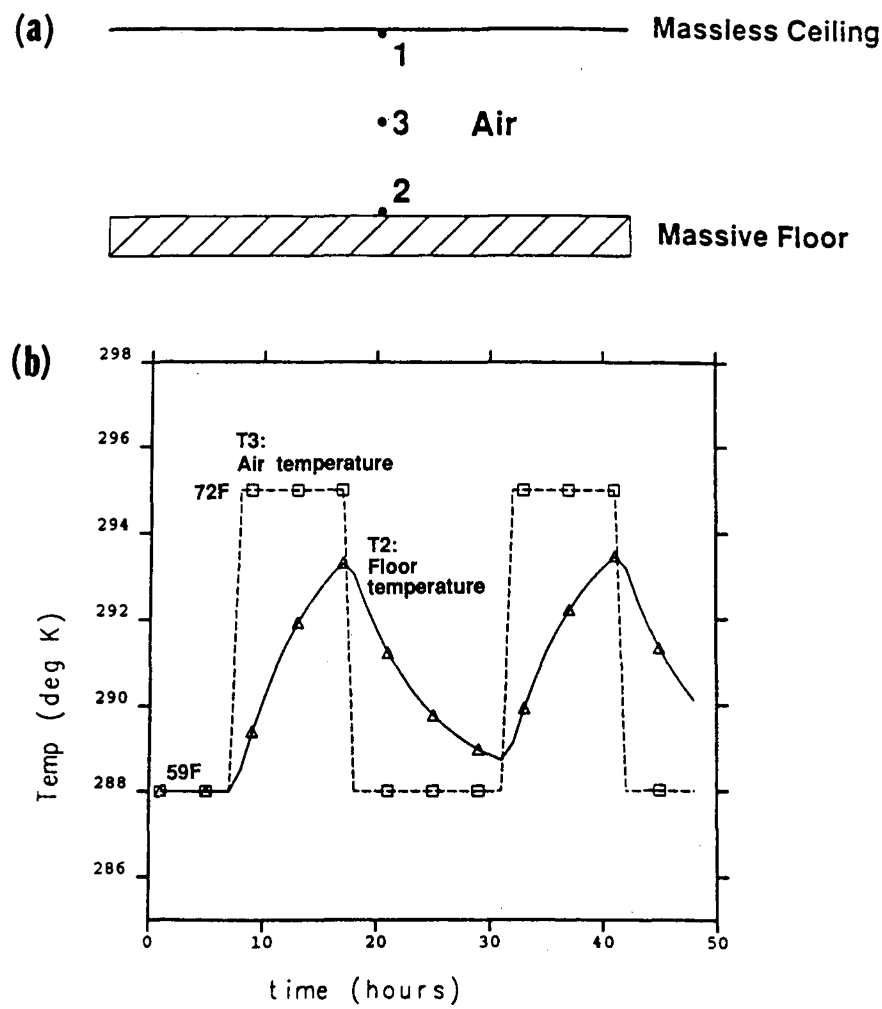

Figure 1. To test the new Dynamic SPANK program, thermal behavior of a simplified room (a) was simulated. In this room, ceiling height is small (relative to other dimensions) and only the floor has heat capacitance. Heat balance at nodes 1, 2, and 3 yields simultaneous equations to be solved that represent exchange of long-wave radiation, convection to room air, and heat storage in floor. SPANK solution (b) shows calculated floor temperature vs. time for user-specified air temperature that varies between night and day setpoints (59 °F and 72 °F, respectively).

differential equations. The network representation facilitates use of graph theory technique to minimize the number of iteration variables, thereby reducing the size of the problem to be solved.

A simulation problem in SPANK consists of a set of coupled equations that describe the physical system to be modeled. Each equation or relation among variables is known as a primitive object. Primitive objects may be combined into macro objects, which can be combined into even more complex macro objects. In this way, modules (sets of equations) that represent complicated physical processes or entities can be constructed from simple components.

After the necessary objects—simple or complex—are defined or obtained from a library, the problem description is completed by linking the objects together, i.e., by specifying the variables common to given equations. (A graphical user interface is being developed to facilitate display and linking of objects.) SPANK then automatically creates a solution sequence (eliminating the need for users to generate procedural algorithms in FORTRAN or other language) and solves the equation set iteratively each timestep using Newton-Raphson methods.

Dynamic SPANK is a version of the program that solves time-dependent problems by integrating differential equa-

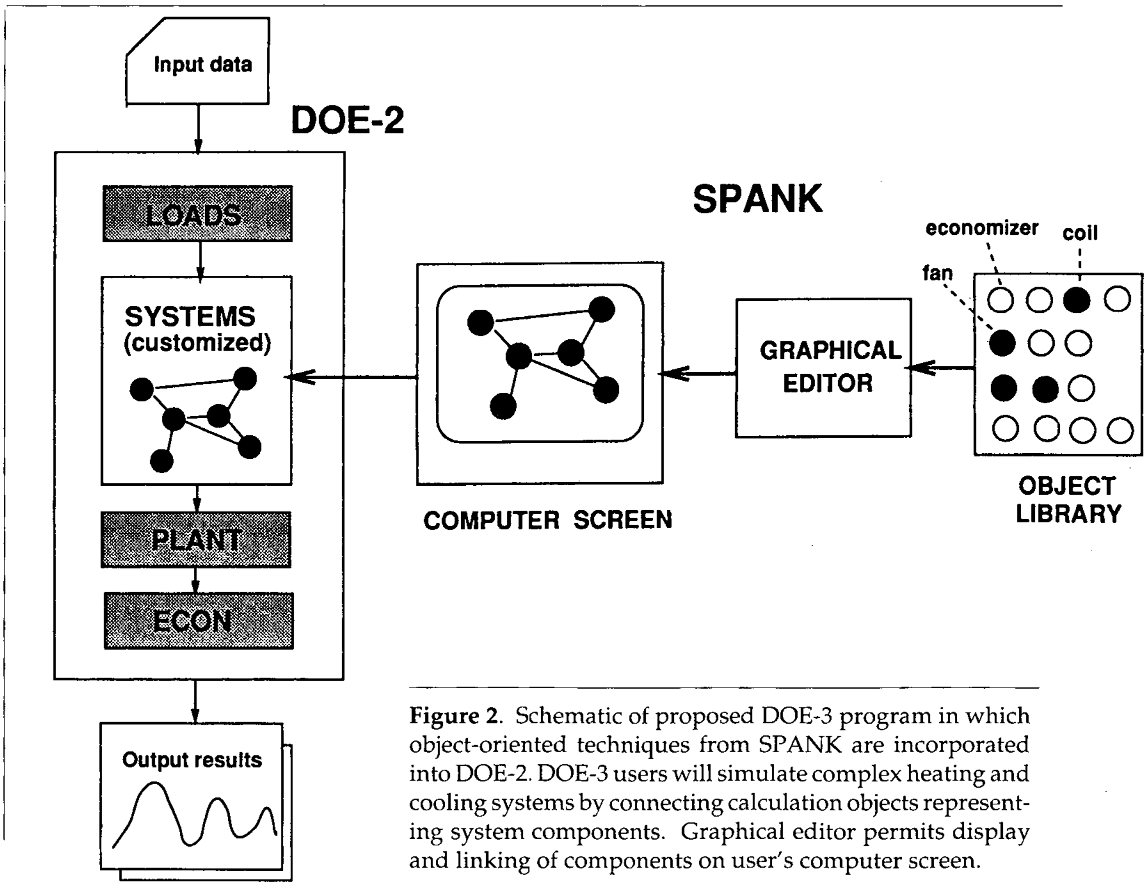

Figure 2. Schematic of proposed DOE-3 program in which object-oriented techniques from SPANK are incorporated into DOE-2. DOE-3 users will simulate complex heating and cooling systems by connecting calculation objects representing system components. Graphical editor permits display and linking of components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

tions. In 1989, for the first time, Dynamic SPANK was made to run. Figure 1 shows a sample Dynamic SPANK problem and its solution.

Other major advances were made in 1989:

- We developed a standard format for describing calculation objects for SPANK and other kernel-type systems. This format will make international exchange of calculation objects possible, thus saving duplication of effort.
- We implemented an interface between SPANK and Macsyma, a symbolic manipulation program. The resulting package automatically creates the C code for SPANK objects from equations input by the user in symbolic form.
- We formulated an improved input language for SPANK that permits different integration methods to be specified as objects.

In 1990, we will continue to maintain and support the DOE-2 program and to publish the quarterly DOE-2 User News. With co-funding from California utility companies, we will begin work on DOE-2.1E ; new features will include simulation of advanced glazings with switchable solar-optical properties, models for residential and commercial evaporative cooling systems, and simulation of ice and eutectic thermal-energy storage.

SPANK development will continue, emphasizing implementation and testing of the graphical user interface.

Work will begin on DOE-3, a hybrid program (Fig. 2) in which SPANK's object-oriented simulation techniques are to be incorporated into DOE-2. DOE-3 will permit new HVAC technologies to be modeled without requiring time-consuming modifications to be made to the DOE-2 code. Using DOE-3, users will simulate complex HVAC systems by graphically linking component models for system components such as fans, coils, heat exchangers, and controls.

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