NEW TOOLS FOR THE ANALYSIS AND DESIGN OF BUILDING ENVELOPES

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ABSTRACT

In this paper the authors describe the integrated development of PowerDOE, a new version of the DOE-2 building energy analysis program, and the Building Design Advisor (BDA), a multimedia-based design tool that assists building designers with the concurrent consideration of multiple design solutions with respect to multiple design criteria.

PowerDOE has a Windows-based graphical user interface (GUI) that makes it easier to use than DOE-2, while retaining DOE-2's calculation power and accuracy. BDA, with a similar GUI, is designed to link to multiple analytical models and data bases. In its first release it is linked to PowerDOE and a daylighting analysis module, as well as to a case studies data base and a schematic graphic editor. These allow building designers to set performance goals and address key building envelope parameters from the initial, schematic phases of building design to the detailed specification of building components and systems required by PowerDOE.

The consideration of the thermal performance of building envelopes through PowerDOE and BDA is integrated with nonthermal envelope performance aspects, such as daylighting, as well as with the performance of nonenvelope building components and systems, such as electric lighting and heating, ventilating, and air conditioning (HVAC). Future versions of BDA will support links to computer-aided design (CAD) and electronic product catalogs, as well as provide context-dependent design advice to improve performance.

INTRODUCTION

Since the energy crisis of the 1970s, a large number of energy-efficient strategies and technologies have been developed that promise significant reductions in building energy consumption and peak electricity demand. Many of these strategies and technologies are designed for improved thermal performance of building envelopes. The performance of any technology, however, depends on the context of its application. Unless thermal and energy benefits can be accurately predicted, along with other, nonenergy performance aspects—such as comfort, aesthetics, and economics—most building designers will not accept the risks associated with approaches that they have not implemented or considered in the past. However, the required modeling for the prediction of building performance often is seen as prohibitively expensive because it requires time-consuming use of complicated methods by specialized consultants. A powerful way to promote energy efficiency in buildings is to provide affordable tools that allow architects and engineers to quickly evaluate energy and nonenergy performance during the design process. Due to the magnitude and complexity of the algorithms required for accurate prediction, such tools only can be implemented in the form of computer programs.

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The rapid decrease in the cost of computing power over the last decade has brought computers into most architectural and engineering offices, initially for word processing and other "business" tasks, and gradually for drafting, rendering, and preparation of construction documents. Over the last few years the continuously increasing computational power of personal computers has become adequate to support the execution of powerful building simulation programs, such as DOE-2—for energy calculations (Birdsall et al. 1990), SUPERLITE—for daylight simulation (Modest 1982), RADIANCE—for lighting analyses and photorealistic rendering (Ward 1990), and COMIS—for airflow simulation (Feustel 1992). Such programs originally were developed on mainframe computers for research purposes and provide powerful, detailed modeling and highly accurate performance prediction. However, they are hard to use because they require the preparation of complicated text files to describe the building and its context, and provide output in the form of numerical tables that are hard to review and understand. Such models use building representations that are incompatible with each other and thus require multiple, specialized descriptions of the building and its context. As a result, such programs are of limited use in the building industry. They generally are used only by experienced consultants for large projects that can justify and support the associated high cost.

The need to control energy use and peak demand in buildings has led the U.S. Department of Energy (DOE) and a research organization into a collaborative effort to develop PowerDOE, a new version of the DOE-2 building energy analysis program, featuring a Windows-based graphical user interface (GUI) and various algorithmic and data base improvements. Through its ease of use and tremendous reduction in time requirements for input preparation and output review, PowerDOE is expected to extend the use of DOE-2 beyond energy specialists to the majority of consultants and engineers involved in building design.

To extend the use of energy tools to architectural decisionmakers in the schematic design phases, additional capabilities not available in PowerDOE are needed. DOE and a California research group have initiated a collaborative effort to develop the Building Design Advisor (BDA), a building design support environment that is intended to meet this need. Using a single, object-based[1] representation of the building, BDA allows designers to concurrently use multiple performance analysis models, data bases, and case studies to compare alternative design solutions with respect to multiple performance considerations.

POWERDOE

PowerDOE combines an enhanced DOE-2.1E simulation engine with a visually oriented user interface, unifying the building description and building analysis processes and allowing dynamic interaction between them.

The PowerDOE interface includes a graphical presentation of the building that reduces the time needed to prepare an accurate building description. The graphical presentation is organized into a hierarchy that groups the building elements in a way that is intuitive and familiar to designers and analysts. Architecturally, each building consists of one or more floors and each floor consists of one or more spaces. Each space is bounded by walls and each wall can have one or more attached windows and/or doors (Figure 1). Each wall and window is further described as a collection of one or more layers of material (Figure 2). Heating, ventilating, and air-conditioning (HVAC) equipment and corresponding graphics (not shown) are grouped by airflow and water flow paths that supply the building's heating, cooling, and ventilating requirements. Electricity and fuel supply and corresponding graphics (not shown) are grouped to reflect the building circuits and provide end-use consumption and demand estimates. The program includes on-line, context-sensitive help, providing detailed information on all interface screens and data entry fields.

The interface allows a system administrator to customize the input screens so new screens can be added or existing screens altered, including the hiding, protecting, and moving of parameters. User inputs and parameter defaults are context-dependent and can be specified as expressions involving other parameters and computed values. This provides a powerful capability to generalize inputs and defaults, as well as enabling rapid parametric analyses. A spreadsheet GUI element allows the user to easily specify multiple parametric runs varying building envelope and/or equipment performance characteristics.

For rapid input, the user can select building elements from libraries of prototypical building components and systems, including materials, wall and window constructions, lighting fixtures, operation schedules, systems, system components (fans, thermostats, etc.), and plant components (boilers, chillers, cooling towers, storage tanks, etc.). These are presented in spreadsheet style, allowing the user to quickly modify the data to conform to the actual design of interest. After a prototype has been customized it can be simulated, entered in the libraries for later reuse, or modified in more detail using the user interface.

The simulation engine performs an hourly time-step calculation based on techniques used in the DOE-2 and

[1]In an object-based representation, the building is seen as a collection of objects, such as "walls," "windows," etc., that have attributes, such as "area," "U-factor," etc., as well as relations among them, such as "part of," "kind of," etc.

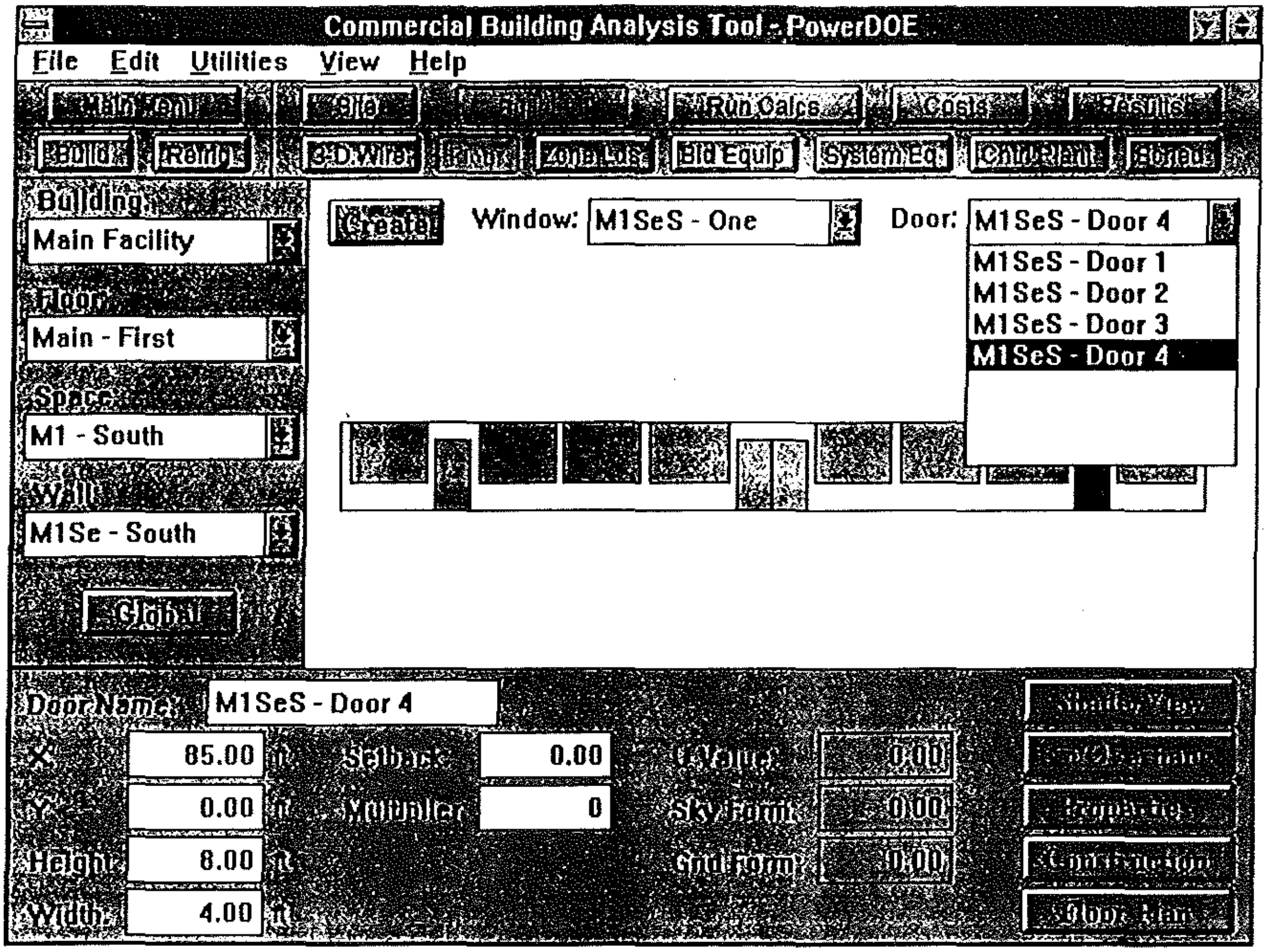

Figure 1 The PowerDOE interface provides graphical feedback on the placement of building envelope elements in perspective, plan, and elevation views. This elevation view of a wall shows placement of windows and doors that can be moved and sized by clicking and dragging or by entering geometrical data.

micro-AXCESS programs. It is structured as a process retrievable from the user interface to perform design calculations, as well as energy-use calculation runs. The user interface calls the simulation engine to perform zone-by-zone peak load calculations and to provide the loads data used to perform default HVAC equipment sizing. In this way, as the user passes from the architectural input phase to the HVAC description phase, all load and resulting equipment sizing are presented and changeable prior to the energy-use analysis. During the simulation phase, all building components are simulated together at each time step. The simulation speed is substantially faster than other DOE-2 program implementations.

In addition to its ability to accurately simulate a wide variety of HVAC system configurations, PowerDOE incorporates important new capabilities in building envelope modeling, as well as significant improvements in old modeling techniques. These include

- shading of direct and diffuse solar radiation by obstructions such as overhangs and neighboring buildings; visual display of shadows cast by obstructions;
- daylighting: stepped and dimming control of electric lighting; visual display of daylighting and electric lighting illuminance distributions;
- window management: deployment of window-shading devices, such as blinds and drapes, to reduce solar gain;
- ability to model complex, dynamic glazings, such as those capable of switching (electrochromics, etc.);
- links to WINDOWS 4.1 for detailed properties of non-standard glazings and windows;
- ability to view the current design as a three-dimensional model to verify correct placement of walls and windows; and
- wall and window selection guides that provide detailed technical and graphic data on each wall and window entry.

A separate PowerDOE program module allows the user to review results and prepare customized reports. Any hourly, monthly, or annual results, or comparisons of several results, can be viewed, graphed, and printed. Standard Windows capabilities allow PowerDOE graphs

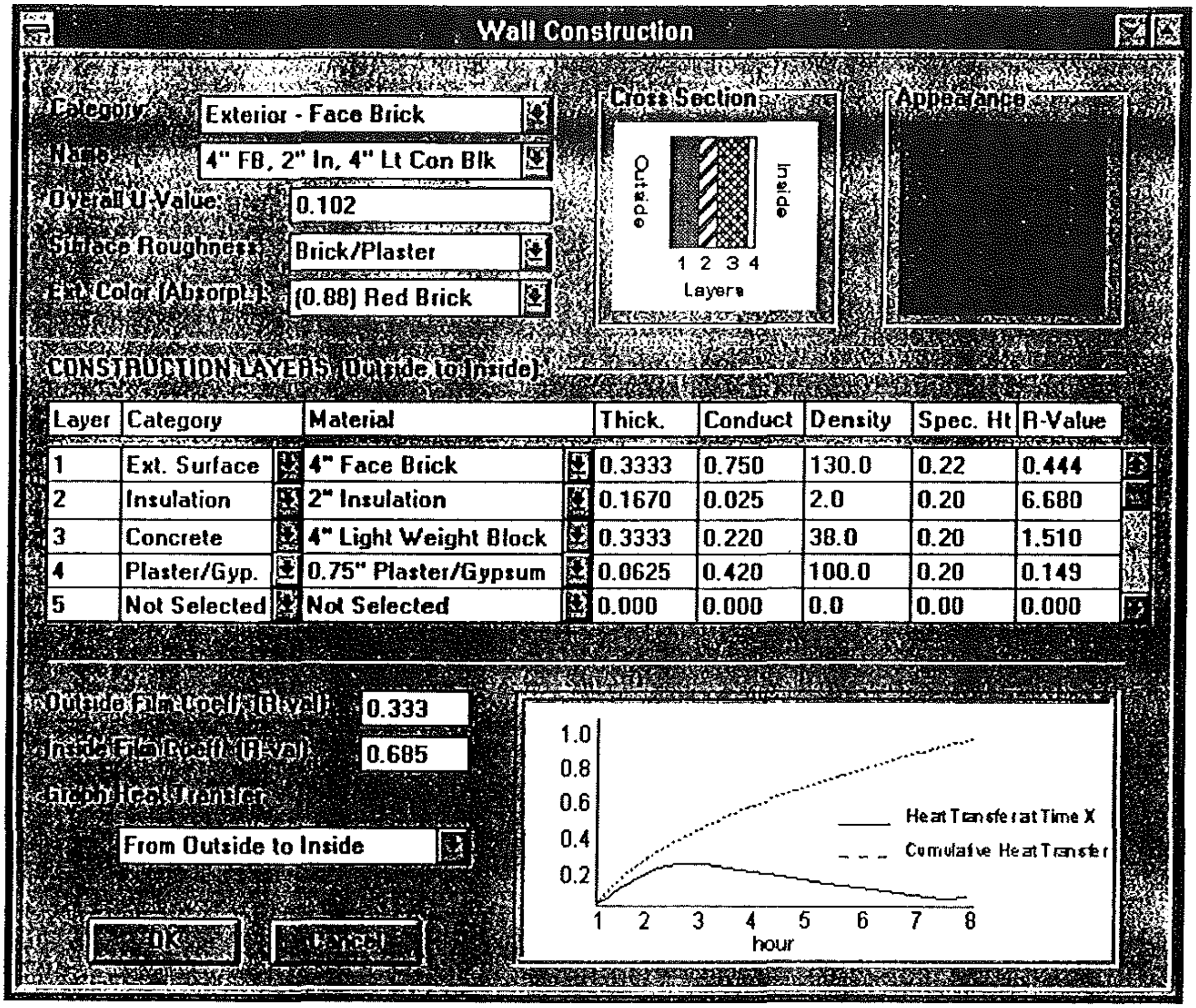

Figure 2 PowerDOE screen in which the layer-by-layer construction of a wall is specified. The graph in the lower right shows the thermal response of the selected construction (heat transfer through interior surface of wall for unit increase of outside surface temperature).

and reports to easily be cut and pasted into presentation documents.

THE BUILDING DESIGN ADVISOR (BDA)

BDA supports the use of analytical tools, such as PowerDOE, from the initial, schematic phases of building design through the combination of a schematic graphic editor (SGE) and a prototypical values data base (PVD). In addition to the geometric specifications of buildings, analysis tools require the specification of many nongeometric attributes, such as thermal properties of walls and windows, occupancy schedules, etc. Through SGE, BDA allows the user to quickly specify the basic geometric attributes of spaces, windows, doors, etc., while it automatically assigns default values from PVD to all nongeometric parameters based on location, building type, and space type. The default values assigned by BDA can be edited at any time through the "Building Browser," which is described later in this section.

BDA is based on a comprehensive design theory developed during the past several years in collaboration with the department of architecture at a U.S. university (Papamichael and Protzen 1993) and uses a "real-world," object-based representation of the building and its context that is "mapped" onto the specialized representations of the analytical models linked to it. In this way, BDA shields building designers from the complexity of the different building representations used by the individual analysis and visualization tools, allowing them to concentrate on design decisions through the consideration of multiple alternative solutions with respect to multiple performance aspects. BDA also is linked to a multimedia case studies data base that follows the same object-based representation of the building and its context. In this way, building designers can compare their designs to existing buildings and create an appropriate, realistic context for performance evaluation. The case studies data base serves as an electronic magazine and supports the use of images, sound, and video for enhanced coverage of building case studies. In addition to the schematic graphic editor, the prototypical values data base, and the case studies data base, the initial version of BDA is linked to PowerDOE and a daylight analysis module, which extends beyond the capabilities of PowerDOE to provide spatial and temporal distributions of daylight workplane illuminance and glare index for a large number of interior reference points, as well as temporal distributions of electric lighting savings for a large number of electric lighting zones.

The GUI of BDA is composed of two major elements: Building Browser (B-Squared) and the Design Decision Desktop (D-Cubed). B-Squared is a GUI element that combines the visualization of two hierarchical structures, one representing the physical description of buildings and their context and another representing the performance parameters considered by the analysis and visualization tools linked to BDA (Figure 3). Through B-Squared, building designers can quickly navigate through the large number of parameters used by detailed analytical models such as PowerDOE and select the ones that they want to display in D-Cubed for decisionmaking. D-Cubed is a spreadsheet-like GUI element whose columns represent alternative design solutions or case studies of actual buildings, and whose rows represent characteristics of the building and its context that are either input or output parameters of the analysis and visualization tools linked to BDA (Figure 4).

Through D-Cubed, building designers can explore the integration of the thermal performance of the building envelope with nonthermal performance aspects, such as daylighting and energy. They can integrate building envelope considerations with those related to nonenvelope building components and systems, such as electric lighting and HVAC equipment.

BDA is developed using state-of-the-art, object-oriented programming that supports incremental development for future links to additional analytical models and data bases. Links to CAD and manufacturers' catalogs currently are being explored along with the development of "advice modules" for context-dependent

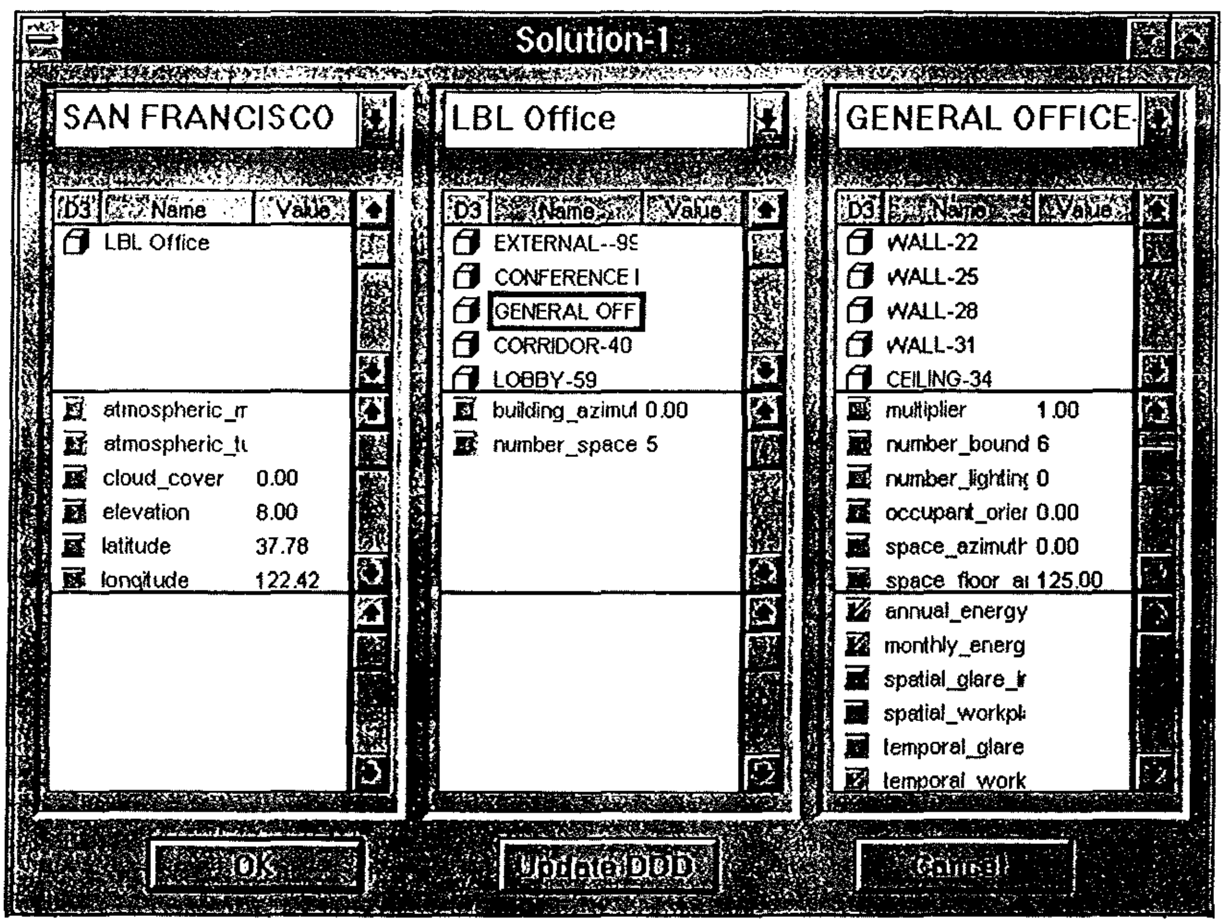

Figure 3 *The Building Browser allows building designers to quickly navigate through the large number of parameters used to describe a building and its context, as well as its performance.*

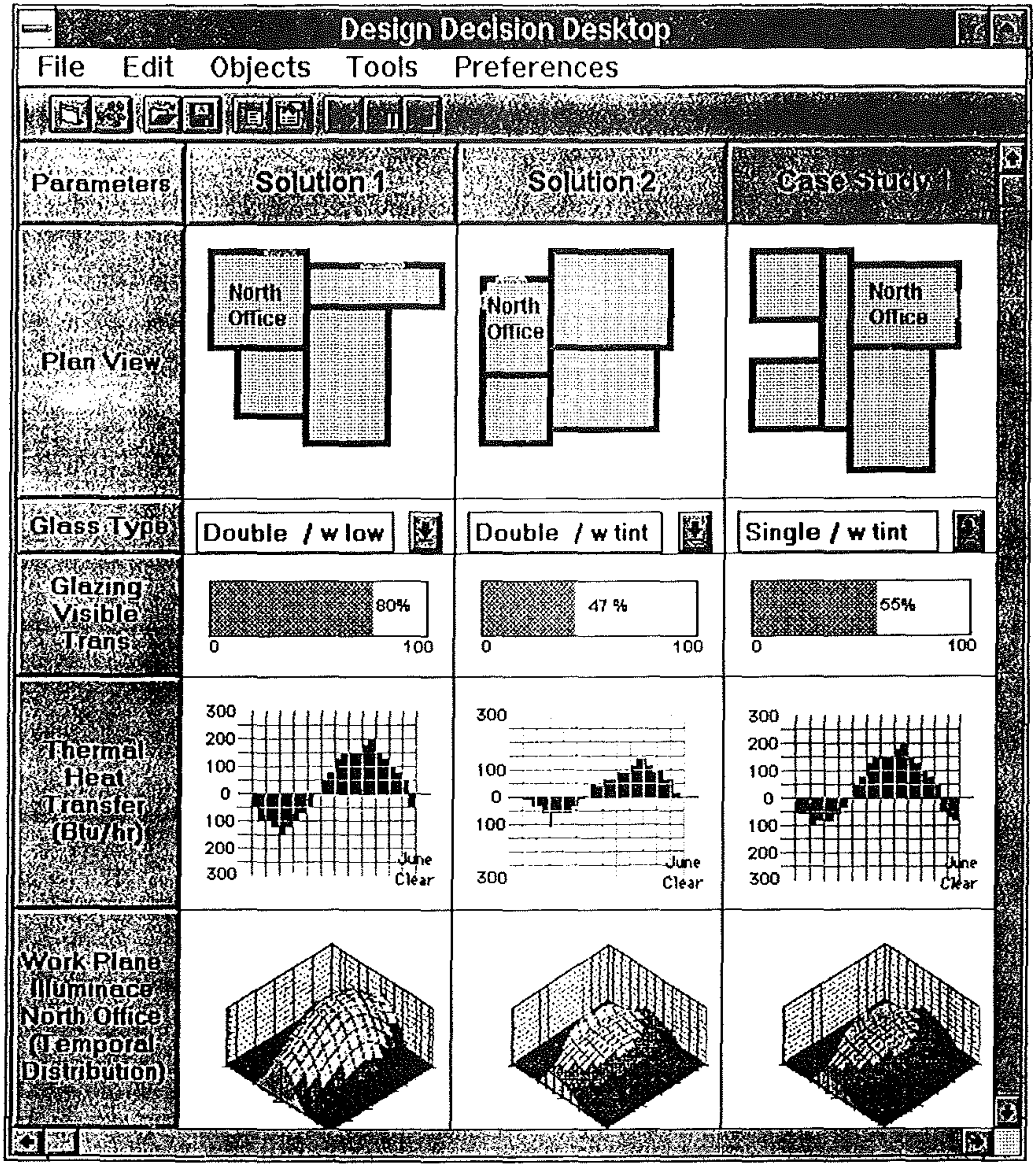

Figure 4 An example of the Design Decision Desktop (D-Cubed) configured for comparison of the heat transfer and daylight illumination of two alternative design solutions and a case study with respect to space layout, glass type, and visible transmittance.

design advice. Future plans also include links to other analytical models such as SUPERLITE, RADIANCE, and COMIS.

BDA and PowerDOE communicate through dynamic link libraries (DLLs) that support concurrent, integrated use of all available resources (Figure 5). Through coordinated development, PowerDOE and BDA capitalize on each other's functionality to support the variety of potential users in the building industry throughout the building design process. Distribution and licensing are aimed at an affordable software environment with sufficient support to ensure widespread use in the building industry. Distribution plans also include collaboration with architectural and engineering departments for appropriate training of future generations of building designers and decisionmakers.

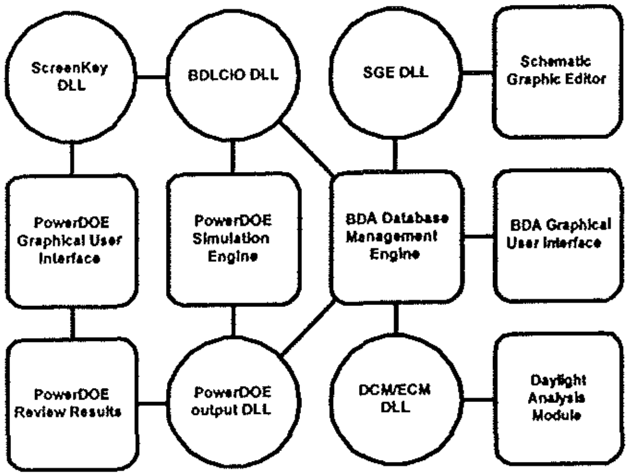

Figure 5 *PowerDOE and BDA communicate through dynamic link libraries (DLLs). BDA uses the same approach to communicate with the schematic graphic editor and the daylight analysis model.*

The initial versions of PowerDOE and BDA are scheduled for release in late 1995. Both programs run on Microsoft Windows 3.1 or higher and require a 486 or Pentium CPU and a color VGA monitor. BDA requires 8 megabytes of memory, while PowerDOE requires 12.

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