An Integrated Environment for Intelligent Energy Design

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Abstract

The design of energy-efficient buildings can be aided by intelligent computer tools that can evaluate design solutions and make recommendations for improving the buildings' energy performance. Such tools can be very productive when they are integrated with existing computer-aided design technology. Pacific Northwest Laboratory, in collaboration with the University of Oregon, the California Polytechnic State University, and the Lawrence Berkeley Laboratory, is developing such tools and integrating them into a computational environment that can be easily used by architects, engineers, and designers. This project, called the *Advanced Energy Design and Operations Technologies* (AEDOT) project, intends to demonstrate how building energy performance can be improved by combining expertise from a variety of domain perspectives during the design process.

This paper describes the first prototype to emerge from the AEDOT work. AEDOT Prototype 1 consists of several design and energy tools that have been integrated using the ICADS framework developed at California Polytechnic State University. The prototype demonstrates how an integrated system responds to a building design as it is being developed on a CAD system. While the designer draws a building floor plan, a number of intelligent design tools (IDTs) examine the drawing and evaluate the design's acoustics, thermal profile, daylighting use, cost, and compliance with energy standards, to name a few. These IDTs also make design-specific recommendations intended to improve the cost, energy performance, and overall quality of the design.

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Introduction

For many years, architects and engineers have been using computer tools to assist them in designing more energy-efficient buildings. These tools have become increasingly sophisticated, not only in their analysis capabilities but in their ability to interact with the designer. Ray-tracing techniques allow designers to observe a building's thermal and lighting characteristics with photo-realistic images. User interfaces are graphically-oriented, providing an intuitive approach to energy inputs and outputs. In addition, powerful processors allow designers to explore the energy consequences of multiple design alternatives quickly and in great detail.

Despite the level of sophistication these energy tools have achieved, they are unused by many architects and engineers. Energy concerns do not rank highly on their priority lists, and many designers believe the cost of such tools outweighs their benefits. Energy tools often appear as stand-alone packages, requiring that users enter input, process information, and receive results independently from all other design-related tasks. For computer-aided design (CAD) software users, this is an added drawback, because they must enter a building design description twice: once for the CAD package, and once again for the energy software. To be of any practical use to the architect or engineer, these energy tools must be integrated with other design activities. In a CAD environment, such tools should ideally operate throughout the design process, providing analysis, evaluation, and recommendations in response to the design being developed on the CAD system.

The development of advanced energy tools and their integration into a computer-aided design environment is one of the goals of the U.S. Department of Energy's *Advanced Energy Design and Operations Technology* (AEDOT) project [Brambley 91][Brambley 88]. These tools employ techniques from artificial intelligence research and knowledge-based systems to bring energy expertise directly to the designer. Many of these tools are capable of offering project-specific recommendations for improving the energy characteristics of the design, thus earning the name Intelligent (Energy) Design Tools, or IDTs.

This paper describes the first results of the AEDOT research, which is a prototype that features three advanced energy tools that can assist the designer as part of an integrated design environment. The Pacific Northwest Laboratory (PNL), the University of Oregon (UO), the California Polytechnic State University (Cal Poly) and the Lawrence Berkeley Laboratory (LBL) have joined in a collaborative effort to develop *AEDOT Prototype 1*. This prototype is intended to demonstrate some of the capabilities envisioned for the future that will help architects and engineers improve the energy efficiency of buildings during the design process.

An Overview of AEDOT Prototype 1

AEDOT Prototype 1 consists of three advanced energy tools that have been implemented as components of a software framework called the Intelligent CAD System (*ICADS*) [Pohl 91][Pohl 89][Pohl 88]. ICADS is a prototype computer-based design environment that contains a commercial CAD drawing package, a geometry interpreter, several databases and intelligent design tools (IDTs), and a blackboard through which the IDTs are connected (see Figure 1). The three advanced energy tools – the *Energy Standards Tool*, the *Building Massing Tool*, and the *Daylighting Tool* – have been developed by PNL, UO, and LBL, respectively. These tools are connected to ICADS via the blackboard in the same way as are the other IDTs.

A designer interacts with the prototype by developing a building design on the computer screen using the CAD drawing package. As architectural elements (e.g., rooms, doors, and windows) are drawn on the screen, they are transformed by the geometry interpreter into corresponding data objects and posted to the ICADS blackboard. Once these objects appear on the blackboard, they become immediately available to the IDTs, including the energy tools, for analysis and evaluation. The Energy Standards Tool, for example, examines the data on the blackboard to determine if the building design complies with lighting and fenestration standards as specified in *ASHRAE/IES Standard 90.1-1989* [ASHRAE 1989]. If the design does not comply, the tool recommends design changes for bringing it toward compliance. The Building Massing Tool examines the form and organization of the building design and suggests alternative building massings that can improve overall energy use. The Daylighting Tool evaluates daylight illuminance within the building design and suggests alternative window configurations to improve daylight contributions.

Each of these tools activates opportunistically, that is, it performs its function whenever it receives sufficient information to do so. Although the user may wish to interact with a specific tool (e.g., to receive an explanation or modify design parameters), this interaction is not mandatory. The tool operates in the "background," allowing the designer to proceed with the design without interruption.

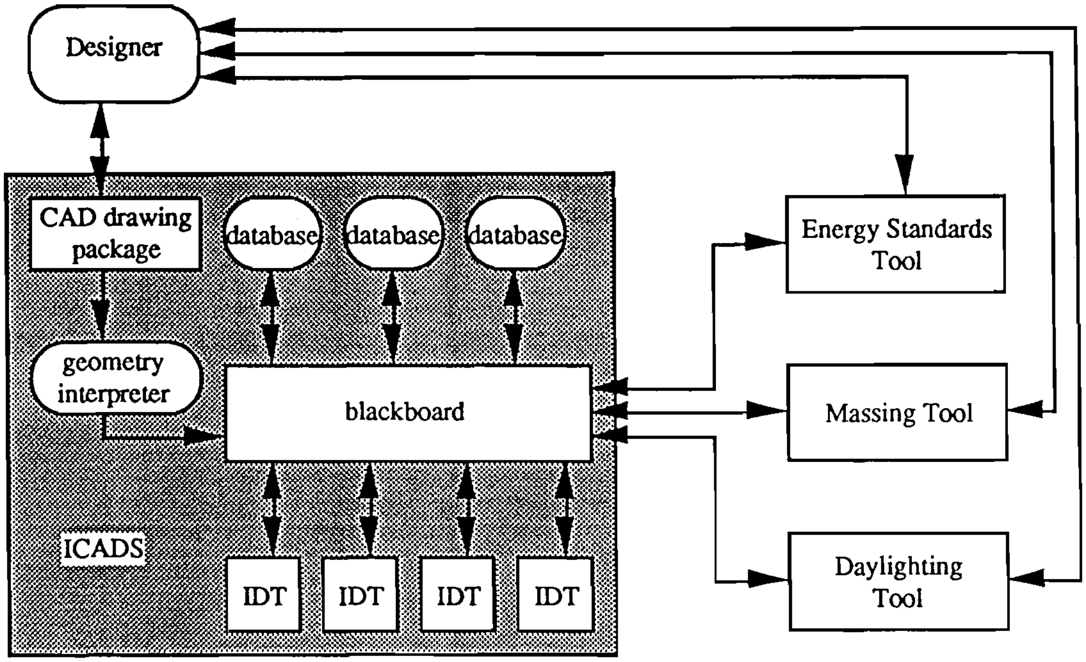

Figure 1. AEDOT Prototype 1 components and information flows.

ICADS

ICADS is a prototype computer-based design environment developed at Cal Poly that assists the user by providing concurrent evaluation and feedback about the building design as it is being drawn on the computer screen. ICADS includes a number of IDTs developed earlier as part of the Cal Poly ICADS project. These IDTs provide performance information in structural, thermal, acoustic, and economic domains, among others.

The *CAD drawing package* is a version of the commercial MountainTop™ CAD package that has been customized for the ICADS environment. As building design elements (e.g., walls, doors, windows) are drawn on the computer screen, the ICADS *geometry interpreter* reads each element and creates a corresponding data object that is posted on the ICADS blackboard. Based on the object's type, ICADS queries the appropriate database and retrieves nongeometric (attribute) information that is added to the data object. For example, a window data object contains not only the dimensions and location of the window (drawn by the user) but information about glazing type, thermal conductance, and visible light transmittance (automatically loaded from the database). These data objects are of great interest to both design and energy tools that are connected to ICADS because they represent the current state of the building design and provide information for tools to evaluate and criticize.

Whenever a data object is posted to the blackboard, ICADS sends *data templates* to the attached tools, indicating that the designer has modified or added something new to the building. Each tool responds to this message according to its capabilities. For example, a change to the window glazing has a different implication for one tool than it does for others: one tool may simply ignore it, while another may suggest a new value for the window's overhang projection depth. ICADS responds to design changes offered by the attached tools in addition to changes made by the designer through the CAD drawing package.

In some cases, multiple tools may suggest different values for the same variable, resulting in a data conflict. ICADS resolves such conflicts by consulting rules that determine which tool or value should receive higher priority. If no such rule exists, ICADS asks the user for assistance.

Energy Standards Tool

The Energy Standards Tool determines whether the current design complies with selected parts of *ASHRAE/IES Standard 90.1-1989.* It reports to the designer instances of noncompliance and provides explanations for the noncompliance condition. The tool also recommends design changes to the user specifically intended to bring the current building design closer to achieving compliance. Although Standard 90.1 sets requirements for electric power, lighting, envelope, HVAC, equipment and service water heating, the Energy Standards Tool evaluates only a subset of these. This subset includes lighting power, lighting controls, ballast efficiency, and fenestration compliance.

Lighting power compliance
The tool determines if the total connected lighting power used by the proposed (indoor) spaces exceeds the internal lighting power allowance as specified by Standard 90.1 for this building. If it does, the tool recommends design options that can reduce the power requirements to a level below allowable limits.

Lighting controls compliance
The tool checks that each space has a sufficient number of lighting controls for each lighted space. It also provides access to a controls catalog, allowing the designer to substitute energy-saving lighting controls for existing controls. This catalog contains approximately 20 different control devices, ranging from simple on/off switches to sensor-based, programmable, and continuous dimming controls.

Ballast efficiency compliance
The ballasts of fluorescent light fixtures must meet certain efficiency standards for the building to comply with Standard 90.1. If the selected fixtures do not meet these standards, the Energy Standards Tool offers the designer an opportunity to replace the designed ballasts with higher-efficiency ballasts that can be selected from a lighting catalog. In this prototype, the lighting catalog has a small sampling of luminaires of different power requirements and ballast efficiencies.

Fenestration compliance
The tool ascertains that the ratio of window area to exterior wall area does not exceed a pre-specified maximum. This maximum is determined by the building's geographic location, internal load density, projection factor, and shading coefficient range. If the ratio is too high, the tool allows the user to move toward compliance by modifying the window dimensions or any of the other contributing variables.

Daylighting Tool

The Daylighting Tool computes daylight workplane illuminance at a user-specified reference point of each space in the building, for a single user-specified time of year. If this illuminance value is less than 100% of the recommended background illumination for the particular space, or less than 50% of the recommended task illumination for the space, then the Daylighting Tool informs the ICADS blackboard, proposing a change to the window area to increase workplane illuminance.

The tool operates by monitoring data on the ICADS blackboard as the designer develops a building design on the computer screen. If the values of one or more of the daylighting-related building parameters are changed, the tool recomputes daylight workplane illuminance based on the altered values.

The designer may interact directly with the Daylighting Tool to further analyze the lighting performance of the building. The tool provides three types of analyses: daylight distribution, electric lighting savings, and imaging.

Spatial and temporal distributions of daylight
The Daylighting Tool computes the spatial and temporal distribution of daylight within a space. The spatial distribution is computed for a user-defined grid of reference points at a user-specified time of the year. The temporal distribution is computed for each hour of the twenty-first day of each month, for a user-specified reference point. The results of these computations are tables of daylight workplane illuminance values presented as three-dimensional plots.

Through direct interaction with the Daylighting Tool, the designer is able to alter various "default parameters," such as window height; floor, ceiling, wall and ground reflectance; reference point location; time of year; and glass transmittance.

Electric lighting savings
The Daylighting Tool computes the potential for electric lighting savings considering on/off and continuous dimming control of the electric lighting system, based on the daylight workplane illuminance at the center of the space, the recommended task illuminance, and the electric lighting power density. The computations are performed for each hour of the twenty-first day of each month, for the CIE overcast and clear sky luminance distributions. The results of these computations are tables of electric lighting savings values, presented as three-dimensional plots, as well as an annual value for electric lighting savings. The user also has the opportunity to compare alternative electric lighting systems with respect to power density and controls.

Imaging
The Daylighting Tool currently provides a limited set of photo-realistic images of the building interior, allowing the user to assess the daylight quality within the space. For the purposes of AEDOT Prototype 1, demonstration images have been pre-calculated using RADIANCE, a ray-tracing computer program developed at LBL. These images illustrate changes in viewer location

and orientation, sequences over time and different sky/ground conditions, and sequences showing the effects of furnishings and reflectances of interior surfaces.

The Daylighting Tool in Prototype 1 is limited to daylight workplane illuminance and potential for electric lighting savings. As a result, the tool always tends to maximize daylight within each space, depending on the location of the reference point and the recommended background and task illuminance values. This tendency might lead to situations where increased solar heat gain defeats the energy-saving purposes of daylighting (unless glazing areas are constrained by another tool, such as the Energy Standards Tool).

Glare caused by daylight from windows is another common undesired side effect of daylighting. Through direct interaction with the Daylighting Tool, the designer can examine the glare index as computed for an occupant located at the workplane reference point looking toward the window.

Building Massing Tool

The Building Massing Tool operates at the conceptual design stage, allowing the designer to explore how energy use patterns vary with building geometric configuration. The tool categorizes a set of spatial configurations by row and column in a *morphological matrix* (Figure 2). As the designer begins to arrange a set of spaces using the CAD drawing package, the Building Massing Tool finds a cell in the matrix whose configuration most closely resembles the current design. Once this cell is located, the designer can explore similar configurations by moving along the same row or the same column as the matched cell, examining how each spatial variation impacts overall building energy use.

A scenario for interaction with the Building Massing Tool from the user's point of view might unfold as follows:

1. While the designer draws on the ICADS screen, the Building Massing Tool's icon blinks if the tool can match the geometry of the current building design and the tool knows of a similar building configuration that has better energy performance. If the tool has a tentative match, it requests verification from the user.

2. If the designer selects the blinking icon, the system displays a control window containing the current design in diagrammatic form and a screen prompt that asks "Does this diagram represent your design?" If the designer selects "yes," the Building Massing Tool uses this cell of the morphological matrix as its starting (reference) point. It also displays the estimated energy use for that building configuration. If the designer selects "no," the tool presents the next most likely geometric match, or it allows the designer to choose a configuration that most closely matches the design.

3. Once a reference cell has been established, the designer can ask the tool to display alternative building configurations that have better predicted energy performance. This results in new massing configurations that can be compared to the original design. The user can follow this procedure to select alternative designs, up to the limit of windows that can be displayed comfortably on the AEDOT screen (6 estimated). After that limit has been reached, the computer cycles through the available windows, saving all configurations for future review.

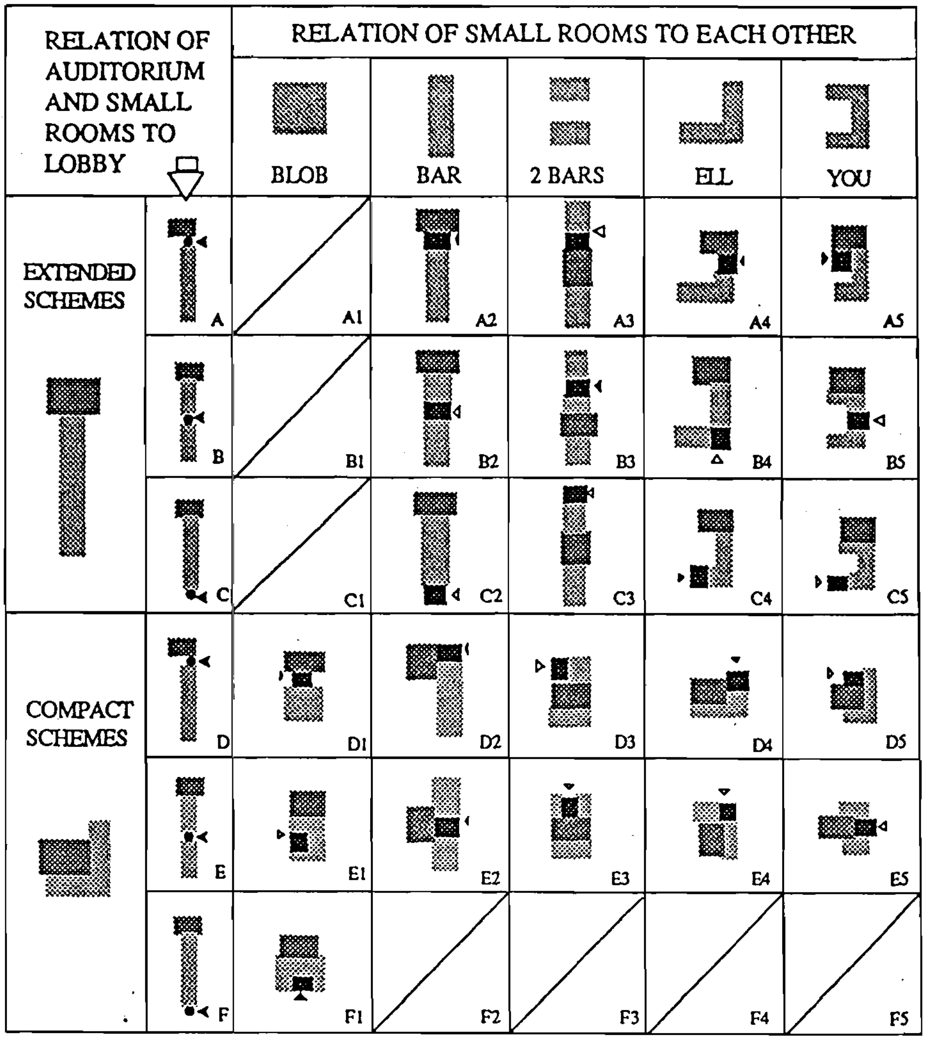

Figure 2. Sample plan morphologies for a rural community center.

Expected Results

The AEDOT Prototype 1 demonstrates how advanced energy tools can be integrated with a CAD capability. By doing this, the prototype illustrates some important concepts.

- The prototype explicitly demonstrates how energy tools can be linked to the drawing/designing activity. Providing an automatic data link frees the designer from the need to prepare separate input data for energy tools, saving time and allowing the energy analysis to proceed concurrently with the design process.

- Energy tools in Prototype 1 work in the "background" – the designer need not interrupt design (creative) thinking to activate these tools. They operate whenever they have sufficient information to activate, and present evaluation and feedback only when the designer asks for them.

- Energy tools operate concurrently, allowing multiple "views" of the problem to be explored in parallel. Concurrent operation provides the basis for intertool negotiation and conflict resolution. It also prevents constraint propagation, which has been shown in serial approaches to limit the exploration of design alternatives.
- The energy tools provide customized assistance to the architect or engineer during the design process. Suggestions and recommendations made by these tools are tailored specifically to the building that is being designed, not to some generic building type.

The AEDOT prototype is a testbed for future research: it is not yet a commercial-grade system. The IDTs have limited scope and are intended only to demonstrate some of the technologies that are being developed for future applications. The prototype not only features the advanced technologies used in the construction of the energy tools, but also emphasizes their seamless connection with other activities in the design process. As a result, energy efficiency becomes an integral part of the conceptualization and development of the building design.

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