SOFTDESK ENERGY: A DESIGN TOOL INTEGRATING CAD AND ENERGY ANALYSIS

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ABSTRACT

Integrating analytic tools within a production Computer Aided Design (CAD) environment provides designers the opportunity to evaluate the impact of design decisions much earlier in the design process than previously possible.

Softdesk Energy is a design tool that integrates building energy analysis capabilities into a highly automated production drafting environment (AutoCAD and Softdesk AutoArchitect). The authors review the technical challenges of integrating analytic tools with drafting tools, the CAD model extensions, and the impact of simplifications on the analytic results.

CAD, Building Data, Geometry, Tool Integration, Energy Analysis.

INTRODUCTION

Conservative estimates, based on building energy performance research, indicate that at least 15% of the energy used in new buildings could be saved, at no additional first cost, if energy-efficient strategies had been incorporated in the original design. Further, when energy efficiency is not adequately considered during design, a building's operating costs are higher over its 50 to 75 year lifetime. Despite significant advances in building technology and tighter building codes, buildings in the United States consume US$200 billion per year [1].

Decisions on building geometry, orientation, space planning, envelope and occupancy made at the early design stages have a significant impact on the energy performance of buildings. At this stage the designer's limited information is inadequate for detailed energy analysis. Because of time constraints and the lack of appropriate tools, energy evaluation is often delayed until the detailed design phase, when it is too expensive to change the basic decisions. Hence, it is critical to enable continuous evaluation of energy impacts from the earliest design stages. Because CAD tools are widely used for drafting the floor plans, there exists a valuable opportunity to assist designers by embedding energy evaluation tools in the CAD environment. Such an approach makes design analysis transparent and allows designers to concentrate on comparing design alternatives for improving overall building performance.

Softdesk Energy [2] is the result of a decade of research and development aimed at developing integrated design tools for improving energy performance as part of the Advanced Energy Design and Operation Technologies (AEDOT) project [3]. The US Department of Energy's AEDOT Prototype 1, developed using workstation technologies, demonstrated the feasibility

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of sharing data and knowledge among drafting and design analysis tools. In an effort to widely disseminate this concept, a commercial drafting environment developed by Autodesk, Incorporated was chosen as the basic platform for development. Softdesk Energy was developed through a collaborative effort between the US Department of Energy, the University of Oregon, and Softdesk, Inc., developers of AutoArchitect [4], a widely used architectural drafting extension for AutoCAD [5].

INTEGRATED ENERGY ANALYSIS

Recent trends in commercial architectural CAD systems are toward the development of integrated design tools that provide support to diverse disciplines throughout the entire building life cycle. Integrated systems can enhance design quality and productivity, and minimize the communication barriers that exist between disciplines. Typically architects; structural, mechanical and electrical engineers; contractors and estimators work together in generating the detailed design of a building. Each professional involved in the process has a specific view of the building data for their design analysis tasks.

Many research prototypes have been developed to demonstrate the feasibility and potential for integrated building design. Integrated Building Design Environment (IBDE) developed by Fenves et al. [6] focuses on the representation and communication of design information. Intelligent Computer-Aided Design System (ICADS) by Pohl et al. [7] demonstrates the integration of drafting and design knowledge to provide expert advice to designers. A Knowledge-Based Design Support Environment (KNODES) by Rutherford and Maver [8] integrates a large number of design tools for distributed problem solving. Several other research efforts are presently underway to explore and solve various problems in integrated design [9, 10].

Though research prototypes have significantly advanced the understanding of integration issues, they have failed to provide a methodology or tool that can lead to commercialization. User-interfaces and development platforms have been the major issues prohibiting the practical application of research prototypes. In architectural design practice, where computers are widely used for drafting, drawings convey a wealth of information that often needs to be extracted manually for design analysis. If design analysis tools were available within the drafting environment, they could provide valuable support to designers from the earliest stages of design.

To be effective, design tools used during design development should be capable of (i) obtaining the maximum data from the current CAD database, (ii) determining appropriate defaults for data that is unavailable, and (iii) dynamically managing the exchange of data between the drafting environment and the analytic tools. These three issues are critical for successful commercial deployment of integrated building design tools.

INTEGRATING ENERGY ANALYSIS WITH CAD

Usually energy analysis is undertaken late in design development by the mechanical engineer to size the heating, ventilation and air-conditioning (HVAC) equipment, design the air distribution systems, or confirm code compliance. Increased costs in HVAC design and equipment are incurred because the impact of energy-saving strategies involving geometry, orientation, and envelope design cannot be explored when they are first being considered. Traditionally, energy evaluation has not been a priority in early building design, not because it is unprofitable or uninteresting, but because it is impractical. The opportunity to build more energy efficient buildings can be enhanced by giving designers a practical tool for exploring strategies that lead to more efficient and cost-effective designs.

The challenge in integrating CAD and energy analysis has three important components: (i) user-interaction, (ii) data exchange and (iii) calculation methods. Most current CAD systems are fundamentally based on the vector drawing paradigm, which has its origin in the very first CAD implementations. To make drafting more efficient, most drafting tools aggregate these vectors into collections used to represent the primitive objects in buildings (e.g., walls, doors, windows). This aggregation is also required for energy analysis. However, energy analysis requires that the relationships between these objects be defined (e.g., windows within walls). In addition thermal, geographic, and usage properties not usually available in drafting tools must be available.

Energy analysis methods have evolved greatly over nearly three decades. A large number of energy analysis software tools have been developed [11]. All available energy analysis methods fall into one of the following three categories: (i) heuristic estimates, (ii) simplified methods such as degree-day or bin methods, and (iii) hourly simulation. The amount of data required and accuracy of results vary depending on the assumptions and nature of analysis techniques used by each method. To be practical during the preliminary design stage, the analysis technique must be reliable but should not impose extensive demands for data input or analysis execution time. During early design stages, the primary objective of analysis is to facilitate comparison of the various design alternatives and make quick decisions to revise geometry or select appropriate materials. Hence, simplified method calculations are more practical for early design support and remain useful as long as the design changes are significant.

INTEGRATED SYSTEM ARCHITECTURE

Softdesk Energy integrates energy analysis capability within a commercially available drafting environment using a geometry interpreter that automatically extracts a building model from CAD drawings. Figure 1 shows a schematic of the interaction between the CAD system and energy load calculation module. The user interacts primarily with the CAD system to generate the floor plan and to specify the building thermal parameters. The geometry interpreter processes all the drawing entities and objects to link them to the building model. In addition to the building geometry, the user specifies other information not available in the drawing (e.g., location, occupancy, lighting, equipment) using the Softdesk Energy user interface. This information can be set using approximate defaults based on building type or specified interactively using menus and dialog windows.

AutoCAD and Softdesk AutoArchitect provide the underlying CAD environment for implementing Softdesk Energy. Softdesk Energy classifies the user input in two categories: basic and extended input data. The basic category consists of building location, building type (e.g., office, residential, industrial) and orientation. The extended category includes envelope thermal properties; schedules for people, lighting and equipment; HVAC control settings and ventilation rate. While the user must specify the essential input data before performing energy analysis, the extended input data can be left as defaults based on building type or modified as needed.

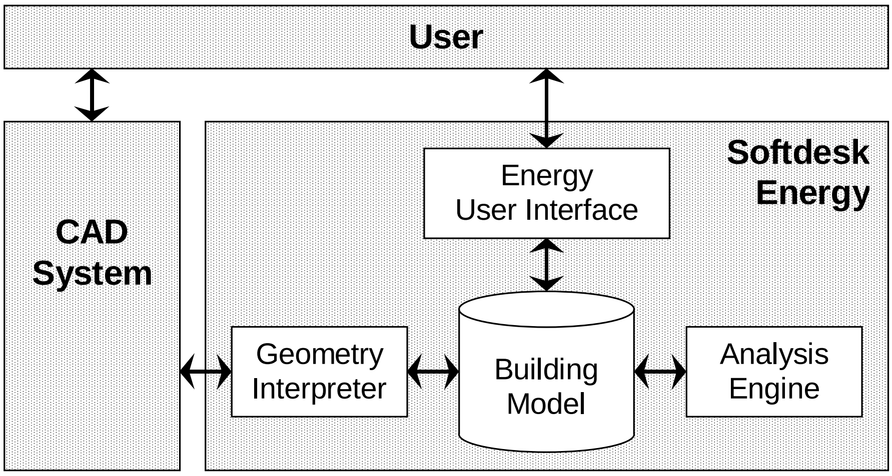


Figure 1- Interaction Between CAD System and Analytic Tool

Once the floor plan is drawn and the essential input data are specified, the user can perform the energy analysis. First the geometry interpreter updates the link between the drawing data and the building model. Then the energy load calculation module is activated to update the loads for each building component and graph the building's yearly energy profile.

GEOMETRY INTERPRETATION

The geometry interpretation is a two-stage process. Stage 1 (called extraction) adds to the building model all the objects that were found in the CAD drawing. State 2 (called purging) deletes from the building model all the objects that are no longer found in the CAD drawing.

The extraction process starts out by searching for the entire building envelope's geometry from an energy standpoint. The AutoCAD entities created by AutoArchitect contain all the relevant geometric data required to extract a complete envelope description, i.e., types, materials, dimensions, positions, orientations, perimeters, areas. Each AutoCAD entity is linked to an energy object defined within the building model. Extended energy data is also appended to the object descriptions. If the user previously selected non-default values, those are delivered at this time; otherwise, default values are introduced automatically. The result of this process is a hierarchical object tree that includes the building at the top level, walls, roof, and foundation below in the mid-level; windows and doors at the bottom level.

The building envelope is developed by scanning the foundation design, each floor, and the roof defined in the AutoCAD drawing file. AutoArchitect assigns AutoCAD entities to floors by layer; thus it is always possible to determine to which floor an entity is assigned. A scan begins by selecting candidate AutoCAD entities on each floor that could be relevant to energy. Each scan begins by locating an arbitrary entity containing a starting point on the perimeter of the building on each floor (usually at the lower left corner). The remaining candidate entities are then sorted and grouped into a list of connected walls having distinct orientations with zero or more apertures (each containing one or more doors or windows). When the scan returns to the original starting point, closure on the perimeter of that floor is obtained and the floor is completed. If at any point the scan finds more (ambiguous geometry) or less (incomplete geometry) than one object to connect, then the scan fails.

THE BUILDING MODEL DATABASE

The building model is maintained in an internal database that is specific to Softdesk Energy. The design of Softdesk Energy requires that (i) the database is simultaneously saved and loaded with the AutoCAD entities, (ii) the database objects are linked to AutoCAD entities, (iii) the user is able to quickly perform analyses, and (iv) the programmers need not familiarize themselves with a new programming paradigm. Thus, the Softdesk Energy building model database is stored within AutoCAD entities, but an Application Programmer's Interface (API) was developed to allow programmers to treat energy objects exactly like AutoCAD entities.

To facilitate development and maintenance, every AutoCAD entity access API function has an analog for energy objects. The energy object access functions perform the translations from AutoCAD's internal extended entities data representation [12] to one that is consistent with AutoCAD's much simpler normal entity data representation (using Lisp dotted pairs). A number of technical innovations were introduced to meet the product requirements.

1) Energy objects are assigned a distinct attribute identification scheme analogous to AutoCAD's standard entity data numbering scheme.

2) Any AutoCAD entity linked to an energy object and retrieved using an energy object API function has both sets of data returned together.

3) An independent and automatic indexing system is implemented to enhance performance. Each search query results in the automatic creation or maintenance of an index.

4) Change and update timestamps and object dependencies are maintained to enhance analysis processing speed.

5) The database schema was defined to support an object-oriented model with a mandatory parent-child relation, and optional geometry and analytic result relations.

ENERGY CALCULATION

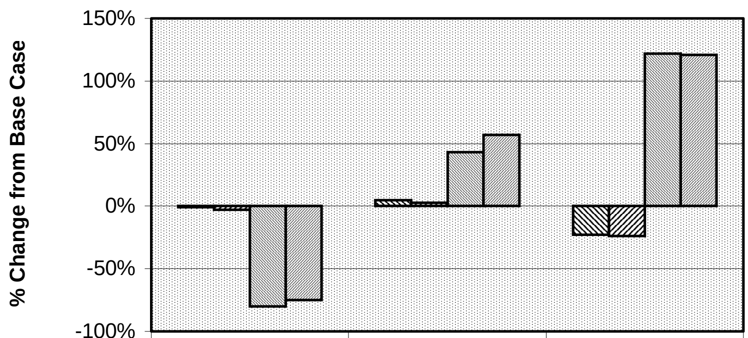
The energy load calculation in Softdesk Energy is based on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Simplified Energy Analysis Method (SEAM) [13]. The current SEAM implementation in Softdesk Energy provides estimates of the heating and cooling loads in the building and not on the energy performance of HVAC systems. The energy load calculation includes internal gain from lights, people, equipment; solar radiation and heat gain; building envelope heat transmission and loss; ventilation heat gain and loss; and thermal mass effects. Softdesk Energy assumes that the entire building has uniform interior thermal conditions and can be characterized as a single zone. This assumption simplifies input requirements and avoids the complicated calculation methods associated with multiple HVAC control points, heat transfer between various zones, and the operating schedules.

The result of the energy analysis performed by the implementation of ASHRAE SEAM is a set of load properties for each object in the building model for each month of the year. Energy use for a building is calculated for peak cooling and heating month conditions. The model then interpolates between these extreme loads to represent all intermediate conditions throughout the year. These constitute the "diversified loads" for the building and not the "design loads". Energy load objects can be assigned to any type of object whose energy loads are modeled by the energy analysis method. The energy load is displayed as a normalized load profile for each building component type (i.e., walls, windows, doors, roof, floors, and equipment) for each month. This allows the user to evaluate the impact of changing thermal properties or other building parameters. It is important to note that energy load components displayed by Softdesk Energy cannot be used for sizing HVAC systems even though they are based on the same peak load calculation typically used for equipment sizing.

COMPARISON OF ANALYTIC RESULTS

Softdesk Energy has been available to the North American architectural design community since June 1995. Softdesk Inc. has distributed more than 10000 copies of the software as a part of AutoArchitect since introducing the product. The following is a case study based on a building renovation project in which an engineer used Softdesk Energy to determine the thermal resistance of envelope components and to help demonstrate compliance to the state energy code requirements. The building is a single-story convenience store located in Albany, New York.

Gowri, et al. [14] studied three “what-if” design scenarios of the Albany building using Softdesk Energy. The study looked at the impact of design changes to the envelope thermal resistance, window area and lighting power density. To assess the load changes predicted by Softdesk Energy, the baseline building model and each design change were simulated using DOE 2.1e [15]. Figure 2 summarizes the percentage of change in loads from the base case for each of the three alternative scenarios considered.



	Insulation	Window	Lighting
DOE 2 (Summer)	-1%	5%	-23%
Energy (Summer)	-3%	3%	-24%
DOE 2 (Winter)	-80%	43%	122%
Energy (Winter)	-75%	57%	121%

Figure 2 - Comparison of DOE-2 and Softdesk Energy Results

Comparison with the DOE 2.1e simulations shows small differences in the evaluation of the insulation design changes and no significant differences in the evaluation of changes in connected lighting power. Comparison with DOE 2.1e show loads that differ by 14% for winter heating loads after the glazing area is increased. Gowri, et al. suggest that Softdesk Energy results tend to be more conservative and increasing glazing area could result in severe penalty for winter heating loads, whereas the DOE 2.1e results show a significantly lower penalty.

These comparisons suggest that Softdesk Energy provides sufficiently accurate information to compare and evaluate energy efficiency measures at preliminary design stages.

TRENDS IN INTEGRATED DESIGN TOOLS

Softdesk Energy has been linked to HVAC load calculations software and code compliance software. In both cases, further software enhancements were required to meet the user's needs. In the former case, the geometry of internal spaces had to be interpreted and transferred. In the latter case, a different building model had to be produced. In both cases the solutions were non-trivial to develop, highlighting the need for a more standardized and comprehensive representation of the building model.

The CAD industry has recognized the critical need to support data sharing among the various design disciplines and the various stages during the life of a building. This is a significant change in philosophy for software developers previously pre-occupied with data exchange between different CAD systems within a given discipline. The International Alliance for Interoperability (IAI), a group of CAD and building industry experts, has begun the long process of developing a common object data model known as Industry Foundation Classes (IFC) [16]. By producing IFCs, the IAI aims to produce a universal modeling language for improving the communication, productivity, delivery time, cost, and quality throughout the design, construction, operation, and maintenance life cycle of buildings. It is expected that CAD software, design tools, and other applications such as estimating and costing will all interact using a set of common IFC-based models. Several CAD systems and software applications supporting the IFC model are currently being developed.

CONCLUSION

Softdesk Energy demonstrates the practical and commercial reality of integrating CAD and analysis tools to assist designers during the preliminary design stages. The response from users of Softdesk Energy suggests that productivity improvements are possible using integrated design tools. By permitting energy to be considered earlier, energy efficiency improvements are achievable with integrated design tools. Though Softdesk Energy results can not be used for sizing HVAC systems, improved geometry acquisition methods by the analysis tool allow the user to more easily quantify the trends in heating and cooling loads for design alternatives. Thus Softdesk Energy's integration strategy is well suited as a design decision-making tool for architects and engineers during the earlier design stages. Recent developments in Industry Foundation Classes for the architecture, engineering, construction, and CAD industries using an object oriented paradigm provide a great opportunity for integrating more sophisticated analysis tools to be linked to CAD systems.

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